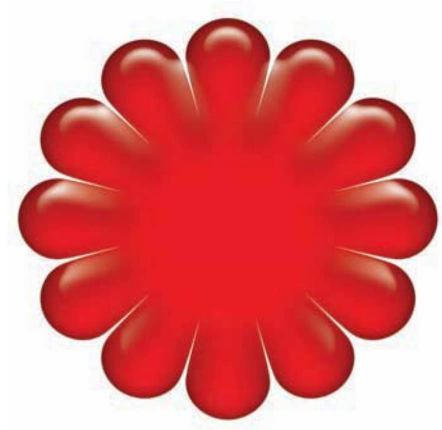
Master Gardener Manual

WSU EXTENSION CURRICULA EC0001



Introduction

Hello and welcome to this new WSU Extension Master Gardener Volunteer Training Manual, published by WSU Extension.

WSU Extension founded the Master Gardener Volunteer movement in 1973, training volunteers to serve as community educators in Washington State. Master Gardeners now serve across the United States and abroad. These university-trained volunteers deliver educational programs and work on projects that address critical needs in their own communities. Master Gardener volunteers strive for outcomes that are long-lasting with deep, positive impacts on the health and well-being of their fellow citizens and the environment in which they live.

This manual is just one of the resources that Master Gardener Volunteers receive during their extensive training program of lectures, online courses, and field tours. It is written almost exclusively by WSU Faculty. Two chapters, *Trees and Woody Landscape Plants* and *Houseplants*, have been adapted with permission from other sources.

For more information about the WSU Extension Master Gardener Program, please visit http://mastergardener.wsu.edu.

WASHINGTON STATE UNIVERSITY
EXTENSION
Master Gardener Program

Volunteer community educators cultivating plants, people and communities since 1973.

ACKNOWLEDGEMENTS

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I appreciate Oregon State University's permission to adapt the chapters on *Soil Science, Lawns, Vertebrate Pest Management,* and *Composting* from their PNW Sustainable Gardening Handbook.

I thank Dr. Linda Kirk Fox, Associate Dean and Associate Director of WSU Extension for her steadfast support of the WSU Extension Master Gardener Program. She recognizes and highly values the crucial role that Master Gardener volunteers have as community educators throughout our state.

Thank you, too, to Dr. Catherine Daniels, WSU Pesticide Coordinator and Director, who reviewed each chapter of this manual for accuracy in any pest management recommendation, frequently squeezing in this task between other pressing publications in order to get it done.

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And finally, the completion of this manual was made possible with a generous grant from the Washington State Department of Natural Resources and the USDOI Bureau of Land Management. Thank you, Sandra Williams, WADNR Wildfire Prevention Education Program Manager, for seeking collaboration with us.

May all your gardens flourish, but if they don't, may Master Gardeners take your phone calls first!

Tonie Fitzgerald
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Learning Objectives

- Know botanical terms related to plant growth, development, and function
- Be able to identify plant parts and understand their role in plant development and function
- Understand the physiological processes in plant development
- Understand the role of environmental factors on plant growth and development

By

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Introduction

Plant anatomy—the study of plant parts and how they are put together in a plant.

Plant morphology—the study of the form (shape) of plants and plant parts. In other words, what a plant and its parts look like. Morphology has its own terminology, and morphological traits are important for the identification of plants. Morphology is discussed in Chapter 2: Plant Identification.

Plant physiology—the study of plant growth and development; the internal workings of a plant. Much of plant physiology involves very complex biochemistry.

Plant taxonomy—the study of the classification of plants.

Plant nomenclature—how plants are named.

Plant geography—the study of the distribution of plants. This is important as we try to determine how plants from a different section of the country or a different part of the world are adaptable to the environments of our own state, county, or neighborhood.

Plant ecology—the study of the interrelationship of a plant to other plants, organisms, and environmental surroundings and the plant's effect on those surroundings.

Plant science encompasses three divisions: Agriculture, which is the science of raising crops and livestock; Horticulture, which is the science of growing high value fruits, vegetables, flowers, and landscape plants; and Botany which is the biology of plants. This chapter will give an overview of botany.

Botany is the study of plant life. This huge discipline has many discrete areas of study, each with its own terminology. A few of these are listed in the sidebar.

Plants are important for maintaining life on earth as we know it. Besides providing food for animals, plants also provide materials for building habitats. Some plants have medicinal qualities. Plants also modify environments by providing cooling shade, moderating wind flows, and controlling water runoff. Plants act as ground covers to protect the earth's soil from erosion. Through the food-making process of photosynthesis, plants take some of the carbon dioxide out of the atmosphere and, in return, replenish the oxygen that both plants and animals need for normal respiration processes. Plants increase the quality of our everyday life, and their value is usually very much underestimated.

Plant Classification

Plants may be classified in a number of different ways—and that classification changes as new information and methods of gathering that information are found. Classically, and most commonly, plants are classified from very simple plants (such as one-celled or few-celled algae) to very complex, highly developed plants such as the trees, shrubs, and grasses that we find in forests, fields, prairies, and other natural landscapes, as well as in our home landscapes (Table 1).

The **higher plants** are called "vascular plants" or "tracheophytes" from tracheophyta, which means these plants have vessels which conduct nutrients and water from the roots or root-like structures to the top of a plant, and vice versa.

The **simple plants** such as algae and other microorganisms (bacteria, fungi, etc.) are of great economic importance to us in both positive and negative ways. Oceanic and other aquatic algae produce a tremendous amount of oxygen while removing carbon dioxide from the atmosphere. Fungi are important for the many fermentation processes which give us our wines, cheeses, antibiotics, and other economically important products. On the negative side there are species of both bacteria and fungi that can cause diseases, injury, or death—of both plants and animals.

Table 1. Some distinguishing characteristics of plants.

Kingdom	Plants					
	Tracheophytes (vascular, "higher" plants)				Bryophytes (non-vascular plants)	
Phylum	**Anthrophyta** Angiosperms: covered seeds		**Coniferophyta** Gymnosperms: naked seeds	**Pterophyta** (ferns)	**Mosses**	**Liverworts**
Reproduction	Reproduce by seeds		Reproduce by seeds	Reproduce by spores	Fused gametes	Fused gametes
Classes	**Monocots**	**Dicots**	**Polycots**	**multiple**	**multiple**	**multiple**
Cotyledons (if present)	One seed leaf	Two seed leaves	Multiple seed leaves			
Leaf shape or venation	Parallel veined leaves	Branched or net-veined leaves	Needles or scales	Leaf-like structures	No true leaves; single cell layer	Lobe-shaped
Flowers or flower parts	Flower parts in 3's or multiples of 3	Flower parts in multiples of 4 or 5	No flowers (modified bracts)	none	none	none
Vascular pattern	Xylem and phloem paired in "vascular bundles"	Xylem and phloem in cambium layer around the stem				
Specialized growth tissue	No cambium layer	cambium layer	cambium layer			
Primary growth regions	Growth from base of plant and or a "primary thickening meristem"	Growth at root and shoot tips plus cambium layer	Growth at root and shoot tips plus cambium layer			
Examples	Grasses, palms, lilies	Broad-leaf plants	Conifers, arborvitae, etc.	Ferns	*Sphagnum*	*Calypogeia*

Plant Taxonomy

Plant taxonomy is not an exact science. There are a few different schemes and these change when new and better information is available. Research-based discussions are all over the board when it comes to agreeing upon a classification system for living organisms. One of the latest additions to the discussion is from Dr. Thomas Cavalier-Smith, a professor of evolutionary biology at University of Oxford in England. Professor Cavalier-Smith distinguishes six kingdoms of life: Animal, Plant, Fungi, Chromista, Protozoa, and Bacteria. There is still much disagreement and controversy in the scientific community about this six-kingdom classification.

Gardeners, of course, will primarily concern themselves with the divisions and phyla of the plant kingdom. But gardeners will learn about other kingdoms and phyla when they study pests and beneficial organisms, including insects, diseases, and microbes in the soil food web.

As practical horticulturists, we are primarily concerned with higher plants (vascular plants), of which the two most important groups are the division Anthrophyta or **angiosperms**, (flowering plants with covered seed) and Coniferophyta or **gymnosperms** (naked-seed plants, such as conifers and ginkgo). Also of some importance in the vascular plant group are the ferns, which belong to the division Pterophyta.

Flowers and fruits are the reproductive parts of a plant—they make or contain seeds. Vegetative material is the rest of the plant. Botanically speaking then, tomatoes, corn, and squashes are fruits, not vegetables, because they contain seeds. Onions, celery, and lettuce are vegetables in both the botanical and culinary senses.

The Anthrophyta division is split into two classes: the Dicotyledones (broadleaf plants with two cotyledons, casually known as **dicotyledons** or "dicots") and the Monocotyledones (plants with one cotyledon: grasses, palms, and lilies, casually known as monocotyledons or "monocots").

Seed plants are those vascular plants which reproduce by seeds. Gymnosperms produce seed in a cone or cone-like structure and the seed does not have a covering. Plants which are in this category are called conifers and include pines, firs, spruces, hemlocks, cedars, ginkgo, arborvitae, and others.

Angiosperms produce seed which have some sort of a covering, such as an apricot (*Prunus armeniaca*) that has a "pit," or the tiny seed inside the woody capsule of a rhododendron fruit. Angiosperms are divided into two very broad groups: monocots and dicots. Seeds of monocot plants, when germinating, have one **cotyledon**, or seed leaf. Another characteristic of the monocots is that the veins in each leaf run parallel to the mid-rib of the leaf. Monocots include grasses, palms, and lilies.

Germinating seeds of dicot plants display two cotyledon leaves. The seed leaves of dicots usually do not look anything like the true leaves which emerge later. The seed leaves contain the stored food of the seed which is used for the initial growth of the seedling. Leaves of dicots have **reticulate** or net veining instead of the parallel veining characteristic of the monocots.

Ferns are plants that have root-like structures called **rhizomes** and leaf-like structures called **fronds**. Fern reproduction is by means of spores, not seeds, which are produced in sacs on the underside of the fronds.

There are a few different systems for plant taxonomy, and they vary slightly. Examples of a taxonomic scheme for three plants is shown in Table 2.

Plant Classification According to Life Cycle

Plants may also be classified as to whether they are annual, biennial, or perennial. Knowing the life cycle of plants is not only important for planting plants, but also for weed control.

Table 2. Examples of taxonomic classification: pear, spruce, and cauliflower.

Classification Unit	Aristocrat Pear	Colorado Blue Spruce	Cauliflower
Kingdom	Plantae	Plantae	Plantae
Division	Anthrophyta	Coniferophyta	Anthrophyta
Class	Dicotyledones	Pinopsida	Dicotyledones
Order	Rosales	Coniferales	Papaverales
Family	Roseaceae	Pinaceae	Brassicaceae
Genus	*Pyrus*	*Picea*	*Brassica*
Species	*calleryana*	*pungens*	*oleracea*
Botanical Variety		*glauca*[1]	*botrytis*[2]
Cultivated Variety or Cultivar	'Aristocrat'[3]	'Montgomery'[4]	'Snow Crown'[5]

1 *glauca* is a naturally occurring blue needled form of the normally green-leafed Colorado Spruce.
2 Compare to varietal name *Brassica oleracea* ***capitata*** which is cabbage, while *Brassica oleracea* ***gemmifera*** is Brussels sprouts.
3 A selected upright form of the Callery Pear
4 A selected slow growing, bushy form of the Blue Colorado Spruce
5 White, self-blanching, drought-resistant All American Selection.

The genus and species name plus any botanical variety or cultivated variety name make up the scientific name or botanical name of a plant.

For more on genus, species, cultivated varieties, and naming of plants, see Chapter 2: Plant Identification.

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Controlling an annual weed may take entirely different measures than controlling a perennial weed.

Annuals are plants which complete their entire life cycle—germinate, mature, and set seed—in one growing season. Summer annuals start growing in the spring of the year, grow, flower, go to seed, and die by mid-summer to fall. Winter annuals generally germinate during the late summer to fall, flower from fall to spring, and then, depending on the species, set seed, and die. Hardy annuals have a certain degree of frost tolerance.

Annual plants go from seed to seed in one growing season.

Biennial plants complete their life cycle in two physiological growing seasons, which is normally two years. The first year the plants grow vegetatively, usually as a rosette close to the ground. The chill of the winter season causes a biennial plant to set up flower buds. This chill-to-reproduce process is called **vernalization**. During the following growing season, the plant will flower, set seed, and die. The biennial process requires a warm period for vegetative growth followed by a cool period for flower bud formation, followed by another warm period for flower and seed development. The two physiological growing seasons are two warm periods interrupted by a chill period. This can be, and unfortunately often is, accomplished in less than a year, in a process known as "bolting."

One example of biennial plants is the cabbage family: Brassica. If not harvested, but left in the garden to overwinter and grow the second year, brassicas will produce nice yellow flowers (and seeds). However, to get a jump on the season, many times kale, cabbage, kohlrabi, etc. will be started early (Jan., Feb., Mar.) in greenhouses where the plants will grow vegetatively. The plants may then be set out as early as March, April, or May. But if cold temperatures occur (40°F or colder), after plants are planted outdoors, they may think they have gone through a winter and set up flower buds and bloom instead of producing their typical head or bulb.

Perennial plants live for three or more years. **Herbaceous perennials** have stems which die back each winter. **Woody perennials** have above-ground stems which will live through the winter. Shrubs are woody plants that have basal activity (can sprout new branches from the base of the plant). Trees are considered to be single- to few-trunked woody plants.

Tender perennials have limited frost tolerance. See "Plant Hardiness" section, later in this chapter, for further discussion of plant survival.

A number of tender perennial bedding and vegetable plants are used as annuals in our climate. Examples include wax begonia (*Begonia semperflorens*), *Coleus* sp., and tomato (*Solanum lycopersicum)*.

Plant Anatomy

Plants are made up of cells which are grouped into tissues, based on similar characteristics. These tissues make up the structures, or organs, of a plant: roots, stems, leaves, flowers, fruit, and seeds. Each of these organs has been developed for a specific purpose or task.

Plant Cells

The basic building unit of the plant is the cell (Figure 1). There are many different types of plant cells. The size, shape, and internal contents of each cell will vary according to the function of the individual cell.

The "typical" plant cell is surrounded by a cell wall that keeps the internal contents contained. Thin-walled cells are usually flexible such as those one would find in leaves and flower petals. Cell walls may also be thicker and more rigid, such as those found in the cells of woody plant stems or walnut husks. Inside the cell wall is a semi-permeable membrane which allows water and dissolved materials to enter and exit the cell.

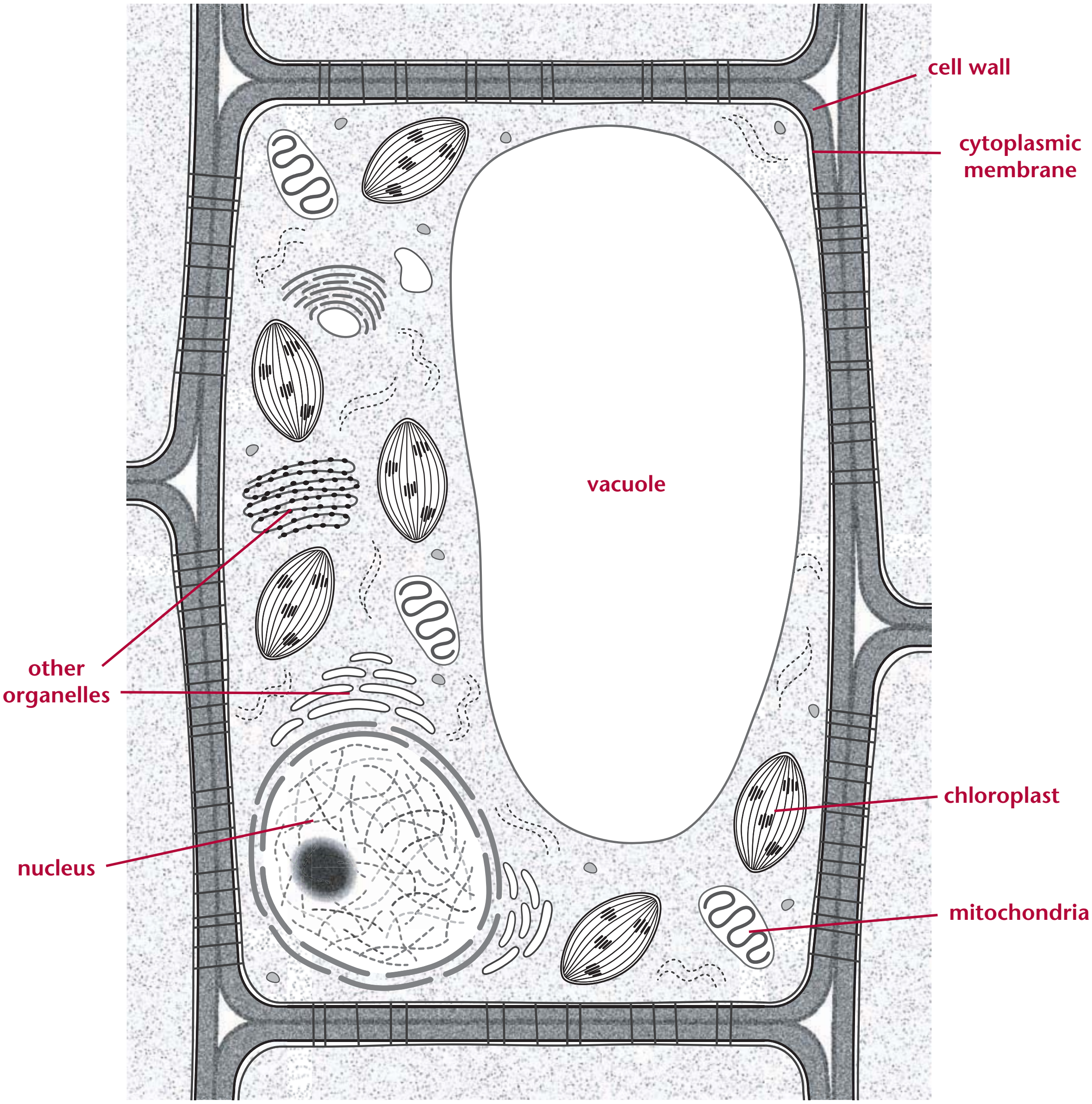


Figure 1. A schematic plant cell, showing the possible components of any given cell. Not all plant cells will have all these components, depending on the cell's degree of specialization and function.

The internal living material within a cell is called **protoplasm**. The protoplasm may have a number of different constituents depending, again, on the particular function of that cell in the total activity of the plant. The **cytoplasm** is everything within the protoplasm minus the nucleus. Cytoplasm includes organelles suspended in a gelatinous material which moves around the in the cell via a process called **cytoplasmic streaming**.

The nucleus could be called the brains of the cell, because it contains all the genetic information to form new cells and, in most cases, an entire new plant. Another cell component, the vacuole, is a membrane-bound void in which the cell puts and contains waste products and other byproducts of metabolism.

Organelles are smaller structures that have specific functions within a cell. For instance, **mitochondria** are the powerhouses of cells, controlling the various chemical functions (metabolism) of a cell. Another important organelle is the **chloroplast**, which contains the chlorophyll and is where photosynthesis takes place.

It is important to stress that cells of different kinds vary in size, shape, and content, depending on the cell's location and function within the plant. Cells in the various plant tissues and from different parts of the plant are extremely variable.

Cell Division. Cells in certain regions of a plant divide by a process called **mitosis**. A cell can divide to form two identical daughter cells; these two daughter cells may then divide, and so on. This cell division happens in specific areas called **meristems**, or meristematic zones. There are two primary, or **apical meristems**, one at the tip of each growing shoot, and the other at the tip of each growing root. A secondary meristem increases the diameter of woody plant stems and is called the **cambium**.

Plant Tissues and Organs

Plant tissues are groups of cells which are alike in structure and function. Types of plant tissues include the epidermis, meristem, parenchyma, sclerenchyma, xylem, phloem, and cambium.

Epidermis. This is the outermost layer of a plant, the "skin" if you will. This single layer usually has a waxy covering, the cutin, to reduce water loss.

Meristem. Meristem tissues are made of actively dividing cells. Meristems are the areas from which active growth springs.

Parenchyma. Parenchyma tissue has thin-walled, simple cells. Parenchyma tissue in leaves is responsible for photosynthesis. Parenchyma cells can become meristematic in order to grow over a wound.

Sclerenchyma. The cells of sclerenchyma tissue have thick walls to support a plant.

Xylem. This structurally complex tissue has cells that interlock and form tubes to conduct water and nutrients from roots to the rest of the plant. As the cells and tissues mature, they form the wood within woody plants.

Phloem. This tissue is also made of plumber cells, but they conduct food and the products of photosynthesis throughout a plant, including back to the roots.

Cambium. This is a layer of active growth and development of xylem and phloem.

When multiple tissues are put together into a much larger unit for a specific function, they form a plant organ. The different plant organs (stems, roots, leaves, and flowers) are discussed in sections below.

Stems

Stems on vascular plants are varied as to their function, structure, and form. Stems grow by increasing in length, and also by increasing in diameter, in the case of woody stems.

Stem Function. Stems have numerous functions in a plant, including support, transport of water and nutrients, and storage of those materials.

Stems support and extend the plant parts, such as leaves, upwards from the roots. This extension may be minimal as in the case of some low growing grasses, low growing herbaceous plants, and ground covers. Stems may also extend the leaves well above the soil as with taller growing grasses, herbaceous plants, shrubs, and trees.

Stems transport water, nutrients, and materials from the roots into the **crown** of the plant. Food and other materials produced by the leaves are transported down toward the roots and also toward the end of the stem, or the stem-growing point.

Stems can store reserve nutrients over the winter to be used for the first flush of growth in the spring. Sometimes stems are modified into specialized structures for storing materials like starches and water.

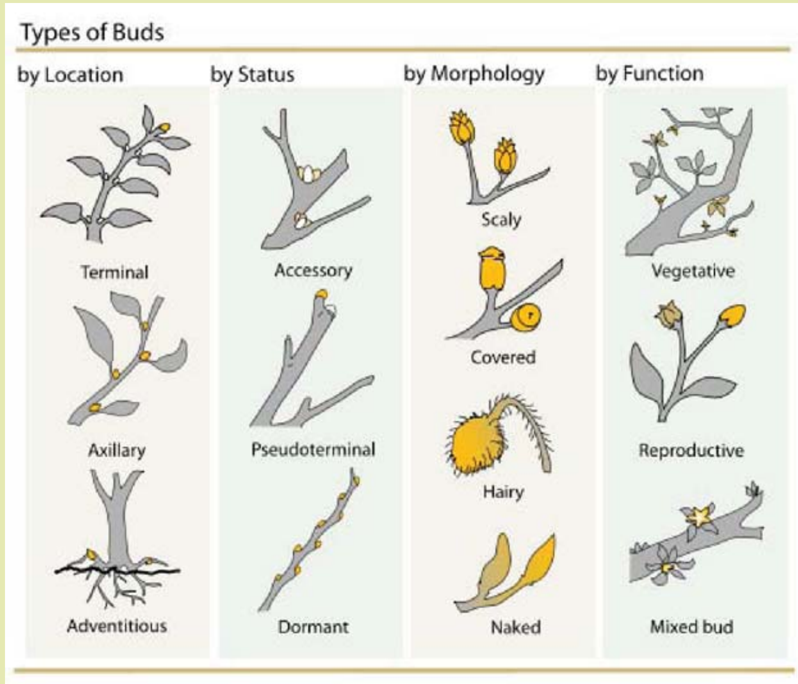
Stems are said to be part of the **shoot system** (stems and leaves) of the plant, and originate in a **bud**. Cells in the **apical meristem** at the tip of a bud start to divide very rapidly when growth starts in the spring. Behind these dividing cells, the just-completed new cells start to elongate and push the tip further out. This is called the zone of elongation. Behind the **zone of elongation** the cells start to change and differentiate, or mature, into specialized plant tissues such as phloem, cambium, xylem, and bud and leaf initials. This area is called the **zone of maturation**, or the **zone of differentiation**.

Stem Structure. A cross-sectional view of a stem of any common plant will present evidence to show what category of plant it is: a woody plant, an herbaceous dicot, or an herbaceous monocot. Each of these categories has a different cross-sectional configuration of the vascular system.

In cross section, a woody stem will display a series of concentric rings. The very outside layer is **bark** which, itself, is made up of a

Plant bud terminology

Plant buds can be described in terms of where they occur and how they are arranged (location), when they will be active (status), what they look like (morphology), and what kinds of tissue they contain (function).



few different layers. The primary purpose of the bark is to protect the stem. It can be quite thick on some species and very thin on others. Bark is usually thinner on young woody plants and thicker on older plants. It may be smooth, or furrowed. In some species it may peel off in elongated strips or patches in a process called **exfoliation**. Bark characteristics vary with the species and often can be diagnostic for species identification.

Inside the bark is a tissue that is a few cells thick, called the **phloem**. Phloem translocates food and other materials produced in the leaves both down toward the roots and also upward, toward the growing end of the stem.

The next layer is the **cambium**. This is where active cell division (growth) takes place. The cambium increases the diameter of a stem, forming phloem to its outside and a tissue called **xylem** to the inside. On any pruning cut or other wound on a woody stem, the initial regrowth process is mostly initiated by the cambium.

Xylem is found inside the cambium and typically forms the bulk of a woody stem. Xylem is a vascular tissue that moves water and mineral nutrients absorbed by the roots, plus other materials

*Figure 2. Section of a yew (*Taxus baccata*) branch, showing 27 annual rings, pale sapwood and dark heartwood, and pith (center dark spot). The dark radial lines are small knots—early branch stubs that were grown over by newer wood.*

produced by the root cells, toward the top of the plant. **Ray cells** are specialized xylem cells that can move water and nutrients laterally, that is, from the inner parts of the xylem outward toward the cambium and the bark, and from the bark area inward toward the center of the stem.

Another function of the xylem is to hold a woody stem, such as a shrub stem or tree trunk, upright. Xylem may also be called "wood" and could be considered the backbone of a tree.

Xylem tissue is divided into two distinct parts (Figure 2). The outer part, called **sapwood**, does the actual conduction from the roots to the top of the plant. Toward the center of the stem, inside the ring of sapwood, is the **heartwood**. Heartwood is plugged up sapwood and does not function as a translocation tissue anymore. However, it provides the structural rigidity that supports larger limbs and holds tree trunks upright. It is also the major portion of larger stems and trunks. The sapwood is often, but not always, lighter in color than the heartwood.

In contrast to woody dicots, herbaceous dicots have their vascular system arranged in bundles inside the stem. Each bundle, or vessel, has phloem on the outside, then a layer of cambium, with the xylem on the inside. Most of the rest of the internal part of an herbaceous dicot stem is made up of a spongy tissue called **pith**. In celery stalks (stems), the “strings” are vascular bundles of xylem and phloem.

Herbaceous monocot stems also have bundled vessels, but they are scattered throughout the cross section of the stem instead of being arranged in a circular pattern.

Stem Morphology. The morphology of a 1-year-old woody plant stem can tell a lot about how the plant grows, and many times is used in the diagnosis of plant problems.

At the tip of a stem is a **terminal bud** which is usually covered with scales, called **bud scales**. Along the stem, there are either leaves or **leaf scars** where there once were leaves. The place where a leaf or leaves attach to a stem is called a **node**. The **internode** is the area on a stem between the nodes.

Where a leaf is attached to a stem, it forms an angle with the stem called a leaf axil. Wherever there is, or was, a leaf, there is a bud. This usually is the only place on a stem where buds are found. These are **axillary** or **lateral buds**, and they may be either simple or mixed, based on their potential. **Simple buds** contain either reproductive parts (flowers) or vegetative parts (leaves, shoots), but not both. Some simple flower buds may contain more than one flower bud. **Mixed buds** contain both reproductive and vegetative parts.

There are usually slightly raised bumps on a stem, called **lenticels**. The lenticels may be indistinct or quite prominent. They may appear as round or oval “blotches” on younger stems. Lenticels serve as an opening for gas exchange between the outside atmosphere and the living cells within the stem. Lenticels allow oxygen from the atmosphere in, and respiratory carbon dioxide from internal living cells out. Sometimes the shape, color, or other distinctive features of lenticels are helpful for plant identification.

When a plant starts to grow in the spring, the bud scales will start to enlarge and unfold away from the emerging shoot and/or flower. The bud scales will eventually fall off (**abscise**), leaving a scar (a ring around the branch), called the **bud scale scar**, or scar of the terminal bud. At the end of the growing season, the distance from the newly formed terminal bud and scar where the terminal bud was at the beginning of the growing season is one season’s growth. Sometimes these scale scars may be evident for a number of years, so it may be possible to tell how well a plant was growing from year to year, based on the demonstrated length of twig growth.

If the seasonal growth is less than optimal or usual, it generally means that some sort of adverse condition affected the plant. This could be an environmental factor such as unsuitable temperature, drought, or flooding. Shorter than normal growth may also be an indication of root damage.

Specialized and Modified Stems. Stems are normally above-ground plant structures, but occasionally they will take on a different form. There are many possible modifications to the typical branch-like stem structure. By definition, stems should have leaves and buds.

Crowns are stems that are very short because of compressed internodes. The leaves are usually in a **rosette** form (many leaves emerging radially from a short stem). Examples are African violet (*St. Paulia ionanthia*) and strawberry (*Fragaria* spp.).

Stolons, or runners, are elongated stems growing very close to the soil surface. These runners will generally leaf out and root at the nodes. An example of this is the strawberry plant.

Rhizomes are similar to stolons, except they are underground stems and usually have parchment-like leaves at the nodes. New shoots arise at the nodes. Examples are wintergreen (*Gautheria procumbens*), bunchberry (*Cornus canadensis*), various blue grasses (*Poa* spp.), and many others. There are also enlarged rhizomes, called fleshy rhizomes, which are underground food/water storage organs. Examples are tuberous iris (as opposed to bulbous iris).

Tubers are enlarged underground stems, the classical example of which is the potato (*Solanum tuberosum*). The "eyes" are actually buds at a node, and the "skin" is actually bark. Another type of tuberous stem is that of the tuberous begonia (*Begonia* spp.).

Bulbs are a compressed shoot surrounded by either fleshy and/or parchment like leaves. Examples are onion (*Allium* spp.) and tulip (*Tulipa* spp.). An onion's layers are modified fleshy leaves.

Corms are short, enlarged underground stems used mainly for food storage. They are sometimes erroneously called bulbs. Corms contain no leaf tissue—parchment or otherwise. Examples are gladiolus (*Gladiolus* spp.) and crocus (*Crocus* spp.).

Roots

Roots are typically the underground portion of the plant usually growing in soil or some other suitable medium. Roots generally receive much less attention than the above ground parts of the plant, as it is usually, "out of sight, out of mind." Roots are very important to a plant's well being, and when root problems arise, the symptoms very often are manifested in the above-ground portions of the plant. It is therefore important to understand how roots develop and function to maintain a plant's health.

Root Function. Roots have many functions in maintaining the health of a plant. For instance, roots anchor and stabilize a plant in a suitable growing medium or substrate such as soil, usually, for terrestrial plants (in contrast to aquatic plants).

Roots absorb water and its associated dissolved mineral nutrients from the growing medium. Dissolved mineral nutrients enter a root via the root hairs (see below) by osmosis: a process whereby water and dissolved materials move across a semi-permeable membrane such as a cell membrane. The flow is from an area of greater concentration of dissolved material to an area of lower concentration of that dissolved material. There also is a lesser flow in the reverse direction.

Roots are the site of **nitrogen fixation**. Nitrate (NO_3^-) absorbed by the plant usually cannot be used in that form and has to be converted to the amino form (NH_2^-). Roots then transport those materials absorbed and metabolites produced to other parts of the plant.

Roots provide respiration: they have to absorb oxygen from the soil air and give off carbon dioxide. And finally, roots produce hormones which affect various phases of a plant's growth and development.

Root Structure. Roots have an epidermis layer with root hairs that are single-celled extensions of epidermal cells. **Root hairs** provide the water and nutrient uptake for a plant. They are delicate structures that are easily killed by dessication or during transplanting. Roots typically do not have buds or leaves.

Interior tissues of roots make up the endodermis. From this tissue, side, or branch, roots are generated.

Root Growth. Root growth is very similar to that of a stem in that there is an apical meristem at the root tip. Behind the apical meristem there is the zone of elongation, where the newly formed cells stretch out and push the tip further into the soil. Behind the zone of elongation there is the zone of differentiation where the unspecialized elongated cells develop into the discrete tissues of bark, phloem, cambium, xylem, etc.

There are many differences between a stem and a root. For instance, the growing root tip is covered with a hard layer of cells called the **root cap** which is produced by the apical meristem. The root cap is a sort of battering ram that forces its way between, and sometimes through, soil particles. The pressure that forces the root cap through the soil comes from the expansion of newly formed cells in the root apical meristem and the expanding cells in the zone of elongation. Behind the apical meristem, in the elongation zone, is where root hairs are produced. Root hairs are very short-lived, from a few hours to a few days. They are the primary water- and nutrient-absorbing structure for the root and, therefore, the plant.

Types of Roots. Roots may simply be classified as fibrous, tap, or fleshy. **Fibrous roots** are generally considered to be stretched out flat and somewhat close to the soil surface, while **taproots** are usually depicted as growing straight downward from the surface. Fleshy roots may be configured as either taproots or fibrous roots.

To a certain extent, root configuration is genetically controlled. Under good conditions, in well aerated, deep, moist soil, maples (*Acer* spp.) will usually have a rather flat, shallow, fibrous root system, while trees like honey locust (*Gleditsia* sp.) and redbud (*Cercis* sp.) will tend to have a more spreading, penetrating root system. Hickories (*Carya* spp.) and walnuts (*Juglans* spp.) are considered to be taprooted. Food plants such as radishes, carrots, beets, turnips, and rutabagas are also examples of, not only taproot systems, but fleshy roots. Other forms of fleshy or tuberous roots are dahlias (*Dahlia* spp.) and sweet potato/yams (*Ipomea batatas*).

Adventitious roots are any roots arising at an unexpected place on a plant. The short, white bumps along a tomato stem are adventitious roots. Aerial roots are adventitious roots that develop from above-ground stem tissues. Aerial roots may grow to support the plant, as with English ivy (*Hedera* spp.). Aerial roots are common with plants such as pothos (*Epipremnum aureum*) and philodendron (*Philodendron* spp.).

Root Extent and Depth. There are many misconceptions and misinformation about the extent and depth of plant roots in both natural and human-dominated landscape settings. Roots basically need two things: gaseous exchange for respiration and soil water with its dissolved mineral nutrients. If either air and/or water is lacking, the roots will not grow. In attempts at plant salvage in the arid regions of the southwestern United States, workers very often find that plant roots extend 12 to 14 feet or more below the surface, where water is present. This condition is not normally found in highly compacted human-dominated landscape soils.

Where the soil is saturated with water, air is mostly excluded—as is the oxygen in the soil air. Respiratory carbon dioxide can not be eliminated and therefore accumulates in root tissue with serious side effects. In this case the roots generally grow more toward the surface and sometimes on top of the surface. Common causes for soil saturation include: a high water table; a hard, impenetrable layer somewhere below the surface with a secondary water table above it; very tightly compacted, poorly drained soil, a common occurrence in many developed residential areas; and just plain over watering, especially on poorly drained soils.

Leaves

There are many different types of plant leaves. The "typical" leaf is a flat, blade-like structure, attached to the stem (usually) by a stalk called a **petiole**. The juncture of the leaf and the stem is called the leaf axil.

Leaf function. Leaves are where the majority of the work of a plant occurs. Leaves are the main site of photosynthesis, respiration, transpiration, and hormone synthesis. Leaves also move water, mineral nutrients, and materials made by the roots around in the leaf and move manufactured food and other metabolites out of the leaf. Leaves provide storage of food and sometimes water, and synthesize hormones that are used throughout the plant.

Leaf Structure. Leaves of dicot plants have net or reticulate veining (Figure 3), while leaves of monocot plants typically have parallel veining. Veining patterns are helpful in plant identification, and are discussed in detail in Chapter 2: Plant Identification.

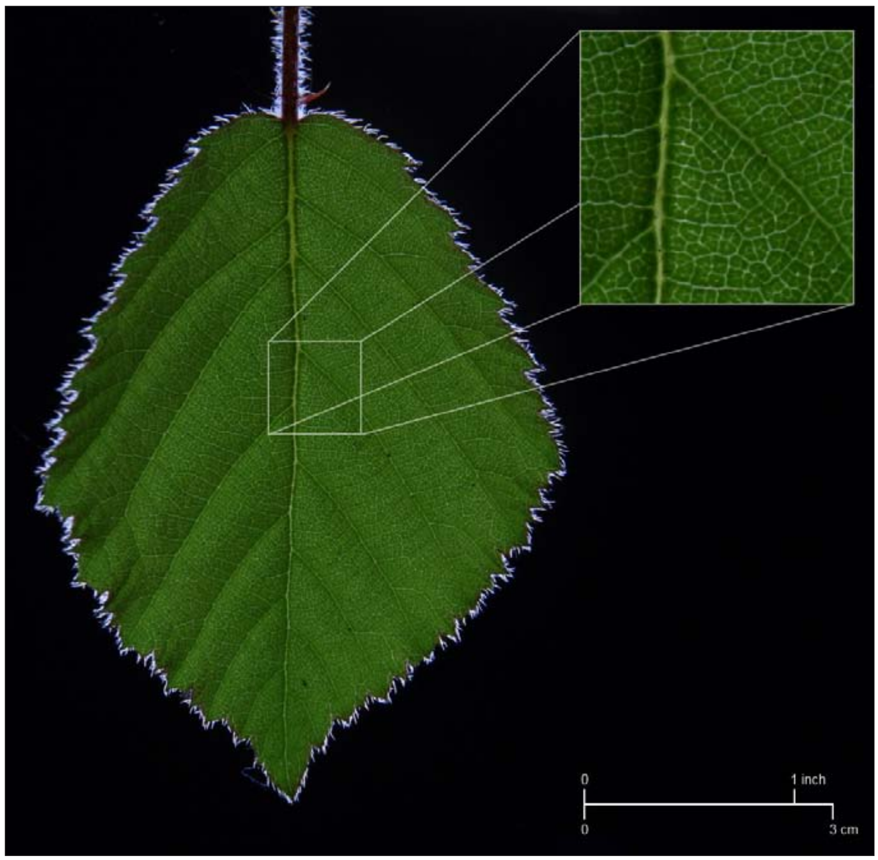


*Figure 3. A bramble (*Rubus *spp.) leaf showing net venation.*

Conifers may have needle-like leaves (Douglas fir, *Pseudotsuga menziesii*; hemlock, *Tsuga* spp.; Ponderosa pine, *Pinus ponderosa*), scale-like leaves tightly pressed onto the stem (arborvitae, *Arborvitae* spp.; California incense cedar, *Calocedrus decurrens*) or awl-like leaves which are short, narrow, sharp-pointed leaves, usually pulled away from the stem (junipers, *Juniperus* spp.; cypresses, *Taxodium* spp.). Junipers may have 2 or 3 different types of leaves on the same plant.

A "typical" leaf has four layers of different types of tissue (Figure 4). The top layer is the upper **epidermis** and its primary function is protection. The epidermis may be covered with a waxy cuticle, or various types of hairs, waxy scales, or other forms of protective structures. The next layer contains **palisade cells**, which are elongated cells set perpendicular to the upper epidermis. These cells are chlorophyll rich and this is one of the areas where photosynthesis takes place. Underneath the palisade layer is the spongy **mesophyll** layer which not only has photosynthetic capabilities but has voids between the cells to facilitate gaseous exchange. The bottom layer is the lower epidermis which provides protection.

The lower epidermis has openings called **stomata** (singular: stoma) that allow gases to enter and exit the leaf. Each stoma has two guard cells that open and close to allow oxygen, water vapor, and other gases to exit and air (with carbon dioxide) to enter. They are closed in the absence of light and when the plant is under water stress. This limits the amount of water the plant loses during dry periods, but also limits the amount of carbon dioxide taken in and, therefore, limits the photosynthetic activity.

Leaf abscission is the process whereby a leaf falls off the stem. A layer of cells between the leaf and the stem, known as the **abscission layer**, is killed by plant hormones at the end of the growing season. On deciduous plants, this process occurs annually. On evergreen plants it takes two or more years. Thus, evergreen plants, while always green, do lose their leaves—just not all at once to go bare like deciduous trees.

Leaf Modifications. As with stems, leaves may be specially modified to provide a particular function for a plant. Leaves may

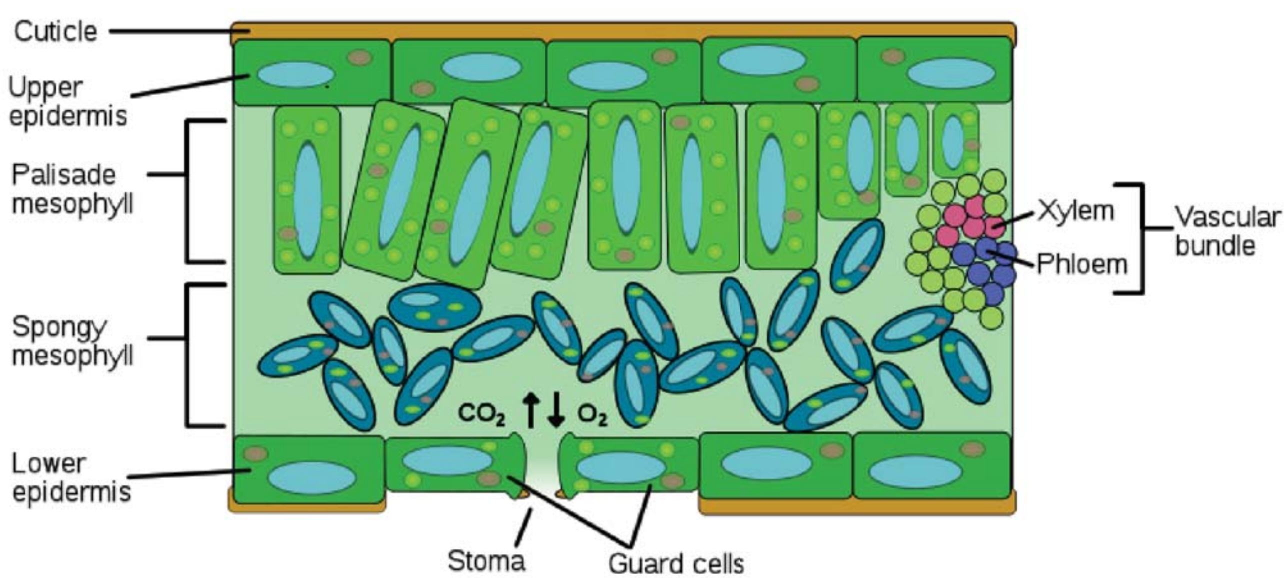


Figure 4. Cross section of a leaf showing the major tissues and layers.

be modified to provide nutrient storage (onion, *Allium* spp.) or water storage as in stonecrops (*Sedum* spp.) and hens-and-chicks (*Sempervivum* spp.).

Cotyledons are the seed leaves of a germinating dicot seed. They usually do not resemble the true leaves. They may come out of the ground on germination, **epigeous germination** (cabbage, tomato), or stay underground, **hypogenous germination** (oaks, *Quercus* spp.).

Flower bracts are usually smaller than petals, but the white showy part of the flowering dogwood (*Cornus florida*) and the (usually red) showy part of the poinsettia flower are, in fact, **bracts**. These are modified leaves. In both of these cases, the actual flower is less noticeable than the bracts and yellow in color.

Bud scales, also called cataphylls, are modified leaves that cover the buds of woody plants. On a hawthorn (*Crataegus* spp.), spines are leaves modified for protection and in some species may help the plant to climb. Tendrils, as for grape (*Vitus* spp.) and clematis (*Clematis* spp.) help the plant cling to things and climb.

Flowers

Flowers are usually the showy part of a plant. Many gardeners grow plants specifically for their flowers. But flowers serve other useful purposes: they are the reproductive organ whereby a species is normally perpetuated, and they are the basis for the classification of flowering plants.

The so-called “flower” of a plant such as lilac (*Syringa vulgaris*), daisy (*Leucanthemum* spp.) or hydrangea (*Hydrangea* spp.) is actually an **inflorescence** which is a group of individual flowers arranged in a cluster. There are many different types of inflorescences and they can be arranged on a plant in a number of ways. As with general plant classification, there is no consensus on defining the different inflorescences.

Flower Parts. **Sepals** are modified leaves which enclose and protect the flower bud. They may expand when the flower bud opens and they may be very showy and look similar to the petals. Together, petals and sepals make up the **calyx**. Petals are the typical showy part of the flower; together the petals of one flower make up the **corolla**. The calyx and the corolla are called accessory parts of the flower.

There are many modifications of flowers. For instance, petals and/or sepals may be fused together to form a tubular flower, as with penstemon (*Penstemon* spp.).

Stamens are the male part of the flower, consisting of the **filament**, a stalk which holds up the **anther**. The anther is the structure which contains the pollen, and the pollen contains the male sex cells.

The female portion of the flower is the **pistil**. It consists of a sticky surface called the stigma which is held above the ovary by the style. The ovary contains the ovule (egg cell, or, cells) which, when fertilized, will become the embryo of the seed. The ovary will develop into other parts of the seed and the fruit typical of the species.

A perfect flower contains both male and female parts. A complete flower contains male and female parts plus petals and sepals (Figure 5). Pistillate flowers have no male parts and staminate flowers have no female parts. Monoecious plants have separate male and female flowers on the same plant, while dioecious plants have male flowers on one plant and female flowers on another.

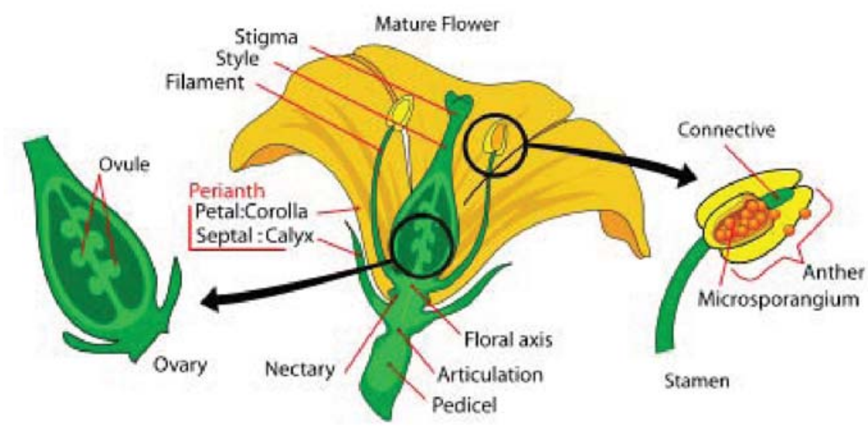


Figure 5. Diagram showing the main parts of a complete flower.

Pollination is the process of a pollen grain from the anther landing on the stigmatic surface of the pistil. The agents for pollination are usually insects or wind, but there are others. The pollen grain "germinates" on the stigmatic surface and a pollen tube containing the male sex cells grows down the style to the ovule or egg cell. The union of the male and female cells is called fertilization. The fruit will then develop in the form that is typical for the species. It is important to note that if the pollination–fertilization process does not occur, normally no fruit will form.

For two plants to cross pollinate, they have to be in bloom at the same time and the agent of transfer has to be present and active.

Self pollination is the transfer of pollen from the anther to the stigma of the same plant or the same clone. **Cross pollination** is the transfer of pollen from one clone to another clone or from one flowering plant to another flowering plant. Cross pollination is necessary for some plants to bear fruit. The apple cultivars 'Liberty' and 'Chehalis' are not **self fruitful**, but 'Liberty' can cross-pollinate 'Chehalis' and vice versa. In order for two plants to cross pollinate, they have to be in bloom at the same time, and the agent of transfer (bees, wind, etc.) has to be present and active.

Buds. Buds are undeveloped new shoots. Active buds are those buds that will do something during the next or current growing season. They will become leaves, shoots, flowers, or a combination of leaves and flowers. Latent buds (sometimes called epicormal buds) are formed in the normal manner, but do not grow and develop without special stimulus. These buds will remain dormant and under the bark until they are forced to grow, either by a pruning cut or limb breakage. This is one of the reasons why, when a large limb is broken off or an improper stub cut is made, shoots are formed below the injury. This is a survival mechanism that plants have.

Adventitious buds are those buds which form in a position on the plant where they are not normally found. This includes bud formation on the internode portions of the stem. This sometimes comes about by radical limb removal (stub cuts on large limbs) or limb breakage because of severe winter weather. The important difference between latent buds and adventitious buds is that the latent buds are formed in the normal manner, and adventitious buds on stems are usually formed in response to injuries, either pruning or limb breakage.

Flowering Patterns. It is important to know when a plant sets up, or initiates, its flower buds and where those buds are, especially if pruning is to be done to enhance flowering. There are a number of different blooming patterns of woody plants.

Woody plants may bloom from buds that were initiated the previous fall, prior to the spring in which they bloom. They may bloom on the terminal end of the branch from simple buds (star magnolia, *Magnolia stellata*; Burkwood viburnum, *Viburnum ×burkwoodii*). They may also bloom from the end of the stem from a mixed bud (horsechestnut, *Aesculus hippocastanum*; Norway maple, *Acer platanoides*). Some woody plants bloom on the end of short, specialized branches, called **spurs**, that have very short, compressed internodes (apples, *Malus* spp.; chokeberries, *Aronia* spp.; serviceberries, *Amelanchier* spp.).

Woody plants can also bloom from the lateral portions of the stem which was produced the previous year. These may be from a simple bud (forsythia, *Forsythia* sp.; Thunberg's spirea, *Spiraea thunbergii*; bridalwreath spirea, *S. prunifolia*) or a mixed bud (large-leaf hydrangea, *Hydrangea ×macrophylla*; red currant, *Ribes sanquinea*; Vanhoutte's spirea, *Spiraea ×vanhouttei*; most mockoranges, *Philadelphus* spp.; and weigelias, *Weigelia* sp.).

Many later-blooming shrubs and trees set up their flower buds as they are growing. These include PeeGee hydrangea, *Hydrangea paniculata grandiflora*; Bumalda spirea, *Spiraea ×bumalda*; Blue Mist, *Caryopteris clandonensis*. Note that both spirea and hydrangea include some species that initiate their flower buds in the fall and other species which set up flower buds as they are growing.

Flowering and Fruiting. A plant has to flower before it can bear fruit (or set seed). Flower buds on many species of temperate zone plants are formed in the late summer or early fall prior to the spring in which they bloom. These plants usually bloom in early to late spring. Other plants set up their flower buds after they break dormancy in the spring of the year. These plants generally bloom later in the summer and into early fall.

Failure to fruit could be for a number of causes:

- Lack of pollination; absence of bees; too cold or wet for the bees to fly.
- Plant didn't flower that year; plant is too young to flower.
- Flower buds were frozen.
- Flower buds were pruned away.
- Plant only has male flowers (as with *Ginkgo biloba*, or *Ilex* sp.).
- Lack of a cross pollinator or the cross pollinator blooms at a different time.
- Alternate-year blooming occurs: having a heavy crop one year leaves a lack of energy to produce many flower buds for the following year.

As with flowers, fruits come in many different sizes and shapes. They are classified based on factors such as number of seeds per fruit, segmentation, fleshiness, seed placement within the fruit, and other characteristics. A few examples of fruit types include:

- Simple—pome (apple, *Malus* spp.; mountain ash, *Sorbus* spp.); drupe (cherry, *Prunus* spp.; viburnum, *Viburnum* spp.); berry (tomato, *Solanum lycopersicum*)
- Aggregate—(raspberry, *Rubus* spp.)
- Dry—capsules (mock orange, *Philadelphus* spp.; rhododendron, *Rhododendron* spp.), samara (maple, *Acer* spp.), nuts (walnut, *Juglans* spp.), pod (goldenchain tree, *Laburnum* spp.; honeylocust, *Gleditisia* spp.)

Plant Growth and Development

Metabolism

Metabolism is the sum total of the biochemical activity within a living organism. Some of the chemical reactions take energy to complete, others release energy when completed.

Photosynthesis

Photosynthesis is an energy harnessing process. Simple carbohydrates are formed by combining carbon dioxide and water, using the radiant energy from the sun and the catalyst, **chlorophyll**. Oxygen is given off as a byproduct. During this process the radiant energy from the sun is converted to chemical energy and is stored in the chemical bonds of the sugar molecule that was formed.

Carbon dioxide comes into a leaf via the stomata with the air, while the water and other necessary nutrients were absorbed by the roots.

Some of the factors affecting the rate of photosynthesis include:

1. The amount of incoming solar radiation.
2. Quantity of chlorophyll-containing cells: leaves developed in the full sun usually have more chlorophyll-bearing cells than shade leaves.
3. Leaf age: older leaves have a lower photosynthetic rate than younger leaves do.
4. Carbon dioxide levels: increasing carbon dioxide levels above the normal atmospheric 300 ppm can increase the rate of photosynthesis, up to a point. Some growers of greenhouse crops will enrich the greenhouse air with carbon dioxide by burning propane. This is called **carbon dioxide fertilization**.
5. Air and soil temperatures: warmer temperatures increase the rate of photosynthesis (up to a point). Note: Higher temperatures will also increase the rate of respiration.

Chlorophyll contains carbon, oxygen, hydrogen, nitrogen, and magnesium. Iron and manganese are two other elements essential for the synthesis of the chlorophyll. Carbon, oxygen, and hydrogen are normally not lacking in plants. If iron, manganese, or magnesium becomes deficient in a plant, there will be less chlorophyll manufactured, and the leaves will look more yellow (**chlorotic**) because there is less chlorophyll.

Respiration

While photosynthesis is an energy-harnessing process, **respiration** is an energy-releasing process where carbohydrates (usually, but other metabolites may be used) are combined with oxygen (through oxidation) resulting in the release of energy, and with carbon dioxide and water given off in the process. The energy liberated by this process may be used to drive other chemical reactions such as the synthesis of proteins or the many other materials the plant needs.

Respiration is photosynthesis in reverse. The energy delivered originally by the sun is now converted to energy the plant can use in chemical reactions and in other processes. Photosynthesis only occurs in the light; respiration occurs in both light and dark. The rate of respiration increases with increasing temperatures.

To recap:

Photosynthesis:

> Carbon dioxide + water + (radiant) energy + catalyst (chlorophyll) => glucose + oxygen

Respiration:

> Glucose + oxygen => carbon dioxide + water + (chemical) energy

Transpiration

Water vapor escapes a leaf through the stomata when their guard cells are open. This process is called **transpiration**. Water movement into the roots, up the stem, into the petiole and out the leaf stomata is called the transpiration stream. The guard cells, surrounding each stoma, are like little balloons. When they are filled with water, they bend to open, and water vapor (and oxygen from photosynthesis) can escape while air with its carbon dioxide can enter. When guard cells lose water they become soft and close, keeping the water and oxygen in and air (and carbon dioxide) out. Stomata are only open under light conditions (natural or artificial) and when the plant is under good water relations. In dark or dry, droughty situations they will close, minimizing water loss. Under dark conditions transpiration stops and so does the photosynthetic process.

Plant Hormones

Plant **hormones** are chemicals produced by the plant in small quantities. Hormones are transported to specific sites within the plant where they have a pronounced effect on some aspect of plant growth and development. The main hormones important for plant growth and development are listed in the sidebar.

Plants have the ability to synthesize hormones and they also have the ability to stop the action of those hormones when necessary by breaking them down or by inhibiting or slowing down their synthesis. This is all part of the plant's checks-and-balances system.

A **plant growth regulator** is a synthetically produced chemical that mimics one of the plant's own internally produced hormones. It also may have a dramatic effect on some phase of plant growth and development. Since these synthetic products are foreign molecules and not produced by the plant, the plant does not have

Examples of Common Plant Hormones

1. Auxin (Indole-3-acetic acid, or, IAA)
    a. Asserts apical dominance—suppresses lateral bud growth
    b. Stimulates cell division and cell enlargement
    c. Stimulates root formation both on roots and stems, as in the rooting of a stem cutting
2. Gibberellins (GA)
    a. Stimulate longer internodes by stimulating cell elongation
    b. Stimulate cell growth
    c. Aid in overcoming physiological dormancy
3. Cytokinins
    a. Aid in overcoming apical dominance
    b. Aid in cell division and enlargement
4. Abscisic Acid (ABA)
    a. Slows down/inhibits cell growth
    b. Causes leaf and fruit abscission
    c. One factor driving physiological dormancy of buds and seeds
5. Ethylene
    a. Aids in leaf and fruit abscission
    b. Aids in fruit ripening
    c. Aids in the flowering of some species
    d. Is active in senescence and aging of plant tissue

the systems to inhibit its actions and/or the ability to destroy them very readily. Therefore the action of this synthetic will be much longer lasting. For instance, IAA (auxin or indole-3-acetic acid) is well known to stimulate adventitious root formation in stem cuttings of plants. If IAA is applied in an above-normal plant level concentration (to stimulate root formation on a stem cutting), the plant will very quickly manufacture the enzyme system to destroy the IAA and reduce the levels in the plant back to what would be more normal. (Note that none of the root-inducing compounds on the market contain IAA as the active ingredient.) By comparison, IBA (indole-3-butyric acid), NAA (naphthalene acid), and some of their chemical derivatives which also have a well documented ability to stimulate new root formation on cuttings, are *not* produced by the plant, so the plant does not have the ability to destroy them, at least not very quickly. Therefore IBA and NAA last much longer in a plant and are much more effective. There are also anti-gibberellin growth regulators which will override the effect of gibberellic acid and cause a plant to be shorter at maturity. The floriculture industry makes use of these compounds to shorten the height of crops such as poinsettias (*Euphorbia* spp.) and Easter lilies (*Lilium* spp.).

Apical Dominance. Growing points of branches, younger leaves, and sometimes older leaves synthesize a hormone called auxin (indole-3-acetic acid). Auxin has many functions in the plant including suppression of lateral buds to keep them from breaking dormancy and starting to grow. As a result of this suppression, the terminal buds will receive more of the nutrients and thus grow more. This is called **apical dominance**. Plants vary in their degree of apical dominance. Some plants will grow without much lateral branching (pines, *Pinus* spp.), while others may have weak apical dominance and branch freely (oaks, *Quercus* spp.). When a heading cut is made and the terminal end of the branch is removed, especially a younger stem, the source of auxin is removed. Lateral buds may then break and start to grow. This is used to stimulate branching where it is wanted, or perhaps to fill the plant in. Another way to "create" a branch where it is wanted, is to find a latent bud, and with a knife make a notch above the bud. This interrupts the auxin flow to the bud and may allow it to grow.

Climatic Factors Affecting Plant Growth

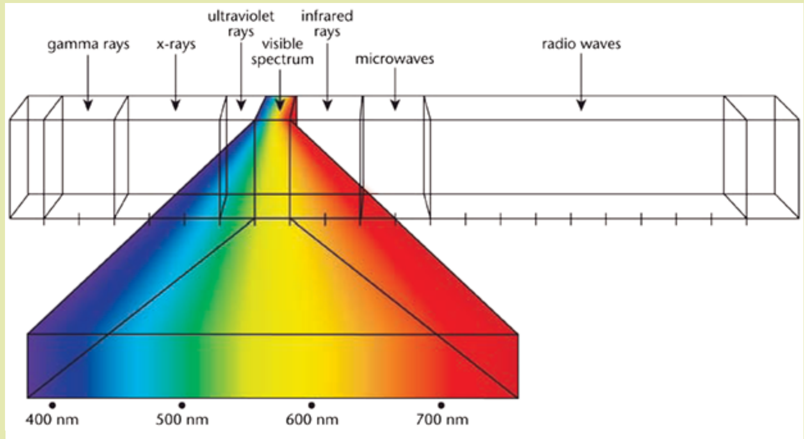
The rate of a plant's growth is governed by many interrelated and interacting factors such as light intensity or quantity, air and soil temperatures, availability of water, nutrients, and plant hardiness.

Light

The rate of plant growth is related to the rate of photosynthesis. Light intensity—the amount of light impinging on a plant—governs the rate of photosynthesis. As the amount of light increases, the rate of photosynthesis increases. There is a point where any increase in light intensity will not increase the photosynthetic rate. This is called the **light saturation point**, and is variable with the species. Understory plants in temperate zone forests and tropical rain forests generally have very low light saturation points, while, in comparison, corn will continue to increase its photosynthetic rate up to and beyond full sunlight intensity. Plants with low light saturation points make good indoor plants where light levels are usually low.

Light quantity, or intensity, is governed by time of year and day, cloud cover, and shade from overhead vegetation, buildings, and anything casting a shadow. Shade can reduce the growth rate of plants because the lower light level decreases the rate of photosynthesis.

Aspects of Light



Light is a form of electromagnetic energy released as photons. The terms quantity, duration, and quality are used when describing light.

Light quantity relates to the intensity or the energy output of a light source. This is measured or described in terms of foot candles (fc).

Light duration indicates the photoperiod or length of time that the light source is emitting light.

Light quality refers to the color of the light emitted by a source. A light's color is determined by the light's wavelength (measured in nanometers, nm). Sunlight is energy of wavelengths from the entire electromagnetic (EM) spectrum. The wavelengths of light that humans can see make up the **visible spectrum**—just a small portion of the EM spectrum, from violet to red light. Wavelengths within the visible spectrum are most effective in stimulating photosynthesis and are referred to as the **photosynthetically active radiation** (PAR).

Objects appear colored because of reflection: they reflect light of a certain wavelength. Green plant leaves appear green to our eyes because they reflect green wavelengths while absorbing the other wavelengths of light. A black object absorbs all wavelengths of light and reflects almost none, while a white object absorbs almost no light and reflects nearly all wavelengths.

The **light compensation point** is the level of light intensity at which the rate of photosynthesis (and a plant's CO_2 requirement) equals the rate of respiration (the plant's CO_2 output).

Photoperiodism is the induction of some change in a plant's growth and development by a change in the relative length of light and dark periods (i.e., night and day). The best examples of this are the initiation of flower bud formation and onset of bud dormancy in the later summer and early fall period.

Flower bud formation is governed by a critical day length. A **long-day plant** (actually, a short-night plant) will set up its flower buds if the critical day length is exceeded (days getting longer). If a plant has a critical day length of 11.6 hrs, this length of light must be exceeded before the plant will initiate flower buds. For **short-day plants** the photoperiod must be less than the critical photoperiod (days getting shorter). Typically, short-day plants bloom more toward the end of summer (chrysanthemums, *Chrysanthemum* spp.) and long-day plants flower more toward the spring–early summer period (lilac, *Syringa* spp.).

Day-neutral plants are not controlled by any specific photoperiod and bloom when they are mature enough to flower and the environmental conditions are suitable for that species to flower (corn, *Zea mays*; dandelion, *Taraxacum* spp.; rose, *Rosa* spp.; and grapes, *Vitis* spp.).

The shorter days of late summer and early fall initiate the onset of **bud dormancy**. Hormones chemically lock up the buds to prevent buds from growing in the fall and during mild spells in the winter. Also during this period of shortening days, other metabolites are synthesized by the leaves and are translocated to other parts of the plant, slightly increasing the hardiness of the plant parts. To overcome this physiological, chemically induced dormancy, the plant usually needs a cold or chilling period for a certain length of time. During this chill period the concentrations of growth inhibiting substances (such as ABA) in the plants are diminished and the concentrations of growth promoting substances (such as GAs) increase.

Temperature

Temperatures are governed by a number of different factors and have many different and pronounced effects on plant growth. Incoming solar radiation, which heats land masses, bodies of water, plants, buildings, etc., is influenced by cloud cover, air pollution, and day length (season). Bodies of water (large rivers, lakes, bays, oceans) heat and cool slowly in comparison to land masses which tend to heat and cool rather rapidly. Even wet, heavy soils will warm up much more slowly than lighter (sandy) soils that do not contain much water.

Cold air is more dense than warm air and will sink to low areas in a landscape. When cold air is regularly trapped in a particular low area, that area is called a **frost pocket**.

Other temperature considerations:

- Increasing temperatures will increase the rates of photosynthesis, respiration, and transpiration.
- A certain period of time at chilling temperatures (40–45°F, or 4–7°C) is necessary for overcoming physiological dormancy of certain plants. The length of chill needed

will vary with the species and even, in some cases, with cultivars or ecotypes within a species.

- There are combinations of light and temperature such as long days and warm temperatures to initiate flowering. Southern magnolia (*Magnolia grandiflora*) and crape myrtles (*Lagerstoemia indica*) are examples. Flowering of both of these species may be diminished by cooler summer temperatures.
- Certain vegetable crops need warmer temperatures to develop or develop properly, while others do much better with lower summer temperatures. Examples of warm season crops are peppers (*Capsicum* spp.) and melons (*Citrullus* spp. and *Cucumis* spp.), while cool season crops would include examples such as lettuce (*Lactuca* spp.) and cole crops (*Brassicas* spp.). For more discussion, see Chapter 6: Vegetable Gardening.
- Higher temperatures may cause some plants to **bolt** or start to flower. Examples are cilantro (*Coriandrum* sp.) and lettuce.
- Some seeds need a chill period to germinate.
- Seeds may germinate over a wide range of temperatures, but most plants have an optimum germination temperature at which the seeds will germinate more quickly and uniformly.
- Tolerance of a plant and its parts to both cold and heat is called its cold hardiness. For further discussion of plant hardiness, see below and Chapter 10: Herbaceous Landscape Plants.
- **Vernalization** is a chilling requirement that some plants need to initiate flower buds. Examples of this are tulips (*Tulipa* spp.) and winter wheat (*Triticum* spp.). Tulips are planted in the fall to get a winter's chill period in order to form a flower bud for spring blooming.

Water

Water has many functions and roles in plant growth and development. Water is a solvent for the materials entering and also materials moving inside the plant, and it is a reactant in many of the internal chemical reactions going on inside the plant. For instance, it is a major constituent of photosynthesis. Water also regulates the turgor pressure (turgidity) of cells, thereby affecting transpiration and cell growth. Similarly, it regulates stomatal opening and closing, thereby regulating transpiration and photosynthesis within a plant. And finally, water is a major agent of evaporative cooling of leaves—transpiration.

Relative humidity (RH) is the amount of water vapor found in the air compared to the amount of water vapor that the air can hold at that particular temperature, expressed as a percent. Air can hold more water vapor at a higher temperature than it can at a lower temperature. Water vapor will move from an area of high RH to an area of low RH. The RH inside a leaf is very high, so therefore water vapor has a tendency to move out of the leaf, to an area of lower RH. There are RH applications in plant propagation where mist and fogging systems have been developed to keep the RH elevated around cuttings (reducing transpiration) while the cutting develops new roots.

Nutrition

Nutrients have specific roles in plant growth. Nutrients may be required as part of some molecular structures or they may be necessary as a sort of catalyst to help complete some biochemical reactions.

Nutrients have to be soluble in water to enter a plant, and they have to be soluble to move within the plant. A nutrient's concentration in plant tissue is usually expressed in parts per million (ppm).

Nutritional elements may also be classified as **mobile** or **non-mobile**. Mobile elements will move in the plant toward the growing point or toward younger leaves. Non-mobile elements will usually stay put once they have entered the leaf. When a mobile nutrient element is lacking, that nutrient is moved to new growth areas, so the deficiency symptom will show up in the older leaves. Conversely, the lack of a non-mobile element will become apparent in the newer leaves since the nutrient cannot move to the growing points.

See Chapter 5—Plant Mineral Nutrition and Fertilizers for an in-depth discussion of nutrients and how plants use them.

Plant Hardiness

Plant hardiness may be defined as a plant's tolerance to extremes. The extremes could be to temperature, water availability, soil pH, etc. In most cases though, hardiness refers to the cold hardiness of the plant.

Temperate zone plants develop hardiness in a fairly predictable manner. The initial stages of cold hardiness and physiological dormancy development begins with shortening days in the late summer, early fall. This process can increase the hardiness of the plant up to about 10°F. Plants at this stage can endure the early fall frosts with little or no freeze damage.

As temperatures start cooling in the fall, plants will adapt by acclimating, or hardening to cold. This process continues until the plant reaches its ultimate mid-winter hardiness, which is genetically controlled. African violets can be killed by mere chill damage at temperatures slightly below 40°F. Arborvitae (*Thuja* spp.) can develop cold hardiness down to −100°F.

Plants will deacclimate, or become less hardy, with increasing temperatures in the latter part of winter and the very early spring. Most plants, when they start to grow or are in active growth, have very limited or no tolerance to freezing temperatures.

Freeze damage, usually not apparent until the following spring, can occur in a variety of situations. All of the below have occurred in Washington on numerous occasions in the last 20 years. Some occur on a yearly basis.

- Very warm fall days (Oct./Nov.) may provide no impetus for hardening or acclimating to cold, followed by a dramatic and sudden drop in temperature well below freezing. It seems this usually happens around Thanksgiving.
- Temperatures drop below the (genetic) ultimate mid-winter hardiness of the plant.
- A week to 10 days of abnormally warm temperatures in mid- to late-winter can lead plants to deacclimate. That balmy period will be followed by a dramatic and sudden drop in temperature back to normal below-freezing temperatures. Similarly, this may also happen when evergreen foliage or tree bark heats up on the southwest side of the plant on a cold (below freezing), sunny, winter day. The plant leaves and/or bark can reach temperatures of 50°F or more from the impact of solar radiation. When the sun goes down, the plant tissue very rapidly, often within minutes, cools down to the ambient air temperature which is below freezing. Cellular water that was loosened up during the heat of the day cannot be withdrawn quickly enough during the very rapid cooling process, so ice crystals form in the cells, bursting them and resulting in tissue death.
- Spring frosts after plants have begun to grow can injure any new growth. When plants start to grow in the spring, the new tissues have very limited or no hardiness. Late freezes affect not only leaves and shoots but also flowers and early setting fruit such as apricot. The flowers of star magnolia (*Magnolia stellata*), saucer magnolias (*M. soulangiana*), and Higan cherry cultivars (*Prunus subhirtella*) are very susceptible to any type of freeze when they are in bloom. In areas where late frosts happen very frequently, substitutions of other, later blooming species, or cultivated varieties of the magnolias and cherries mentioned above may be made.

Ultimate mid-winter hardiness of plant parts varies as follows: stem tissue is usually hardier than vegetative buds, which are usually hardier than flower buds, which are usually hardier than roots. The bottom line is that, in some cases, stems may be hardier by 30 to 40°F (or more) than the roots.

Zones of cold hardiness have been mapped by the USDA. That map is available at http://www.usna.usda.gov/Hardzone/ushzmap.html.

Learning More

There are many good books on various aspects of botany and plant sciences. They vary in their scope of coverage of the different subject matters and they vary in their depth of coverage, ranging from basic gardening books with a single chapter on botany to in-depth college-level texts. There are also reference materials on specific subjects within botany such as plant anatomy, plant physiology, plant geography, taxonomy, plant ecology, etc.

A good general horticulture book usually has chapters on botanical principles as related to the various horticultural crops. These text books and references are usually a little bit more practically oriented.

Further Reading

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Errata

EM001 – Master Gardener Manual

Chapter 1: Basic Botany — Image Attributions

Sidebar image: Plant bud terminology. (Public domain image available at http://en.wikipedia.org/wiki/File:Plant_Buds_clasification.svg.)

Figure 2. Section of a yew (*Taxus baccata*) branch. (Photo available under CCA-SA 3.0 license at: http://en.wikipedia.org/wiki/File:Taxus_wood.jpg.)

Figure 3. A bramble (*Rubus* spp.). (Photo courtesy of Richard Wheeler, a.k.a. Zephyris, under a CCA-SA 3.0 license at: http://en.wikipedia.org/wiki/File:BrambleLeaf_CrossPolarisedLight_Diagram.jpg.)

Figure 4. Cross-section diagram of a leaf. (Diagram courtesy of H. McKenna, under a CC-BY-SA 2.5 license at: http://en.wikipedia.org/wiki/File:Leaf_anatomy.svg.)

Figure 5. Diagram of a complete flower. (Public domain image available at http://en.wikipedia.org/wiki/File:Mature_flower_diagram.svg.)

Plant Nomenclature & Identification

2

Topics covered:

- Introduction
    - Study Tips
- Nomenclature
    - Scientific Names
    - Common Names
- Diagnostic Plant Morphology
- Identification Keys

Learning Objectives

- Understand the importance of botanical names and the conventions used in naming
- Know botanical terms related to plant morphology that are used in identifying plants
- Understand how to use a dichotomous key to identify plants

By

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Illustrations by Mrs. Iva Shoup & Edward R. Speck, Jr.

Introduction

The primary purpose of this chapter is to acquaint you with methods of identifying plants and plant materials commonly used for landscape purposes. While most of the principles in plant identification may be botanical in nature, the ultimate objective is to determine the genus and perhaps the species of the plant in question. Once you have identified a plant, then you can determine its characteristics—its cultural requirements, ultimate size, flowering and fruiting requirements, propagation methods, hardiness, problems, etc. When you know the genus and species of a plant, you can identify pathological problems and make diagnoses more easily, efficiently, and with more certainty. You will find that many insect and disease problems are fairly host-specific, that is, they will attack only certain species (sometimes only certain individuals within a species), a certain genus, or only a few genera within a family.

There are many complexities in learning how to identify plants—it requires attention to detail. Scientific plant names are not only hard to pronounce, but very difficult to spell. Further, the terms used to describe the morphological characteristics of plant parts are part of a whole new language. And, the use of plant keys to determine the identity of an unknown plant can at times be frustrating.

In spite of the difficulties, there is a good degree of satisfaction derived from being able to identify plants, especially the less common ones. You can help friends and clients identify their plants and you can impress (and befuddle?) your friends with large words.

Below are listed some of the things to know which will greatly help in identifying plants.

- Plant names: family, genus, species, variety or cultivar, common name(s).
- Leaves: arrangement, type, shape, margin, color, other distinguishing characteristics.
- Buds: location, type, form.
- Flowers: type, color, season of bloom.

Study Tips

The best methods for studying a subject will vary with the individual. The initial step is to learn the principles involved in plant identification.

- Say the genus and species names together many times. Some people benefit by writing the plant names many times together to remember them and get the spelling correct.

- Spend a little time each day reviewing plant information. The names and characteristics should become more familiar with repetition.
- Spend some time just looking at the plants; this makes it a lot easier to identify them.
- Try to learn the meaning of the botanical terms; this will make plant identification much easier. For example, *macrophyllum* = large leaf; *tomentosum* = densely woolly; *sinensis* and *chinensis* = from China; and *douglasii* = named for David Douglas.
- Visit arboreta, nurseries, and garden centers. Plants in these locations are usually labeled correctly. Get an idea of different growth habits, varieties, and what is available.
- Cultivate friends who are knowledgeable on the subject.

Nomenclature

Nomenclature is the naming of things. In botany, derivation of plant names is related to taxonomy, in that each plant's botanical name includes the name of the genus it belongs to.

The International Code of Botanical Nomenclature (ICBN), published by the International Association for Plant Taxonomy, contains the rules and recommendations for official botanical names for plants: http://ibot.sav.sk/icbn/main.htm.

Scientific Names

Scientific name = botanical name = Latin binomial = *Genus species*

Genus species and any cultivar or botanical *variety* name make up the botanical name of a plant. The genus (or generic name) is derived from a Latinized noun and is capitalized. The species name (or specific epithet) is usually a Latin or Greek adjective that describes or further identifies the particular plant of that genus, and is not capitalized. A botanical variety, which is also usually a Latinized or Greek descriptive term, may follow the species name, and is also not capitalized. All three names are italicized, or if not italicized, they are underlined to denote it as a botanical name. Use lower case for species and variety.

Genus, species, and varietal names must be italicized in writing, or underlined if italics are not possible.

Examples:

Kalmia latifolia is the species (mountain laurel).

Kalmia latifolia rubra is the botanical variety (red or pink-flowered mountain laurel).

Kalmia latifolia 'Ostbo Red' is the cultivated variety, selected through breeding.

Pseudotsuga menziesii is the species (Douglas fir).

Terms in plant nomenclature

Species. A uniform population of individuals, distinct from other individuals in terms of predetermined or marked characteristics. There are many definitions of this term. Each species has a unique Latin binomial name consisting of the genus name followed by the species name (the specific epithet).

Variety (Botanical). A fairly consistent natural variation of the species, which will, more or less, breed true.

Cultivated variety or **cultivar (cv.)**. A variation of a species which originated in cultivation and persists under cultivation. Perennial plant cultivars are normally perpetuated by asexual propagation, that is, cuttings, grafting, layering, tissue culture, etc. Cultivars may arise via:

- A chance seedling that is very different.
- Selection of a plant with good traits from a seedling or mature plant group. These traits may not only include the usual aesthetic qualities (flower, fruit, color, etc.) but also factors such as disease/insect resistance, drought tolerance, cold hardiness, plant form, and other attributes.
- A mutation (bud sport).
- Selective breeding and hybridizing.

Clone. An individual plant or plants which have been asexually (vegetatively) propagated from a single individual source or "parent" plant.

Cline. A gradual change in the characteristics of a species over a continuous distance. Example: Plants of a given species at higher elevation are typically not exactly the same as plants in the same species growing at lower elevations. There is a gradual biological change in the plant with the increase in elevation.

Ecotype. Differences in the characteristics of a species at discrete locations in its geographical distribution. Examples are dry site vs. wet site plants, low land plants vs. plants from higher altitudes, plants native to seashore locations vs. the same species found further inland.

Line. An inbred group of plants, with homogeneous genetic material whose seed give very uniform progeny. Lines are usually associated with annual crops, vegetables, and flowers.

Hybrid. Cross between two inbred lines of a species, or, the cross between two species within a genus (interspecific hybrid), or sometimes two genera within a family (intergeneric hybrid). Hybrid vegetable and corn seed are derived from crossing different lines of each particular species.

Pseudotsuga menziesii glauca is the botanical variety (blue Douglas fir).

Pseudotsuga menziesii 'Pendula' is the weeping form of the Douglas fir.

Cultivar names are no longer Latinized, but are usually in the language of the country of origin. They are not italicized, but are set off either by single quotes or preceded by the abbreviation "cv.".

Examples:

Japanese maple 'Sango Kaku' (Japanese), known as 'coral bark' Japanese maple in the U.S.

Willow-leaf cotoneaster 'Herbst Feuer' (German), literally 'autumn fire'.

Red maple 'October Glory' (United States).

Hybrids are denoted by a "×" (cross) before the species name. Interspecific hybrids are a cross between two species within one genus. For instance, *Forsythia ×intermedia* (border forsythia) is the result of a cross between *Forsythia suspensa* (weeping forsythia) and *Forsythia viridissima* (greenstem forsythia).

Sometimes a hybrid will have just a *Genus* ×'Cultivar' name, as in the case of *Rhododendron* ×'PJM'.

An intergeneric or bigeneric hybrid is a cross between two genera, so in its name the × is put before the genus. The new genus name is a combination of the genus names of the two parents.

Examples:

×*Cupressocyparis leylandii*, commonly known as the Leyland cypress. This is *Cupressus macrocarpa* crossed with *Chamaecyparis nootkatensis*.

Mahoberberis, is the result of many crosses between *Mahonia* and *Berberis*.

+*Laburnocytissus adami* is the result of a grafted hybrid: *Laburnum anagyroides* and *Cytissus purpureus*. This intergeneric hybrid occurs above the graft union. Notice the "+" before the generic name.

Botanical names do sometimes change. When a person discovers or originates a new plant, that person gets to give the plant its botanical name by publishing the description and name of the plant in a "scholarly" journal. These journals range from very popular and widely read, to rather obscure. If a plant is found and named in a rather obscure journal, it may not be immediately noticed. That same plant may be "rediscovered" by someone else at a later date, given a different name, and that name published in a very popular, widely read journal. The second name may become the accepted name. But by botanical rules, the first name is the valid name. If someone goes back in the literature and finds the original botanical name, the plant name should revert back to that original botanical name.

As an example, our native Douglas fir has been known as *Pseudotsuga taxifolia* (literally "false hemlock" + foliage like a yew) then as *Pseudotsuga douglasii* (named after David Douglas) and currently as *Pseudotsuga menziesii* (named after Archibald Menzies).

Common Names

Standard botanical names are accepted worldwide. In comparison, common names are regional, vernacular, and confusing. The same common name may refer to many different plants, and conversely, the same plant may be known by many different common names.

Lay people often only know common names, so in any casual writing or oral presentations, common names have to be used. But to avoid confusion in any communication involving the use of plant names, the botanical name should be used at least once when the common name is first mentioned.

Common names do not translate from one language into another, this includes American English into British English and vice versa.

Examples:

- *Tilia* species
  - German—lindens, as in "Unter dem linden"
  - American—lindens
  - English—lime trees
- *Sorbus aucuparia*
  - German—Vogel Beere, literally "bird berry"
  - American—European mountain ash
  - English—rowan

Some species do not have a common name, and are usually called by their generic name. For example, *Idesia polycarpa* (a small, relatively rare, desirable landscape tree) is commonly just called idesia. Other popular plants that are known by their generic name include aster, coleus, forsythia, hibiscus, impatiens, iris, pachysandra, rhododendron, salvia, sedum, verbena, and viburnum.

What's in a name?

"Cedar" is a common name used across several genera.

Thuja plicata, known variously as western red **cedar** and giant arborvitae.

Chameacyparis nootkatensis, known variously as Alaska **cedar** and yellow **cedar**.

Chameacyparis lawsoniana known as Port Orford **cedar** and Lawson's falsecypress.

Chameacyparis thyoides, eastern white **cedar**.

Cedrus spp., commonly known as true **cedars**: atlas **cedar**, deodar **cedar**, **cedar** of Lebanon, etc.

Cryptomeria japonica, known as Japanese **cedar**.

Juniperus virginiana, eastern red **cedar**.

Juniperus scopulorum, western red **cedar**. (Notice the same common name as *Thuja plicata*, which actually is an arborvitae not a juniper.) This is also known as Rocky Mountain **cedar** and Rocky Mountain juniper.

"Ironwood" and "hornbeam" are common names used for several species of trees. Here are two different plants with the same common names, with each also having different names in different regions:

Ostrya virgininana over its range is known variously as ironwood and hornbeam.

Carpinus carolinianum over its range is known as ironwood and hornbeam, but also as blue beech (no relation to true beech).

Diagnostic Plant Morphology

Botanists use visible plant characteristics that can be described, measured, and compared to assess a plant for identification and classification purposes. There are many diagnostic characteristics, including such features as leaf form (Figure 1), arrangements of leaves on a stem, flower types, flower forms and arrangement, and stem shape. Sometimes a certain characteristic is diagnostic for a plant family, such as square stems in the mint family.

Identification Keys

Keys are tools for identifying an unknown. They may be used to identify an individual entity, given a large number of possibilities. There are several types of identification keys. For instance, a random access key asks numerous specific questions about the plant in question and presents a list of possible answers. An online random access key, sponsored by the Burke Museum of

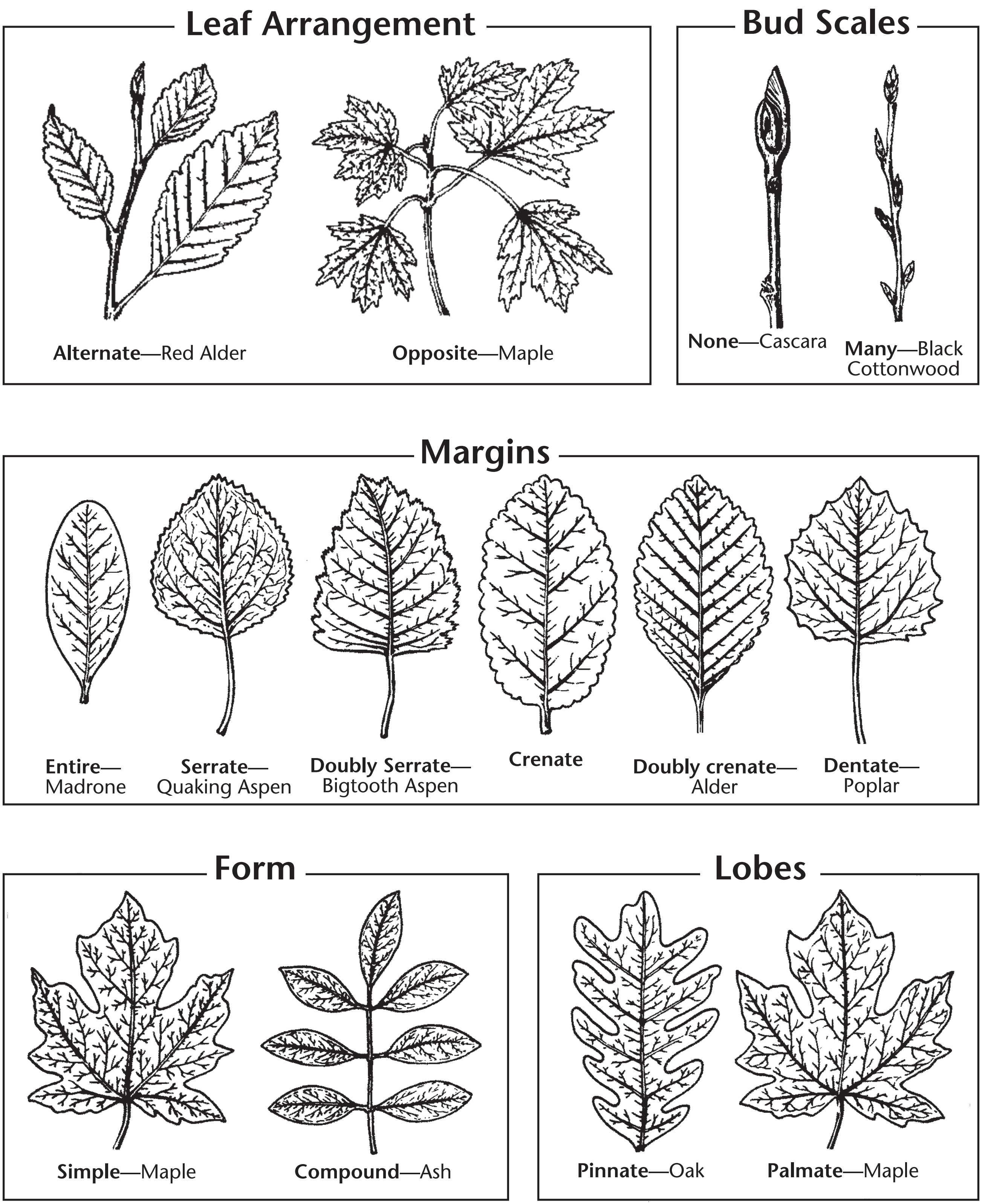

Figure 1. Distinguishing leaf characteristics and terms. (From Trees of Washington, EB0440. http://cru.cahe.wsu.edu/CEPublications/eb0440/eb0440.pdf.)

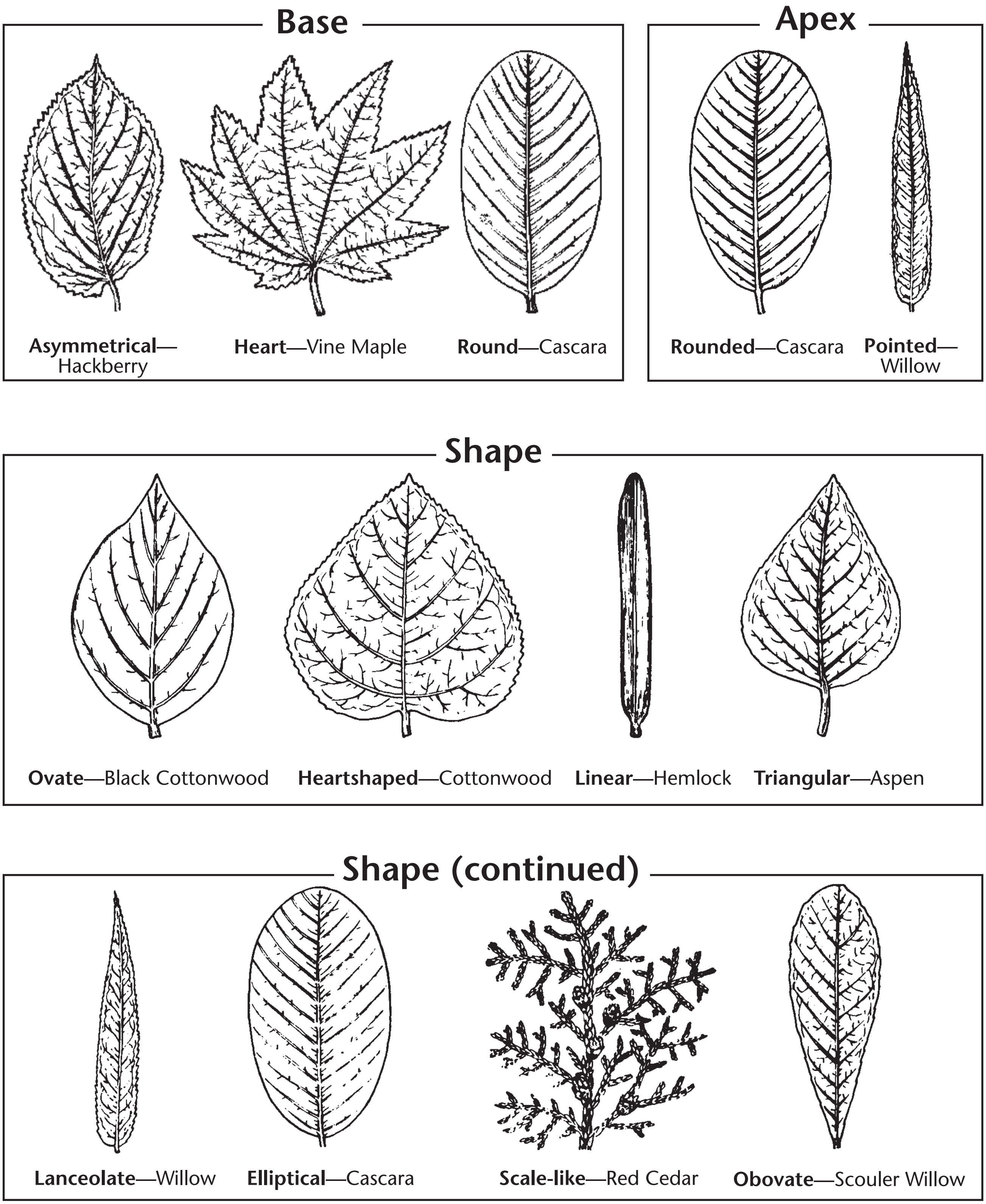

Figure 1 continued. Distinguishing leaf characteristics and terms. (From Trees of Washington, EB0440. http://cru.cahe.wsu.edu/CEPublications/eb0440/eb0440.pdf.)

Natural History and Culture at the University of Washington, can be found at http://biology.burke.washington.edu/herbarium/imagecollection.php?Page=plantkey.php.

Probably the most common type of identification key is the dichotomous key, wherein you must choose between two contradictory descriptive statements, called leads, accepting one and rejecting the other (both cannot be true of the specimen in question). These contradictory sets are called couplets.

Each couplet starts with the same word characteristic of the plant such as leaves, inflorescences, flowers, buds, fruit, or some other morphological characteristic. The user must choose which lead fits the plant in question. The user must then consider the next couplet, then the next, and so on, until the plant is keyed out. Keys and their couplets may be either numbered or lettered. A dichotomous key for identifying trees can be found on line at http://oregonstate.edu/trees/dichotomous_key.html.

An Identification Key

This is a very simple key used to distinguish 8 evergreen plants.

1. Leaves opposite
    2. Leaves mostly less than 1 5/8 inch
        3. Leaf margins toothed
            4. Leaf margins spiny toothed (dentate)
                Osmanthus delavayi, Delavey's osmanthus
            4. Leaf margins crenate
                Euonymus fortune, creeping euonymus
        3. Leaf margins entire
            Buxus sempervirens, boxwood
    2. Leaves more than 1 5/8 inch
        Viburnum davidii, David viburnum
1. Leaves alternate
    5. Leaves mostly less than 2 3/8 inch
        6. Stems armed (thorny)
            Pyracantha sp., firethorn
        6. Stems not armed
            7. Leaves oblanceolate
                Pieris japonica, Japanese andromeda
            7. Leaves ovate
                Vaccinium ovatum, evergreen huckleberry
    5. Leaves greater than 2 3/8 inch
        8. Leaves ovate
            Prunus lusitanica, Portuguese laurel
        8. Leaves obovate
            Prunus laurocerasus, cherry (English) laurel

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3

Soil Science

Topics covered:

Soil Profiles
Soil, Water, and Productivity
Water Management in Your Garden
Soil Organisms
Soil Nutrients
Soil Tests
Soil pH
Soil Salinity
Mulch

Learning Objectives

- Know the physical and biological properties of soil, related to plant growth and development.

By

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Soil is a mixture of weathered rock fragments and organic matter at the earth's surface. It is biologically active—a home to countless microorganisms, invertebrates, and plant roots. It varies in depth from a few inches to 5 feet or more. Soil is roughly 50 percent pore space. This space forms a complex network of pores of varying sizes, much like those in a sponge.

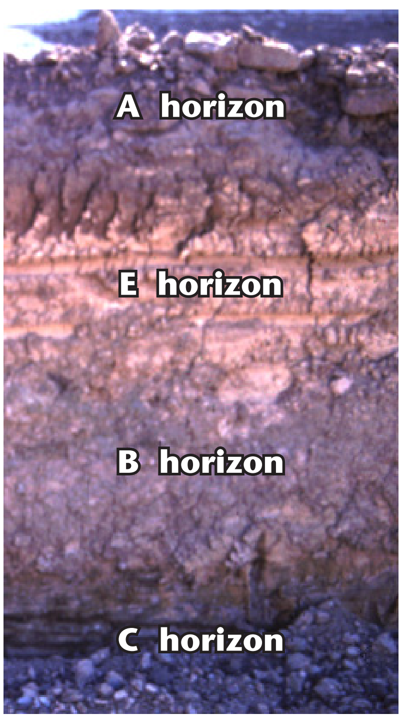
Soil provides nutrients, water, and physical support for plants as well as air for plant roots. Soil organisms are nature's primary recyclers, turning dead cells and tissue into nutrients, energy, carbon dioxide, and water to fuel new life.

Soil Profiles

In a natural environment, soils are composed of several layers, or **soil horizons**, in a **profile** (see Figure 1). Horizons form as a result of four main processes:

- additions of material to the soil,
- losses of materials from the profile,
- transformations of mineral and organic matter within the soil, and
- translocations (vertical movement) of materials within the profile.

Figure 1. A soil profile showing typical soil horizons. Not all horizons are present in all soil profiles.



Layers within a soil profile are defined by the material within the layer and denoted by the letters A, E, B, and C.

The surface layer (the A horizon) is usually darker than the subsurface layers (the E, B, and C horizons) and is a zone of **eluviation** or natural loss of material. Organic matter gives the A horizon its characteristic dark color while enhancing desirable physical properties such as tilth (ease of tillage), structure, water infiltration, and water-holding capacity. Topsoil is defined as the A horizon only.

The E, B, and C horizons are the subsoil. Subsoil horizons commonly have higher levels of clay, salts and lime, and lower levels of organic matter, than topsoil. These features make subsoil a poor substitute for topsoil.

The E horizon is another zone of eluviation; it is a subsoil layer from which most of the mineral and/or organic material has been leached. The E horizon is typically lighter colored than the underlying B horizon, and contains primarily sand and silt particles. The B horizon is a zone of illuviation, where downward moving material (especially finer particles) accumulates. The C horizon is unconsolidated "parent material" from which the soil above has developed.

Soil, water, and productivity

A productive soil is permeable to water and is able to supply water to plants. A soil's permeability and water-holding capacity depend on its porosity, or network of pores:

- **Macropores** are relatively large pores or channel ways through the soil that control a soil's permeability and aeration. Macropores include earthworm and root channels. Because macropores are large, water moves through them rapidly by gravity. Thus, rainfall and irrigation infiltrate into the soil and excess water drains through it.
- **Micropores** are small, or fine, soil pores, typically a fraction of a millimeter in diameter. They are responsible for a soil's water-holding capacity. Like the fine pores in a sponge or towel, micropores hold water against the force of gravity. Much of the water held in micropores is available to plants, while some is held so tightly that plant roots cannot use it.

Soil that has a balance of macropores and micropores provides adequate permeability and water-holding capacity for good plant growth. Soils that contain mostly macropores drain readily, but need more frequent irrigation. Soils that contain mostly micropores have good water-holding capacity, but take longer to dry out and warm up in the spring. Runoff of rainfall and irrigation water also is more likely on these soils.

Several soil properties affect porosity, including texture, structure, compaction, and organic matter. You can evaluate your garden soil with respect to these properties to understand how they affect your soil's porosity. The only tools you need are your eyes and fingers and a shovel.

Soil texture

Texture describes how coarse or fine a soil is. The coarsest soil particles are sand. They are visible to the eye and give soil a gritty feel. Silt particles are smaller than sand—about the size of individual particles of white flour. They give soil a smooth, floury feel. On close inspection, sand and silt particles look like miniature rocks (Figure 2).

Clay particles are the smallest—about the size of bacteria and viruses—and can be seen only with a microscope. They typically have a flat shape, similar to a sheet of mica. Soils rich in clay feel very hard when dry, but are easily shaped and molded when moist.

Although all of these particles seem small, the relative difference in their sizes is quite large. If a typical clay particle were the size of a penny, a sand particle would be as large as a house.

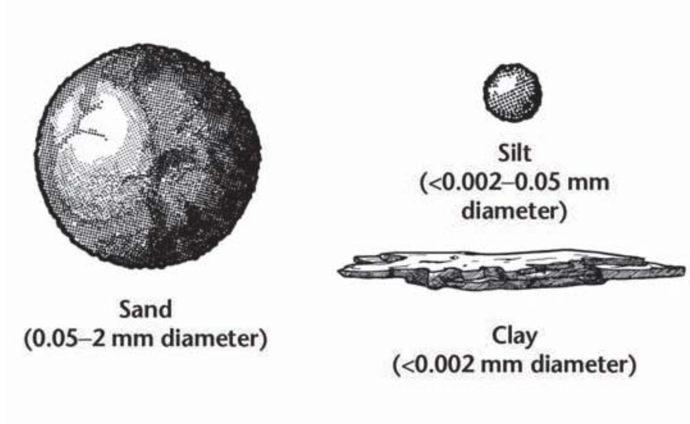


Figure 2. General shapes of soil particles (not drawn to scale).

Soil texture directly affects porosity. Pores between sand particles tend to be large, while those between silt and clay particles tend to be small. Thus, sandy soils contain mostly macropores and usually have high **permeability** with rapid water flow-through but limited water-holding capacity. Micropores predominate in soils containing mostly silt and clay, creating high water-holding capacity, but reducing permeability.

Particle size also affects the **surface area** in a volume of soil. Surface area is important because particle surfaces are the most active part of the soil. They hold plant nutrients, bind contaminants, and provide a home for microorganisms. Clay particles have a large surface area relative to their volume, and a small amount of clay makes a large contribution to a soil's surface area.

Nearly all soils contain a mixture of particle sizes and have a pore network containing a mixture of pore sizes. A soil with roughly equal influence from sand, silt, and clay particles is called a loam (Figure 3). Loams usually make good agricultural and garden soils because they have a balance of macropores and micropores. Thus, they usually have good water-holding capacity and moderate permeability.

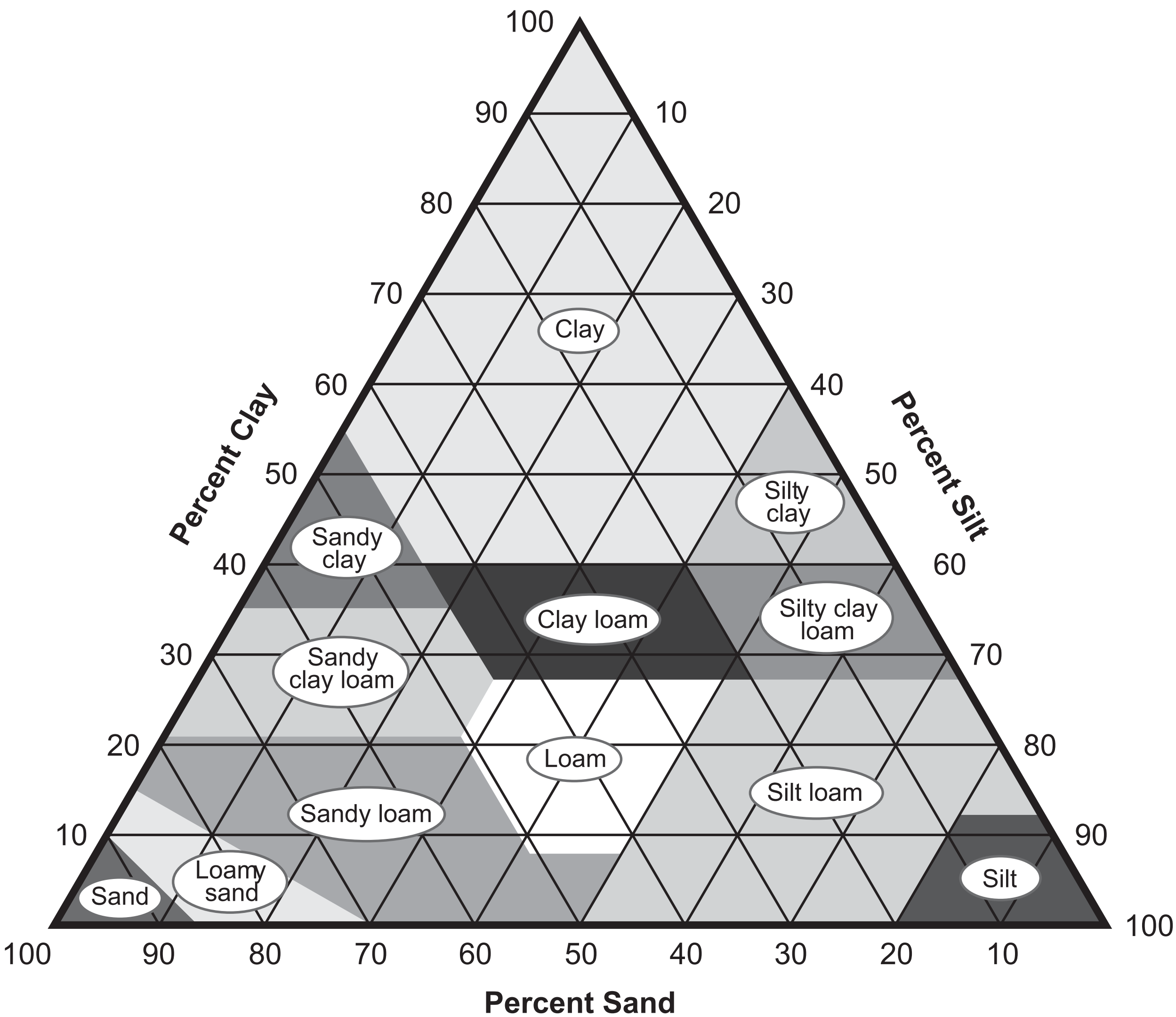
A sandy loam is similar to a loam, except that it contains more sand. It feels gritty, yet has enough silt and clay to hold together in your hand. Sandy loams usually have low to moderate water-holding capacity and good permeability.

Silt loams are richer in silt and feel smooth rather than gritty. They are pliable when moist, but not very sticky. Silt loams usually have high water-holding capacity and low to moderate permeability.

Clays and clay loams are very hard when dry, sticky when wet, and can be molded into wires and ribbons when moist. They generally have high water-holding capacity and low permeability.

Almost any texture of soil can be suitable for gardening, as long as you are aware of the soil's limitations and adjust your

Figure 3. Soil classification chart showing the percentages of sand, silt, and clay in the basic soil textural classes.



management to compensate. Clay soils hold a lot of water, but are hard to dig and they dry slowly in the spring. Sandy soils need more frequent watering and lighter, more frequent fertilization, but you can plant them earlier in the spring. All soils can benefit from additions of organic matter, as described in Chapter 5: Plant Mineral Nutrition and Fertilizers.

Many soils contain coarse fragments, such as gravel and larger rocks. Coarse fragments do not contribute to a soil's productivity and can be a nuisance when you are digging. Don't feel compelled to remove them all from your garden, however. Coarse fragments aren't harmful, and your time is better spent doing other gardening tasks. The only time rocks are a problem is when you have nothing but rocks on your land. Then, water- and nutrient-holding capacities are so low that it is difficult to grow healthy plants.

Soil structure

Individual particles of sand, silt, and clay tend to cluster and bind together, forming aggregates called **peds,** which provide structure to a soil. Dig up a piece of grass sod and examine the soil around the roots. The granules of soil clinging to the roots are examples of peds. They contain sand, silt, clay, and organic matter.

Aggregation is a natural process caused largely by biological activity such as earthworm burrowing, root growth, and microbial action. Soil organic matter is an important binding agent that stabilizes and strengthens peds.

The spaces *between* peds are macropores, which improve permeability, drainage, and recharge of air into the soil profile. The pores *within* peds are predominantly micropores, contributing to the soil's water-holding capacity. A well-structured soil is like a sponge, allowing water to enter and soak into the micropores and letting excess water drain downward through the macropores. Good structure is especially important in medium- to fine-textured soils, because it increases the soil's macroporosity, thus improving permeability and drainage.

Figure 4. Compacted soil resists root penetration and water movement.

Compaction and loss of structure

Soil structure is fragile and can be damaged or destroyed by compaction, excessive tillage, or tillage when the soil is too wet. Loss of organic matter also weakens structure.

Compaction squeezes macropores into micropores and creates horizontal aggregates that resist root penetration and water movement (Figure 4). Compaction often occurs during site preparation or house construction, creating a difficult environment for establishing plants. Protect your soil from compaction by avoiding unnecessary foot or machine traffic.

Tilling when soil is too wet also damages soil structure. If you can mold a piece of soil into a wire or worm in your hand, it is too wet to till. If the soil crumbles when you try to mold it, it is dry enough to till.

Structural damage caused by human activity usually is most severe within the top foot of soil and can be overcome by proper soil management. In some soils, there is deeper compaction resulting from pressure from ancient glaciers. Glacially compacted subsoils (a type of hardpan) are common in the Puget Sound area, where the compacted layer often begins 18 to 36 inches below the soil surface. Where the land surface has been cut, leveled, or shaped for development, the compacted layer may be much closer to the surface. This layer looks like concrete and is so dense and thick that it is nearly impossible to work with. If your garden has a glacially compacted layer close to the soil surface, consider using raised beds to increase soil depth.

Organic matter

Adding organic matter is the best way to improve the environment for plants in most soils. Organic matter helps build and stabilize structure in fine-textured and compacted soils, thus improving permeability and aeration and reducing the risk of runoff and erosion. When organic matter decomposes, it forms humus, which acts as a natural glue to bind and strengthen soil aggregates. Organic matter also helps sandy soils hold water and nutrients. See “Adding organic matter” in Chapter 5: Plant Mineral Nutrition and Fertilizers for information on amending soil with organic matter.

Slope, aspect, depth, and water

Slope, aspect (direction of exposure), and soil depth (thickness) affect water availability and use in a soil. Choose plants that are best suited to conditions on your property.

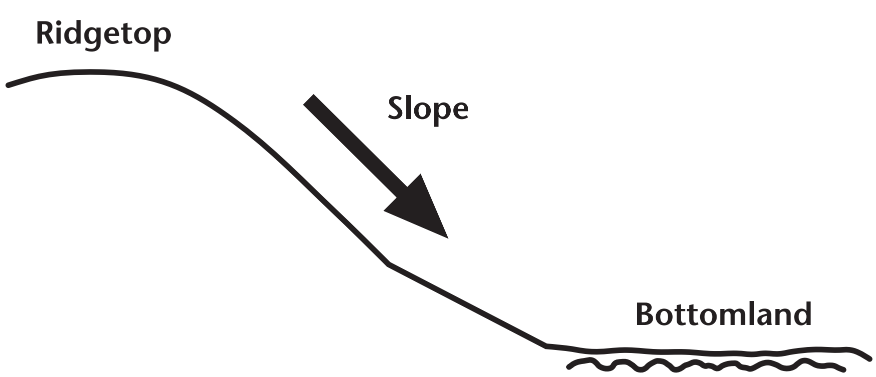
Choose plants that are best suited to conditions on your property.

Ridgetops and side slopes tend to shed water, while soils at the bottoms of slopes and in low areas collect water (Figure 5). Often, soils that collect water have high winter water tables, which can affect the health of some plants. Soils on ridgetops are more likely to be “droughty.”

Site aspect also is important. South- and southwest-facing exposures collect the most heat and use the most water.

Soil depth affects water availability by determining the rooting zone. Soil depth is limited by compacted, cemented, or gravelly

Figure 5. Ridgetops and slopes tend to shed water, while soils at the bottoms of slopes and in low areas collect water.



layers, or by bedrock. A shallow soil has less available water simply because the soil volume available to roots is smaller. Dig below the topsoil in your garden. The deeper you can dig before hitting a restrictive layer, the greater the soil volume for holding water.

Water management in your garden

Soils and irrigation

Most gardens in the Northwest require summer irrigation. The need for irrigation varies, depending on soil water-holding capacity, weather, site aspect, the plants grown, and their growth stage.

In most cases, the goal of irrigation is to recharge the available water in the top foot or so of soil. For sandy soil, 1 inch of irrigation water is all you need. Any more will leach (move downward) through the root zone, carrying nutrients with it. A silt loam or clay soil can hold more than 2 inches of water, but you may need to irrigate more slowly to prevent runoff.

Wet soils

If your soil stays wet in the spring, you will have to delay tilling and planting. Working wet soil can damage its structure, and seeds are less likely to germinate in cold, wet soil.

Some plants don’t grow well in wet soil. Raspberries, for example, often become infected by root diseases in wet soil and lose vigor and productivity.

A soil’s color gives clues to its tendency to stay wet. If a subsoil is brown or reddish, the soil probably is well drained and has few wetness problems. Gray subsoils, especially those with brightly colored mottles, often are wet. If your soil is gray and mottled directly beneath the topsoil, it probably is saturated during the wet season.

Sometimes, simple actions can reduce soil wetness problems. For example:

- Divert runoff from roof drains away from your garden.
- Avoid plants that perform poorly in wet conditions.
- Use raised beds for perennials that require well-drained soil and for early-season vegetables.
- Investigate whether a drain on a slope will remove excess water in your situation. When considering drainage, make sure there is a place for the water to go. Installing drainage can be expensive, however, and may require a permit.

Check with local regulatory agencies to see whether there are restrictions on the project.

- Consider installing a rain garden. See Rain Garden Handbook for Western Washington Homeowners, at http://www.pierce.wsu.edu/Lid/raingarden/Raingarden_handbook.pdf for more information.

Soil organisms

Soil abounds with life. Besides the plant roots, earthworms, insects, and other creatures you can see, soil is home to an abundant and diverse population of microorganisms. A single gram of topsoil (about 1⁄4 teaspoon) can contain as many as a billion microorganisms (Table 1). Microorganisms are most abundant in the **rhizosphere**—the thin layer of soil surrounding plant roots.

Table1. Approximate quantities of microorganisms in agricultural topsoil.

Organism	Number per gram (dry weight basis)
Bacteria	100 million to 1 billion
Actinomycetes	10 million to 100 million
Fungi	100,000 to 1 million
Algae	10,000 to 100,000
Protozoa	10,000 to 100,000
Nematodes	10 to 100

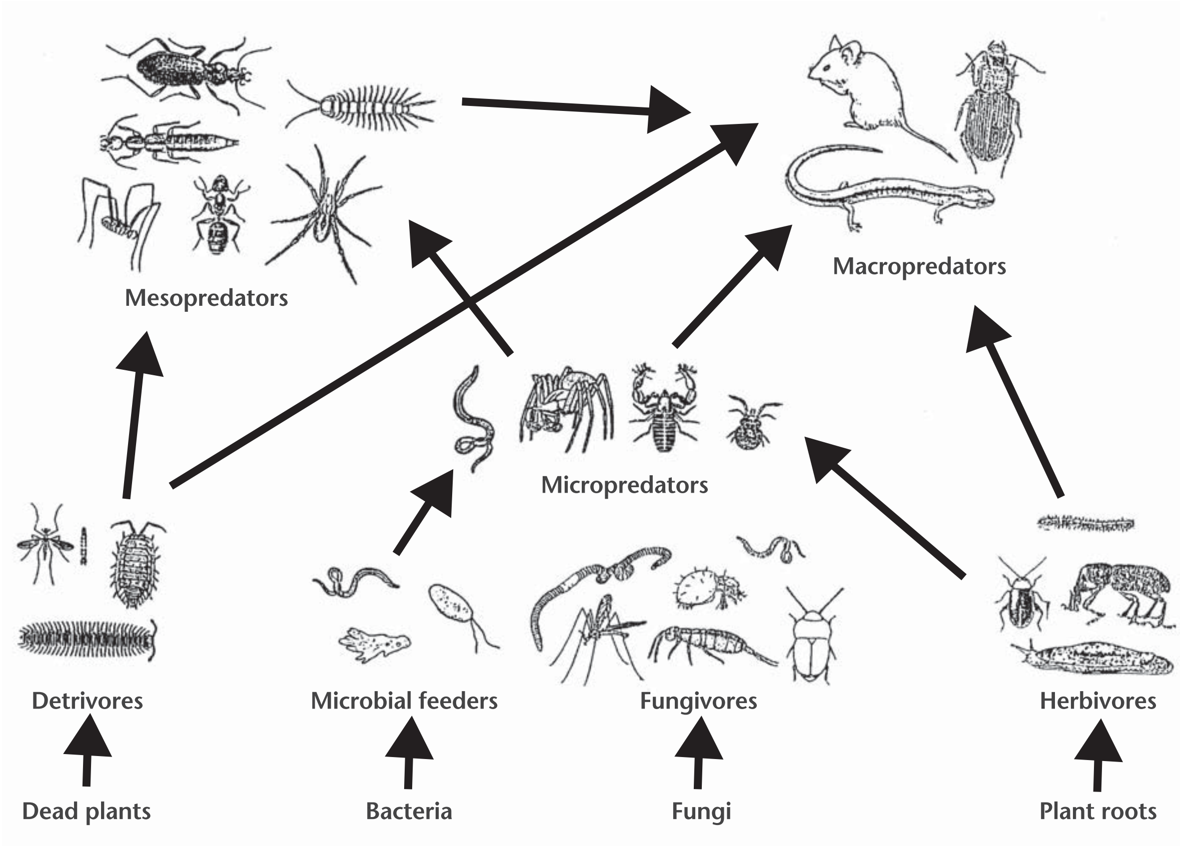
The main function of soil organisms is to break down the remains of plants and other organisms. This process releases energy, nutrients, and carbon dioxide, and creates soil organic matter.

Organisms ranging from tiny bacteria to insects and earthworms take part in a complex soil food web (Figure 6). Mammals such as moles and voles also are part of the food web, feeding on insects and earthworms.

Some soil organisms play other beneficial roles. Mycorrhizae are fungi that inhabit plant roots and increase roots' ability to take up nutrients from the soil. Rhizobia and *Frankia* bacteria are two of the bacteria responsible for converting atmospheric nitrogen to plant-available forms, a process known as **nitrogen fixation**. Earthworms mix large volumes of soil and create macropore channels that improve permeability and aeration (Figure 7).

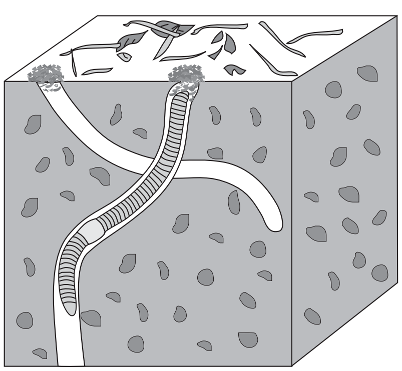
Not all soil organisms are beneficial to garden plants. Some are pathogens that cause diseases such as root rot of raspberries and scab on potatoes. Moles can damage crops and lawns, and slugs are a serious pest in many Northwest gardens.

Figure 6. The soil food web.



The activity of soil organisms depends on soil moisture and temperature, as well as on the soil's organic matter content. Microorganisms are most active when soil temperatures are between 70° and 100°F, while earthworms are most active and abundant at about 50°F. Most organisms prefer moist soil. Because organic matter is at the base of the soil food web, soils with more organic matter tend to have more organisms.

Figure 7. Earthworm channels create macropores which improve a soil's permeability and aeration.



The relationships between gardening practices, microbial populations, and soil quality are complex and often poorly understood. Almost all gardening activities—including tillage; the use of fertilizers, manures, and pesticides; and the choice of crop rotations—affect the population and diversity of soil organisms. For example, amending soils with organic matter, returning crop residues to the soil, and rotating plantings tend to increase the number and diversity of beneficial organisms.

Soil nutrients

Soil supplies 14 essential plant nutrients. Each nutrient plays one or more specific roles in plants. Nitrogen, for example, is a component of chlorophyll, amino acids, proteins, DNA, and many plant hormones. It plays a vital role in nearly all aspects of plant growth and development, and plants need a large amount of nitrogen to grow well. In contrast, plants need only a tiny amount of molybdenum, which is involved in the functioning of just a few plant enzymes. Molybdenum nonetheless is essential, and plant growth is disrupted if it is deficient. Plants also require carbon, hydrogen, and oxygen, which they derive from water and air, so these elements are not considered nutrients.

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A soil nutrient is classified as a **primary nutrient**, **secondary nutrient**, or **micronutrient**, based on the amount needed by plants in general (Table 2). If a soil's nutrient supply is deficient, fertilizers can provide the additional nutrients needed for healthy plant growth.

Table 2. Essential plant nutrients.

Name	Chemical symbol
Primary nutrients	
Nitrogen	N
Phosphorus	P
Potassium	K
Secondary nutrients	
Sulfur	S
Calcium	Ca
Magnesium	Mg
Micronutrients	
Zinc	Zn
Iron	Fe
Copper	Cu
Manganese	Mn
Boron	B
Molybdenum	Mo
Chlorine	Cl
Nickel	Ni

Nutrient deficiencies

The most common nutrient deficiencies are for primary nutrients—N, P, and K—which are in largest demand by plants. Nearly all soils lack enough available N for annual crops, gardens, and lawns.

Secondary nutrients also are deficient in some soils in the Pacific Northwest. For instance, sulfur deficiencies are common west of the Cascades. Calcium and magnesium may be deficient in acid soils, also typically west of the Cascades.

Except for boron and zinc, micronutrients rarely are deficient in the Northwest. Boron deficiencies occur most often west of the Cascades, particularly in root crops, brassica crops (such as broccoli), and caneberries. Zinc deficiency usually is associated with high pH soils and most often affects tree fruits.

Each nutrient deficiency causes characteristic symptoms. In addition, affected plants grow more slowly, yield less, and are less healthy than plants with adequate levels of nutrients. See Chapter 5: Plant Mineral Nutrition and Fertilizers for more information on plant nutrient deficiencies.

Excess nutrients

Excess nutrients can be a problem for plants and for the environment. Excesses usually result because too much of a nutrient is applied or because a nutrient is applied at the wrong time.

Too much boron is toxic to plants. Too much nitrogen can lead to excessive foliage production, increasing the risk of disease; wind damage; and delayed flowering, fruiting, and dormancy. Available nitrogen left in the soil at the end of the growing season can leach into ground water and threaten drinking water quality.

The key to applying fertilizers is to meet plant needs without creating excesses that can harm plants or the environment.

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Nutrient availability to plants

Plants can take up only nutrients that are in solution (dissolved in water). Most soil nutrients are not in solution; they are tied up in soil minerals and organic matter in insoluble forms. These nutrients become available to plants only after they are converted to soluble forms and dissolve into the soil water.

This process occurs through weathering of minerals and biological decomposition of organic matter. Weathering of minerals is a very slow process that releases small amounts of nutrients each year. The rate of nutrient release from soil organic matter is somewhat faster and depends on the amount of biological activity in the soil.

Nutrient release from soil organic matter is fastest in warm, moist soil and nearly nonexistent in cold or dry soil. Thus, the seasonal pattern of nutrient release is similar to the pattern of nutrient uptake by plants. About 1 to 4 percent of the nutrients in soil organic matter are released in soluble form each year.

Soluble, available nutrients are in ionic form. An ion is an atom or molecule with either a positive or negative charge. Positively charged ions are **cations**, and negatively charged ions are **anions**. Potassium (K^+), calcium (Ca^{+2}), and magnesium (Mg^{+2}) are examples of cations. Chloride (Cl^-) is an example of an anion.

Clay particles and soil organic matter have negative charges on their surfaces and can attract cations. They hold nutrient cations in a ready reserve form that can be released rapidly into soil solution to replace nutrients taken up by plant roots. This reserve supply of nutrients contributes to a soil's fertility. A soil's capacity to hold cations is called its **cation exchange capacity** or CEC.

The nitrogen cycle

Managing nitrogen is a key part of growing a productive and environmentally friendly garden. Nitrogen is the nutrient needed in the largest amount by plants, but excess nitrogen can harm plants and degrade water quality. Understanding how the nitrogen cycle affects nitrogen availability can help you become a better nutrient manager (Figure 8).

Managing nitrogen is a key part of growing a productive and environmentally friendly garden.

Nitrogen is found in four different forms in the soil (Table 3). Only two of them—ammonium and nitrate—can be used directly by plants.

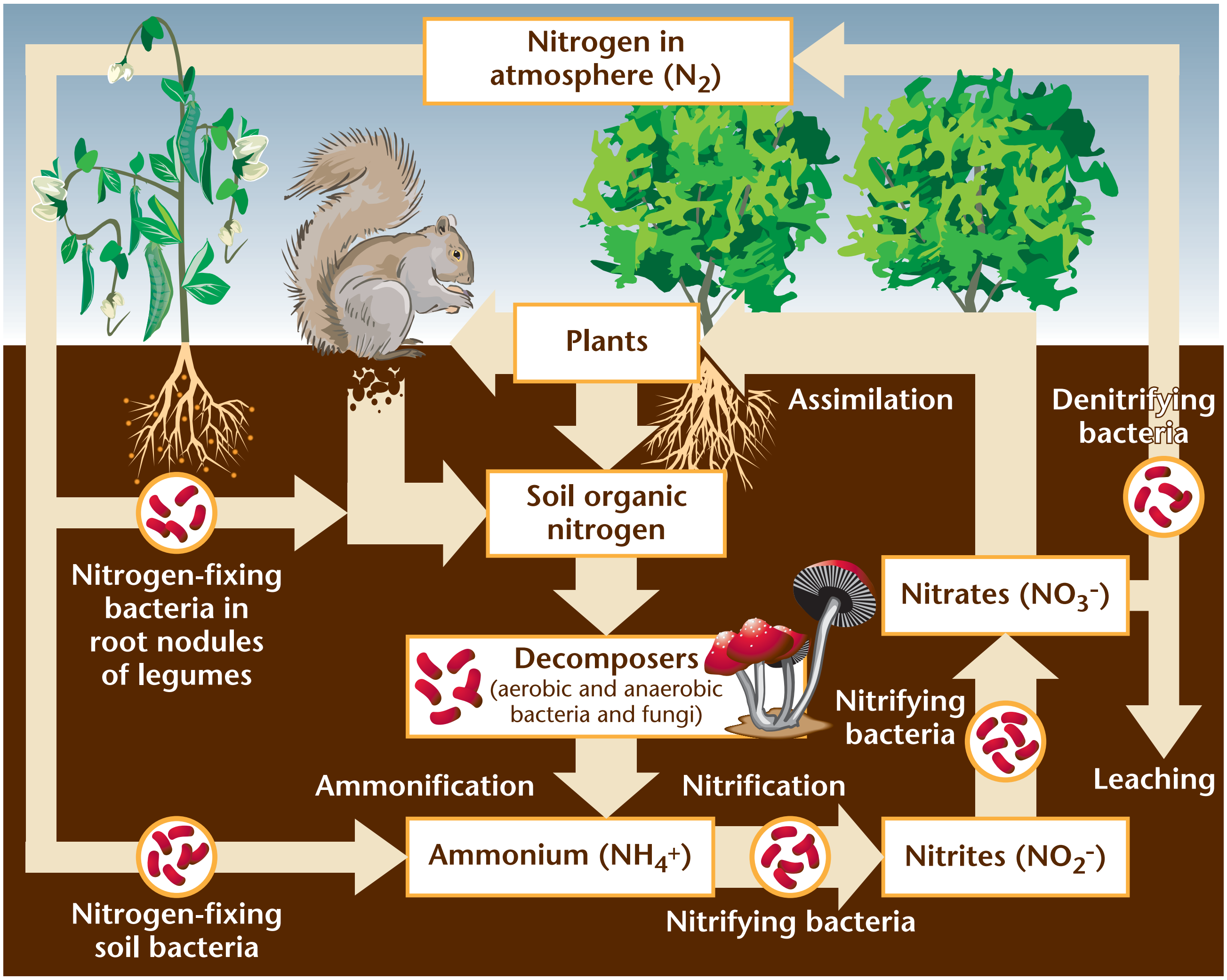
Most nitrogen in soil is tied up in organic matter in forms such as humus and proteins. This organic nitrogen is not available to plants. As soil warms in the spring, soil microbes begin breaking down organic matter, releasing some of the nitrogen as ammonium (NH_4^+). Ammonium is a soluble ion that is available to plants and soil microbes. When the soil is warm, microbes called **nitrifiers** convert the ammonium to nitrate (NO_3^-). Nitrate also is soluble and available to plants. The ammonium and nitrate ions released from soil organic matter are the same as the ammonium and nitrate contained in processed fertilizers.

Because nitrate has a negative charge, it is not held to the surface of clay or organic matter, so it can be lost readily by leaching. Nitrate remaining in the soil at the end of the growing season will leach during the fall and winter and may reach groundwater, where it becomes a contaminant. In soils that are saturated during the wet season, soil microbes convert nitrate to nitrogen gases, which diffuse back into the atmosphere.

Table 3. Common forms of nitrogen in soil.

Form of nitrogen	Characteristics
Organic N	Primary form of N in soil. Found in proteins, lignin, amino acids, humus, etc. Not available to plants. Mineralized to ammonium by soil microorganisms.
Ammonium N (NH_4^+)	Inorganic, soluble form. Available to plants. Converted to nitrate by soil microorganisms.
Nitrate (NO_3^-)	Inorganic, soluble form. Available to plants. Can be lost by leaching. Converted to gases in wet soils.
Atmospheric N (N_2)	Makes up about 80 percent of the earth's atmosphere. Source of N for N-fixing plants (legumes). Not available to other plants.

Figure 8. The Nitrogen Cycle: Legumes, soil organic matter, crop residues, and organic additions such as manure and compost are sources of nitrogen in the soil. That nitrogen is turned by soil microbes into ammonium (NH_4^+). Commercial fertilizer also adds nitrogen to the soil as ammonium or nitrate (NO_3^-). In the soil, microbes process the ammonium to nitrite (NO_2^-)and then nitrate which is, in turn, taken up by plants, leached into ground water, or released as gaseous nitrogen into the atmosphere. Harvesting plants removes their nitrogen from the system. Plant residues return some nitrogen back to the soil. Adapted from the EPA.



Ammonium and nitrate taken up by plants are converted into plant tissue. When plant residues are returned to the soil, they decompose, slowly releasing nitrogen back into available forms.

The nitrogen cycle is a leaky one, with losses to leaching and to the atmosphere. Harvesting crops also removes nitrogen. To maintain an adequate nitrogen supply, nitrogen must be added back into the system through fixation or fertilization.

Nitrogen fixation, or "fixing nitrogen," is a natural process involving certain plants and nitrogen fixing bacteria such as *Rhizobium spp.* ("Rhizobia") and *Frankia spp* ("Frankia"). The bacteria form nodules in the plant roots, and through these nodules they are able to take atmospheric nitrogen (N_2 gas) from air within the soil profile and convert it to available N within the plant. The plants supply the bacteria with energy and nutrients. Legumes such as peas, beans, alfalfa, clover, and Scotch broom fix nitrogen using Rhizobia. Alder trees fix nitrogen with *Frankia.* Growing legumes as a cover crop will supply nitrogen to future crops.

Fertilizers supplement a soil's native nutrient supply. They are essential to good plant growth when the soil nutrient supply is inadequate. Rapidly growing plants such as annual vegetable crops generally need more nutrients than slowly growing plants such as established perennials.

Soil tests

Soil test results give information on the levels of nutrients in your soil and recommend how much fertilizer or other amendment to add each year based on the test results and the crops you grow. You don't need to test your soil every year; every three to five years is often enough.

A garden soil test typically analyzes for the following nutrients: phosphorus, potassium, calcium, magnesium, and boron. The test report also includes soil pH and, based on the results, recommends lime if needed to raise pH or sulfur if needed to lower pH. In arid areas, a test for soluble salts can be worthwhile.

Soil test labs don't routinely test for nitrogen, because there is no simple way to predict nitrogen availability. The lab will give a general nitrogen recommendation, however, based on the plants you are growing and on information you provide about the soil (such as whether there is a history of manure applications, which would increase soil-available nitrogen).

Soil sampling. To take a soil sample, first collect subsamples from at least 10 different spots in your garden. Avoid any unusual areas, such as the site of an old trash dump, burn pile, or rabbit hutch. Sample the top foot of soil (0- to 12-inch depth). Air-dry the samples and mix them together well. Send about a pint of the mixed sample to the lab.

Because management and fertilizer recommendations vary for different crops such as vegetables, lawns, and berries, send separate samples for each area.

Washington State University and Oregon State University do not test soils, but private labs in both states do. WSU Extension and OSU Extension Service county offices have lists of testing labs. Before choosing a lab, call to make sure they test and make recommendations for garden soils. Ask the lab:

- Do you routinely test garden soils for plant nutrients and pH?
- Do you use WSU or OSU test methods and fertilizer guides?
- Do you give recommendations for garden fertilizer applications?
- Are there forms to fill out? What information do you need?
- How much does a test cost?
- How quickly will you send results?

You can estimate fertilizer needs using Extension publications. These publications usually give recommendations for processed fertilizers, but some give guidelines for organic fertilizers as well. Oregon State University and Washington State University have published fertilizer recommendations for a variety of crops. Typical Extension recommendations are for 2 lb of nitrogen per 1,000 square feet of garden, usually applied in a mixed fertilizer with a 1:1:1 ratio. Gardens with a history of fertilizer application may need less phosphorus and potassium than these rates supply. Fast-growing crops such as sweet corn need more nitrogen. (See Chapter 5 for an in-depth discussion of fertilizers and Chapter 22 for details on making and using compost.)

Soil pH

Soil pH is the measure of the acidity or alkalinity of a soil. At a pH of 7 (neutral), acidity and alkalinity are balanced. Acidity increases by a factor of 10 with each one-unit drop in pH below 7. For example, a pH of 5.5 is 10 times as acidic as a pH of 6.5. Alkalinity increases by a factor of 10 with each one-unit increase in pH above 7.

Native soil pH depends both on the minerals present in the soil and on rainfall. Soils in rainy areas tend to be acid, and soils in arid areas tend to be alkaline. Soils in Washington range from highly acidic in coastal areas with high rainfall and organic matter levels, to highly alkaline in the Columbia Basin where arid (low rainfall) conditions and the presence of free lime in the soil buffers pH at values above 8. Human activities such as gardening and farming also affect soil pH. For instance, certain fertilizers, especially acidic forms of nitrogen, tend to reduce soil pH, while lime increases soil pH.

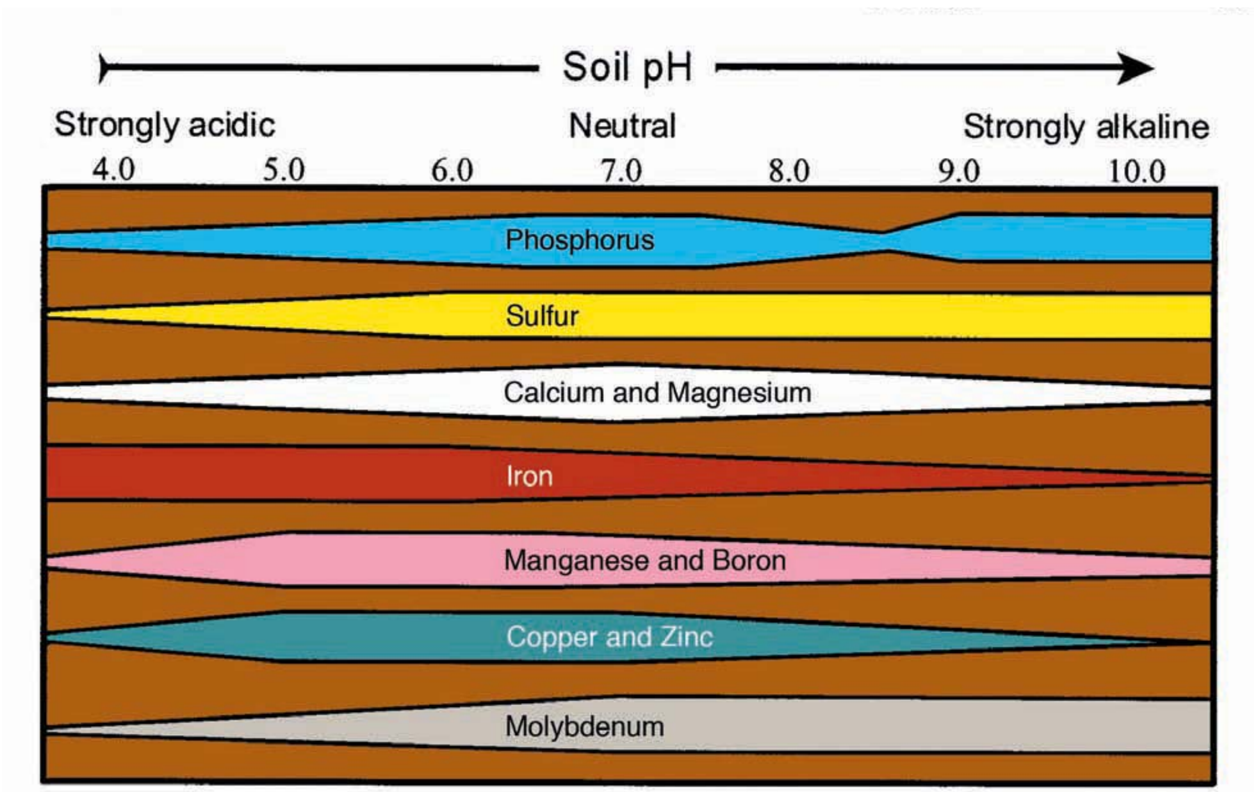
Soil pH influences plant growth in three ways.

1. It affects availability of plant nutrients (Figure 9).
2. It affects availability of toxic metals.
3. It affects the activity of soil microorganisms, which in turn affects nutrient cycling and disease risk.

With plant nutrients, for example, the availability of phosphorus decreases in acid soils, while the availability of iron increases. In alkaline soils, the availability of iron and zinc can be quite low. (See Figure 9.)

Aluminum availability increases in acid soils. Aluminum is one of the most common elements in soil, but it is not a plant nutrient and is toxic to plants in high concentrations. As pH declines and aluminum availability increases, aluminum toxicity can become a problem.

Figure 9. The influence of pH on nutrient availability in soil. Wider parts of the bar indicate greater availability of the nutrient.



Soil organisms such as microbes also are affected by soil pH. The most numerous and diverse microbial populations exist in the middle of the pH range, that is, at or near neutral conditions. Fewer organisms are adapted to strongly acid or strongly alkaline soils. Nutrient cycling is slower in acid and alkaline soils because of reduced microbial populations.

Many garden plants and crops perform best in soil with pH of 5.5 to 7.5, but some (such as blueberries and rhododendrons) are adapted to more strongly acid soils. Before amending soil to adjust pH, it is important to know the preferred pH ranges of your plants. Table 4 shows optimum pH ranges for common garden and landscape plants.

Table 4.—Soil pH adaptation of some common garden and landscape plants.

Neutral-alkaline (7.0 to 8.0)	Asparagus Beets Cabbage Cauliflower Celery	Carrot Lettuce Parsley Spinach
Near neutral (6.5 to 7.5)	Beans Beets Broccoli Chives Corn Cucumber Melons Grape	Pepper Peach Pumpkin Radish Squash Tomato Peas
Neutral-acidic (6.0 to 7.0)	Potato Strawberry	Raspberry Grape
Acidic (4.5 to 5.5)	Blueberry Cranberry	Azalea Rhododendron

Increasing soil pH

The most common way to increase soil pH is to add lime. Lime is ground limestone, a rock containing calcium carbonate. It is an organic (natural) amendment, suitable for use by organic gardeners.

Lime raises the pH of acid soils and supplies calcium, an essential nutrient. Dolomitic lime contains magnesium as well as calcium. It is a good choice for gardeners in western Washington and Oregon, where soils often are deficient in magnesium.

The best way to determine whether your soil needs lime is to have it tested.

Gypsum (calcium sulfate) is not a substitute for lime. It supplies calcium and sulfur, but has little effect on soil pH. Gypsum has been promoted as a soil amendment to improve soil structure, but in the vast majority of cases, it does not work. Gypsum improves structure only when poor structure results from excess sodium in the soil, a rare condition in the Northwest. Use organic amendments to improve soil structure, as described in Chapter 5: Plant Mineral Nutrition and Fertilizers. Note that some compost products can increase soil pH.

Decreasing soil pH

Elemental sulfur lowers soil pH. Soil testing is the best way to determine whether sulfur is needed and, if so, how much. Ammonium sulfate fertilizer also lowers pH, but it takes longer than sulfur to have an effect. Urea also reduces pH slowly, as do some organic fertilizers. See Chapter 5: Plant Mineral Nutrition and Fertilizers for application rates and schedules.

Soil Salinity

Soil salinity is a measure of the total amount of soluble salts in soil. Soluble salts are inorganic compounds dissolvable in water. Dissolved salts (present as ions) increase the electrical conductivity of water. Soil salinity, then, is expressed as the electrical conductivity of solution extracted from the soil at water saturation. Salinity values are given in units of millimhos per centimeter (mmhos/cm) or deciSiemens per meter (dS/m). Soil salinity values below 1 dS/m are normal. Salinity values above 2 dS/m begin to cause problems with salt sensitive plants, and values above 4 dS/m are problems for many garden and landscape plants. As with soil pH, some plants are more tolerant of high salinity than others. Table 5 summarizes the salinity tolerance of common garden and landscape plants. A salinity test measures the total soluble salts in a soil. Table 6 shows how to interpret salinity test results.

When soluble salt levels are high, plants have difficulty extracting water from soil. This is known as **chemical drought**, since affected plants show visual symptoms similar to plants suffering from a lack of water.

Soil salinity can be a problem in irrigated soils in arid areas of eastern Washington and Oregon. Salts from irrigation water, fertilizer, compost, and manure applications can accumulate to the point where they harm plant growth. In areas with more rainfall, salts are leached from the soil each winter and do not accumulate in the root zone. High soluble salt concentrations can also be created by poor soil drainage, improper irrigation

Table 5. Salinity tolerance of some common garden and landscape plants. (Adapted from Soil Test Interpretations and Fertilizer Management for Lawns, Turf, Gardens, and Landscape Plants by Carl J. Rosen, Peter M. Bierman, and Roger Eliason, from University of Minnesota Extension.)

Intolerant (0–2 mmhos/cm)	beans blueberry cabbage carrot celery lettuce onion pea pepper	potato radish raspberry strawberry sweet corn turnip most fruit trees most berries	azalea Begonia Cotoneaster rose Viburnum Norway spruce red maple sugar maple white pine
Slightly tolerant (2–4 mmhos/cm)	broccoli cucumber grape muskmelon pumpkin spinach squash tomato	Forsythia Kentucky bluegrass linden perennial ryegrass red fescue snapdragon blue spruce	cottonwood firs honey locust Norway maple oaks poplar walnut
Moderately tolerant (4–8 mmhos/cm)	asparagus beet boxwood buffalograss chrysanthemum	Geranium marigold tall fescue zinnia	black locust red oak white ash white oak
Tolerant (8–16 mmhos/cm)	Swiss chard Arborvitae	juniper Russian olive	alkali grass

(frequent, short increments), irrigation water with high levels of salts (such as house water running through a softener), or when de-icing salts used on sidewalks and roads run off and enter the soil.

If you garden in an arid area, be aware that some compost products may increase the salinity of your soil. Yard debris compost generally contains few salts, but manure- or biosolids-based compost may contain enough salt to be harmful in some environments. If you have problems with salinity in your garden soil, reduce or avoid the use of manure compost products.

You can leach salts from soil by flooding the soil: applying irrigation water in excess of the water-holding capacity of the soil. The excess water must drain downward through the soil to carry away excess salts. When leaching, apply water slowly enough that it drains freely through the subsoil. Six inches of excess water removes about half of the soluble salts in a soil. A foot of water removes about 80 percent.

Table 6. Soil salinity measured in conductivity units (millimho/cm) and potential effects on plants.

Conductivity (mmho/cm)	Interpretation
4 or above	Severe accumulation of salts. May restrict growth of many vegetables and ornamental plants. Reduce salt by leaching.
2 to 4	Moderate accumulation of salts. Will not restrict plant growth, but may require more frequent irrigation to prevent wilting.
Less than 2	Low salt accumulation. Will not affect plants.

Mulch

Mulches are any material such as bark chips, leaves, straw, or pine needles applied to the surface of the soil to reduce evaporative loss of water, protect the soil surface, reduce compaction, smother weeds, and modify the temperature of the soil. In annual gardens you can apply mulches after harvest to protect the soil from raindrop impact and erosion during the winter, or you can mulch between rows during the growing season to conserve water and reduce weeds. A thin layer of mulch will conserve water, but you need at least 2 to 4 inches of mulch to smother weeds. Straw, leaves, cover crop residues, and compost are effective annual mulches. At the end of season they are often worked into the soil. Since straw and leaves have a high C:N ratio, you will need to add extra N when you dig these mulches into the soil.

Materials such as wood chips, pine needles, and bark resist decay, and make effective, long-lasting mulches for perennial beds. As long as these mulches remain on the soil surface, they usually have little effect on available nutrients in the underlying soil. If you incorporate these mulches into the soil, they can reduce nitrogen availability for a year or more.

Further Reading

WSU Extension Publications available at: http://cru84.cahe.wsu.edu/

Washington State University Extension Bulletins

Backyard Composting (EB1784)

Cover Crops for Gardens in Western Washington and Oregon (EB1824)

Growing Small Fruits in the Home Garden (EB 1640)

Home Lawns (EB 0482)

Organic Gardening (EB 0648)

Rain Garden Handbook for Western Washington Homeowners. Available from Pierce County Extension at: http://www.pierce.wsu.edu/Lid/raingarden/Raingarden_handbook.pdf.

Oregon State University Extension Bulletins

English:

Acidifying Soil for Blueberries and Ornamental Plants in the Yard and Garden: West of the Cascade Mountain Range in Oregon and Washington (EC 1560-E). Available through Oregon State University Extension at: http://extension.oregonstate.edu/catalog/details.php?sortnum=0620&name=Techniques&num_results1=54&s=12&num_pages=5&sort=snumbera.

Improving Garden Soils with Organic Matter. Oregon State University Extension. (EC 1561).

Laboratories Serving Oregon: Soil, Water, Plant Tissue, and Feed Analysis. Oregon State University Extension. (EM 8677).

Raised Bed Gardening. Oregon State University Extension. (FS 270).

Soil Sampling for Home Gardens and Small Acreages. Oregon State University Extension. (EC 628).

Español:

Algunos Materiales para Mejorar el Suelo (Materials for Soil Improvement). Oregon State University Extension. (1540-S).

La Construcción de Camas Elevadas (Building Raised Beds). Oregon State University Extension. (EC 1537-S).

Los Cultivos de Cobertura: Una Manera Fácil de Mejorar el Suelo (Cover Crops: An Easy Way to Improve Your Soil). Oregon State University Extension. (EC 1538-S).

Other Publications

Brady, N.C. and R.R. Weil. The Nature and Properties of Soils, 13th edition. (Prentice Hall, 2001).

Hillel, D. Out of the Earth: Civilization and the Life of the Soil. (University of California Press, 1992).

Kohnke, H. and D.P Franzmeier. Soil Science Simplified, 4th edition (Waveland Press; 1994).

The Soil Biology Primer. Soil and Water Conservation Society. www.swcs.org.

Urban Soil Management

4

Topics covered:

- Urban Soils
- Soil Quality
  - Assessing soil quality
  - Preserving quality soil
  - Improving soil quality
  - Special considerations—Trees
- Soil Management during Construction
  - Controlling erosion
  - Soil disturbance and replacement
  - Addressing compaction
  - Placing topsoil after construction
- Runoff in Urban Soils
- Soil Contamination
- Soil Structure and Compaction
  - Identifying compaction in urban landscapes
  - Preventing compaction
  - Treating compaction
- Salinity
  - Managing soil salinity problems
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- Poor Drainage
  - Improving soil drainage
- Extreme Practices for Extreme Conditions
  - Extreme amending
  - Soil replacement
  - Compaction-resistant soils
  - Container and vault plantings
  - Vertical mulching
  - Special growing media for urban plantings
- Nutrient Management

Learning Objectives

✿ Understand the physical, chemical, and biological disturbances and processes unique to urban environments and how they impact plant growth, development, and health.

By

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Urban Soils

Soils in urban settings are subjected to a myriad of physical, chemical, and biological disturbances and processes that are fundamentally different than those in agricultural or natural environments. Consider, for example, the intensity of use of, and direct human impacts on, soil in a home landscape, school campus, city park, street tree basin, or other urban horticultural setting (Figure 1). During construction, valuable topsoil may be removed entirely from a site or stockpiled and used later for landscaping. Heavy equipment causes compaction, and construction debris becomes mixed with soil. After construction, vehicle and foot traffic impact the physical structure of soils. Fertilizers and pesticides, as well as petroleum and deicing chemical residues and other contaminants enter urban soils and affect chemical and biological processes and properties.

Coupled with a high degree of disturbance and intensity of use, there is a high expectation for performance from urban soils. Homeowners desire aesthetic quality in landscape plants and high productivity and food quality in gardens. City parks and school campuses desire uniform, green turf for play areas and healthy trees for shade and aesthetic purposes. Increasingly, urban soils are valued for the environmental role they have in absorbing and filtering contaminants from urban runoff water. In order to support these goals, soil may be amended or otherwise altered to support non-adapted plants and more intensive methods of production and use.

Urban soil management is a rapidly evolving field. Certain solutions and management recommendations for urban soil problems are complex and outside the scope of this chapter. Therefore, an extensive bibliography of print and web resources is included for further reading at the end of this chapter.

Figure 1. Examples of urban soil environments: A) street trees and sidewalk planters in downtown Seattle; B) an apartment construction site in Pullman.

Soil Quality

Quality soil is the foundation of quality landscapes. The growth rate, health, and visual appearance of plants are directly related to soil quality. High quality soil is also effective as a filter for contaminants that might otherwise enter ground or surface water sources. A fundamental first step in landscape design and installation should be to assess the quality of topsoil resources on the site. Once identified, provisions should be made to preserve quality soil for later use during landscaping stages. If quality soil is not present on the site, measures should be taken to improve the resident soil or acquire quality replacement soil before continuing with landscape installation.

Assessing soil quality

Soil quality is defined by an array of physical, chemical, and biological parameters known to be important to soil functioning as a medium for plant growth (Table 1). Certain soil quality parameters can be assessed through a basic soil test and on-site inspection of the material, while other parameters require more elaborate testing. Many of the physical quality parameters are a function of how soil has been handled and placed on the site. It is imperative that basic soil quality be assessed before significant investments of time and money are made in the landscape. The old adage "an ounce of prevention is worth a pound of cure" applies to soil. It is generally easier and less expensive to address soil problems before establishing plants and other landscape features.

*Assess basic soil quality **before** investing significant time or money in a landscape project.*

Table 1. Select chemical, physical, and biological indicators of urban soil quality.

Chemical indicators	Physical indicators	Biological indicators
Organic matter content pH Soluble salts (salinity) Plant nutrient levels Heavy metal contaminants Pesticide residues Petroleum residues	Topsoil depth Rooting depth/depth to restrictive layer Structure/aggregation Bulk density/compaction Infiltration ("perk") rate Water-holding capacity Drainage Aeration (gas exchange) Construction debris	Microbial activity Earthworm numbers

At a minimum, soil should be tested for the parameters described in Table 2 and compared with appropriate guidelines for the region and for the plant species being grown.

Soil properties vary considerably across Washington. For example, soil quality guidelines appropriate for areas west of the Cascades are difficult and expensive to achieve in arid central Washington—and likely not sustainable once achieved. Also, different plant materials adapted to regional environments are often also adapted to regional soil conditions such as pH and salinity, further necessitating regional guidelines. General soil quality guidelines for different regions in Washington are summarized in Table 2. If the soil falls outside the recommendations for one or more of the parameters, consider making improvements before proceeding with landscaping, or employ remedial measures such as selecting adapted plant materials and modifying installation techniques for landscape plants (discussed below and in other chapters of this Master Gardener Manual).

Table 2. A summary of topsoil quality guidelines for landscaping in different areas of Washington State.[1]

Parameter	Units	West of Cascades	Central WA Arid Areas	Eastern WA
		Guideline value or range		
Soluble salts	dS/m or mmhos/cm	Less than 0.5	Less than 2.0	Less than 1.0
pH	No units	5.5 to 7.0	6.5 to 7.5	5.5 to 7.5
Sodium adsorption ratio	No units	Less than 10		
Organic matter	% by weight	Greater than 5.0	Greater than 1.0	Greater than 2.0
Texture class	No units	Loam, silt loam, sandy loam, sandy clay loam, clay loam, or silty clay loam		
Sand content	%	Less than 70		
Silt content	%	Less than 70		
Clay content	%	Less than 30		
Coarse fragments (>1 inch diameter)	%	Less than 10		
Depth	Inches	Minimum of 4 for turf; 8 for trees and shrubs		
Nutrient levels	Various	Reported with recommendations to correct deficiencies		

[1] For a list of analytical laboratories serving Washington State, see: Daniels, C. H. 2009. Analytical Laboratories and Consultants Serving Agriculture in the Pacific Northwest. http://www.puyallup.wsu.edu/analyticallabs/.

Preserving quality soil

Quality soil is a limited resource. During construction, the resident soil may be stripped and stockpiled for use later during landscaping. If the resident soil is good enough, this is the most desirable option. Retaining and reusing the native soil on site is less expensive than importing new soil and will reduce potential problems associated with texture and other differences between imported and resident soil. Through good planning, it is also possible to increase the depth of quality soil on finished landscape areas by preserving soil originally covering sites intended for buildings and hardscape surfaces and then redistributing this soil over landscaped areas. See the sidebar for more information on topsoil depth and volume relationships used to assess available soil resources.

Before any construction begins, inventory the soil resources on the site. Consider developing a soil management plan detailing how soil will be removed, stockpiled, and reapplied during final landscaping of the site. Begin by identifying areas that can be preserved without disturbance and partition these off from areas where construction activities and equipment will be concentrated. In areas scheduled for disturbance, measure the depth of the original topsoil layer by performing minor excavation at several locations with a soil probe or shovel. Topsoil depths vary widely throughout Washington but are relatively easy to identify based on their dark color. (Refer back to Figure 1 in Chapter 3: Soils). Specify that the topsoil be removed to the prescribed depth and stockpiled separately from subsoil to prevent mixing of these materials (Figure 2).

Figure 2. Soil stored in a large stockpile on a residential construction site.

Research has shown that when soil is stored in large piles for long periods of time, the soil structure is damaged and density (compaction) increases, organic matter levels decline, key beneficial organisms and overall organism activity decreases, and other undesirable chemical changes occur. Weeds may also colonize stockpiled soil, causing problems later in the landscape. To preserve soil quality in stockpiles, store soil in several smaller piles placed at strategic locations on the site. If possible, make stockpiles no more than six feet tall. Plant the piles with a cover crop or cover them with a layer of organic mulch rather than plastic to stabilize the material. Vegetative and mulch covers help control weeds, contribute some organic matter to the soil,

Depth–Volume Relationships for Landscape Soils

The soil management plan should include a survey of the depth and volume of quality topsoil on site before construction begins. When assessing the site, determine the average depth of topsoil that will be preserved for landscaping. Also determine the square footage of area covered by the soil. One inch of material covering a 1000-square-foot area is equivalent to 3 cubic yards volume. Estimate the total volume of the topsoil resource in cubic feet according to the following equation:

_____ inches of topsoil × _____ square feet of area × 0.003 = _____ cubic yards

Next, from the landscape plan determine the square footage of area that will be covered by the preserved soil. Calculate the depth of topsoil coverage for the landscaped area according to the following equation:

_____ cubic yards ÷ _____ square feet of area ÷ 0.003 = _____ inches of coverage

This is an estimate of the final depth of topsoil if the material is stockpiled before construction begins and later redistributed on the landscaped areas.

and help sustain biological activity. Annual small grains such as wheat, barley, and oats make good cover crops for stockpiles since they establish rapidly and do not become weeds later when the soil is used in the landscape. Finally, minimize the handling of topsoil and the length of time the material is stored in stockpiles.

Improving soil quality

In some situations, quality topsoil may be removed from a site or the resident soil might be of poor quality or insufficient depth. In these cases, additional soil may need to be imported to the site. Locating quality replacement soil can be difficult and costly.

Test potential replacement soil and compare its quality to local guidelines or standards such as those in Table 2, as well as to the quality of resident soil on site, before making a purchasing decision. One of the most important considerations is that the texture class of the replacement soil should closely match the original topsoil or at least not differ substantially from the subsoil base on which the topsoil will be placed. Textural discontinuities (sand over clay, for example) interfere with water movement and root growth.

Imported topsoil should also be free from noxious weeds and not have been treated with persistent herbicides. It is difficult and expensive to test for weed seeds and herbicides. Ask the supplier if the material was treated to control weeds and if so what the residual or planting restriction time is for the chemical used.

If adequate replacement soil cannot be identified, it may be easier or less expensive to improve the soil on site. Soil can be amended to increase organic matter content, available plant nutrients, and pH. It is extremely difficult to amend soil to change sand, silt, and clay content and texture class. Organic matter is the most common amendment used to improve soil physical conditions before establishing permanent vegetation. Some recommendations call for unusually high rates (1/3 by volume, for example) of organic matter addition. In normal landscape situations, consider reasonable rates of organic matter addition based on guidelines identified in Table 2. Recognize that organic matter will decompose over time and may result in settling and compaction if amended levels in soil are substantially above what can be sustained under normal contributions from plants growing in the landscape.

Special considerations—Trees

Most research suggests that there is no benefit from amending backfill soil to improve quality in routine tree plantings. There may be some benefit associated with loosening the soil in a larger volume of backfill to encourage better rooting. Amending backfill soil creates textural, structural, and other discontinuities between the backfill and native soil. This can create a barrier to root growth and water movement, at times resulting in water saturation of the backfill material and root system in the planting hole. Also, tree roots eventually have to grow beyond the backfill soil into the native soil. If the tree species is not adapted to the native soil conditions, amending the backfill is not likely to improve tree survival once roots grow into the native soil. In special cases such as tree vaults installed in urban areas, backfill soil may be amended or designed for specific water retention and drainage needs. This is discussed in more detail later in this chapter.

Soil Management during Construction

Controlling erosion

Soil erosion is a major concern during construction. Large areas of bare soil may be exposed to wind and rain during construction. Dust is a nuisance as well as a health issue. Sediment can have significant offsite impacts such as filling gutters and storm drains, and degrading stream water quality (Figure 3). State and local ordinances require that measures be taken to minimize soil erosion from construction sites. Erosion control can be accomplished by implementing one or more best management practices (BMPs) designed to a) reduce erosion and b) retain eroded sediment on site (Figure 4).

Figure 3. Uncontrolled erosion from a residential construction site. Sediment has completely filled in the street gutter. (Photo courtesy of USDA-NRCS)

Figure 4. Common erosion control measures on construction sites: A) silt fence used to control gradual (sheet) runoff and erosion; B) sediment basin for retaining concentrated flow.

Some best management practices for reducing erosion:

- Schedule construction during periods of lower erosion potential (generally, May 1–October 1 in Washington);
- Site potential sediment source areas (stockpiles, access roads, etc.) away from steep slopes and areas that drain into surface water bodies or conveyance systems;
- Limit disturbance to areas essential to construction;
- Preserve and protect existing vegetation with fences, walls, or other barriers;
- Cover small stockpiles of soil with a tarp; plant larger stockpiles or cover them with a layer of organic mulch.

Some best management practices for retaining eroded sediment:

- Place fabric fence or straw bale barriers to capture gradual (sheet) runoff;
- Install sediment basins, check dams, or retaining walls to interrupt concentrated flow on steep slopes.

Soil disturbance and replacement

The conditions under which topsoil is removed, stored, and replaced affect future landscaping options and success. Compaction of subsoils during construction also affects the physical condition of soils and subsequent water movement and root growth. During construction, topsoil may become mixed with less desirable subsoil, and the final product may include synthetic materials such as concrete and asphalt, as well as wood and other debris common in urban environments. These issues are relatively easy to address in the topsoil management plan or specifications, and are discussed in greater detail below.

Addressing compaction

Construction activities and equipment will compact soil on the site. Compaction, as well as abrupt changes in soil texture and organic matter content between the topsoil and subsoil, can inhibit rooting and water flow in the finished landscape. Before spreading topsoil use a heavy-duty rotary tiller or tractor mounted implement with a deep ripper blade to fracture compacted subsoils. The depth of tillage required is a function of the depth of compaction. Inspect subsoils on site and use the appropriate implement capable of fracturing compacted soil to the necessary depth.

Placing topsoil after construction

To address discontinuities in texture, structure, and organic matter content between subsoils and topsoils, soil should be replaced on the site in layers or lifts (Figure 5). First spread approximately 1/3 of the total replacement topsoil and incorporate this into the subsoil with a rotary tiller. Spread the remaining soil depth on top of this “transitional” layer.

Figure 5. Topsoil layered over subsoil during final site grading and preparation for planting.

Runoff in Urban Soils

Controlling and treating runoff water, or stormwater, is an increasing concern in urban areas. In addition to sediment, nutrients and pesticides from urban landscapes and petroleum residues from road and parking lot surfaces can be transported in runoff water. New and existing commercial and residential developments in many parts of Washington are now required to develop stormwater management plans (Figure 6). Various agencies have prepared detailed guidelines and BMPs to improve urban stormwater retention and quality. Specific information can be found in the stormwater manuals for eastern and western Washington:

Stormwater Management Manual for Western Washington:
http://www.ecy.wa.gov/programs/wq/stormwater/manual.html#Background

Stormwater Management Manual for Eastern Washington:
http://www.ecy.wa.gov/biblio/0410076.html

Stormwater management programs are designed to promote infiltration, filtration and detainment of urban waters. Best management practices in these areas include:

- Installation of infiltration trenches, basins, and porous pavement surfaces to promote water infiltration;
- Creation of vegetative strips, grassed swales, and sand traps to filter sediment and contaminants;
- Creation of impoundments, ponds, and constructed wetlands to detain runoff water, allow sediment to settle out, and filter nutrients and other contaminants.

Figure 6. A stormwater catchment and infiltration basin in Pullman, Washington. These basins are now common sights in new residential and commercial developments.

Several routine soil management practices can reduce runoff from urban landscapes. For instance, raising the organic matter content of soil improves water infiltration into that soil and reduces runoff. The Washington Organic Recycling Council's program *Soils for*

Salmon promotes using compost to amend urban soils to a target 10% organic matter content. Aerification (discussed later in this chapter) also promotes water infiltration in compacted turfgrass soils. Maximizing the use of mulch in bare soil areas and around perennial vegetation also promotes water infiltration and reduces water and sediment runoff.

Soil Contamination

Urban soils may contain physical and chemical contaminants not found in natural soil environments. Bulky but relatively inert materials such as concrete, asphalt, steel, wood, and glass pose physical problems if they interfere with landscaping activities or plant rooting, soil drainage, aeration, and water-holding capacity. Proper collection and disposal of debris during and after construction, rather than burying it on site, can limit future landscape problems. Chemical contaminants are a larger concern in that their presence cannot be determined visually and they may impact human health as well as plant health.

Surveys comparing urban landscape soils with their native counterparts reveal consistently higher levels of potentially toxic inorganic elements such as copper, cadmium, lead, nickel, and arsenic. Sources of these contaminants include lead-based paint, leaded gasoline, treated wood products, and the long-term use of certain soil amendments such as sewage sludge.

Many landscape plants can tolerate relatively high levels of inorganic contaminants without showing adversely affected growth. Inorganic contaminants are a greater hazard in places where children play, where exposed soils are a source of dust, and in gardens where vegetables may be grown for human consumption. If the history of a site is not known or the presence of inorganic contaminants is suspected, a relatively inexpensive soil test is recommended to determine levels of these contaminants. A test for common inorganic contaminants will cost approximately $25 per sample.

Residual herbicides may also be a concern in landscapes now located on what had been agricultural fields or on urban lots that had been treated with a long-acting herbicide. Obtaining information on the history of chemical use on a site can prevent future problems with plantings. Testing for residual herbicides may be warranted but is very expensive. Tests for specific classes of herbicides may cost more than $200 per sample and some guidance must be provided to the testing lab about which herbicide class might be present. Certain herbicides may have to be removed from the site or planting delayed until levels decline naturally. In some situations, activated carbon can be added to the soil to reduce the activity of lingering herbicides.

Soil Structure and Compaction

Structure is a desirable characteristic in soils and is essential for optimum plant performance. Well-structured soils promote root growth and have good drainage characteristics, optimum water holding capacities, and good aeration (gas exchange) properties. Compaction destroys soil structure and causes significant plant growth problems in urban landscapes. Compaction forces soil particles closer together, reducing pore space and thus the volume of air and water in soil. Compaction also seals off the surface of the soil, reducing the amount of air and water that can enter the soil. Reduced gas exchange and, in particular, a low oxygen concentration in the root zone is the primary cause of plant decline in compacted soils. Physical resistance to root growth is a secondary problem with soil compaction.

Compaction is caused by repeated foot or vehicle traffic over the same soil area (Figure 7). The traffic may be associated with construction activities, or be expected foot or vehicle traffic in established landscapes. In urban landscapes, vibrations caused by vehicle traffic may also aggravate soil compaction problems.

Moist conditions make soils more susceptible to compaction. Fine-textured soils are also more prone to compaction than coarsely textured or sandy soils.

Figure 7. A compaction trail in turfgrass on the campus of Utah State University.

Identifying compaction in urban landscapes

Sparse growth or barren areas of turf are common indicators of soil compaction, as are water runoff and/or dry spots in irrigated

Figure 8. Tree roots growing at the surface of heavily compacted soil in a parking lot on the campus of Washington State University in Pullman.

turf. Indicators of soil compaction specifically around trees include rooting near the surface, reduced tree vigor or growth rates, and differing growth rates among several trees planted at the same time (Figure 8). Exploring an area with a soil probe, shovel, or long-handled screwdriver can help identify soil compaction. Probes should easily enter moist soil that is not compacted. Probe any areas that may be compacted as well as normal-looking areas for comparison.

Preventing compaction

Soil compaction during construction is unavoidable but must be addressed during subsequent rough grading and landscaping phases. Maintenance or renovation activities may also drive additional heavy equipment traffic in established landscapes. Soil compaction may be minimized or even avoided by making sure activities occur when soil is dry and by placing a layer of mulch in travel areas. Steel grates and plywood surface treatments, while less effective than mulch, can limit compaction for three to five passes of heavy equipment. Surface brickwork can also be used to maintain some vegetative cover in high traffic areas (Figure 9). The brick absorbs the force of traffic while allowing plant growth in open areas between and within the brick.

In established landscapes, restrict foot traffic in sensitive or compaction-prone areas. Signs generally do not work and fences are visually unappealing. Landscape design methods using vegetation, hardscape (such as curbing or railings) or other planned barriers can successfully direct traffic onto sidewalks and off of sensitive soil areas (Figures 10, 11). In turf areas where

Figure 9. Surface brickwork absorbs the compressive forces of traffic and still allows some vegetation growth through voids in the brick.

compaction appears repeatedly in defined paths, consider adding a sidewalk. An alternative would be to use a surface treatment such as a mulch layer to improve path appearance. Grates and surface mulch layers also reduce soil compaction around the base of trees. Certain situations may call for the installation of compaction-resistant soil, as described in the section *Extreme Practices for Extreme Conditions*.

Treating compaction

Subsoiling or deep ripping (tilling) using agricultural or other heavy tillage implements may be necessary in heavily compacted areas, especially after construction and before installing landscape features and irrigation systems.

In established turfgrass areas, compacted soil can be aerated with a hollow tine implement that removes small cores of soil. Aeration should be performed at least once a year in turfgrass areas subjected to heavy traffic; more frequently in areas prone to developing compaction trails. A thin (less than ½ inch) layer of fine organic matter can be spread immediately after aerating to backfill the holes created during the process. This can be helped by mowing or raking the area to fill the holes with organic matter.

In severely compacted turfgrass trails, the addition of approximately 1 inch of organic matter followed by tillage with a rotary tiller and reseeding or sodding may be required. Limit traffic on the area while turgrass re-establishes, and take measures to prevent compaction from recurring in the future.

Figure 10. Multiple sidewalks dissecting a large open area on the campus of Utah State University. Sidewalks were placed to avoid compaction trails created when pedestrians walk between buildings.

Figure 11. Surface pavers are a low-technology solution to the problem of compaction trails in turfgrass.

Treating compaction around trees and other woody perennials is difficult without damaging existing root systems. Implements have been developed to inject water or air under high pressure to fracture compacted soil in the root zone of trees. Research has shown mixed results with these methods. Where possible, just placing a thick layer of coarse organic mulch will limit further compaction and, over time, improve compacted soil conditions. Vertical mulching and radial trenching are other possible approaches to treating severe compaction in the root zones of trees. These approaches are described in the section *Extreme*

Practices for Extreme Conditions. Another option is to select tolerant tree species for areas prone to soil compaction. See *Further Reading* at the end of this chapter.

Salinity

Salinity is a measure of the total amount of soluble salts in soil. As soluble salt levels increase, it becomes more difficult for plants to extract water from soil. This problem has been referred to as chemical drought, since affected plants show visual symptoms similar to water stress. Soil salinity levels can be assessed with a simple and inexpensive soil test.

Saline (high salt) soils are most common in arid areas of central Washington. However, high soil salinity can be created virtually anywhere as a result of poor soil drainage; use of irrigation water with high salt content; application of excessive amounts of fertilizer, manure, or compost; or contamination by de-icing salts used on sidewalks and roads nearby (Figure 12).

Figure 12. Turfgrass damage caused by deicing salts running off of sidewalks.

Managing soil salinity problems

Different plants vary widely in their salt tolerance. One method of addressing a soil salinity problem is to select and plant salt-tolerant vegetation in saline soil areas or areas prone to receiving salts from deicing activities. Several excellent resources are available for selecting plants that tolerate salinity in the root zone. See the section on selecting tolerant plants in *Further Reading* at the end of this chapter for more information.

Alternative deicing chemicals are available that have less impact on plants than traditional sodium or calcium chloride-based materials. Calcium magnesium acetate is more expensive but has minimal impact on plants. Abrasive (traction) and dark colored materials that enhance solar radiation absorption can also be used alone or in combination with salts to melt ice. See *Further Reading* for more information on managing deicing chemicals. Curbing and raised planting areas also serve to channel deicing salts away from soil around plants.

Treating a saline soil

Soluble salts can be leached (washed) from the soil if there is adequate drainage and a clean source of irrigation water available. Good drainage is essential for reclaiming saline soils since water must move *through* the soil (rather than run off the surface) to leach salts from the plant root zone. Compaction, a restrictive layer (such as hard pan), poor structure, or fine texture (silt or clay) can cause poor drainage and must be addressed.

Once drainage has been established, apply clean water to the site to leach salts. Based on the initial soil test, estimate the amount of water necessary to reduce salinity to desirable levels for the plants to be grown. In general, to leach salts from the upper 12 inches of the root zone apply 6 inches of water to reduce salinity levels by 50%, 12 inches to reduce salinity levels by 80%, and 24 inches to reduce salinity levels by 90%. The total amount of water necessary should be applied over a period of several days and the soil should be kept moist during the leaching treatment to maintain the downward movement of water.

Poor Drainage

Poor drainage is a common problem in urban landscapes. Virtually any discontinuity, interface, or seam between different soil types has the potential to impede water flow. Common examples are compacted subsoils from construction traffic, contrasting textures between topsoil and subsoil, soil layering during placement, and compaction produced during the excavation of tree planting holes (Figure 13).

Poor drainage subjects plants to a perpetually wet soil condition which restricts aeration (gas exchange properties) in soil and limits oxygen availability to root systems. The result is an increase in the occurrence of root diseases, nutrient (such as iron) deficiencies, and other growth problems. Restricted drainage can also make soils more prone to compaction from traffic when soils are moist.

Often, drainage problems can be identified by inspecting the soil before planting. Many fine-textured soils will have drainage

Figure 13. Water retention in a poorly draining tree hole prepared for planting.

problems. The presence of compacted soil layers can be identified using a soil probe, metal rod, or shovel. Water pooling in an area such as a low spot in the landscape or a planting hole also indicates a drainage problem. Ideally, pooled water in a depression or planting hole should drain away through the soil within 24 hours.

Certain landscape plants are adapted to poorly drained soil conditions. Species native to swampy environments or areas with a high water table may tolerate such conditions. See the section on selecting tolerant plants in *Further Reading* at the end of this chapter for more information. In areas where poor drainage is a recurring problem consider selecting plants tolerant of this condition.

Improving soil drainage

A drain tile is not actually tile, but a length of perforated plastic pipe buried beneath the soil surface.

Several cultural and managerial practices can be used to alter soil drainage.

- Amend soils with organic matter. Organic matter improves drainage in fine-textured soils. Amending soil with organic matter may improve drainage near the surface but subsurface drainage may still be a problem if the subsurface layer impedes water movement.
- Install subsurface drain tile. A drain tile is not actually tile, but a length of perforated plastic pipe buried one to several feet beneath the soil surface. Excess soil water enters the pipe and is conducted to an open ditch or gutter out of plant root zones. There are many potential and creative uses for subsurface drain tile systems in landscapes: in planting beds, behind retaining walls, in tree vaults.

Many home improvement stores sell drain tile materials and provide informational brochures on installation. Information can also be found on the Internet.

- Install vertical drains in planting holes. A vertical drain or "dry well" is a hole, 4- to 6-inches in diameter and 3- to 5-feet deep, dug in the bottom of a tree or shrub planting hole. A soil bucket auger or posthole digger can be used to excavate the hole. The hole is then filled with coarse gravel to provide a drainage outlet for water that might otherwise pool in the bottom of a planting area.
- Construct raised beds or planting boxes. Raised beds or planting on hills or berms raises a part of the plant root system above the native, poorly drained soil. Beds 8 to 12 inches high are adequate for many garden plants, while hills or berms 2 to 3 feet high are better for woody plants.

Extreme Practices for Extreme Conditions

Some urban situations call for more extreme soil management practices. Examples might include soil in planting areas where annuals are replaced several times during the growing season, containers, intensively used turfgrass areas, and trees growing in urban settings where expanses of pavement and sidewalk limit rooting and surface soil access around the tree. Considerations such as maintaining soil tilth, minimizing compaction, and providing drainage while retaining water and nutrients require creative and intensive solutions. More information can be found in *Further Reading* at the end of this chapter.

Extreme amending

Intensively managed areas, raised beds, and planter boxes or containers where several crops of annuals are grown each year may require a soil amended with large amounts of organic matter such as peat moss or bark fines, or inorganic materials such as perlite and vermiculite. In fact, growing media in some of these intensive situations is more like soilless media found in greenhouses than mineral soil used in landscapes. Such "extreme amending" presents few problems since organic matter and other amendments can be replenished when necessary. This becomes impractical and is not recommended for large areas of landscape and where perennials will be grown since it is difficult to maintain and amend soils in these situations.

Soil replacement

In extreme cases when urban soil is contaminated with pesticides or petroleum residues, or becomes severely degraded as a result of compaction and loss of organic matter, soil replacement may be required. Obviously, soil replacement in annual planting beds is easier than in perennial beds. In extreme cases perennial plants may be in such poor condition they are not worth saving, and replacement of both soil and vegetation is justified. In situations where very old and/or valuable trees exist, it may be possible—though difficult—to partially replace soil within the root zone. Before attempting soil replacement, review other options for renovating the soil and improving growing conditions.

Methods for soil replacement around established trees are described in the reference by Watson et al. (1996). These involved digging a series of four radial trenches beginning 10 feet away from the trunks of large trees. Each trench was 10 feet long, 2 feet deep and 14 inches wide and was positioned in areas without large roots. Trenches were backfilled with a mixture of leaf compost and quality topsoil. Another procedure involved using a combination of pressurized water and a vacuum to dislodge and remove soil with minimal damage to roots. This "hydraulic excavation" technique was performed in holes 4 inches in diameter and 24 inches deep spaced from 12 to 30 inches apart in a grid pattern within the drip line (outer edge of the canopy) of trees. Pits were also excavated to a depth of 24 inches, covering up to 65 square feet of area using this technique. High quality replacement soil was used to backfill the excavated areas.

Compaction-resistant soils

In general, coarse textured (such as sandy) soils are more resistant to compaction than fine textured (such as high silt or clay) soils. In areas where repeated compaction from foot traffic is a problem, the topsoil can be specified or replaced with a loamy sand or sandy loam texture material. In extreme cases, a medium designed with 20 to 30% soil and the remainder composed of coarse sand or pea gravel is less prone to compaction but can still retain some water and nutrients to support plant growth.

Container and vault plantings

Many urban settings have virtually no exposed soil and therefore must rely on traditional container plantings or, in the case of trees, large vaults placed below ground to contain the growing medium and root system (Figure 14). Considerations such as sizing for critical soil volume to meet water needs, as well as access for fertilization and drainage are important.

For trees, critical soil volumes are normally based on providing adequate water during dry periods. Various methods have been used to estimate critical soil volumes. These estimates are summarized in a paper written by Lindsey and Bassuk (1991) cited at the end of this chapter. In this paper they also describe

Figure 14. Confined tree plantings on a downtown street in Seattle necessitate creative and engineered designs to ensure adequate rooting volume and drainage, and access to irrigation water and fertilizer.

a method for estimating the soil volume required for trees in different locations. In Seattle, they estimate 1.5 cubic feet of soil volume required for each square foot of surface encompassed by the drip line.

Drainage is a major challenge in container and vault systems. Depending on the configuration of the hardscape, runoff from streets, sidewalks, and other surfaces can substantially increase or decrease the amount of water entering soil.

In addition to providing adequate rooting volume, tree vaults include provisions for irrigation, flushing of salts, drainage, fertilizer injection and oxygen supply (aeration) to root systems in vaults with minimal surface access and total enclosure. Jewell (1981) notes that no single vault system is appropriate for all situations, but that the design should be based on the specific problems expected on a site.

Vertical mulching

Though labor intensive, vertical mulching has been shown to improve the performance of declining trees in urban settings by enhancing soil permeability and air and water movement beneath the compacted soil surface. In practice, two to four-inch diameter holes are made with an auger in the drip line of the tree. Holes are normally two to three feet deep beginning two feet from the base of the tree and extending in a square grid or 5-spoke radial pattern to the edge or slightly beyond the drip line. The holes may be filled with coarse organic matter like wood chips, or gravel. Some recommendations call for the addition of slow release fertilizer with the backfill material.

Special growing media for urban plantings

In order to support structures, sidewalks, road surfaces and other hardscape features, soil and fill materials must be compacted to prevent settling and shrinking and swelling. The level of compaction required to meet construction standards is high enough to prevent root growth into or through the material. This severely limits the rooting volume of all plants, but especially trees, grown in urban settings. Alternatives to compacting soil and fill materials include using coarse sand or stone as fill. These materials are capable of bearing the loads required for urban structures and surfaces while maintaining some pore space to accommodate root growth. However, these coarse alternatives have relatively low water and nutrient retention properties. Structural soil materials consisting primarily of crushed rock with a diameter of ½ to 1 ½ inch with some soil material have been tested in research and found to meet bearing standards while also allowing root growth through the material. These alternatives offer the potential to expand rooting volumes of urban plants to areas under hardscape surfaces. References to these alternative soil materials are presented at the end of this chapter.

Nutrient Management

Over-application of lawn and garden fertilizers, as well as manure and some composted organic materials result in high levels of phosphorus in soil and urban runoff water.

Fertilization is important to correct nutrient deficiencies and promote plant growth. Increasingly, however, nutrient management and fertilization practices are becoming environmental issues in urban settings. Over-application of lawn and garden fertilizers containing phosphorus, as well as the application of manure and some composted organic materials purely for organic matter benefits, is resulting in high levels of phosphorus in soil and urban runoff water. In Utah, for example, more than 90% of soil samples from established urban and home landscapes have very high or excessive levels of phosphorus. Beginning in 2005, Minnesota banned the use of lawn fertilizers containing phosphorus except in new lawn establishments and where a soil test confirms a need for phosphorus fertilizer. No detailed soil test information is available for urban areas in Washington State; however, stormwater and urban runoff control programs are targeting the same issues of nutrient loading and transport from urban areas to surface water sources.

Nutrient management and fertilization practices for urban soils are largely the same as for other garden and landscape situations. Fundamentally, nutrient applications should be based on diagnostic soil or plant tissue testing to define nutrient needs, rates calculated to meet these needs, and methods of application used to ensure nutrients remain in the soil. Refer to other chapters in this Master Gardener Manual for specific information and recommendations.

Further Reading

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Kristoffersen, P. 1998. Designing urban pavement sub-bases to support trees. Journal of Arboriculture 24(3): 121-126.

Landscape Architecture Technical Information Series (LATIS) Publication: http://www.asla.org/latis/pdf/Structural_soils_updated081202.pdf

The Urban Horticultural Institute: http://www.hort.cornell.edu/uhi/outreach/csc/article.html

Compost quality and standards for Washington

Washington State Department of Ecology: http://www.ecy.wa.gov/programs/swfa/compost/

Managing urban runoff

U.S. EPA, Nonpoint Source Pollution - Management Measures for Urban Areas http://www.epa.gov/owow/nps/MMGI/Chapter4/index.html

Municipal Services and Research Center for Washington (storm and surface water management) http://www.mrsc.org/Subjects/Environment/water/SW-issue.aspx

Washington State Department of Ecology, Stormwater Management Manual for Western Washington http://www.ecy.wa.gov/programs/wq/stormwater/manual.html#Background

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Suppliers of soil probes and other sampling devices

Ben Meadows Company: www.benmeadows.com

Forestry Suppliers: www.forestry-suppliers.com

5

Plant Mineral Nutrition & Fertilizers

Topics covered:

Essential Plant Nutrients
Nutrient Deficiencies
Nutrients in Excess
Fertilizer as a Source of Nutrients
Determining Nutrient Needs
Fertilizer Selection
Calculating Application Rates
Fertilizer Application Methods
Application Timing
Cover Crops and Green Manures
Soil pH

Learning Objectives

- Know the nutrients required by plants for growth and development
- Understand fertilizer products including label information, differences between organic and non-organic forms, and relative advantages and disadvantages of each in lawn and garden situations
- Recognize potential problems related to over-application of fertilizer products

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Introduction

Proper nutrition is just as important for plant health and performance as it is for human health and performance. Most homeowners, gardeners, and nursery/landscape professionals recognize the need for timely “feedings” or applications of nutrients to enhance plant growth. Many also understand that different plants have different nutrient requirements. The native or natural fertility level of a soil can supply many of the nutrients plants need, but some form of additional fertilizer is usually necessary. The challenge is in assessing native soil fertility levels and nutrient needs for plants and then selecting the right source and rate of fertilizer to meet those needs.

The number of different inorganic fertilizers on the market is overwhelming. Add to that an increasing diversity of commercial organic fertilizer products as well as manure, compost, and green manure options for supplying nutrients to plants, and the task of selecting which nutrient source to use becomes daunting. To further complicate matters, different fertilizers contain different amounts of plant nutrients and those nutrients may be released at different rates. In the end, one fertilizer may be better for a specific situation than another, and different fertilizers need to be applied at different rates to supply the correct amount of plant nutrients.

The purpose of this chapter is to describe the role and importance of essential plant nutrients, to describe methods used to determine when certain nutrients are deficient, and to provide recommendations on how to select and manage nutrient sources to meet plant needs. This chapter includes balanced information on inorganic and organic approaches to managing fertility. Throughout this chapter the term **fertilizer** refers to any material used as a source of plant nutrients.

Essential Plant Nutrients

Seventeen elements are required by plants to complete their life cycle. Three of these—carbon, hydrogen and oxygen—are obtained from air and water. The remaining 14 are obtained primarily from the soil and are referred to as **mineral nutrients**. Mineral nutrients are classified as primary, secondary or micronutrients based on their relative requirements and concentrations found in plant tissue. Table 1 summarizes the 14 essential mineral nutrients and the roles each play in plants.

Table 1. A summary of important characteristics of the fourteen mineral nutrients required by plants.

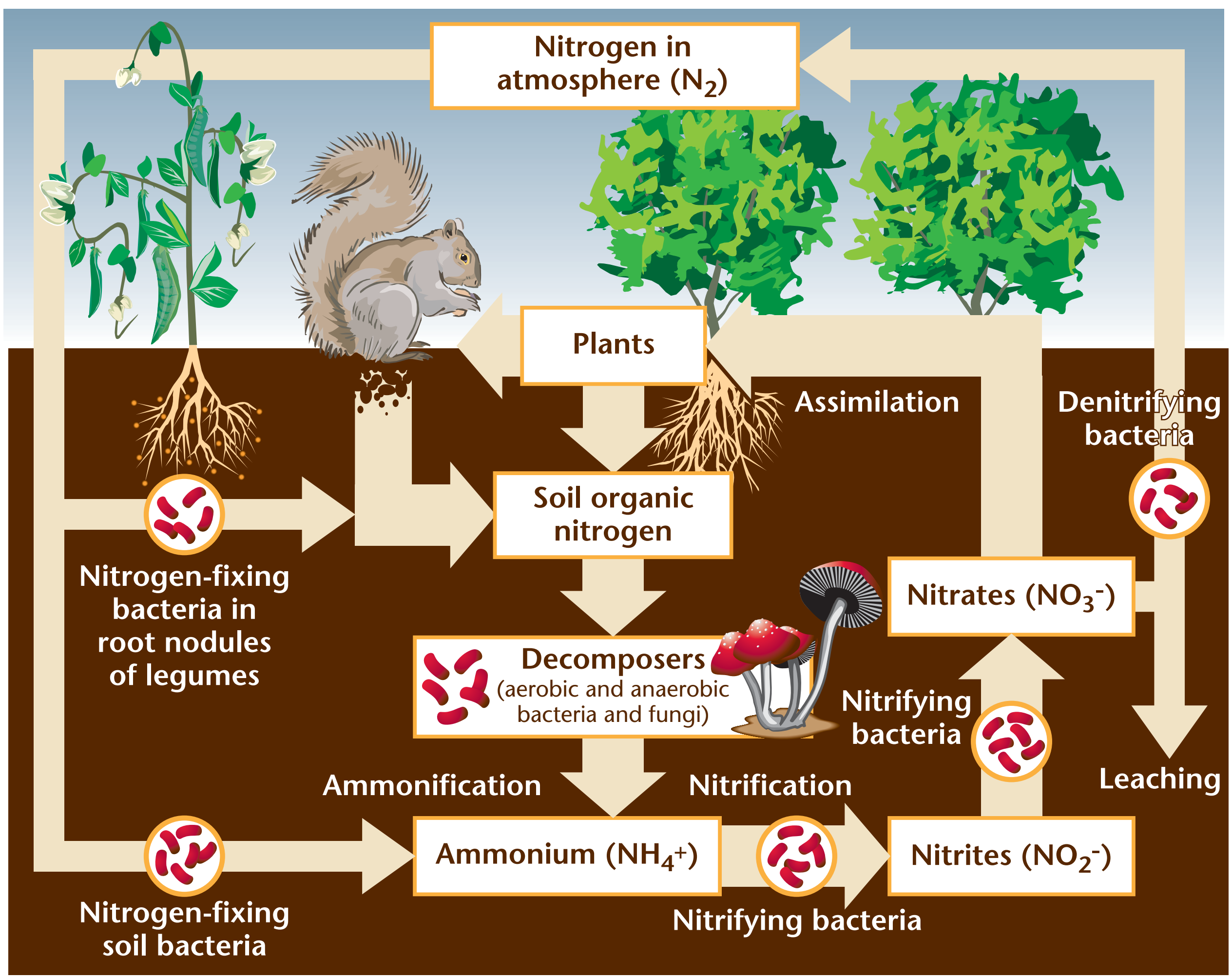
Element (symbol)	Concentration range in plant	Roles in plant
Primary nutrients		
Nitrogen (N)	1 to 4%	Constituent of amino acids, proteins, and enzymes that control most plant functions; also a component of chlorophyll and DNA; promotes overall growth.
Phosphorus (P)	0.1 to 0.3%	Constituent of DNA molecules and critical energy transfer systems in plants; promotes flowering, seed formation, and maturity.
Potassium (K)	0.5 to 4%	Important in the function of **stomata** (openings) on leaf surfaces, in cell water relations, drought tolerance, and disease resistance.
Secondary nutrients		
Calcium (Ca)	0.1 to 0.2%	Important in cell wall development of young tissues; enzyme activator.
Magnesium (Mg)	0.05 to 0.15%	Constituent of chlorophyll molecule; necessary for many enzyme reactions.
Sulfur (S)	0.15 to 0.3%	Important constituent of certain amino acids, proteins, and enzymes that control many plant functions.
Micronutrients		
Boron (B)	1 to 10 ppm*	Important in the development and differentiation of growing points in shoot and root.
Chlorine (Cl)	25 to 1,000 ppm	Enhances drought tolerance, stem strength and disease resistance.
Copper (Cu)	2 to 10 ppm	Essential in many enzyme functions involved in carbohydrate and protein formation.
Iron (Fe)	10 to 75 ppm	Key element in chlorophyll molecule and photosynthesis reactions.
Manganese (Mn)	10 to 20 ppm	Essential in many enzyme functions; chlorophyll synthesis.
Molybdenum (Mo)	0.1 to 0.7 ppm	Required for nitrogen metabolism in plants.
Nickel (Ni)	Trace amounts	Involved in enzyme reactions during nitrogen metabolism.
Zinc (Zn)	10 to 30 ppm	Essential in many enzyme functions involved in hormone production and growth and development in plants.

*ppm = parts per million concentration; ppm ÷ 10,000 = %

Mineral nutrients cycle through soil and plant systems in complex pathways helped along, in many cases, by diverse groups of microorganisms. **Nutrient cycles** describe inputs such as fertilizer, manure, and crop residues; transformations between inorganic and organic forms; and outputs such as plant removal, leaching, and runoff. Figure 1 shows one illustration of the nitrogen cycle. This is one of the more complex cycles because nitrogen can exist in many different forms in soil, can be transformed in many ways by microorganisms, and is subject to many different losses.

Understanding nutrient cycles leads to better nutrient management. For example, applications of compost contribute large amounts of organic nitrogen to soil (Figure 1). This nitrogen must go through the decomposition process mediated by soil microorganisms before becoming available to plants. Time is required for that decomposition to occur, so organic nitrogen sources are best applied several weeks or months before plant growth demands it. Inorganic (commercially processed) forms

Figure 1. Nitrogen cycle: Legumes, soil organic matter, crop residues, and organic additions (manures, composts, etc.) are sources of organic nitrogen. Organic nitrogen is mineralized into ammonium (NH4+) by soil microbes. Commercial fertilizers supply nitrogen as ammonium or nitrate (NO3-). Microbes nitrify ammonium to nitrite and then nitrate. Plants, microorganisms, leaching below the root zone, and release of gaseous nitrogen to the atmosphere all remove dissolved nitrogen from the soil. Crop harvest removes nitrogen stored in plants. Nitrogen present in both crop residues and soil microorganisms becomes a part of the soil organic nitrogen content.



of nitrogen are primarily in the ammonium or nitrate forms. Applications of large amounts of inorganic nitrogen can lead to high concentrations of nitrate in the soil and potential leaching losses when rainfall or irrigation is high.

Nutrient Deficiencies

Nitrogen is the most common nutrient deficiency in Washington landscapes and gardens. Phosphorus, potassium and sulfur deficiencies are also relatively common in Washington. It is more difficult to generalize about phosphorus, potassium and sulfur deficiencies since soil can store relatively large reserves from previous applications. Calcium and magnesium deficiencies are encountered mainly in acidic (low pH) soils west of the Cascades. Zinc and iron deficiencies are limited to areas in central and eastern Washington with alkaline (high pH) soils. Deficiencies of other nutrients are rarely encountered in Washington.

Nutrient deficiencies can be difficult to diagnose visually. Complicating factors in visual diagnosis include simultaneous, multiple deficiencies; a similarity in symptoms for deficiencies of certain nutrients; poor or inconsistent expression of the symptoms; and similarities with disease and insect symptoms. Plants may also suffer from a deficiency without showing visual symptoms, a problem referred to as **hidden hunger**. Nevertheless, with experience, visual diagnosis can be used to identify nutrient deficiencies. Certain indicator plants can also be used to determine when certain nutrients are deficient, since they tend to show symptoms before the majority of other plants (see Box A).

Various keys exist to aid in visual diagnosis of nutrient deficiencies. Keys guide the reader through the diagnostic process by asking specific questions about the location and nature of the plant symptoms. Table 2 is one example of a key to plant nutrient deficiencies. Try using the key in situations where you know what the deficiency is in order to become more familiar with its use.

Tissue testing is another way to diagnose nutrient deficiencies; however, tissue testing can cost up to $50 per sample and results are not always conclusive. Proper sampling is critical for an accurate tissue test. Specific guidelines are available describing which plant part to sample and at what stage in the growth cycle. See the publications at the end of this chapter for more information on tissue sampling and testing.

Box A
Corn—the indicator plant.

Corn is an excellent indicator plant for nutrient deficiencies. Rapid growth with high nutrient demand means that corn often expresses deficiency symptoms before other plants in the garden. The large leaves also make nutrient deficiency symptoms in corn easy to identify.

Visually inspect corn plants growing in the garden and watch for these symptoms. Adjust the fertility program accordingly when symptoms are seen.

The following images are examples of major nutrient deficiency symptoms for corn.

Photo A. Nitrogen deficiency on corn: overall pale green color of the plants, and yellowing and senescence of leaves on the lower (older) part of the plant (A-1). Leaves in photo A-2 are from lower (left) to upper (right) parts of the plant.

Photo B. Phosphorus deficiency on corn: distinct purple color. Phosphorus deficiency commonly causes stunting in plants. Plants may grow out of a phosphorus deficiency as their root systems develop and soil temperatures rise.

Photo C. Potassium deficiency on corn: brown (necrotic) tissue on the outer leaf margins.

Photo D. Iron deficiency on corn: characteristic pattern of a network of green veins on a yellowed leaf. This symptom is called interveinal chlorosis and commonly expressed in berries, grapes, trees, and shrubs growing in alkaline (high pH) soil (also see Figure 4).

Photo E. Zinc deficiency on corn: light green color and yellow bands crossing several leaf veins. Zinc deficiency commonly stunts plants, giving them a "compressed" look.

Table 2. A key to plant nutrient deficiency symptoms. The key is designed to guide the reader to a plant nutrient deficiency diagnosis. Read through the symptoms and identify the one that most closely matches the visual symptom.

Symptom	Nutrient Deficiency
1. Growth reduced: leaves small, on shortened internodes:	
2. Leaves darker green than normal, often purple	phosphorus
2. Leaves normal color; later becoming yellow or streaks of yellow; puckered	zinc
1. Growth may be normal, producing average sized plants; leaves may or may not be normal:	
3. Bud formation affected, or apical growth of shoot and root inhibited:	
4. Bud formation severely affected; death of root tips	calcium
4. Bud formation may be normal but shoot and root tips decay	boron
3. Bud formation may appear normal; apical growth may appear normal:	
5. Younger leaves are darker green than normal, misshaped with necrotic spots	copper
5. Leaves yellowing or yellowing and having green vein areas:	
6. Leaves yellowing only:	
7. Yellowing first on older leaves:	
8. Necrotic spots not present	nitrogen
8. Necrotic spots on leaf edges common; stems weak	potassium
7. Yellowing first associated with younger leaves or with necrotic spots:	
9. Younger leaves yellow first	sulfur
9. Necrotic spots present; leaves may wilt; bronze color	chlorine
6. Leaf yellowing associated with green vein areas:	
10. Necrotic spots present	manganese
10. Necrotic spots not common:	
11. Symptoms appear in young leaves first	iron
11. Symptoms appear in older leaves first:	
12. Younger leaves often severely twisted	molybdenum
12. Younger leaves greener than normal	magnesium

Nutrients in Excess

Over-application of nutrients can have serious environmental consequences. Nutrients that are mobile in soil can be washed or leached through soil and enter groundwater (Figure 1). Surface runoff water may also contain high levels of nutrients or soil particles with nutrients attached. These can enter surface water bodies such as lakes and streams. Improper use of any nutrient source—whether inorganic (chemical) fertilizer, organic fertilizer, manures, or composts—can contribute to surface and groundwater pollution. When used properly, inorganic and organic fertilizers are safe for the environment.

In addition to environmental concerns, excess levels of nutrients impact plant growth in many undesirable ways. Excess nitrogen, for example, results in vigorous vegetative growth but low fruit yield for many garden plants. Tomatoes, potatoes and pumpkins are excellent examples of plants that, when over-fertilized with nitrogen produce excessively large vines that bear few fruit or tubers. In landscapes, over fertilization of turf produces lush growth that requires more frequent mowing and can be more susceptible to disease. Over-fertilization of trees can delay leaf senescence, resulting in limb damage from early-season snowfall. Perennials can also be more susceptible to winter damage if over fertilized, since excess nitrogen in late summer or fall will delay natural hardening processes that prepare plants for winter.

Fertilizers as a source of nutrients

Many different sources of nutrients are available, including conventional and controlled-release inorganic (or "processed") fertilizers, organic fertilizers and manures, and legumes grown as green manure crops. Any material sold as a nutrient source is required by law to state the concentrations (in percent of dry weight) of nitrogen–phosphorus–potassium (N–P–K), always in that order, in a prominent location on the label (Figure 2, see also sidebar). Phosphorus and potassium are expressed in the oxide forms P_2O_5 and K_2O. This method of expression is a holdover from earlier times when phosphorus and potassium in fertilizers were analyzed after burning the materials to remove any impurities.

A fertilizer label represents a guarantee that the material contains the levels of nutrients stated. If present, concentrations of other nutrients such as calcium, magnesium, sulfur, or zinc are specified elsewhere on the label and serve as a similar guarantee of content.

Some inorganic fertilizers contain a single nutrient. An example is urea, which has the label designation 46–0–0, or 46% nitrogen by weight. Some fertilizers contain all three macronutrients and are called **complete fertilizers**. The vast majority of inorganic fertilizers are complete fertilizers created to give specific ratios of

Figure 2. All inorganic and organic fertilizer packages must be clearly labeled with their percentage of nitrogen, phosphorus, and potassium (N–P–K).

Labeling Requirements

(from http://agr.wa.gov/PestFert/Fertilizers/ProductRegistration.aspx)

Any commercial fertilizer distributed in Washington must have a label attached to the package which provides the following information:

1. net weight;
2. product name, brand, and grade (the grade is not required if no primary nutrients are claimed);
3. guaranteed analysis and the sources listed in a derivation statement below the completed guaranteed analysis;
4. name and address of the registrant or licensee (the name and address of the manufacturer, if different from the registrant or licensee, may also be stated); and
5. any information required under the Department of Labor & Industries - Hazardous Communications rule, WAC 296-62-054; the Labor & Industries rule has changed to the WAC 296-839, Content and Distribution of Material Safety Data Sheets (MSDS) and Label Information;
6. at a minimum, one of the following label statements:
    a) "Information received by the Washington State Department of Agriculture regarding the components in this product is available on the Internet at http://agr.wa.gov."
    b) "Information regarding the contents and levels of metals in this product is available on the Internet at http://agr.wa.gov."
    c) "Information regarding the contents and levels of metals in this product is available on the Internet at http://www.regulatory-info-xx.com."

        Each registrant must substitute a unique alphanumeric identifier for "xx." This statement may be used only if the registrant establishes and maintains the Internet site and the Internet site meets the following criteria:

        (i) there is no advertising or company-specific information on the site; and

        (ii) there is a clearly visible, direct hyperlink to the department's Internet site specified in (a) and (b) of this subsection.
    d) "Information regarding the contents and levels of metals in this product is available on the Internet at: "http://www.aapfco.org/metals.htm."

If a commercial fertilizer is distributed in bulk, a written or printed statement meeting the labeling requirements must accompany delivery and be supplied to the purchaser at the time of delivery. This includes truckloads and railcar loads.

N–P–K (Table 3). For example, 25–3–5 is a common turf fertilizer. There are literally hundreds of different inorganic fertilizer blends on the market, and blends containing virtually any combination of N–P–K can be found.

Table 3. Common fertilizers available in landscape, garden, and farm supply stores.

Fertilizer type	Common Name	Fertilizer label % Nitrogen – % Phosphorus (as P_2O_5) – % Potassium (as K_2O)
Single nutrient fertilizers	Ammonium nitrate	34–0–0
	Ammonium sulfate	21–0–0
	Urea	46–0–0
	Triple superphosphate	0–45–0
	Potassium chloride	0–0–60
Multi-nutrient fertilizers	Ammonium phosphate	11–52–0, 18–46–0
	Turf fertilizer	30–10–0
Complete fertlizers	Lawn fertilizer	29–3–4
	Lawn food	25–3–5
	Turf builder	32–3–2
	Starter fertilizer	20–27–5
	Winterizer	22–4–14
	Balanced fertilizer	16–16–16
Special purpose fertilizers	Vegetable food	12–12–12
	Rose food	20–10–5
	Acidic fertilizer	30–10–10

Nutrient concentrations from the label can be used to calculate the amount of nitrogen, phosphorus and potassium in a given quantity of that fertilizer.

For instance: Calculate the amount of nitrogen, phosphorus and potassium contained in 10 pounds of 25–3–5 fertilizer. This is done by multiplying the decimal equivalent percent (label concentration ÷ 100) of each nutrient in the fertilizer by the quantity of fertilizer.

10 pounds of 25–3–5 fertilizer contains the following:

$0.25 \times 10 = 2.5$ pounds of nitrogen

$0.03 \times 10 = 0.3$ pound of phosphorus (as P_2O_5)

$0.05 \times 10 = 0.5$ pound of potassium (as K_2O)

The rest of the material in the fertilizer is filler and does not supply nutrients.

If sold as a nutrient source, organic fertilizers are subject to the same labeling requirements as inorganic fertilizers. For example, bone meal sold as a nutrient source may have the label designation 6–12–0, or 6% nitrogen and 12% phosphorus (as P_2O_5) and 0% potassium by weight. The amount of each nutrient in a given weight of organic fertilizer can also be calculated from the nutrient concentrations stated on the label. For example, 10 pounds of 6–12–0 contains 0.6 pounds of nitrogen (10 × 0.06), 1.2 pounds of phosphorus (as P_2O_5) (10 × 0.12), and no potassium. Different organic materials also tend to have inherent nutrient concentrations and, unlike inorganic fertilizers, specific combinations of nutrients are more difficult to obtain with organic materials.

Organic fertilizers often contain much lower and more variable concentrations of nutrients than inorganic fertilizers. A wide variety of organic materials are available, and many materials available in bulk can serve as nutrient sources (Table 4). Many organic fertilizers also contain other nutrients like sulfur, iron,

Table 4. Average nutrient concentrations and rates of availability for various organic materials.

Material	% Nitrogen	% Phosphorus	% Potassium	Availability*	Notes**
Alfalfa hay	2–3	0.5–1	1–2	moderate	
Bone meal	1–6	11–30	0	moderate	alkaline
Blood meal	12	1–2	0–1	rapid	acidic
Canola meal	6	2	1		
Cottonseed meal	6	3	1	slow	acidic
Composts	1–3	1–2	1–2	moderate	alkaline
Crab shell meal	4	1.5	0		
Feather meal	12	0	0	moderate	
Fish emulsion	3–5	1	1		
Fish meal	6–12	3–7	2–5	rapid	acidic
Grass clippings	1–2	0–0.5	1–2	moderate	
Green sand	0	0	3–7		
Hoof/horn meal	12–14	1.5–2	0	moderate	alkaline
Kelp	1–1.5	0.5–1	5–10	moderate	zinc, iron
Leaves	1	0–0.5	0–0.5	slow	
Legumes	2–4	0–0.5	2–3	moderate	
Manures: *Cattle*	2–3	0.5–1	1–2	moderate	weedy
Horse	1–2	0.5–1	1–2	slow	weedy
Swine	2–3	0.5–1	1–2	rapid	
Poultry	3–4	1–2	1–2	rapid	high in salts
Sheep	3–4	0.5–1	2–3	moderate	weedy
Pine needles	0.5	0	1	slow	acidic
Rock phosphate	0	25–30	0	very slow	Use only in acid soils
Sawdust	0–1	0–0.5	0–1	very slow	ties up nitrogen
Sewage sludge	2–6	1–4	0–1	moderate	zinc, iron
Seaweed extract	1	2	5	rapid	zinc, iron
Straw/corn stalks	0–0.5	0–0.5	1	very slow	ties up nitrogen
Wood ashes	0	1–2	3–7	rapid	high in salts

*Approximate rate that nutrients are released from the material.
**Special properties or characteristics of the material.

and zinc; however, concentrations of these are usually not given on the label because levels are either too low or too variable to be specified. In addition to supplying nutrients, regular use of organic fertilizers also increases soil organic matter levels, which improves soil physical properties like water holding capacity, drainage, and tilth (the physical condition of soil related to its structure and the ease of tillage).

Most inorganic fertilizers are highly water soluble and immediately available to plants. This can also cause problems since high solubility means that plants will be burned if materials are over-applied or placed too close to sensitive plants. Soluble materials are also more subject to leaching losses since the majority of the nutrients are available soon after application, but plant demands are slower and prolonged throughout the growing season. Nutrients in most organic fertilizers are much less soluble. This reduces the potential for burning with organic materials, but also results in release rates that are at times difficult to predict and may not match plant demand.

Special Purpose Fertilizers

Some fertilizers have special properties that make them more desirable in certain situations (refer back to Table 3). Acidic fertilizers may be beneficial for acid-loving plants such as rhododendrons and blueberries. Special formulations are available for certain plants requiring, for example, higher phosphorus levels for bloom or fruit set. Some nitrogen fertilizers have controlled release properties that mete out nitrogen over several weeks or months. Finally, certain inorganic fertilizers have additives such as herbicides and insecticides. Read label instructions carefully when selecting and using inorganic fertilizers with pesticides. More than one gardener or landscaper has applied a fertilizer with herbicide to gardens or flower beds and damaged or killed desirable plants.

Manure Fertilizers

The amount of nutrients in manure varies depending on the source, age, and handling of the material Table 5). It doesn't take much of a nutrient-rich manure, such as poultry broiler litter, to fertilize a garden. A 5-gallon bucket of broiler litter contains enough nutrients to fertilize 100 to 150 square feet of garden. A similar amount of rabbit manure will fertilize 20 to 30 square feet of garden. If you apply more, you risk harming crops and leaching nitrogen into groundwater.

Dilute manures, such as separated dairy solids and horse manure with bedding, contain far fewer available nutrients, and can be applied in larger amounts. You can use as much as an inch of these materials in the garden every year. Consider these manures mainly as a source of organic matter.

Table 5. Typical nutrient content of uncomposted animal manures at the time of application[1].

Type	N	P_2O_5[2]	K_2O
	lb per cu yard, as-is[3]		
Broiler with litter	33	29	30
Laying hen	26	40	33
Sheep	13	6	24
Rabbit	11	7	10
Beef	8	4	12
Dry stack dairy	6	3	13
Separated dairy solids	3	1	2
Horse	6	4	11

[1]Divide these numbers by 40 to estimate the nutrients in a 5-gallon bucket of manure.
[2]Phosphorus and potassium in this table are shown in units of P_2O_5 and K_2O. These are the units typically used on fertilizer labels. To convert from P to P_2O_5, multiply P by 2.3. To convert from K to K_2O, multiply K by 1.2.
[3]*As-is* is typical for manure stored under cover.

To fine-tune your application rate, experiment with the amount you apply and observe your crops' performance. It's better to be conservative and add more nutrients later if crops seem deficient, than to apply too much at the start.

To use manure, apply it evenly over annual beds, or between rows of perennial crops. Digging or tilling manure into the soil reduces the risk of nutrient loss and environmental harm from runoff.

Biosolids as Fertilizer

Biosolids are a by-product of municipal wastewater treatment. Federal organic standards do not include biosolids as an organic fertilizer, however, biosolids do have two important characteristics of organic fertilizers: 1) their nutrients are released slowly from the organic form by natural processes in the soil; and 2) they are a product of the waste stream that can benefit crop growth.

Most of the biosolids produced in Washington are used to fertilize agricultural and forest crops. The material used on farms is rich in nutrients and acts on plants as poultry manure does. Biosolids typically contain 4 to 6% N, 3 to 6% P_2O_5, and less than 1% K_2O as a percentage of dry weight.

Some communities in Washington produce a special class of biosolids and market them to gardeners. These are called Class A biosolids; they have been treated using heat or composting to reduce pathogens to background levels, making them safe for all garden uses. Three types of Class A biosolids are available in Washington: composts, blends, and heat-dried pellets.

Soil Sampling Guidelines

An important first step in testing garden and landscape soils is to collect a representative sample. Areas that have been treated differently should be sampled separately. For example, gardens should be sampled separately from lawn areas. Avoid unusual or problem areas, or sample them separately to define the problem.

Collect samples from the surface to a depth of 12 inches. In disturbed or tilled areas a shovel works well to collect samples. A hollow-tube soil probe is easier to use when sampling lawns or around perennial vegetation.

Collect a minimum of five samples from different locations in the test area and mix them together in a clean bucket. Air-dry the soil and transfer approximately two cups to a separate container or plastic bag to send to the lab. If multiple samples are submitted for analysis, label each so that the test area they represent can easily be identified.

For a list of soil-testing laboratories, see WSU Extension publication EB 1578E: Analytical Laboratories and Consultants Serving Agriculture in the Pacific Northwest. http://www.puyallup.wsu.edu/analyticallabs/.

Biosolids composts are made from biosolids and yard debris or woody materials, and can be used like other composts. Biosolids blends are formulated for different uses, including turf topdressing, mulches, and soil amendments. Heat-dried pellets are rich in nutrients and are used like commercial organic fertilizers. Check with your local wastewater treatment plant to see if they have Class A biosolids available for home use.

Determining Nutrient Needs

Nutrient needs vary widely depending on soil conditions, previous additions of fertilizer and organic matter, and the types of plants grown. The best way to accurately assess nutrient needs is by testing the soil. A soil test from a commercial lab typically costs between $25.00 and $50.00 per sample, but commercial labs are much more accurate than home testing kits. A soil test report will be accompanied by interpretations and nutrient recommendations for specific conditions.

Testing is recommended every three to five years for landscapes and gardens, or more frequently if problems develop. Testing should be mandatory in a new home developments to diagnose and correct problems before homeowners invest in costly landscape plantings.

Nitrogen is the most common nutrient deficiency in landscapes and gardens. General annual nitrogen needs for different groups of plants and maintenance levels are listed in Table 6. Other chapters in this book provide specific recommendations for different plants. Landscape trees and shrubs, as well as turf, will grow at slower rates if less nitrogen is used than the recommendations listed in Table 6. Slower growth rates may be desirable depending on the goal of the landscaper and the intensity of management. Vegetable nitrogen requirements are designed to produce optimum yields in a garden setting.

Fertilizer Selection

The wide variety of inorganic and organic fertilizers on the market means a product can be found to meet virtually any need. If a soil test report indicates levels of some nutrients are high or excessive, gardeners can and should select products containing lower concentrations of those nutrients since further applications may create an imbalance and adversely affect plant growth. For example, if a soil test report recommends only nitrogen, consider using ammonium nitrate (34–0–0), ammonium sulfate (21–0–0; Table 3), blood meal (12–1–1), or fish meal(6–3–2) (Table 4). If nitrogen and phosphorus are recommended, use a fertilizer such as 30–10–0 or fish meal (6–3–2). Try to select a fertilizer

Table 6. Annual nitrogen recommendations for landscape and garden plants.

General plants	Maintenance level	Recommended rate of nitrogen (per 1000 sq ft)
Ornamentals	Low: xeriscapes, natural areas	0 to 1 lb
	Intermediate: standard landscapes	1 to 2 lb
	High: flower beds, new landscapes	2 to 4 lb
Turf*	Low maintenance	0 to 1 lb
	Intermediate maintenance (most home lawns)	2 to 3 lb
	High maintenance (parks, play fields, golf courses)	4 to 6 lb
Vegetables, fruits	Low: peas, beans	0 to 1 lb
	Intermediate: asparagus, beet, carrot, melon, cauliflower, broccoli, Brussels sprouts, celery, pepper, tomato, lettuce, radish, spinach, turnip, squash, pumpkin	2 to 3 lb
	High: berries, onion, sweet corn, potato**	4 to 6 lb

*Split the total amount of nitrogen into 2 or more separate applications made over the growing season. To prevent burning do not apply more than 1 lb nitrogen/1000 sq ft in a single application.
**For high maintenance level vegetables, apply one-half of the nitrogen at planting and broadcast or band the remainder after plants are well established and entering their rapid growth phase.

material with approximately the same proportions of nutrients as recommended in the soil test report.

Fertilizers vary considerably in price. The cost of different fertilizers should be compared on a per-pound-of-nutrient basis. Cost per pound depends on the package price, weight, and nutrient concentration in the fertilizer.

For example, if a 36-lb bag of 29–3–4 fertilizer cost $15.88 and a 20-lb bag of 21–0–0 fertilizer cost $2.99, which is the least expensive source of nitrogen? The cost per pound of nitrogen, in these examples, is $1.52 for the 29–3–4 and $0.71 for the 21–0–0. More expensive fertilizers often contain additives for pest control and may have added micronutrients or slow-release characteristics. Compare prices and only purchase fertilizers with special additives if they are needed. Bulk quantities of organic materials are generally less expensive than small packages.

Calculating Application Rates

Nutrient recommendations for landscapes and gardens are commonly expressed in pounds per 1000 square feet (Table 6).

Extension bulletins and most labs performing soil test analyses for landscapes and gardens also express recommendations in this form. The information required to calculate the amount of a fertilizer material needed is the nutrient recommendation, the concentration of nutrient in the fertilizer material, and the size of the area to be fertilized. See the sidebar for examples of the fertilizer rate calculations.

Once the amount of fertilizer is calculated, weigh out or carefully estimate the weight of fertilizer needed for the area. A useful approximation is one pint (2 cups) of dry inorganic fertilizer weighs approximately one pound. A pint-measuring cup can be used to estimate pounds of fertilizer for application. Fertilizer labels also contain general guidelines for application rates in different situations. Always read the label on products before using them.

Fertilizer Application Methods

Mineral nutrients are absorbed primarily through the root system, though small quantities can be applied as foliar sprays and absorbed through the leaves. Fertilizers are commonly broadcast on the surface then tilled or watered into the soil. A common fertilizer spreader can be used to apply either inorganic or organic fertilizers. Organic materials may need screening before spreading to remove large particles and facilitate more uniform applications.

Two main types of broadcast applicators are the drop spreader and the rotary spreader (Figure 3). Most drop spreaders are capable of applying a wide range of rates, but the spread is limited to the width of the drop box (normally 18 inches to 3 feet). Rotary spreaders may broadcast material in a 5- to 10-foot-wide path but with less uniformity and rate control than drop spreaders. Most spreaders are adjustable for different fertilizer materials and rates of application. The spreader manufacturer normally supplies calibration settings for various rates of nutrients applied as inorganic fertilizers. Spreaders need to be calibrated for organic materials.

To calibrate a spreader, adjust the spreader to a relatively high setting. Place two or three pounds of organic material in the hopper and proceed to spread this amount in a continuous straight path. Note the width of the spread path and the distance traveled to broadcast all of the material. Calculate the area of coverage by multiplying width by length. Calculate the rate of application in pounds per 1000 square feet by dividing the pounds

Example Fertilizer Calculations

Situation 1: 30–10–0 will be used to fertilize a garden at the rate of 2 lb of nitrogen per 1000 sq ft. The garden area is 10 feet wide by 50 feet long. How much 30–10–0 is needed to fertilize this area at the desired nitrogen rate?

Step 1: Calculate how much 30–10–0 is required to fertilize 1000 sq ft at 2 lb of nitrogen per 1000 sq ft. Divide the amount of nitrogen required in 1000 sq ft by the decimal equivalent of nitrogen in the fertilizer (30% ÷ 100 = 0.30):

2 lb of nitrogen ÷ 0.30 = 6.7 lb of 30–10–0 per 1000 sq ft

Step 2: Calculate the area to be fertilized by multiplying the length by the width (in feet):

50 ft long × 10 ft wide = 500 sq ft area

Step 3: Divide the area to be fertilized (from Step 2) by 1000 sq ft and multiply by the required amount of fertilizer (from Step 1):

(500 sq ft ÷ 1000 sq ft) × 6.7 = 3.4 lb of 30–10–0

Answer: A total of 3.4 pounds of 30–10–0 is necessary to fertilize the 10-by-50-foot garden area at a rate of 2 pounds of nitrogen per 1000 square feet.

Situation 2: 0–45–0 will be used to fertilize a lawn at the rate of 1 lb of phosphorus (as P_2O_5) per 1000 sq ft. The lawn area is 50 feet wide by 100 feet long. Calculate how much 0–45–0 is needed to fertilize this area at the desired rate.

Step 1: Calculate how much 0–45–0 is required to fertilize 1000 square feet at a rate of 1 lb of phosphorus per 1000 sq ft. To do this, divide the amount of phosphorus required in 1000 sq ft by the decimal equivalent of phosphorus in the fertilizer (45% ÷ 100 = 0.45):

1 lb of phosphorus ÷ 0.45 = 2.2 lb of 0–45–0 per 1000 sq ft

Step 2: Calculate the area to be fertilized by multiplying the width by the length (in feet):

50 ft wide × 100 ft long = 5000 sq ft area

Step 3: Divide the area to be fertilized (from Step 2) by 1000 sq ft and multiply by the amount of fertilizer calculated in Step 1:

(5000 sq ft ÷ 1000 sq ft) × 2.2 = 11 lb of 0–45–0

Answer: A total of 11 pounds of 0–45–0 is necessary to fertilize the 50-by-100-foot lawn at a rate of 1 pound of phosphorus per 1000 square feet.

Situation 3: Blood meal (12–2–1) will be used to fertilize a garden at the rate of 2 lb of nitrogen per 1000 sq ft. The garden area is 20 feet wide by 100 feet long. Calculate how much 12–2–1 blood meal is needed to fertilize this area at the desired nitrogen rate.

Step 1: Calculate how much 12–2–1 is required to fertilize 1000 square feet at 2 pounds of nitrogen per 1000 square feet. To do this, divide the amount of nitrogen required in 1000 square feet by the decimal equivalent of nitrogen in the fertilizer (12% ÷ 100 = 0.12):

2 pounds of nitrogen ÷ 0.12 = 16.7 pounds of 12–2–1 per 1000 square feet

Step 2: Calculate the area to be fertilized by multiplying the width by the length (in feet):

20 ft wide × 100 ft long = 2000 square ft area

Step 3. Divide the area to be fertilized (from Step 2) by 1000 sq ft and multiply by the amount of fertilizer calculated in Step 1:

(2000 sq ft ÷ 1000 sq ft) × 16.7 = 33.4 lb of 12–2–1

Answer: A total of 33.4 pounds of 12–2–1 blood meal is necessary to fertilize the 20-by-100-foot garden area at a rate of 2 pounds of nitrogen per 1000 square feet.

Figure 3. Two common types of broadcast applicators are the drop spreader (right) and the rotary spreader (left).

of fertilizer spread by the area covered, and multiplying by 1000. Compare this value to the rate needed (see the example in the box below).

Calibrating a broadcast spreader

A spreader broadcasts a five-foot-wide path and traveled 20 feet to empty 3 pounds of compost. Calculate the application rate and how much is needed at that rate, to cover 1000 square feet.

Answer:

The area covered is 5 feet × 20 ft = 100 square feet.

Therefore, the rate of application is: 3 lb ÷ 100 sq ft) = 0.03 lb/sq ft.

To cover 1000 sq ft, 0.03 lb/sq ft × 1000 sq ft = 30 lb needed to cover 1000 square feet.

Compare this with the application rate of compost needed and if necessary adjust the spreader and calibrate again.

Because of their relatively low nutrient content, organic fertilizers are applied at much higher rates than inorganic fertilizers. Therefore, even at the highest spreader settings you may have to make two or more passes over an area to apply the required amount of material. Once a spreader is calibrated for a specific nutrient rate and organic fertilizer, keep a record of the setting for future use with this material.

When applying fertilizer, avoid streaking caused by skips and overlap by applying one-half of the fertilizer while traveling in one direction and the other half while traveling in a perpendicular direction. This method is especially important for fertilizing turf where streaking is common. An alternative method of broadcasting large quantities of organic material is to space piles of the material throughout the area and spread the piles out uniformly using a garden or leaf rake.

Banding is a convenient way to make in-season applications to high nitrogen-requiring vegetables like corn (Table 5). Banding also works well to put immobile nutrients like phosphorus near plant roots. If banding an organic fertilizer, select a material with rapid nutrient release (Table 4).

To band a fertilizer, first calculate the amount of material needed for the area as if you were going to broadcast the material. Divide this amount by the number of plant rows in the area to determine the amount of fertilizer to apply for each row. Open narrow furrows 6 to 8 inches away from the base of the plants, 2 to 3 inches deep. Distribute the fertilizer evenly in the furrow and cover with soil.

Liquid and foliar fertilizer applications can be made with water-soluble inorganic products or materials such as fish emulsion, seaweed extract, or even compost or manure. There is a potential for leaf burning with foliar applications, so follow product label instructions carefully. A “tea” of manure or compost can also be used as a liquid fertilizer. To make a tea, partially fill a burlap or cloth bag with manure or compost and submerge it for several days in a bucket of water exposed to the sun. The resulting solution can be applied directly to the soil or foliage of plants.

Application Timing

Nutrient applications should be made at the right time to meet plant demands—both for plant performance and to reduce the potential for nutrient losses through leaching or evaporation. Unless the product label states that the material has slow release properties, nutrients in inorganic fertilizers are available within a few days of application. Organic fertilizers generally release nutrients more slowly than inorganic products, and release rates vary among different organic materials (Table 4). Release of nutrients from organic sources is also dependent on soil microorganisms, which are more active during warm periods.

Inorganic fertilizers are normally applied in the spring prior to planting or when growth starts for perennials. Organic fertilizers often need to be applied earlier than inorganic products, even as early as the fall before a spring planting. Generally, the slower the nutrient release rate from organic materials, the earlier these materials need to be applied prior to plant needs. For slow-growing plants and xeriscapes fertilized with low rates of nitrogen (Table 3), a slow-to-moderate availability organic material can be used. Organic materials with very slow nutrient availability, while good sources of organic matter, generally make poor sources of nutrients for plants needing nitrogen early in the growing season.

For plants with high nitrogen requirements like corn, potatoes, and intermediate- to high-maintenance turf (Table 6), split applications of a soluble inorganic fertilizer or rapidly available organic material are recommended. A portion (25–50%) of the annual nitrogen requirement is usually applied at planting or early in the spring. The remainder is split into 2 or 3 applications made during the growing season. If organic nutrient sources are used to fertilize high nitrogen-demand plants, select materials that release nutrients rapidly for best performance (Table 4).

Often, combined approaches—where nutrients from organic materials are supplemented with more soluble inorganic fertilizers—allow gardeners and landscapers to capture the benefits of both. The organic material provides a slow but continuous supply of nutrients while inorganic materials can be added at appropriate times such as during the rapid growth phase of high-demand garden crops.

Cover Crops and Green Manures

Cover crops (also called **green manures**) are plants grown, not for harvest, but for the express purpose of incorporating them back into the soil to increase organic matter levels. Cover crops can, in addition to improving soil conditions, aid in the control of erosion and weeds and prevent soil compaction. They also provide a habitat for beneficial insects, improve soil fertility, stimulate soil biological activity, and absorb and help recycle plant nutrients—especially nitrogen—between growing seasons.

Many plants can be grown as cover crops. Different plants vary in their benefits, adaptation to sites and climates, and role in garden rotations. For example, legumes add nitrogen as well as organic matter to soil. Fast growing plants with fibrous root systems such as wheat, barley, and oats produce large amounts of organic matter and help control erosion. Compaction can be reduced by growing plants with a deep tap root such as alfalfa, sweet clover, or mustards. Deep taproots can grow through compacted soil and hardpan layers, breaking up the compacted material. Later, those rootways become conduits for water and other plants' roots.

Cover crops can be grown in rotation in a garden, sown in summer or fall after removing garden plants, or grown between rows of plants in the garden. Cover crops can also be grown in new landscapes to control erosion and increase soil organic matter levels before final site preparation and the installation of lawns and landscape plants. Table 7 lists some common cover crops and seeding recommendations. Be sure to mow or till in the cover crop before it sets seed, to avoid an unintentional second crop.

Table 6. Commonly used cover crops, growth characteristics and seeding rate recommendations.

Name	Type and Growth characteristics	Seeding rate (lb/1000 sq ft)
Alfalfa	Perennial. Cold tolerant, nitrogen-fixing legume. Low shade tolerance; deep rooted; drought tolerant.	½–1
Hairy indigo	Perennial. Short-lived, not cold tolerant (killed by frost) legume. Low shade tolerance; drought tolerant. Slow establishment.	½
Red clover	Perennial. Short-lived, cold tolerant, nitrogen-fixing legume. Shade and drought tolerant.	½–1
Sweetclover	Annual or biennial types. Short-lived, cold tolerant, nitrogen-fixing legume. Strong tap root.	½–1
Buckwheat	Summer annual. Cold sensitive; moderate shade and drought tolerance; rapid establishment and growth.	1–2
Garden pea	Summer annual. Cold sensitive, nitrogen-fixing legume. Low shade tolerance.	5–15
Mustard or turnip	Summer annual. Cold tolerant; tap-rooted.	¼
Spring grains	Summer annual. Includes wheat, barley, and oats. Cold tolerant; rapid growth rate; inexpensive seed.	2–4
Austrian winter peas	Winter annual. Moderately cold- and drought-tolerant, nitrogen-fixing legume. Low shade and traffic tolerance.	2–4
Hairy vetch	Winter annual. Cold tolerant, nitrogen-fixing legume. Moderately shade- and drought-tolerant.	1–2
Winter wheat	Winter annual. Cold tolerant and rapidly establishing; inexpensive seed.	2–3
Winter rye	Winter annual. Cold tolerant and rapidly establishing; drought- and shade-tolerant; inexpensive seed.	2–3

Soil pH

Soil pH influences nutrient availability and toxicity, and microbial activity. In most cases, pH does not influence the total amount of nutrient in a soil, only the chemical form in which nutrients are present. However, for many nutrients it is the chemical form and not the total amount in soil that influences availability to plants.

Fortunately, most plants grow well in soil at a pH range of 5.5 to 7.5. A few acid loving plants require soil with lower pH, while some native plants from arid desert environments appear to require alkaline soil conditions. Table 4 in Chapter 3 (Soil Science) shows optimum pH ranges for common garden and landscape plants.

Plants grown in soil with a pH outside of their adapted zone frequently suffer nutrient deficiency or toxicity symptoms. One example of a pH-induced nutrient deficiency is iron chlorosis, a yellowing of leaves on certain trees, shrubs and small fruits (Figures 4 and 5). This problem commonly occurs when plants adapted to acidic soil conditions are grown in alkaline soils. Control of pH-induced nutrient deficiencies can be difficult since applications in the

Figure 4. Interveinal chlorosis, a symptom of iron deficiency, showing on a silver maple growing in alkaline (high pH) soil.

Figure 5. Inverveinal chlorosis in rhododendron; iron deficiency due to overly alkaline (high pH) soil. (Note: notching on leaves in photo is from insect feeding and has nothing to do with mineral deficiency.)

form of fertilizers are rapidly rendered unavailable in the soil unless the underlying problem of soil pH is addressed.

Raising Soil pH

Soil pH is increased by adding lime. Ground limestone is a white powdered material composed primarily of calcium carbonate. Dolomitic lime is composed of calcium and magnesium carbonates. Lime materials react in soil to neutralize excess acidity. In the reaction, calcium and (if dolomite is used) magnesium are released. Lime can be an important source of these nutrients since they are commonly deficient in soils with low (acidic) pH.

Wood ashes are a readily available source of potassium, calcium, and magnesium. Like lime, they also raise soil pH. However, high rates of wood ashes may cause short-term salt injury, so apply less than 15 to 25 pounds per 1,000 square feet. Wood ashes are not recommended for use in alkaline soils.

A simple and inexpensive test can be used to determine soil pH. A more elaborate test called a "lime requirement" can indicate exactly how much lime is required to increase soil to a specific pH. Once soil pH is known, a decision can be made whether or not to apply lime based on the plants being grown. Most areas needing lime will be located west of the Cascades.

Average application rates are approximately 50 lb of lime per 1000 sq ft. Lime should be tilled into soil if possible. Lime is a slow-release material, so apply it in the fall to benefit spring crops.

Lowering Soil pH

If soil pH is above 8.0 or acid-loving plants are desired in an alkaline soil, some action should be taken to reduce pH. Soils with greater organic matter content tend to have lower pH. Peat and sphagnum peat moss are acidic and will lower soil pH more than other organic amendments. Elemental sulfur (90 or 99% sulfur on the label) oxidizes slowly in the soil to form acid. Application at rates of 2 to 4 lb per 1000 sq ft of area can reduce pH.

Test the soil regularly and stop adding sulfur when pH has reached the desired level. Acidifying fertilizers such as ammonium sulfate and other products with label designations indicating an acidic reaction in the soil can also lower pH. Finally, planting on raised beds in a sandy medium amended with peat moss or another source of acidic organic matter and elemental sulfur can create acidic areas for specialty plants.

Further Reading

WSU Extension Publications available at: http://cru84.cahe.wsu.edu/

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6

Vegetable Gardening

Topics covered:

- Introduction
- Getting Started
  - Choosing a Vegetable Garden Site
  - Design
  - Soil Management
  - Variety Selection
- Planting
  - Direct Seeding
  - Growing Transplants
  - Planting Schedule
- Maintenance
  - Plant Nutrition
  - Watering
- Winter Gardening
- Saving and Storing Vegetable Seeds

Learning Objectives

- Know site, soil, and environmental conditions for optimal home garden production
- Know how to plan for, plant, and maintain healthy vegetable plants
- Understand the difference between cool and warm season crops

By

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Introduction

Sustainable gardening means growing plants in an environmentally friendly way. In the vegetable garden, this may include using cover crops to improve soil tilth and nutrition, rotating crops to prevent disease, and choosing an irrigation system that conserves water and reduces disease pressure. Also, making the right choices regarding types of crops and varieties to grow will enable you to produce a healthy crop while reducing the need for pesticides. Many of the practices that we will discuss in this chapter are the same practices that are used in organic gardening. Our goal is to grow a healthy, productive vegetable garden while minimizing outside inputs such as purchased fertilizer and pesticides. In addition, by recycling plant debris through composting you will be able to reduce the amount of waste that your garden produces.

In this chapter we will discuss common cultural practices and techniques to use in your vegetable garden. Some topics such as soils, fertility, and composting are covered in detail in separate chapters in this manual.

Getting Started

Establishing a new vegetable garden that will be successful requires some advance assessment and planning similar to implementing any landscape design. There are decisions to be made about exactly where the garden will be for best sun access and wind protection, what that site needs in terms of soil enhancement, what sort of beds will be set up, what methods of irrigation will be used, what types and quantities of vegetables will be grown, and so on. Some of these issues are ongoing and can be addressed or modified throughout the growing season or between seasons. Others, such as where the garden sits, are not so flexible. Also keep in mind your own needs as a gardener: if the garden is not where and what you want it to be, you will be less inclined to give it the attention it needs to be sustainable and successful.

Choosing a Vegetable Garden Site

The first step to growing a healthy and productive vegetable garden is selecting a site that has these four important elements:

1) Full sunlight.
2) Easy access to water.
3) Protection from heavy winds.
4) Soil with good tilth.

Sunlight. Most summer vegetable crops need at least eight hours of direct sunlight a day. If trees or shrubs are shading your garden, prune branches to allow in more light. If a solid fence is the source of the shade, consider replacing it with a post and rail fence that will let in more light. Light can be improved by painting nearby walls or fences white so they are more reflective. Areas receiving less sunlight may make a good composting site or work area. If the only garden site you have is shady, start by growing crops with low light requirements, such as leafy green crops like lettuce, or asparagus, garlic, and leeks. If these do well, expand into medium light-needing crops such as beans, radishes, and peas.

Water. Regardless of where you live in Washington, if you are going to grow summer vegetables you will need a steady supply of clean water for irrigation all summer long. The easiest way to irrigate is from a water spigot located in or near your vegetable garden. If the spigot is in an inconvenient place, you may want to extend the line and put a spigot closer to the garden. In climates that freeze, bury the pipe deep enough (below the **soil frost line**) to prevent it from bursting. Check with your local water company and county building department to learn how deep the soil frost line is in your area, and to determine if there are any required permits or procedures for extending a water line. See the Watering section to learn more about how and when to irrigate your vegetable garden to conserve water and optimize crop production. If your garden is very wet during the winter, it will require drainage if you plan to grow winter vegetable crops. Use raised beds and deep pathways to create a drier growing area for winter crops (see the section on Raised Beds).

Wind Protection. Vegetables tend to be very easily damaged by winds. Not only can plants be blown over, but if there are particles of soil in the wind, these will abrade leaves and stems, thereby sand blasting them. If your site is exposed to wind, plant or build a windbreak so that it protects the garden but does not shade plants. See "Trees Against the Wind" listed in Further Reading for details on planting a wind break.

Soil Tilth. A deep, loose garden soil that is high in organic matter is ideal, but few gardens start out this way. If you are lucky enough to have such good soil, maintain it by adding compost each year. If your soil is poor quality to begin with, or if you cannot dig more than a few inches deep, or if it is full of rocks, you can slowly improve the soil by adding organic matter several times a year. See the section on Soil Management for suggestions on building soil tilth.

Access and Convenience. It is best to plant your garden in an area where you have easy access for maintenance. Vegetables usually require care several times a week so choose a location that is convenient. You will also need to move things in and out of the garden such as wheelbarrows of compost. If you will be adding compost by the pickup load, make sure the garden gate area is large enough for this.

Site Protection. Another primary consideration for your vegetable garden is fencing. Deer can be a nuisance throughout the state and they may feed in your garden year-round. If you know there are deer in your area, be prepared to construct an 8-foot deer fence. Neighborhood dogs can also be destructive pests—digging, rolling and leaving droppings—so fencing them out as well is often necessary. See Chapter 18: Vertebrate Pest Management, for methods of dealing with other large pests.

Design

Once you have decided where your vegetable garden will be located, your next step is to design the garden layout. Committing your design to paper helps you plan quantities of seed, mulch, and other materials. It also serves as a record of what was done, to help with future design changes or rotational plantings.

Many gardens often look like smaller versions of farms: long, single rows of vegetables with wide alleys between the rows. If you have lots of land and a rototiller, you may choose this system. If you have limited space or would like to maximize space usage, you may choose to use raised beds. See the Raised Beds section for information on how to make a raised bed.

Pathways. Whether you choose to plant in rows or beds, make the main pathways in your garden at least 3 feet wide so that you can easily use a wheelbarrow. If you use a garden tractor, make sure you have room to drive in and out of the garden and to turn around if needed. If you plant vegetables in long, single rows, allow enough space to walk between the rows for weeding and harvesting. If your garden is arranged in raised beds, pathways between the beds should be wide enough for you to work. For example, if you work on your knees, measure the distance between the front of your knee and the toe of your shoe, then allow at least this much space for the width of your pathway. Do not make the beds or rows too wide: plan to plant, weed, water and harvest by reaching into the bed while standing or kneeling on the pathway to avoid compacting the soil within the bed.

Cover all pathways with mulch or a cover crop to control weeds in the alleys and to keep your feet clean and dry year-round. For mulch, use wood chips, straw, pine needles, or any other product that is readily available in your area. To make the mulch more effective, first lay down heavy cardboard and then cover with mulch. If you use degradable mulch such as woodchips or straw, scrape the decomposed mulch off the pathways and into the rows or beds every 2 to 3 years and add new, fresh mulch to pathways.

If you plant a cover crop in the alleyways, mow it several times a year to keep it from getting too tall and setting seed. If you use this technique, make sure your alleys are wide enough for your lawn mower. See the Cover Crop section for information about different cover crops that can be used. The major disadvantage with this technique is that the cover crop will grow into the beds and will require edging or weeding several times a year. If you use framed beds, this may not be an issue.

Raised Beds. Raised beds have some important advantages that make them very popular for many vegetable gardeners including gardeners with mobility issues. For example, raised beds have improved water drainage that results in increased soil temperatures, especially in the spring months. It is possible to work a drier soil earlier and it is possible to plant a warmer soil earlier, so, raised beds lead to an earlier garden. An added benefit of warmer, drier soil is decreased incidence of root rot, a common disease problem of many vegetable crops. Raised beds are usually semi-permanent or permanent, and although they may require more labor to start with, they are generally easier to maintain.

While a raised bed can be of any dimension, they are usually 6 inches to 1 foot high, 3 to 4 feet wide, and 10 feet long or longer. It is best to custom-fit the width and length of your beds to suit your needs. First, make sure you can easily reach the middle of the bed while squatting, kneeling, or sitting on either side of a bed. If a bed is against a wall or a fence and you only have access from one side, make sure you can reach all the way across the bed without stepping into the bed. Make the beds short enough so that you can easily get from one place to another in the garden without going too far out of your way. If children assist you in the garden, place stepping stones across the beds every 10 feet or so for easy crossing over. Do not walk on beds—avoiding foot traffic will minimize soil compaction and will result in better soil tilth in the bed.

For more information about the design and use of raised beds for people with limited mobility, refer to the publication "Gardens for All," listed in Further Reading at the end of this chapter. Typically, when used for this purpose, raised beds are built 2 to 3 feet high and are spaced far enough apart to allow wheelchair access.

If you are starting a new garden or redesigning your garden space, use string to mark off the beds and pathways. Make sure to leave enough space in pathways for a wheelbarrow, garden tractor, or other equipment that you commonly use. A primary objective will be to build a loose, rich, deep soil throughout the bed. If you are able to dig about a foot deep in your soil, consider using the double digging method to build raised beds. Double digging is an old, traditional gardening technique that is used to build soil for permanent raised beds and is discussed below.

Double Digging. Double digging is an old, labor-intensive technique used to prepare raised beds and is generally only done once for each bed. Double digging is most popular in areas where the soil is easy to dig, as the recommended depth for double digging is about 1 foot. The basic concept of double digging is to add compost deep at the bottom of a bed to improve rooting potential, water drainage, and soil nutrition. Here are the steps for double digging a bed (Figure 1):

1. Outline your bed with string or mark the outline in the soil.
2. Dig a trench across the width of the bed at one end. The trench should be approximately 1 foot deep and 1 foot wide, but a few inches more or less is just fine. As you remove the soil, pile it into a wheelbarrow and dump it at the far end of the bed—not on the bed, but next to the far end.
3. Fill the trench at least half full with compost, but not to overflowing. You will likely only double dig each bed once, and the compost you add here will play a key role in the health of the soil you are building, so add enough to make it worth your while. Also, the compost will settle and decompose the first year, losing about half its volume, which will cause the bed to lose half its height.
4. Dig another trench across the width of the bed, right next to the first trench, and place all the soil from this second trench on top of the compost in the previous trench.
5. Repeat steps 2–4 until the entire bed has been dug and the trenches have all been filled with compost and topped by soil. When you dig the final trench, fill it with the soil from the first trench that you piled at the far end of the bed (Step 1). Spread any remaining soil across the entire bed.
6. Rake the surface of the bed to smooth it out and break up any large clods.

Soil Management

Establishing and maintaining a healthy, fertile soil is the foundation of a healthy, productive vegetable garden. A healthy soil will have air, organic matter, nutrients, and good water-holding capacity. Organic matter is a good source of plant nutrients and will also increase water-holding capacity. Do not dig in the garden when the soil is too wet, as this will destroy soil structure. If your garden tends to be very wet until late spring, use raised beds to increase soil drainage and to enable you to plant earlier.

Air. Plants are living, breathing organisms and require air in their root zones as well as around their foliage to thrive. Because roots are buried in soil, it is easy to think that air is not an essential part of a healthy soil system. On the contrary, air in the root zone is as necessary to plant growth as water and nutrients. Soil organisms such as worms, bacteria, and fungi also need air to survive and do their jobs of breaking down organic matter and making nutrients available to plants. Air is added to the soil

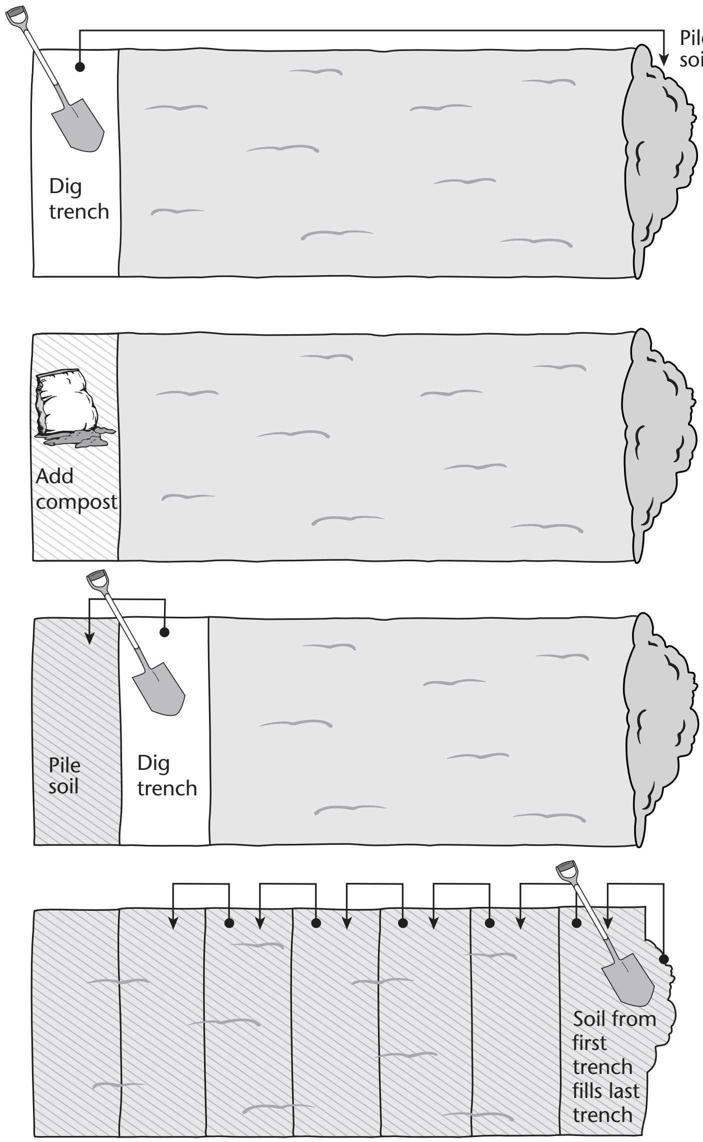


Figure 1. Steps for double-digging a garden bed.

when you cultivate for planting, when you incorporate compost, or when you till in plant residue after harvest. A rototiller will generally turn the top 5–6 inches of soil, while hand digging can reach a foot or more deep. Worm tunnels and decomposing deep plant roots will create channels several feet deep in the soil for aeration and water drainage. Soil that has high organic matter content will have large pore spaces that can be filled with air.

A well-aerated, deep soil allows plants to establish a deep rooting system. Plants with deep root systems are more drought tolerant and more effective at capturing soil nutrients. It is especially important to have deep, well-aerated soils in intensive beds where plants are spaced close together and there is greater potential for competition for water and nutrients.

Organic Matter. Plant residues such as fallen leaves, grass clippings, vegetable crop debris, and compost are all sources of organic matter for your vegetable garden. Naturally occurring bacteria and fungi in the soil decompose organic matter, turning it into humus, which is generally seen as the dark brown or black layer at the top of the soil. Soil organic matter generally accounts for only 1–5% of the total soil weight, whereas the majority of soil is made up of mineral particles in the form of sand, silt or clay. Soil organic matter improves soil tilth (soil health and structure), water-holding capacity, nutrient retention, nutrient availability, and aeration. Soil organic matter helps to improve soil structure by binding mineral soil particles together into larger soil aggregates. Large soil aggregates result in larger pore spaces that are available for air and water retention, and for root growth.

Whether your soil is too heavy due to high clay content or too light due to high sand content, adding organic matter regularly is the best thing you can do to improve it. Soil that is high in organic matter is easier to work and generally is more productive than soil that lacks organic matter. To increase soil organic matter, add 2–3 inches of compost to the beds or rows each year. In addition, you can grow cover crops or use composted animal manures from local farms to build a healthy, productive soil.

Building the soil. If your garden soil is very rocky or compacted, it is easiest to build the soil up over the course of several years rather than trying to dig deep the first year. To build your soil up, apply a 4–6 inch layer of compost uniformly over beds the first year. After you have applied the compost the first year, remove the top few inches of good soil from the paths and place it on top of the compost in the beds. This increases the depth of good soil in the beds and discourages weed growth in the poorer soil left in the paths. Apply a 2–3 inch layer of compost to the beds each year after.

You can leave compost on the surface of the bed or you can turn it into the soil. Compost left on the surface will act as mulch and will help retain soil moisture and smother weeds. By incorporating the compost, you are placing nutrients where they are needed most—in the rooting zone. Whether you choose to leave the compost on top of the bed or turn it in, rake the beds to level them and to break up any large clods. Your decision may be based on how easy it is to turn the soil in your garden and you should do what is easiest for you. If your soil is compact and difficult to dig, plant deep-rooted vegetables such as tomatoes, winter squash, and melons for the first 2–3 years. Decomposing deep roots will create channels for water drainage and aeration, which will, in turn, enable medium- and shallow-rooted crops to grow and be more productive in following years.

Compost. Compost is decomposed plant material and is easily made from plant residues from your garden and kitchen. Homemade compost is the easiest and least expensive way to provide your garden soil with fresh organic matter each year. In general, you should think of your compost pile as a place to recycle garden debris and kitchen vegetable scraps. Do not compost food wastes such as meat that might attract rodents or other animals. Be cautious when composting problem weeds such as quack grass, morning glory, and comfry because roots of these weeds can be very resistant to decomposition and may begin to grow again when incorporated back into garden soil. Also, some plant seeds may not be killed unless you are very diligent about turning the compost pile to ensure that high enough temperatures have been reached for the necessary time period. Diseased plants with infections such as club root or late blight should not be be put in your compost pile because the disease organisms can survive the composting process. There are several techniques and "recipes" for making compost effectively, and to learn more, refer to Chapter 22: Composting.

Cover Crops. Cover crops are planted to protect the soil from erosion, control weeds, trap or add nutrients, add organic matter, break up a pest cycle in the soil, improve soil moisture retention, and increase soil drainage. When the primary purpose of planting a cover crop is to add nutrients, then the crop is often referred to as a "green manure crop." Cover crops and green manure crops are the same crops—they are just referred to differently depending on the primary purpose for planting them. In this chapter, these crops will be referred to as cover crops. If you have unplanted areas in your garden in the summer, or are not growing a winter vegetable crop, consider planting a cover crop. Cover crops are usually legumes or grain crops such as wheat, oats, or barley.

Cover crops improve soil nutrition by taking up nutrients from the soil that would otherwise be lost due to leaching or erosion. Nutrients are held in the green, living tissue of the cover crop and are not available for the vegetable crop until the cover crop is killed and it has decomposed in the soil. Mowing is generally a good method to kill annual grass cover crops while light tillage generally works well for most legume crops. If the legume crop has a lot of top growth, you may mow it first and either remove the tops and add them to your compost pile or leave them on the surface for a few weeks and then till. Note that legume plants will not form an association with *Rhizobium* bacteria if the plants have received sufficient nitrogen fertilizer to meet their needs. Therefore, to take advantage of nitrogen fixation by a legume cover crop, only use a small amount of nitrogen fertilizer for legume plants.

Wait at least two weeks after killing or tilling the cover crop before planting a new crop. As the cover crop breaks down during these two weeks, nutrients are not available for new plant growth, and any new seedlings will suffer from nutrient deficiencies during this period. Mow or kill the cover crop before it sets seed. If it does set seed, it will likely become a weed in the next season.

Cold-tolerant crops can be planted as summer or winter cover crops, while tender crops should only be planted in the summer (Table 1). Depending on the minimum winter temperatures in your area, somewhat cold tolerant crops may also be suitable for both winter and summer planting. Plant your summer cover crop before the rains end, as soil moisture is needed for good germination. Although some cover crops can survive all summer long without irrigation, they generally will not be very productive. If you want a vigorously growing cover crop it may be necessary to irrigate it during the summer.

Table 1. Cold hardiness of cover crops commonly grown in Washington.

Cold Tolerant	Somewhat Cold Tolerant	Not Cold Tolerant
Hairy vetch (annual)	Annual ryegrass (annual)	Buckwheat (annual)
Red clover (-30 to -20°F)	Barley (annual)	Alfalfa (-10 to -5°F)
Subterrandean clover (-30 to -20°F)	Crimson clover (annual)	Mustard (canola, rapeseed) (annual)
White clover (-30 to -20°F)	Fava beans (annual)	Oats (annual)
Winter wheat (annual)	Field peas (annual)	Sundangrass & sorghum (annual)

Plant a winter cover crop by mid-September. Winter temperatures vary around the state and some cover crops listed in Table 1 as cold tolerant may not be winter hardy in your area. The best way to determine which cover crops will do best in your area is to experiment. Start by planting 2 or 3 cover crops and discard those that do not do well. Each year test another crop until you can identify several that do well. You may also consult with your area Extension agronomist for suggested cover crops.

If you would like to plant a cover crop earlier than mid-September but have not finished harvesting the summer vegetable crop, simply broadcast the cover crop seed around and under the vegetable plants and rake in the seed. The cover crop will germinate under the vegetable crop and will be ready to take off when the vegetable crop is harvested. Cut the spent vegetable plants at the soil surface and place the tops in your compost pile. Leave the roots in place in the garden and they will decompose, adding organic matter where it is needed most—deeper in the soil.

To avoid contamination of your vegetable crops by E. coli and Salmonella, do not use fresh livestock manure in your garden.

Livestock Manure. Livestock manure can be rich in organic matter and crop nutrients, but must be handled safely to avoid problems due to potential pathogen contamination. The two major pathogens of concern are *E. coli* O157 and *Salmonella*. To avoid potential contamination of your vegetable crops with these pathogens, do not use fresh livestock manure in your vegetable garden, only use composted livestock manure. High temperatures achieved in a well-managed, aerobic compost pile can kill most harmful pathogens. See Chapter 22: Composting, for more details on composting.

If you are receiving fresh or aged livestock manure for your garden, store it as far away as practical from areas where fresh vegetables are grown and handled. If necessary, erect physical barriers to prevent runoff and wind drift of manure onto vegetable crops. If you are using aged manure in your vegetable garden, apply it in the fall, preferably when soils are still warm and unsaturated. Incorporate aged manure immediately after application and wait two weeks before planting winter vegetable crops or cover crops. The 2-week wait is to allow for organic matter decomposition that ties up soil nutrients, which can result in severely stunted crop plants. Do not harvest vegetables until 120 days after aged manure application. Therefore, do not apply aged manure to short season crops such as lettuce.

Do not harvest vegetables until 120 days after aged manure application.

Also be aware that using manure in gardens may result in the addition of weed seeds and, in some cases, herbicides to the garden. Seeds and some herbicides can pass unaltered through the digestive system of a grazing animal.

Variety Selection

Select crops and varieties that are likely to do well in the climate of your local area. Washington State is known for its cool nights that result in relatively mild average daily summer temperatures. In Central and Eastern Washington, the average temperature on a summer day can be quite warm (80–90°F), whereas in Western Washington summer temperatures are quite a bit cooler (65–75°F). Throughout the state, night temperatures are quite low all summer long (50–60°F). The maximum and minimum daily temperatures impact plant growth, and vegetable crops are classified based on how cold hardy or tender they are (Table 2).

Table 2. Classification of vegetable crops according to their adaptation to warm and cold temperatures (Adapted from: Knott's Handbook for Vegetable Growers; Vegetable Production, Nonnecke).

Warm-season Crops			
Tender		Very Tender	
Cowpea	Soybean	Cucumber	Pepper
New Zealand spinach	Sweet corn	Eggplant	Pumpkin
Snap/green bean	Tomato	Lima bean	Squash
		Muskmelon	Sweet potato
		Okra	Watermelon
Cool-season Crops			
Hardy		Half-hardy	
Artichoke	Kohlrabi	Carrot	Chinese cabbage
Asparagus	Leek	Cauliflower	Endive
Beet	Mustard	Celery	Lettuce
Broad bean	Onion	Chard	Potato
Broccoli	Parsley		
Brussels sprouts	Radish		
Cabbage	Rhubarb		
Chive	Spinach		
Collards	Turnip		
Garlic	Parsnip		
Horseradish	Salsify		
Kale			

Wait to plant tender crops until all danger of frost has passed, and do not set very tender crops in the garden until temperatures are quite warm. Hardy crops can be grown during the winter months with some protection (see the Winter Gardening section), while half-hardy crops are suitable for fall and spring production.

Growing Degree Days. Plants grow in response to the amount of heat they accumulate above a base temperature. Warm season crops have a higher base temperature than cold season crops. Table 3 is a summary of the base temperatures for many common vegetable crops. When the temperature is below a plant's base temperature, that plant does not actively grow.

The equation that measures heat accumulation is referred to as **growing degree days**. Growing degree days (GDD) for a given crop on a single day are calculated by:

(Average daily temperature) [minus] (the base temperature)

where the average daily temperature equals:

$$\frac{\text{(Maximum daily temperature) + (Minimum daily temperature)}}{2}$$

Table 3. Growing degree day (GDD) base temperatures for some common vegetable crops (Source: Knott's Handbook for Vegetable Growers).

Crop	Base Temperature (°F)
Asparagus	40
Bean, snap	50
Beet	40
Broccoli	40
Carrot	38
Collards	40
Cucumber	55
Eggplant	60
Lettuce	40
Muskmelon	50
Onion	35
Okra	60
Pea	40
Pepper	50
Potato	40
Squash	45
Strawberry	39
Sweet corn	48
Sweet potato	60
Tomato	51
Watermelon	55

It is important to know the minimum and maximum temperatures in your area because they will determine which crops or varieties you are able to grow. Table 4 provides monthly average maximum and minimum temperatures for some locations in Washington. To find a summary of temperatures year-round for your area, one source is the Western Regional Climate Center, http://www.wrcc.dri.edu/summary/climsmwa.html.

In Washington, the average number of GDD for the summer growing season (June through August) at a base temperature of 50°F (the base temperature for most summer crops) varies considerably depending on your location. For instance, in Western Washington, GDD range from700 (Long Beach) to 1350 (Vancouver), whereas in Eastern and Central Washington they range from 1200 (Pullman) to 2000 (Richland). In comparison, in the mid-western U.S. there are, on average, 1800–2300 GDD for the summer growing season (50°F base temperature). You can see that in some areas of Washington there is less than one-half the heat for crop growth in the summer than in the mid-western U.S. This is the essential reason why it is necessary to select early maturing varieties, especially for cooler areas of the state.

Table 4. Average maximum and minimum temperatures (°F), average precipitation (inches), and Growing Degree Days (GDD) for some locations in Washington State. (Source: Western Regional Climate Center)

Location															GDD[1]	
Eastern Washington		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	J-A	M-S
Ellensburg	Ave. Max. Temp	34.3	41.5	53.1	61.7	69.4	76.1	84.2	83.4	74.7	62.3	45.7	35.6	60.2		
	Ave. Min. Temp	18.6	22.8	28.6	34	41.6	48.2	52.8	51.4	43	33.9	26.9	21	35.2		
	Ave. Total Precip	1.27	0.92	0.68	0.51	0.55	0.65	0.28	0.27	0.45	0.59	1.24	1.45	8.87		
	GDD[2]					170.5	364.5	573.5	539.4	265.5					1477	1695
Ephrata	Ave. Max. Temp	34.3	42.2	54.1	65	74.7	81.9	90.2	88	79.3	64.8	46.7	37.3	63.2		
	Ave. Min. Temp	21.2	26.5	33.2	40.5	48.4	55.6	61.6	59.9	52.6	42.1	31.3	25	41.5		
	Ave. Total Precip	0.98	0.71	0.6	0.62	0.68	0.77	0.22	0.27	0.42	0.64	1	1.16	8.04		
	GDD					358.1	562.5	802.9	742.5	478.5					2108	2526
Prosser	Ave. Max. Temp	38.2	46.1	56.3	64.9	73.3	80.3	88.1	86.8	78	65.1	48.7	40	63.8		
	Ave. Min. Temp	23.9	27.7	32.5	37.6	44.3	50.2	54	53	46.7	38.6	30.9	26.2	38.8		
	Ave. Total Precip	0.97	0.73	0.61	0.58	0.62	0.66	0.2	0.28	0.39	0.72	0.98	1.12	7.86		
	GDD					272.8	457.5	652.6	616.9	370.5					1727	2049
Pullman	Ave. Max. Temp	34.7	40.6	47.3	56	64.4	71.4	81.7	82	72.9	59.9	43.7	36.1	57.5		
	Ave. Min. Temp	22.7	27	30.7	35.5	41.3	46.3	49.7	49.7	44.3	37.2	30.3	25	36.7		
	Ave. Total Precip	2.76	2.06	2	1.61	1.66	1.43	0.59	0.79	0.99	1.69	2.84	2.85	21.26		
	GDD					88.35	265.5	486.7	491.4	258					1244	1417
Richland	Ave. Max. Temp	40.4	48.5	58	66.6	75.2	82.6	90.3	89.2	80.6	66.9	50.9	41.9	65.9		
	Ave. Min. Temp	26.2	30.3	35.1	40.9	48.2	54.8	59.5	58.8	50.7	41	33.8	28.6	42.3		
	Ave. Total Precip	1.01	0.71	0.6	0.49	0.56	0.5	0.21	0.25	0.27	0.51	0.94	1.04	7.09		
	GDD					362.7	561	771.9	744	469.5					2077	2493
Spokane	Ave. Max. Temp	34.5	42.5	49.6	59.2	68.8	76.8	85.8	84.5	74.4	60.3	44	37.1	59.8		
	Ave. Min. Temp	23.9	28.8	31.2	36.8	44.3	51.2	56	54.7	47.2	38.4	31.5	27.2	39.3		
	Ave. Total Precip	2.24	1.65	1.56	1.25	1.52	1.33	0.56	0.79	0.86	1.13	2.16	2.58	17.62		
	GDD					203.1	420	647.9	607.6	324					1676	1939
Walla Walla	Ave. Max. Temp	39.6	46.4	56.6	66.8	74.8	81.3	91.3	88.8	79.8	66.1	49.8	43.3	65.4		
	Ave. Min. Temp	25.8	30.1	34.9	40.3	46.3	51.8	57.4	55.7	48.3	40.9	32.7	30.3	41.2		
	Ave. Total Precip	1.73	1.46	1.53	1.29	1.47	1.2	0.25	0.33	0.82	1.48	1.72	1.73	15		
	GDD					327.1	496.5	754.9	689.8	421.5					1941	2315
Wenatchee	Ave. Max. Temp	34.6	42.4	54.4	64.7	73.1	79.9	87.9	86.8	78.1	63.6	46.6	36.7	62.4		
	Ave. Min. Temp	22.1	25.8	32.7	40	47.9	54.8	60	58.6	50.2	39.8	31.3	25.6	40.7		
	Ave. Total Precip	1.26	0.91	0.62	0.54	0.55	0.72	0.21	0.39	0.37	0.6	1.21	1.47	8.85		
	GDD					325.5	520.5	742.5	703.7	424.5					1967	2342
Yakima	Ave. Max. Temp	37.3	45.9	55.5	63.9	72.6	79.8	87.5	86.1	77.8	64.2	48.2	38.2	63.1		
	Ave. Min. Temp	20.8	25.7	29.9	34.8	42.3	49	53.2	51.8	44.2	34.8	27.7	22.8	36.4		
	Ave. Total Precip	1.27	0.77	0.65	0.52	0.52	0.68	0.19	0.33	0.34	0.55	1.01	1.32	8.15		
	GDD					231	432	630.9	587.5	330					1650	1931

[1] GDD are calculated for June through August (J-A) and for May 15 through September 15 (M-S).
[2] GDD are calculated for a base temperature of 50°F.

Table 4. (continued) Average maximum and minimum temperatures (°F), average precipitation (inches), and Growing Degree Days (GDD) for some locations in Washington State. (Source: Western Regional Climate Center)

Location															GDD	
Western Washington		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	J-A	M-S
Bellingham	Ave. Max. Temp	43.2	47.7	51.1	56.4	62.3	66.7	71.2	71.3	67.1	58.4	49.6	44.5	57.4		
	Ave. Min. Temp	31.4	33.9	35.9	39.9	45.2	50.4	53.2	53.1	48.1	42	36.7	33.1	41.9		
	Ave. Total Precip	4.56	3.45	3.02	2.65	2.16	1.8	1.24	1.37	1.83	3.43	5.02	4.82	35.36		
	GDD					116.3	256.5	378.2	378.2	228					1013	1185
Centralia	Ave. Max. Temp	46	50.4	55.2	61.6	68.1	72.9	78.5	78.4	73.2	62.4	51.9	46.6	62.1		
	Ave. Min. Temp	33.9	35	36.6	39.6	44.4	49	52.2	52.2	48.6	43.2	38.3	35.3	42.4		
	Ave. Total Precip	6.7	5.27	4.79	3.13	2.16	1.85	0.76	1.17	1.93	4.28	6.91	7.51	46.45		
	GDD					193.8	328.5	475.9	474.3	327					1279	1539
Goldendale	Ave. Max. Temp	37.7	44.8	52.6	61.3	69.8	76.3	85.7	84.2	76.9	63.6	48	39.6	61.7		
	Ave. Min. Temp	23.7	26.9	30.3	33.8	39.6	45.3	49.6	48.3	42.6	35.4	30	26.8	36		
	Ave. Total Precip	3.06	1.94	1.64	0.9	0.82	0.74	0.19	0.27	0.57	1.47	2.62	3.22	17.44		
	GDD					145.7	324	547.2	503.8	292.5					1375	1594
Long Beach	Ave. Max. Temp	48.3	51.1	52.2	55.6	59.7	63.3	65.9	66.5	66.9	61.8	54.3	50	58		
	Ave. Min. Temp	35.8	37	36.2	39.8	43.6	48.3	50.4	50.3	47.1	43.7	39.2	37.2	42.4		
	Ave. Total Precip	12.91	9.46	8.38	6.01	3.09	2.87	1.33	2.2	3.05	7.86	12.07	11.91	81.15		
	GDD					51.15	174	252.7	260.4	210					687	818
Mt. Vernon	Ave. Max. Temp	45.5	49.2	52.8	57.7	63.9	68.6	73.2	73.8	68.6	59.4	50.7	45.9	59.1		
	Ave. Min. Temp	33.6	35.1	37.1	39.9	44.7	48.8	50.6	50.9	47	41.9	37.8	34.6	41.8		
	Ave. Total Precip	4.02	2.84	2.73	2.43	2.21	1.83	1.16	1.49	1.84	3.23	4.43	4.08	32.3		
	GDD					133.3	261	368.9	382.9	234					1013	1196
Olympia	Ave. Max. Temp	44.5	49.2	53.4	59	65.7	71	77.1	77.1	71.6	60.6	50.5	44.8	60.4		
	Ave. Min. Temp	31.6	32.4	33.8	36.5	41.5	46.6	49.4	49.5	45.2	39.6	35.5	32.8	39.5		
	Ave. Total Precip	7.95	5.82	5.12	3.35	1.98	1.57	0.72	1.2	2.04	4.74	8.1	8.18	50.76		
	GDD					111.6	264	410.8	412.3	252					1087	1269
Port Angeles	Ave. Max. Temp	45.1	47.7	50.5	55.3	60.6	64.7	68.4	68.4	65.7	57.4	50	45.9	56.6		
	Ave. Min. Temp	34	35.5	36.9	40.1	44.7	49	51.6	51.6	48.8	43.3	38.1	35.2	42.4		
	Ave. Total Precip	4.02	2.75	2.19	1.34	0.96	0.86	0.55	0.8	1.11	2.64	4.19	4.25	25.66		
	GDD					82.15	205.5	310	310	217.5					825.5	975.3
Puyallup	Ave. Max. Temp	46.3	50.5	54.8	60.9	68.1	72.6	78.2	78	72.2	62.3	51.9	47	61.9		
	Ave. Min. Temp	32	33.6	35.3	38.5	43.1	47.9	50.3	50.1	46.5	41.6	36.1	33.4	40.7		
	Ave. Total Precip	5.59	4.5	4.01	2.84	1.94	1.78	0.82	1.1	1.87	3.55	5.67	6.16	39.84		
	GDD					173.6	307.5	441.8	435.6	280.5					1185	1412
Seattle	Ave. Max. Temp	44.7	50.1	53.4	59.4	66.7	71.2	76.9	76.3	71	61.3	52	47.1	60.8		
	Ave. Min. Temp	34.2	37.1	38.2	41.6	47.1	52.2	55.1	55.6	52.1	46.1	40.5	37.1	44.7		
	Ave. Total Precip	4.94	4.23	3.52	2.3	1.5	1.5	0.96	1.08	1.92	3.24	4.89	5.79	35.86		
	GDD					213.9	351	496	494.5	346.5					1341	1622
Vancouver	Ave. Max. Temp	44.7	49.8	55.4	61.4	67.4	72.7	78.9	79.1	73.9	63.6	52.4	45.9	62.1		
	Ave. Min. Temp	34.2	34.4	37.4	40.7	45.6	50.5	53.7	53.4	49.2	43.4	38.1	34.3	42.7		
	Ave. Total Precip	5.71	4.48	3.79	2.67	2.2	1.65	0.6	0.87	1.82	3.17	5.94	6.31	39.23		
	GDD					201.5	348	505.3	503.8	346.5					1357	1631

Our summers do not provide enough heat for rapid crop growth, and as a result, it can take varieties longer to mature in Washington than in warmer regions of the country. It may be necessary to add days to the "days to maturity" numbers that are given in seed catalogs or on seed packets from warmer parts of the country. Add 10 days for short-maturing varieties (40–50 days to maturity) and add 30 days for long-maturing varieties (100 or more days to maturity). Seed companies that are located in mountain states or in the Pacific Northwest tend to provide days-to-maturity numbers that better match what we can expect in Washington.

Experiment with varieties and note how many days they take to mature in your garden. It takes 3 or more years to determine an average number of days to maturity. In order to grow long-maturing varieties, start seeds indoors in mid-spring and transplant them when appropriate in early summer. In this way, you can get a 4- to 6-week jump on the growing season.

Disease resistance. When selecting varieties to grow, it is also important to select those varieties that are resistant to the most common diseases that affect your area. Table 5 is a summary of the primary diseases affecting vegetable crops. If you know a particular disease is a problem in your area, select a variety with resistance whenever possible. Seed catalogs can be a good source of information regarding the disease resistance of particular varieties.

Table 5. Vegetable crop rotation recommendations to avoid soil-borne diseases.

Crop	Disease	Rotation Recommendation
Asparagus	Fusarium Wilt, Root & Crown Rot	Indefinite; use transplants grown from treated seed, plant on clean ground in raised beds; rotate with grasses and cereals
Basil	Fusarium Wilt	Indefinite; plant disease-free seed in disease-free soil or potting mix
Bean, Dry	White Mold (Sclerotinia Rot)	8–9 years of non-host crops
Bean, Green	Fusarium Root Rot	5–6 years, rotate with grass or small grain crops
	Gray Mold	2 years, rotate with cereals and corn
	White Mold (Sclerotinia Disease)	2–3 years; avoid tomato, potato, lettuce, cabbage, celery, carrot, peas
	Bacterial Blight	2 years; eliminate overhead irrigation
Beet, Red	Cercospora Leaf Spot	3 years
	Root Rots	3 years; rotate with grain crops and sweet corn
Cabbage and Cauliflower	Blackleg	5 years; no adjacent crucifer crops for this time period
	Black Rot	2–3 years, no crucifer crops
	Club Root	6+ years; no crucifer crops; adjust pH to 6.8 or above
	Damping-off and Wirestem	3 years; rotate with cereals
	Leaf Spot	3 years
	Phytophthora Root Rot	3 years, rotate with nonsusceptible crops such as grass or grains
	Water Soft Rot (White Blight)	3 years, rotate with nonsusceptible crops such as grass or grains
	White Mold (Scelerotinia)	3 years, rotate with grains and sweet corn
Cabbage	Nematode (Sugar Beet Cyst)	2 years for slight infestations, 5-6 years for severe infestations; avoid crucifers. Rotate with beans, clover, corn, grains, peas, potatoes, and tomatoes annually. Alfalfa is suitable for a long rotation period.
Cantaloupe	Fusarium Wilt	4+ years; no cucurbit crops; avoid soil with a history of this disease
	Leaf Blight	2+ years; do not plant other cucurbits
	Leaf Spot, Gummy Stem Blight, & Scab	2+ years; do not plant other cucurbits
Carrot	Alternaria Leaf Spot & Leaf Blight	1–2 years
	Bacterial Leaf Blight	2–3 years
	Black Rot	1–2 years
	Cavity Spot	6–7 years; avoid fields with a recent history of cavity spot
	Cercospora Leaf Spot, Leaf Blight	1–2 years
	Cottony Soft Rot (White Mold)	2 years; rotate onions, grasses, cereals; do not rotate with beans, lettuce, parsnips, crucifers; do not grow early or late crops in fields with a history of this disease as heavy rains can cause severe losses
	Nematode (Root-knot)	4–5 years; rotate with a nonhost crop such as corn or cereals
	Violet Root Rot	4–5 years, rotate with cereals and grasses
Celery	Fusarium Yellows	2–3 years, rotate with corn, crucifers, cucurbits, or onions
	Late Blight	2 years
	Leaf Blight	2 years
	Sclerotinia Pink Rot	2–3 years, rotate with corn, cereals, beets, onions, and spinach

Crop	Disease	Rotation Recommendation
Corn	Leaf Spots and Blights	2–3 years
	Seed Rot and Seedling Blight	2–3 years
	Smut (Head)	3–4 years
	Stalk Rots	2–3 years
Cucumber	Alternaria Leaf Spot	2 years
	Powdery Mildew	2-year, plant no cucurbits during this time
	Scab (Gummosis)	2–3 years, plant no cucurbit crops during this time
	Sclerotinia Stem Rot (White Mold)	2–3 years, do not follow potato or tomato crops
Eggplant	Anthracnose	Rotate crops
	Cercospora Leaf Spot	Rotate crops
	Root Rot	Practice light irrigation and crop rotation
	Verticillium Wilt	4–5 years, rotate with grasses and grains, no solanaceous crops, strawberry or brambles
Garlic	Leaf Blight	2–3 years
	Nematode (Stem & Bulb)	2 years
	White Rot	6–7 years; plant only disease-free cloves in disease-free soil
Ginseng	Verticillium Wilt	3–4 years; rotate with alfalfa or cereal crops
Lettuce	Anthracnose	4–5 years
	Bottom Rot	3 years, rotate with sweet corn or onions
	Drop (Watery Soft Rot)	3 years; rotate with corn, cereals, grasses, onions, table beets, spinach; avoid tomato, potato, beans, cabbage, celery, carrots
	Varnish Spot	2–3 years
Onion	Basal Plate Rot	4 years
	Botrytis Leaf Blight	2–3 years, no allium crops
	Downy Mildew	3–4 years
	Nematode (Stubby-root)	5–6 years, do not plant after a mint crop
	Pink Root	3–6 years
	Purple Blotch	5–6 years, no allium crops
	White Rot	6–7 years, plant only disease-free matierial in disease-free soil
Parsley	Damping-off	3 years
Parsnip	Leaf Spot and Root Canker	2 years
Pea	Aphanomyces Root Rot	4–5 years
	Ascochyta Blight (Basal Stem Rot or Black Stem)	4 years; do not include vetch or alfalfa in the rotation
	Downy Mildew	2–3 years, do not rotate with legumes
	Nematode (Pea Cyst)	4 years for slight infestations, eliminate peas if high infestation
	Powdery Mildew	1 year
	Root Rots	5 years
	Seed Rot and Damping-off	3 years
	Wilt and Near-wilt	5 years
Pepper	Anthracnose	3 years
	Cercospora Leaf Spot	3–4 years
	Phytophthora blight	3 years; avoid tomato, eggplant, cucurbits
	Root Rot	3–4 years
	Verticillium Wilt	3 years, rotate with grass and grain crops

Crop	Disease	Rotation Recommendation
Potato	Black Dot	2–3 years
	Early Blight	2 years; do not plant tomatoes
	Fusarium Wilt	4–5 years
	Nematode (Potato Rot)	2–3 years, rotate with cereals and corn
	Nematode (Root-knot)	2–3 years, rotate with cereals or sweet corn
	Nematode (Root-lesion)	2–3 years, rotate with cereals or sweet corn
	Powder Scab	3–4 years; avoid planting on previously contaminated ground
	Pythium Leak, Pink Rot	4 years
	Rhizoctonia Canker (Black Scurf)	3 years; best with cereals or grass
	Scab	2–3 years; no root crops; adjust pH to 5.2 or below
	Sclerotinia Stalk Rot	4 years, avoid tomato, lettuce, beans, cabbage, celery, carrot, beans
	Silver Scurf	3 years
	Verticillium Wilt (Potato Early Dying)	3–4 years, do not solanaceous, cucurbits, mint, or nursery maple crops; rotate with alfalfa or cereals
Radish	Black Root	3–4 years
	Clubroot	7 years; do not plant crucifers; adjust pH to 6.8
Spinach	Downy Mildew & White Rust	2–3 years
Tomato	Anthracnose	1–2 years; alternate every other year with nonsolanaceous crop
	Bacterial Canker	3–4 years
	Bacterial Spot	2 years; do not plant peppers
	Early Blight	3–4 years
	Wilt	4–6 years
Turnip and Rutabaga	Black Root Rot	3 years, do not plant any crucifers during this period
	Club Root	6–7 years; do not plant crucifers; adjust pH to 6.8
	Powdery Mildew	1 year
Winter Squash & Pumpkin	Alternaria Leaf Blight	2–3 years, do not plant any cucurbits during this period
	Angular Leaf Spot	2 years
	Crown and Foot Rot (Fusarium Root Rot)	3–5 years, plant no cucurbits
	Gummy Stem Blight (Black Rot)	2–3 years, plant no cucurbits
	Phytophthora Blight	3 years; do not plant tomato, pepper, eggplant, or cucurbits
	Pythium Root Rot	2 years
	Scab (Gummosis)	2–3 years, plant no cucurbits
	Sclerotinia Stem Rot	2–3 years, do not plant potatoes

Table 5 courtesy of Debra A. Inglis and Babette Gundersen, WSU-Mount Vernon REC Vegetable Pathology Program, and Carol Miles, WSU-Vancouver REU Agricultural Systems Program. Based on crop rotation recommendations listed in the 2000 PNW Plant Disease Control Handbook. Adapted from A.A. McNab and T.A. Zitter, Do Rotations Matter Within Disease Management Programs, Cornell Cooperative Extension of Oswego County.

Rotating Vegetable Crops. The primary reason to rotate vegetables in the garden is for disease prevention. As a general rule, rotate crops based on family, as many crops in the same family are often hosts to the same diseases. For example, potato and tomato, both in the Solanaceae family, are affected by *Phytophthora infestans*, commonly called Late Blight. Therefore, do not plant potatoes in the bed or area where the previous year you had tomatoes. The families of common vegetable crops are presented in Table 6.

Table 6. Families of common vegetable crops.

Family Name	Common name, *Genus and species*
Aizoaceae	
	New Zealand spinach, *Tetragonia expansa*
Apiaceae	
	carrot, *Daucus carota* var. *sativa*
	celeriac, *Apium graveolens* var. *rapaceum*
	celery, *Apium graveolens* var. *dulce*
	dill, *Anethum graveolens*
	fennel, *Foeniculum vulgare*
	parsley, *Petroselinum crispum*
	parsnip, *Pastinaca sativa*
Asteraceae	
	artichoke, *Cynara scolymus*
	cardoon, *Cynara cardunculus*
	chicory, *Cichorium intybus*
	dandelion, *Taraxacum officinale*
	endive, *Cichorium endivia*
	Jerusalem artichoke, *Helianthus tuberosus*
	lettuce, *Lactuca sativa*
Brassicaceae/Cruciferaceae	
	broccoli, *Brassica oleracea* var. *italica*
	bok choy, *Brassica chinensis*
	Brussels sprouts, *Brassica oleracea*, var. *gemmifera*
	cabbage, *Brassica oleracea* var. *capitata*
	cauliflower, *Brassica oleracea* var. *botrytis*
	Chinese cabbage, *Brassica chinensis* or *pekinensis*
	collard, *Brassica oleracea* var. *viridis*
	cress, *Lepidium sativum*
	horseradish, *Armoracia rusticana*
	kale, *Brassica oleracea* var. *viridis*
	kohlrabi, *Brassica oleracea* var. *gongylodes*
	mustard, *Brassica juncea*
	radish, *Raphanus sativus*
	rutabaga, *Brassica campestris* var. *napobrassica*
	turnip, *Brassica rapa*

Family Name	Common name, *Genus and species*
Chenopodiaceae	
	beet, *Beta vulgaris*
	chard, *Beta vulgaris* var. *cicla*
	spinach, *Spinacia oleracea*
Cucurbitaceae	
	cucumber, *Cucumis sativus*
	gherkin, *Cucumis anguria*
	muskmelon/cantaloupe, *Cucumis melo*
	pumpkin, *Cucurbita pepo*
	summer squash, *Cucurbita pepo* var. *melopepo*
	watermelon, *Citrullus lanatus*
	winter squash, *Cucurbita maxima* or *moschata*
Fabaceae	
	bean, broad *Vicia faba*
	bean, dry *Phaseolus vulgaris*
	bean, Lima *Phaseolus limensis*
	bean, scarlet runner *Phaseolus coccineus*
	bean, snap *Phaseolus vulgaris*
	edamame, *Glycine max*
	pea, *Pisum sativum*
Liliaceae	
	asparagus, *Asparagus officinalis* var. *altilis*
	chive, *Allium schoenoprasum*
	garlic, *Allium sativum*
	leek, *Allium porrum*
	onion, *Allium cepa*
	shallot, *Allium ascalonicum*
	Welsh onion, *Allium fistulosum*
Poaceae	
	sweet corn, *Zea mays* var. *rugosa*
Solanaceae	
	eggplant, *Solanum melongena*
	husk tomato, *Physalis pubescens*
	pepper, *Capsicum frutescens*
	potato, *Solanum tuberosum*
	tomato, *Solanum lycopersicum*
Valerianaceae	
	corn salad, *Valerianella olitoria* or *locusta*

Planting

Seeds can be sown outside directly in the garden or started earlier inside to be set out as transplants. Table 7 provides recommended plant spacing information for many vegetable crops. In row cropping, the between-row spacing is generally quite a bit wider than the in-row spacing. In raised beds, plants are grown with the same spacing between the rows as within the rows. This results in more plants per square foot in a raised bed, compared with row cropping, and this is the reason why raised beds are commonly used for intensive gardens.

Table 7. Recommended planting depth and spacing, days to germination, and germination light requirements of common vegetable crops.

	Seeds		Seeding Distance			
Vegetable	Depth to Plant (inch)	No. to Sow (per ft)	Within Row (inch)	Between Rows (inch)	No. Days to Germinate	Needs Light to germinate
Asparagus	1 1/2		18	36	7–21	–
Beans: snap bush	1 1/2–2	6–8	2–3	18–30	6–14	–
snap pole	1 1/2–2	4–6	4–6	36–48	6–14	–
Lima bush	1 1/2–2	5–8	3–6	24–30	7–12	–
Lima pole	1 1/2–2	4–5	6–10	30–36	7–12	–
Fava (broad bean) Winsor bean	2 1/5	5–8	3–4	18–24	7–14	–
Garbanzo (chick pea)	1 1/2–2	5–8	3–4	24–30	6–12	–
Scarlet runner	1 1/2–2	4–6	4–6	36–48	6–14	–
Soybean	1 1/2–2	6–8	2–3	24–30	6–14	–
Beets	1/2–1	10–15	2	12–18	7–10	–
Black-eye cowpea (Southern peas)	1/2–1	5–8	3–4	24–30	7–10	–
Yardlong bean (Asparagus bean)	1/2–1	2–4	12–24	24–36	6–13	–
Broccoli	1/2	10–15	14–18	24–30	3–10	–
Brussels sprouts	1/2	10–15	12–18	24–30	3–10	–
Cabbage	1/2	8–10	12–20	24–30	4–10	–
Cabbage, Chinese	1/2	8–16	10–12	18–24	4–10	–
Cardoon	1/2	4–6	18	36	8–14	–
Carrot	1/2	15–20	1–2	14–24	10–17	–
Cauliflower	1/2	8–10	18	30–36	4–10	–
Celeriac	1/8	8–12	8	24–30	9–21	–
Celery	1/8	8–12	8	24–30	9–21	Yes
Celtuce-Asparagus lettuce	1/2	8–10	12	18	4–10	–
Chard, Swiss	1	6–10	4–8	18–24	7–10	–
Chicory-Witloof (Belgian endive)	1/4	8–10	4–8	18–24	5–12	Yes
Chives	1/2	8–10	8	10–16	8–12	–
Chop suey greens (Shungiku)	1/2	6	2–3	10–12	5–14	–
Collards	1/4	10–12	10–15	24–30	4–10	–
Corn, sweet	2	4–6	10–14	30–36	6–10	–
Corn salad	1/2	8–10	4–6	12–16	7–10	–
Cress, garden	1/4	10–12	2–3	12–16	4–10	Yes
Cucumber	1	3–5	12	48–72	6–10	–
Dandelion	1/2	6–10	8–10	12–16	7–14	Yes

Vegetable	Seeds: Depth to Plant (inch)	Seeds: No. to Sow (per ft)	Seeding Distance: Within Row (inch)	Seeding Distance: Between Rows (inch)	No. Days to Germinate	Needs Light to germinate
Eggplant	1/4–1/2	8–12	18	36	7–14	–
Endive	1/2	4–6	9–12	12–24	5–9	–
Fennel, Florence	1/2	8–12	6	18–24	6–17	–
Garlic	1		2–4	12–18	6–10	–
Ground cherry husk tomato	1/2	6	24	36	6–13	–
Horseradish: division			10–18	24		–
Jerusalem artichoke: tubers	4		15–24	30–60		–
Kale	1/2	8–12	8–12	18–24	3–10	–
Kohlrabi	1/2–1	8–12	3–4	18–24	3–10	–
Leeks	1/4–1/2	8–12	2–4	12–18	7–12	–
Lettuce: head	1/4–1/2	4–8	12–14	18–24	4–10	Yes
leaf	1/4–1/2	8–12	4–6	12–18	4–10	Yes
Muskmelon	1	3–6	12	48–72	4–8	–
Mustard	1/2	8–10	2–6	12–18	3–10	Yes
Nasturtium	1/2–1	4–8	4–10	18–36		–
Onion: sets	1–2		2–3	12–24		–
plants	2–3		2–3	12–24		–
seed	1/2	10–15	2–3	12–24	7–12	–
Parsley	1/4–1/2	10–15	3–6	12–20	14–28	–
Parsnips	1/2	8–12	3–4	16–24	15–25	–
Peas	2	6–7	2–3	18–30	6–15	–
Peanut	1 1/2	2–3	6–10	30		–
Peppers	1/4	6–8	18–24	24–36	10–20	–
Potato: tubers	4	1	12	24–36	8–16	–
Pumpkin	1–1 1/2	2	30	72–120	6–10	–
Radish	1/2	14–16	1–2	6–12	3–10	–
Rutabaga	1/2	4–6	8–12	18–24	3–10	–
Salsify	1/2	4–6	2–3	16–18		–
Salsify, black	1/2	8–12	2–3	16–18		–
Shallot: bulb	1		2–4	12–18		–
Spinach:	1/2	10–12	2–4.	12–14	6–14	–
Malabar	1/2	4–6	12	12	10	–
New Zealand	1 1/2	4–6	18	24	5–10	–
Tampala	1/4–1/2	6–10	4–6	24–30		–
Squash: summer	1	4–6	16–24	36–60	3–12	–
winter	1	1–2	24–48	72–120	6–10	–
Sunflower	1	2–3	16–24	36–48	7–12	–
Sweet potato: plants			12–18	36–48		–
Tomato	1/2		18/–36	36–60	6–14	–
Turnip	1/2		1–3	15–18	3–10	–
Watermelon	1	14–16	12–16	60	3–12	–

There are several planting schemes or designs for vegetable beds (Figure 2). A single row is generally used for large crops such as corn and tomatoes, but a double row can also work well for these crops and can save space. In bed planting, offset the rows so that the maximum number of plants are fitted into the bed and the bed space is fully utilized.

There are several other ways you can maximize your garden space usage. First, interplant a slow-growing crop such as tomatoes, broccoli, or peppers with a fast-growing crop such as radish or lettuce. After you harvest the fast-growing crop, the slow-growing crop will fill the space. Second, when you direct seed or transplant crops such as lettuce, beets, or spinach, you can plant heavily and later thin plants to their final spacing after they have become established. The thinned plants can be eaten rather than discarded. And third, you can maximize your garden space by interplanting shallow-rooted crops with deep-rooted crops (Table 8).

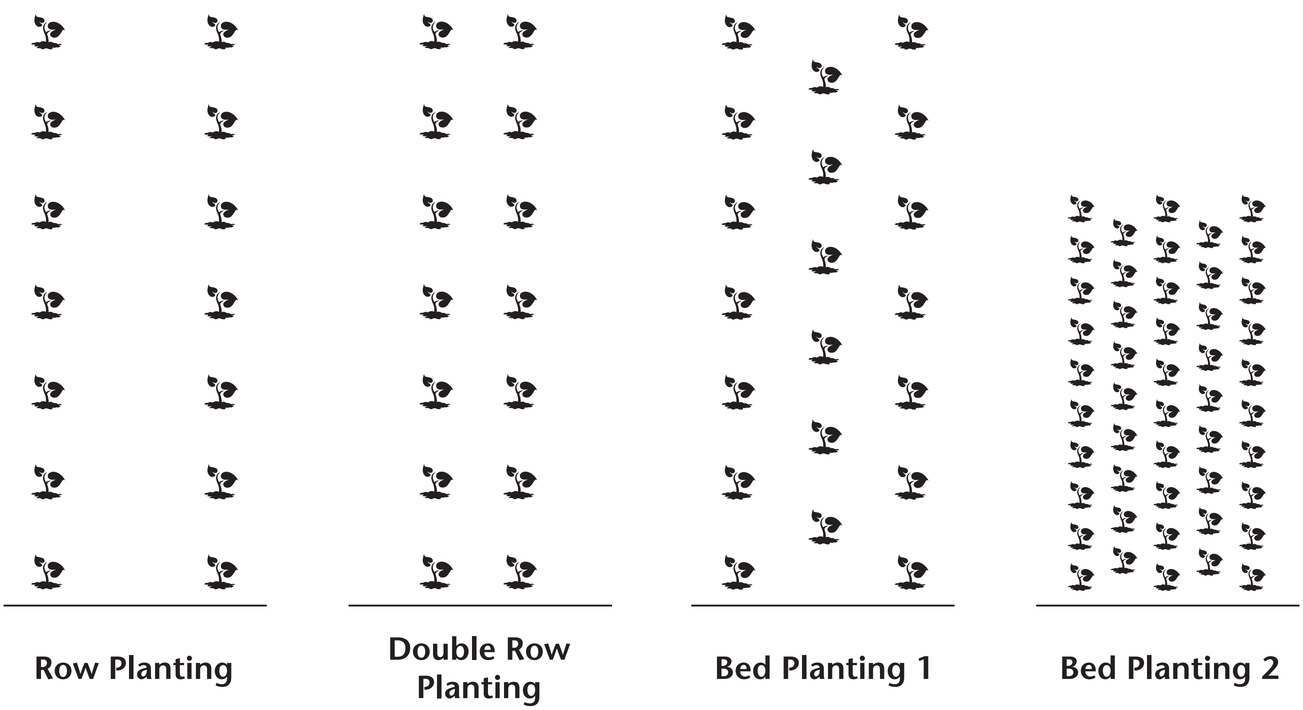


Figure 2. Row and bed planting designs for vegetable crops. Bed Planting 1 is used for larger crops such as tomatoes and broccoli while Bed Planting 2 is used for smaller crops such as radishes, lettuce, and onions.

Table 8. Average rooting depth of some common vegetable crops.

Shallow Rooting (1 ft or less)	Medium Rooting (1–3 ft)	Deep Rooting (3–6 ft or more)
Broccoli	Bean (bush & pole)	Artichoke
Brussels sprout	Beet	Asparagus
Cabbage	Carrot	Lima bean
Cauliflower	Chard	Muskmelon
Celery	Cucumber	Pumpkin
Chinese cabbage	Eggplant	Squash (winter)
Garlic	Honeydew melon	Sweet potato
Leek	Mustard	Tomato
Lettuce	Pea	Watermelon
Onion	Pepper	
Potato	Rhubarb	
Radish	Rutabaga	
Spinach	Squash (summer)	
Sweet corn	Turnip	

Direct Seeding. Plant seeds of your vegetable crops directly into the ground when soil temperatures are within the optimum range for good germination (Table 9). Some crops such as cabbage, carrot, cauliflower, lettuce, pea, radish, and spinach will germinate when soil temperatures are quite low (40–45°F), but all crops germinate best when soil temperatures are quite warm (around 75°F). All cucurbit crops (cucumbers, melons, and squash) and solanaceous crops (tomatoes, peppers, eggplants) will not germinate well unless soil temperatures are warm (at least 65–70°F). Regardless of the crop, do not seed into cold, wet soil because the disease incidence under these conditions can be quite high. Some crops such as carrots and turnips do not transplant well and so it is always best to direct seed them.

All vegetable crops germinate best when soil temperature is warm, about 75°F.

Table 9. Minimum, maximum, and optimum soil temperatures for vegetable seed germination (Source: Knott's Handbook for Vegetable Growers).

Vegetable	Minimum (°F)	Optimum Range (°F)	Optimum (°F)	Maximum (°F)
Asparagus	50	60–85	75	95
Bean	60	60–85	80	95
Bean, Lima	60	65–85	85	85
Beet	40	50–85	85	95
Cabbage	40	45–95	85	100
Carrot	40	45–85	80	95
Cauliflower	40	45–85	80	100
Celery	40	60–70	70	85
Chard	40	50–85	85	95
Corn	50	60–95	95	105
Cucumber	60	60–95	95	105
Eggplant	60	75–90	85	95
Lettuce	35	40–80	75	85
Muskmelon	60	75–95	90	100
Okra	60	70–95	95	105
Onion	35	50–95	75	95
Parsley	40	50–85	75	90
Parsnip	35	50–70	65	85
Pea	40	40–75	75	85
Pepper	60	65–95	85	95
Pumpkin	60	70–90	90	100
Radish	40	45–90	85	95
Spinach	35	45–75	70	85
Squash	60	70–95	95	100
Tomato	50	60–85	85	95
Turnip	40	60–105	85	105
Watermelon	60	70–95	95	105

As a general rule, the planting depth for most seeds is equal to twice the size of the seed. The planting depth for most small-seeded crops is $^{1}/_{8}$ to ½ inch, while large-seed crops are generally planted 1–2 inches deep. Refer back to Table 7 for recommended planting depths for many specific vegetable crops. Seed large crops in rows, and place 2 seeds per planting hole (thinning one if both emerge) to ensure that you attain the correct plant stand (number of plants in a given area). Small crops such as radish can be sown close together in rows or broadcast seeded.

Growing Transplants. Using transplants enables you to get a jump on the season and perhaps try some varieties and crops that might not otherwise mature in our relatively cool summer climate. Many small-seeded crops such as lettuce, tomatoes, basil, etc., do better as transplants than when direct seeded because they tend to be susceptible to adverse environmental conditions and seedling diseases.

Plant seeds for transplants 4 to 6 weeks prior to the date when you plan to set them out in the garden. Refer to Table 7 for more specific information regarding the number of weeks needed to produce transplants of specific crops. Sow large-seeded crops directly into the final transplant pot. Sow small-seeded crops very close together in seeding trays to conserve space and "prick out" seedlings into larger transplant pots after the cotyledons have fully emerged. Do not allow transplants to become root bound, especially cucurbits (melons, cucumbers, and pumpkins) as plants can become permanently stunted.

Use a disease- and weed-free potting medium to grow transplants. Although it is possible to use garden soil or compost to make your own potting mix, it is generally not recommended. Garden soil and compost tend to contain weed seeds, insects, and diseases, and soil forms a crust and drains poorly under transplant growing conditions.

Use disease-free seed to prevent seedling disease problems. If you wish to use seed that you have saved from your own garden, only save seed from healthy, disease-free, and non-hybridized plants.

If you are using recycled or previously used seeding trays or pots, first wash them in a 10% bleach solution and scrub them clean. Rinse in clean water to remove bleach residue.

Fill transplanting trays or pots with potting medium and press down the medium so that it is compact. Saturate the potting medium with water and allow any excess moisture to drain out. Plant seeds at the recommended depth, and place trays or pots into a clear plastic bag. Close the bag with a clothespin to conserve moisture, and in this way you will not need to water the trays or pots as long as they are in the bag (Figure 3).

Observe germination through the clear bag, and when 50% of the seedlings have emerged in any pot or tray, remove that tray or pot from the bag. If seedlings are left in the moist, humid environment of the sealed bag, they will likely develop foliar and root disease problems. After you have removed the trays or pots from the bag, water lightly once a day or as needed to maintain moist, but not saturated, soil conditions.

To optimize time to emergence and plant vigor, grow transplants at the appropriate temperature for each crop type. Cooler temperature will result in greater incidence of disease, while hot temperatures can result in spindly seedlings.

Transplant seedlings after 2–4 true leaves have emerged.

Figure 3. A simple "conservatory" made from a clear plastic bag: planting medium is well moistened first, pots are seeded with 1 variety each (up to 6–8 seeds per pot), and bag is sealed with a clip to conserve moisture.

Hardening Off. Before transplanting, "harden" transplants to better enable them to withstand transplant shock that results from new exposure to outdoor growing conditions: low temperatures and drying winds, plus the root injury and moisture stress that occurs during transplanting. Plants that are hardened off have a temporarily decreased growth rate, which enables the plant to store energy. Common hardening treatments include reduced watering and exposure to cold temperatures, and a combination of these two is better than either one alone.

In the one to two weeks prior to transplanting, gradually reduce watering, but do not allow plants to dry out suddenly or develop severe wilting. Set plants outside during the day in the first week and for the entire day and night in the second week—make sure plants are covered at night to avoid cold damage. Hardening temperatures should be just 5–10°F less than the inside growing temperatures. Do not apply fertilizer immediately before or during hardening. At transplanting, water and fertilize plants well to encourage quick plant establishment and growth.

Planting Schedule. Recommended dates for direct seeding and transplanting vary across the state and depend on minimum temperatures and type of vegetable crop. See Table 10a for a suggested planting schedule for Western Washington, and Table 10b for recommended planting schedule for Eastern Washington. As always, the best way to determine what dates work best in your area is to experiment and talk with other gardeners.

Table 10a. Suggested planting calendar for vegetable crops in Western Washington. Specific dates will vary by location and microclimate.

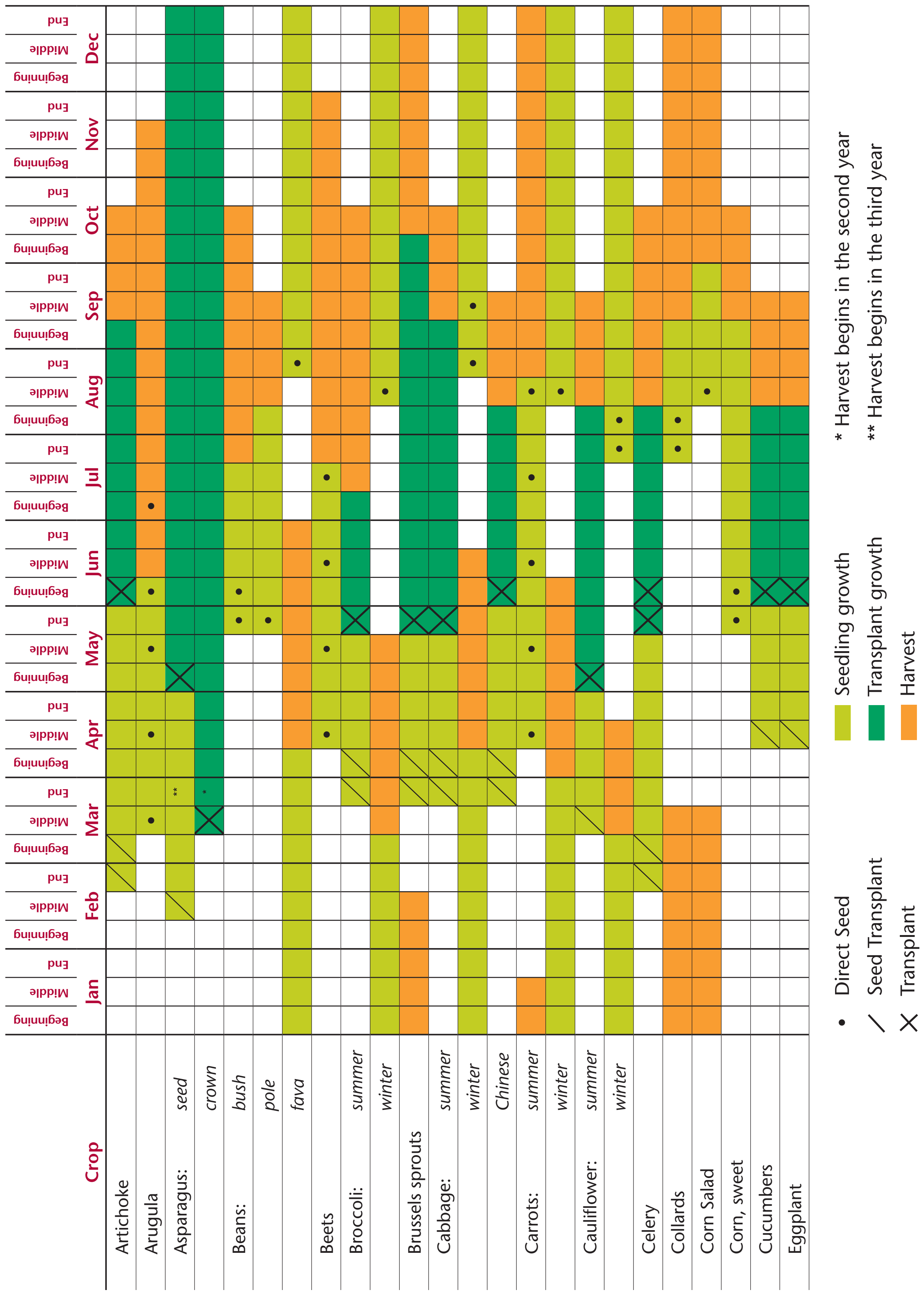


Table 10a. (continued) Suggested planting calendar for vegetable crops in Western Washington. Specific dates will vary by location and microclimate.

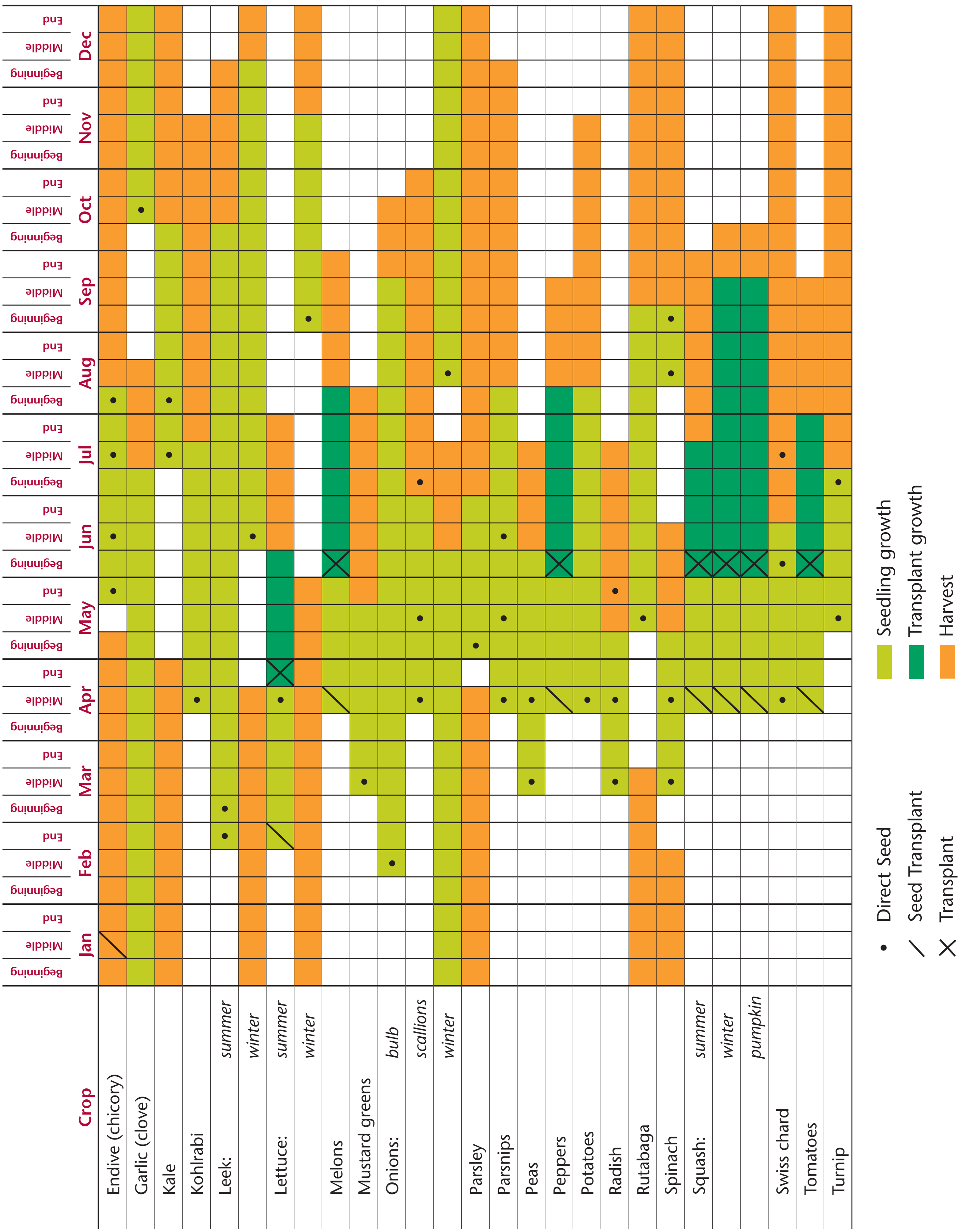


Table 10b. Suggested planting calendar for vegetable crops in Eastern Washington. Specific dates will vary by location and microclimate.

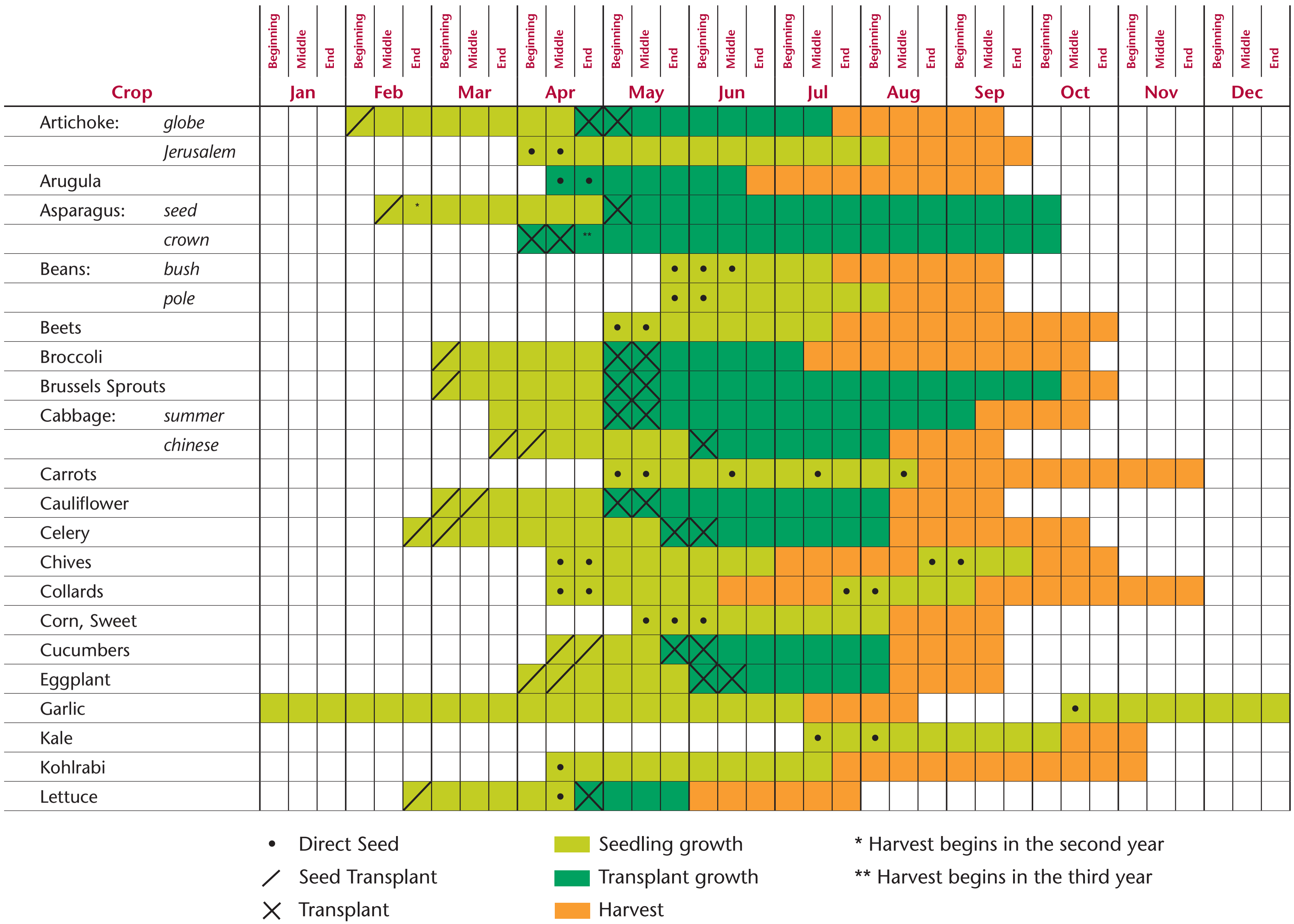
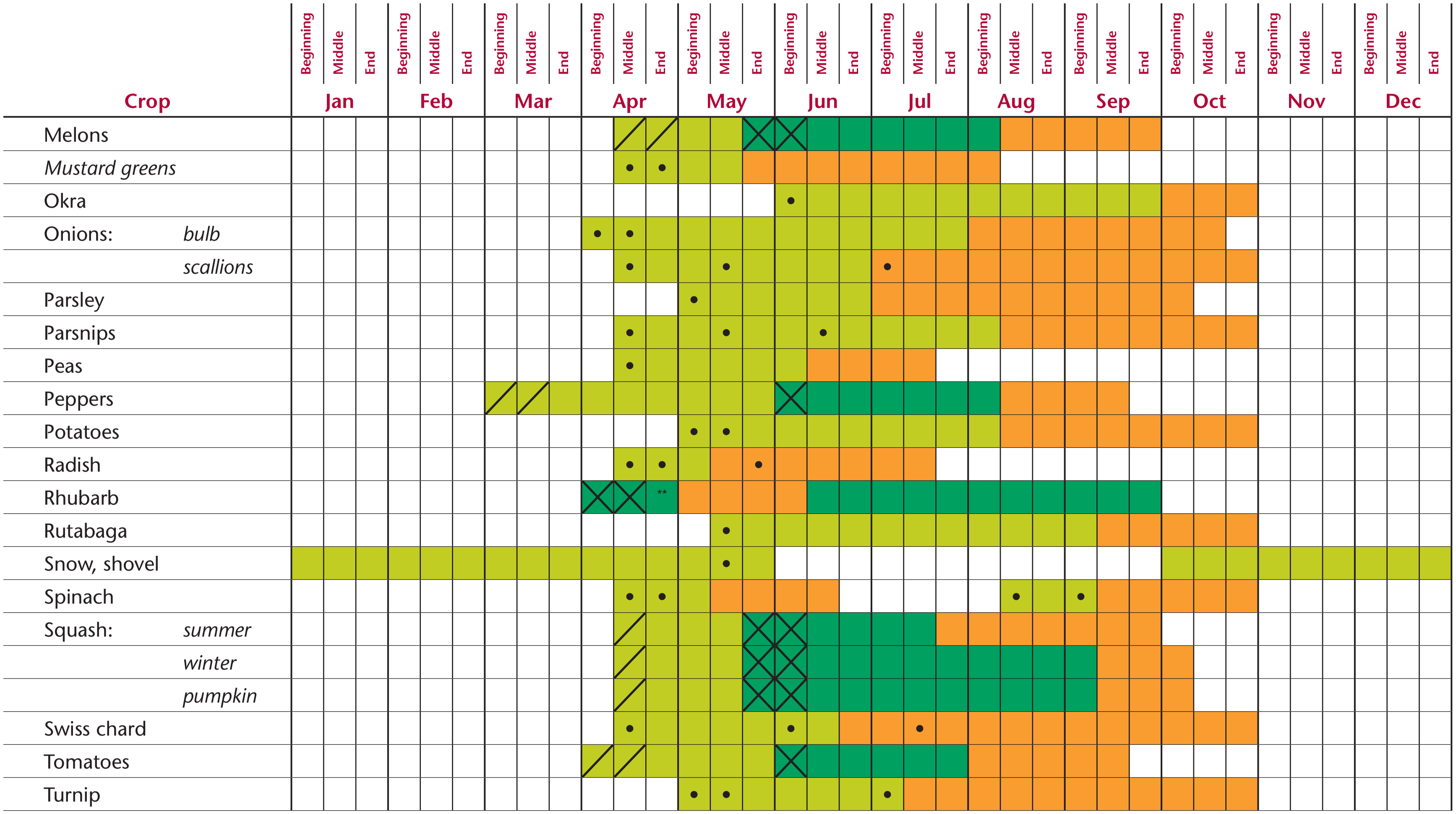


Table 10b. (continued) Suggested planting calendar for vegetable crops in Eastern Washington. Specific dates will vary by location and microclimate.



• Direct Seed
/ Seed Transplant
X Transplant

Seedling growth
Transplant growth
Harvest

* Harvest begins in the second year
** Harvest begins in the third year

Maintenance

Plant Nutrition

Plants require macro- and micronutrients to grow well and be productive. For fertilizer information and application methods, refer to Chapter 5: Plant Mineral Nutrition and Fertilizer.

If you are adding compost to your garden each year, you may be adding sufficient levels of most macro- and micronutrients for adequate crop growth. To determine if your soil has appropriate nutrient levels to meet the needs of your vegetable crops, have your soil tested every 3 to 4 years. If your soil is low in one or more nutrients, add the appropriate fertilizer at the recommended rate to meet your crop needs. If the level of any nutrient in your soil is above the recommended level, reassess your practices so that you do not continue to add that nutrient. For example, compost made from dairy manure tends to be high in phosphorus (P) while compost made from poultry manure tends to be high in potassium (K).

Remember that soil pH affects nutrient availability. In acid soils (at low soil pH), nutrients are not readily available for uptake by most vegetable crops. To increase nutrient availability, maintain a soil pH between 6.0 and 7.0. If you are adding compost to your garden each year, the organic matter will act slowly to increase soil pH. If your soil pH is still too low, add agricultural lime at the rate of about 6 pounds (12 cups) per 100 square feet for most soils. For clay soils, add 8 pounds of lime, and for sandy soils add 4 pounds. Lime does not react quickly in the soil and it takes at least half a year to be effective. In addition, water is needed to activate the lime; therefore it is best to apply lime in the fall. Lime is rarely needed in Eastern Washington.

Watering

Summers are quite dry throughout Washington, and you need to be prepared to water your vegetable garden from May through September. The amount of water and method of irrigation you use will often determine the success of your vegetable garden. The following is a guide to help you determine how best and how frequently to water.

Timing. If you are using an overhead sprinkler, irrigate in the early mornings so that foliage can dry off before cool evening temperatures occur. Disease potential is increased when foliage remains wet during the night. If you use soaker hoses or drip irrigation, irrigate in the late afternoon or evening. By watering at the end of the day, more water will be absorbed into the soil and less water will be lost due to evaporation and transpiration, thereby increasing irrigation efficiency. Regardless of your irrigation method, do not irrigate in the heat of the day (11 am to 2 pm), as excessive evaporation loss and foliage burn will occur. Windy weather is also a poor time to water due to increased evaporation rates.

Sprinkler Irrigation. Sprinkler irrigation is generally the least expensive and the simplest irrigation method for home vegetable gardens, but unfortunately it is also the least efficient. With a sprinkler, the entire garden area is watered and thus the total amount of water used to irrigate is much greater. Evaporation loss is also larger when the water is broadcast into the air. Weeds are also being watered, which leads to greater weed growth. In addition, diseases are encouraged by wet foliage and can be transferred to neighboring plants by splashes of water.

Soaker Hoses. Soaker hoses are much more efficient than sprinkler systems and can reduce water use by up to 50%. Soaker hoses can be flat or round, and they have tiny holes through which water leaks or seeps out. Evaporation, runoff, and weed growth are reduced by nearly a half, while water application to the vegetable crop is optimized. The occurrence of foliar plant diseases is also substantially reduced with the use of soaker hoses.

Drip Irrigation. The water efficiency and plant health benefits of drip irrigation are quite similar to those of soaker hoses, but drip lines tend to be more complex and expensive to install and operate. Depending on the size of the irrigation system, gauges and water-pressure reducers may be required. When selecting drip lines for your garden, it is important to choose ones with the appropriate emitter spacing. The emitter is the hole in the tape or hose where the water comes out. Use an emitter spacing of 9 inches for a continuous row (as with radishes, beans, peas). Choose a wider emitter spacing to match the plant spacing for those crops that are spaced far apart; for instance, 18 inches for tomatoes, peppers, broccoli and 36 inches for squashes, cucumbers, melons.

Frequency. Water seedlings and transplants in the garden gently and frequently (every 2 to 3 days, depending on rainfall) for the first week or two. Apply approximately ¼ inch of water in each application. Thereafter, irrigate once a week or as needed and apply 1 inch of water at each application. Shallow watering encourages shallow root growth, resulting in plants that are inefficient in water uptake and are less drought tolerant. To determine the amount of water applied, see Calculating Amount to Irrigate, below.

Rate. Irrigation is most effective when applied at approximately ½ inch or less of water per hour. A faster rate will cause runoff. If you begin to see runoff or puddling, turn off the irrigation and resume watering in about an hour.

Rain Gauges. Observe and note any rainfall that your garden receives. Adjust irrigation accordingly so that rainfall plus irrigation equals 1 inch per week.

Calculating Amount to Irrigate. The amount of water that vegetable crops need is usually given in inches. For example, most vegetable crops require 1 inch of water (per square foot) every week. You can use indicators such as depth of soil moisture to determine if you have applied the right amount of water or you can measure and calculate the actual amount of water you apply.

The easiest method for determining how long to irrigate is to simply use a shovel to check the depth of moisture in the soil, and adjust your watering schedule accordingly. For most clay and loam soils, 1 inch of water will penetrate about 6 inches deep. Measure the amount of time it takes for your first irrigation to wet the soil to a depth of 6 inches, and this is the amount of time it takes to apply 1 inch of water. Irrigate again for this same amount of time when the top 1–2 inches of soil is dry. After several weeks of irrigation, the soil should be moist throughout the root zone. At this point, you will only need to check the top 4–6 inches to see the soil moisture level.

1 inch of water per square foot equals 0.62 gallons

It is helpful to know that 1 inch of water per square foot equals 0.62 gallons. If you are watering by hand, apply 0.62 gallons per plant per week for those plants that are spaced more than a foot apart, or apply this same amount of water per linear foot of row for those crops that are spaced close together.

To measure the amount of water you are applying with a sprinkler, place a bucket near one of the vegetable plants. Measure the depth of the water in the bucket after one hour; this will be the amount in inches that the plant received in that hour. Or, measure the volume of water in the bucket, and this will be the amount in gallons that the plant received. Use this measurement to determine how long to keep your sprinkler system on so that plants receive 1 inch of water.

If you are using a sprinkler, measure the area (in square feet) of the garden that will be reached by the sprinkler. Multiply this number by the number of inches of water needed (1 inch in most cases), and then multiply by 0.62 (1 inch of water per square foot = 0.62 gal). This will give you the total number of gallons you need to apply. Divide the total number of gallons that you need to apply by the gallons-per-hour rate of your irrigation system to determine the irrigation time.

Soaker hoses vary slightly in the amount of water they deliver, but in general they emit approximately 0.1 gallon per linear foot per hour. Soaker hoses generally wet an area of 6 inches on either side of the hose, or a 1-foot total width. You would need to irrigate six hours in order to apply the amount of water that is needed (0.62 gallon per square foot). You can measure the amount of water delivered by your soaker hose or drip tape by placing a container under the hose or tape. The volume of water in the container at the end of an hour tells you the number of gallons of water the plant is receiving. Or you can place the entire hose or tape in a small wading pool to measure the total amount of water applied.

Winter Gardening

In Western Washington, crops listed as hardy (refer back to Table 2) can be grown without cold protection while crops listed as half-hardy do best with protection. In Central and Eastern Washington, cold protection is needed for most vegetable crops.

The two most common materials used for cold protection to extend the growing season are fabric row covers and clear plastic. Fabric row covers come in different weights and can increase day temperatures by 4–8°F. Lighter fabric row covers (0.45–0.55 oz/sq yd) are generally promoted as insect barriers and are not recommended for winter use. Heavier fabric row covers (0.9–1.5 oz/sq yd) are used for frost protection.

Day temperatures under greenhouse-grade clear plastic (6 ml) can be 10–20°F greater than outside temperatures on a clear, sunny day. Night temperatures under bug-shield row covers and plastic tend to be equal to outside temperatures. Do not place row cover or plastic so they are touching plants, because frost damage can occur where the fabric or plastic comes into contact with the plant. Construct a cloche by shaping metal or PVC hoops and laying the row cover or plastic over these hoops (Figure 4).

Figure 4. Movable garden winter cloche (a small "hoop house") made from PVC hoops and greenhouse-grade plastic.

Saving and Storing Vegetable Seeds

When saving seeds from your own garden, choose seeds from healthy non-hybridized plants. Seeds from hybrid cultivars do not produce plants with the same traits as the parent plants. Also, for open-pollinated plants, unless you can control cross-pollination, the seeds you collect may produce hybridized plants.

If you plan to dry and store vegetable seeds, you will need to control the seed moisture and to store seeds at moderate temperatures. High moisture and temperature cause rapid seed deterioration and loss of seed viability. The longer seeds are stored, the more important moisture and temperature conditions become.

An ideal method of drying seed is a food dryer/dehydrator at a very low temperature setting. It is essential that a fan blows air away from the seed to prevent heat from building up around the seed. To reduce seed moisture, dry seed at temperatures of 110–120°F. For small seeds, drying time may be 1 hour while large seeds may require 3 hours. Drying time will depend on the starting seed moisture content, the thickness of seed being dried, whether or not the seed is still in the pod, and the volume and dryness of the air.

Once the seed is dried, seed moisture will reach equilibrium with the surrounding atmosphere in a few weeks: 3 weeks for small seeds and up to 6 weeks for large seeds. To maintain low seed moisture, store dried seed in an airtight container with desiccant such as calcium chloride or silica gel. Re-dry the desiccant as needed.

Ideally, seed moisture should be maintained at around 12%, and storage temperatures should be about 50°F. Under these conditions, seed of most vegetable crops can be stored for several years (Table 11).

For much more in-depth information regarding saving and storing seed, we recommend the publication "Seed to Seed" (listed in the Further Reading section at the end of this chapter).

Table 11. Approximate life expectancy of vegetable seeds stored under favorable moisture and temperature conditions.

Vegetable	Years	Vegetable	Years
Asparagus	3	Kohlrabi	3
Bean	3	Leek	2
Beet	4	Lettuce	6
Broccoli	3	Muskmelon	5
Brussels sprouts	4	Mustard	4
Cabbage	4	New Zealand spinach	3
Cardoon	5	Okra	2
Carrot	3	Onion	1
Cauliflower	4	Parsley	1
Celeriac	3	Parsnip	1
Celery	3	Pea	3
Chard, Swiss	4	Pepper	2
Chervil	3	Pumpkin	4
Chicory	4	Radish	5
Chinese cabbage	3	Rutabaga	4
Collards	5	Salsify	1
Corn, sweet	2	Sea Kale	1
Corn salad	5	Sorrel	4
Cress, garden	5	Southern pea	3
Cress, water	5	Spinach	3
Cucumber	5	Squash	4
Eggplant	4	Tomato	4
Endive	5	Turnip	4
Fennel	4	Watermelon	4
Kale	4		

Further Reading

WSU Extension Publications available at: http://cru84.cahe.wsu.edu/

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Home Orchards

7

Topics covered:

Are You up to the Challenge?

Fruit & Nut Trees for the Pacific Northwest

Planning Your Home Orchard

- Variety Selection
- Rootstock Selection
- Pollination Requirements

Site Selection & Tree Planting

Proper Irrigation

Tree Pruning & Training

Fertilizing Fruit Trees

Fruit Thinning

Weed Management

Insect Management

Vertebrate Pests

Harvest & Handling

Learning Objectives

- Know the legal responsibilities of home orchardists to control the insect and disease pests on all horticultural trees on their properties.
- Understand variety selection, planting, maintenance, and pest management for fruit production in home orchards.
- Know applicable IPM strategies in order to reduce reliance on broad-spectrum pesticides.

By

Michael R. Bush, Extension Educator, Yakima Co., Washington State University Extension

Jeff Olsen, OSU Extension Horticulturist, Willamette Valley, Oregon State University Extension Service

Are You up to the Challenge?

Growing tree fruit or nuts in your backyard can provide a great deal of personal satisfaction. Many of the fruit trees that we can grow in the Pacific Northwest will yield colorful, tasty, and nutritional crops, plus provide a beautiful display of blooms in the spring. Nothing can be more satisfying than harvesting a tree-ripened piece of fruit and sharing those fruits of your labor with family and friends.

In Washington State, home orchardists have a legal responsibility to control the insect and disease pests that may plague their fruit and nut trees.

Along with the pleasure and satisfaction of growing your own tree fruits and nuts, comes responsibility. In Washington State, home orchardists have a legal responsibility to control the insect and disease pests that may plague their fruit and nut trees. This responsibility is a year-round commitment that extends throughout the lifetime of these perennial crops. Pest problems that arise one year can impact fruit production the next season, and these pests can spread from your fruit trees to other fruit trees in the neighborhood. These pests may also spread to, and negatively impact, any commercial fruit or nut operations in your region. For most fruit and nut trees this will inevitably require that home orchardists use of pesticides, but through the use of various IPM strategies, reliance on broad-spectrum pesticides can be minimized. The Pacific Northwest has a global reputation for producing quality tree fruits and nuts. Please help us maintain this reputation by properly managing the insect and disease pests in your home orchard.

Fruit & Nut Trees for the Pacific Northwest

A wide range of deciduous tree fruit can be grown in the Pacific Northwest including apples, sweet cherries, pears (European and Asian), peaches, nectarines, tart cherries, plums, prunes, pluots (inter-species hybrids) and apricots, as well as nut trees such as walnuts, hazelnuts, and chestnuts. Since there are many different climatic and geographic regions in the Pacific Northwest, the best source of information on what you can and cannot grow in your area will be your local Extension office. You may also contact your local Extension agent for specific recommendations on fruit varieties, horticultural practices, and pest management strategies.

Climate is often the limiting factor that determines what can and cannot be planted in your home orchard. Throughout most of Washington, we are blessed with adequate water, suitable soil, long and warm summer days, cool nights, adequate winter chilling during tree dormancy, and a sufficiently long **growing season**. The length of the growing season (measured in average number of frost-free days) is quite variable throughout Washington, ranging from 90 days north of Spokane to 180 days along the Pacific Coast. Most fruit trees require at least 150 frost-free days, but fruit varieties exist that do better at either end of the state-wide range of growing seasons.

Average minimum temperature during the winter months will have a great impact on what fruit and variety can be planted. Apples, tart cherries and American plums are the most hardy of the deciduous fruits and can withstand winter temperatures as low as –30°F. Pears and European plums can usually tolerate winter temperatures down to –20°F. Sweet cherries, Japanese plums and apricots are hardy enough to survive –10°F to –15°F. Peaches and nectarines are the most sensitive fruit trees and can be injured at temperatures of –8°F to –12°F. Therefore, planting peaches and nectarines in a hardiness zone of 5 (where the average minimal winter temperature can reach –20°F to –10°F) would result in winter injury to that tree most of the time—making it difficult to maintain that tree in good health.

Springtime temperatures can sometimes limit the productivity of a fruit or nut tree from year to year. Tree fruit buds tend to be the most sensitive tissues to extremely cold temperatures—especially early in the spring as the buds start to swell. Thus, late spring frosts or temperatures below 28°F (a "killing frost") can damage and kill off the fruiting buds. If you live in an area that is prone to late season frosts, you should consider selecting fruit and nut trees that are late-blooming varieties.

Planning Your Home Orchard

While choosing the right fruit or nut tree for your backyard can be as easy as driving to the nearest Home and Garden Shop and buying what they happen to have in stock, this decision is much more challenging, and exciting, when properly done. There are three major considerations that home orchardists must take into account when making this decision: variety selection, rootstock selection, and pollination requirements. The more information you can gather on the fruit or nut tree you eventually select, the better the chances you have of successfully growing a fully productive backyard tree.

Variety Selection

Variety selection can be the most exciting step—and is an important one—in planning your home orchard. For some fruits, like apples, there are literally hundreds of varieties to choose from. A word to the wise, start your home orchard simple and small. Generally, the more varieties of fruit you grow, the more complex it will be to manage them. As you gain experience and meet with success, you may choose to diversify and meet the challenge of managing more varieties. Important considerations in variety selection will be winter hardiness, fruit maturity time, insect and disease tolerance, fruit color and flavor, and how the crop is

A word to the wise: start your home orchard simple and small—the more varieties you grow, the more complex it will be to manage them.

consumed and stored (i.e., eaten fresh off the tree, canned, frozen, or dried).

Apples. There are hundreds of varieties of apples including Old World varieties, antique varieties, and new cultivars produced through unique crosses at breeding research centers and nurseries as well as chance mutations or sports. One important criterion in selecting a variety for your backyard is **tree vigor** (see Table 1). In general, more vigorous apple varieties have the potential to become larger trees. Therefore these varieties will require more intensive tree training and pruning to control vegetative growth, to encourage **fruit precocity**, and to maintain fruit production zones closer to the ground.

Table 1.—Apple tree variety vigor ratings.

High vigor	Earligold Gravenstein Mutsu	Northern Spy Winter Banana
Low vigor	Spur Delicious Spur Golden	Spur Granny Smith
Very low vigor	Spur Delicious Spur Rome	Super Spur
Moderate vigor	Akane Braeburn Cortland Criterion Delicious Elstar Empire Fuji Gala Golden Delicious	Granny Smith Idared Jonagold Jonathan LIberty Melrose Newtown Rome Beauty Styman

If you are considering planting more than one variety of apple in the backyard, it would be to your advantage to select varieties based on when the fruit is harvested; that is, you should stagger your harvest so you can enjoy fresh fruit over a longer period of time. Table 2 lists apple varieties by anticipated time of harvest. Typically, the early harvested apple varieties mature around mid- to late August. Midseason apples are harvested September to early October, and late season apples in mid-October to November. Of course, weather conditions during the growing and the harvest seasons can affect harvest times.

Table 2.—Apple varieties grouped by relative timing of fruit harvest.

Early	Akane Gravenstein Jersey Mac Lodi Pristine	Red Melba Sansa Tydeman's Red William's Pride
Midseason	Empire Gala Jonathan Liberty	McIntosh Wealthy Honeycrisp
Late	Braeburn Cortland Delicious (Golden & Red) Fuji Granny Smith Jonagold	King Macoun Melrose Mutsu Newtown Rome Beauty Pink Lady

West of the Cascades in the Pacific Northwest, where frequent precipitation and high humidity are the norm, home orchardists should select disease-resistant apple varieties. These varieties can reduce the number of fungicides needed to protect your trees and fruit from plant diseases such as apple scab and apple mildew (Table 3a). In the low-humidity and low-rainfall parts of the Pacific Northwest, disease incidence is not a major concern and harvest times can be the chief selection criteria (Table 3b).

Table 3a.—Apple varieties recommended for western Washington.

Scab-resistant only	Chehalis Enterprise Freedom Goldrush Liberty Pristine	Raritan Red Baron Sansa Sir Prize Tompkins King William's Pride
Scab- and mildew-resistant	Bramley's Seedling Brown Russet Buckley Giant Hudson's Golden Gem Mother	Prima Priscilla Stirling Tydeman's Early Wolf River

Table 3b.—Apple varieties recommended for eastern Washington.

Early	Akane Earligold Gingergold Gravenstein Lodi	Paulared Redfree* Sansa* Summerred Tydeman's Early*
Midseason	Chehalis* Elstar (not heat-tolerant) Empire Enterprise* Honeycrisp Liberty*	McIntosh Prima* Priscilla* Royal Gala Spartan
Late	Braeburn Cortland Fuji Golden Delicious Goldrush Granny Smith Idared Jonafree*	Jonagold Jonamac Melrose Newtown Pippin Pink Lady Red Delicious Sundowner
	*Scab-resistant	

Cherries. The important criteria in selecting cherry varieties are fruit flavor and appearance. Sweet cherries are best eaten as fresh fruit off the tree while sour cherries (such as Montmorency and Balaton), also known as pie cherries, have an intense cherry flavor and are better for baking and cooking. Sweet cherry varieties may have dark red skin colors or have yellow/white skin colors with red blushes. Bing is the most popular of the sweet cherry varieties and tends to ripen in the last week of June and first week of July. Most sweet cherry varieties ripen in a short period around Bing, but Chelan, Royal Ann, and Tieton are early varieties that ripen about one week before Bing. Lapins, Skeena, Regina, and Sweetheart may ripen two to three weeks later. One main criterion used to select east-side versus west-side varieties is cherry susceptibility to rain cracking (Tables 4a and 4b). Precipitation just prior to harvest can cause the fruit of many cherry varieties to swell and split their skins. Disease tolerance is a desirable trait in cherry varieties selected for home orchards in eastern Washington.

Table 4a.—Cherry varieties recommended for western Washington.

Sweet (dark)	Bing Kordia (Attika) Lambert Lapins Regina	Sandra Rose Skeena Sweetheart Van
Sweet (light-skinned)	Bada Corum	Rainier Royal Ann (Napoleon)
Sour	Balaton Danube	Montmorency Surfire

Table 4b.—Cherry varieties recommended for eastern Washington.

Sweet	Bing Chelan Kordia (Attika) Rainier (light-skinned) Regina Royal Ann (Napoleon) (light-skinned)	Sandra Rose Skeena Sweetheart Tieton Van
Sour	Balaton	Montmorency

Pears. There are two types of pears that can be grown in the Pacific Northwest—European and Asian pears. Most of us are familiar with the shape and texture of European pears including the Bartlett and winter pears. European pear varieties can sport yellow or red skin color. Asian pears, sometimes called apple pears, are shaped more like apples and have a crisper and juicer texture than European pears. Most pears in Washington are grown on the east side of the state (see Table 5). The wetter climate on the east side tends to be too conducive to disease problems; however, disease-resistant pear varieties like Blake's Pride, Orcas, and Rescue may be ideal for home orchards in western Washington.

Table 5.—Pear varieties for the Pacific Northwest.

European (green)	Anjou Bartlett	Bosc Comice Conference Seckel
European (red)	Red Anjou Red Bartlett	Reimer Red Starkrimson
Asian (light or yellow-skinned)	Kikusui Kosui	Nijisseiki (Twentieth Century) Shinseiki (New Century)
Asian (russet or golden-skinned)	Chojuro Hosui	Shinko

"It is, in my view, the duty of an apple to be crisp and crunchable, but a pear should have such a texture as leads to silent consumption."

—Edward Bunyan, in The Anatomy of Dessert

Stone Fruits. There has been an explosion of stone fruit varieties in the last decade with a number of varieties that do exceedingly well here in the Pacific Northwest (Tables 6a–b). Fruit productivity and disease susceptibility are two limiting factors in variety selection for peaches, nectarines, and apricots in western Washington, but there are some varieties that show some tolerance to stone fruit diseases (Table 6a).

Table 6a.—Peach, nectarine, and apricot varieties for western Washington.

July maturity	**Peaches**	Early Redhaven Gemfree Golden Gem	Harbelle Harrow 719 Springcrest
August maturity	**Peaches**	Earlihale Fairhaven Glohaven Harken Harmony July Elberta Loring Redglobe	Redhaven Redtop Rochester Slappy Suncrest Sunhaven Veteran
September maturity	**Peaches**	Bisco Early Elberta	Flamecrest J.H. Hale
	Nectarines	Juneglo Karko	Redgold Fantasia
	Apricots	Puget Gold	

Table 6b.—Peach, nectarine, and apricot varieties for eastern Washington.

Peaches	Early Elberta Early Hale Elberta Golden Jubilee Halehaven	July Elberta Newhaven Redhaven Rosa
Nectarines	Fantasia Flavortop Juneglo	Nectared Red Gold Sunglo
Apricots	Goldbar Goldcot Goldrich Moorpark	Perfection Wenatchee Rival Tilton Tomcot

Nut Trees. A number of hazelnut, walnut, and chestnut tree varieties can be productive here in the Pacific Northwest (Table 7). Frequently, the limiting factor to sustainable production on the east side of the state is winter injury due to early spring frosts and severe winter temperatures. In western Washington the most limiting factor is the cool, wet growing seasons.

Table 7.—Nut trees for the Pacific Northwest.

Hazelnuts (filberts)	Barcelona Lewis Clark	Wilamette Hall's Giant
Walnuts	Carpathian Franquette (can freeze out)	Hartley Manregian Spurgeon
Chestnuts	Colossal Layeroka	Skioka Skookum

Rootstock Influence

Nearly all commercially available fruit and nut trees are actually two plants grafted together. The above-ground portion of the fruit tree is called the **scion** and presents the variety characteristics discussed above. The bottom portion of the fruit tree is called the **rootstock** and makes up the root and collar system of the tree. A tree's rootstock will control tree size, **fruiting precocity**, and soil moisture tolerance, and will provide some resistance to soil insect pests and diseases.

While home orchardists can select the variety of fruit tree they want, they generally do not have a choice about the rootstock it is grafted on (Figure 1). However, it's important to know the purpose of rootstocks and, whenever possible, choose dwarfing rootstocks that limit the ultimate size of a tree.

The main purpose of fruit tree rootstocks is to control overall tree size. An apple tree that is sprouted from seed (that is, grown on **seedling rootstock**) tends to be a highly vigorous-growing tree that can easily grow to 30 feet or taller. Most home orchardists do not have the equipment or desire to effectively spray, thin, or harvest fruit from a tree this tall. Dwarfing rootstocks can reduce the need for ladder work during pruning, fruit thinning, and crop harvest and will facilitate insect and disease management in the upper canopy of the tree. The ultimate height of any tree can be greatly influenced by pruning and training. Rootstocks that impart more vigor to the apple tree simply make it harder to contain trees to a desired height and width.

Apples. Apple trees present the greatest variety of rootstocks for home orchardists to choose. Horticultural researchers in

England developed the Malling and the Malling Merton series of apple rootstocks. These rootstocks provide home orchardists an opportunity to select trees that will grow to specific heights. Each rootstock is identified by the letter "M" (for Malling) or "MM" (for Malling Merton) and a series number. Please note that the higher numbers do not represent taller trees. The height may be anywhere from dwarf (4 to 8 feet) to semistandard (16 to 18 feet). There are other commercially available apple rootstocks that will provide vigor control, disease resistance, and winter hardiness. The Budagorsky ("Bud") series was introduced from central Russia. The Geneva ("G") series was developed at Cornell University in New York.

The following apple rootstock list shows approximate tree size as a percentage compared to the size of the same tree on seedling rootstock:

- MM.111: 90 percent
- MM.106: 60–75 percent

Figure 1.—Labels on fruit trees for sale will give the name of the variety of the scion, but typically do not name the rootstock. However, the label should specify whether the tree will be dwarf or semi-dwarf, etc. in size at maturity.

- M.7, G.30, Supporter 4: 55–65 percent
- M.26, G.11: 40–50 percent
- M.9, Bud 9: 25–35 percent
- M.27: less than 25 percent

Home orchardists should select dwarf rootstocks such as M.9 or M.26. Apple trees on these rootstocks are workable tree heights (6 to 8 feet tall) that should minimize ladder work. One drawback to these rootstocks is that your apple tree may need additional support by stakes, poles, or wires to keep it in an upright position. One bonus is that the growth habit of apple trees on these dwarf rootstocks is conducive to being trained to grow along a trellis, such as an espalier training system.

The M.27 rootstock is one of the most dwarfing apple rootstocks and the only choice for growing apples in containers. For container plantings, you should also use **spur-type** varieties (refer back to Table 1). Spur-type varieties are the least vigorous growing varieties, yet they still set good apple crops.

The M.7 rootstock produces semi-dwarf apple trees (8 to 10 feet tall) that do not require staking; however, some support might be required if early production is encouraged. The MM.106 and MM.111 produce larger trees (12 to 18 feet tall) that require no staking and are suitable for the home orchard. In nursery catalogs, these trees are identified as semi-standard sized.

Other Fruit & Nut Trees. Dwarfing rootstocks are not as common among the other fruit and nut trees. Most European pears are grown on one of many rootstock selections from the Old Home × Farmingdale cross. Asian pears sometimes use these rootstocks, but they also are grown on two species of *Pyrus* rootstocks. Meanwhile, plums are produced on a wide variety of *Prunus* rootstocks, such as peach, plum, apricot, and almond. Peaches usually are grown on their own seedling rootstocks. There are no suitable dwarfing rootstocks for peaches, although St. Julian A is often sold as such. Peach tree size can be best controlled through pruning, so dwarfing rootstocks are not as necessary as with apple trees.

Most cherry trees in Oregon and Washington are grown on Mazzard rootstocks, a fibrous rootstock that does well in poor soils. Current research on growth-controlling cherry rootstocks is producing more choices for home orchardists. The most common of the dwarf cherry trees available to home orchardists are grafted to dwarfing rootstocks Gisela 5, Gisela 6, and Gisela 12. These rootstocks will produce trees that are 50, 70–90, and 60 percent, respectively, the size of equivalent cherry trees grafted onto Mazzard rootstock. Other new rootstocks include MxM2, MxM60, and MxM14 (tree size is about 75–85 percent of an equivalent variety on Mazzard). Cherry trees on these rootstocks will bear fruit earlier and have better disease resistance to bacterial canker than the Mazzard rootstocks. Some of these newer rootstocks are now available to home orchardists from a few Northwest nurseries.

Pollination Requirements

Pollination, or the transfer of pollen from male parts of the flower (stamen) to the female parts of the flower (pistil), is necessary for a backyard fruit and nut trees to produce fruit. Frequently, honeybees or other insects carry pollen from one flower to the next, but wind and rain also contribute to this process. To complicate the pollination picture, trees can be grouped into two categories. Trees that bear fruit after self-pollination are called **self-fruitful.** That means that each flower can be pollinated with pollen originating from the same fruit variety. The second category is trees that bear fruit only when their flowers are pollinated with pollen originating from another fruit variety. These varieties are called **self-unfruitful.**

Most apple varieties that cannot set fruit when self-pollinated do have viable pollen that sets fruit on other varieties. For example, Red Delicious doesn't set its own fruit with its own pollen, but Red Delicious pollen does set fruit on Golden Delicious, and vice versa. Gravenstein requires an early-blooming pollinizer such as Lodi, but does not produce good pollen for other varieties. Mutsu does not pollinize other varieties, yet requires another variety to set fruit. McIntosh is self-unfruitful, but pollinizes other early-blooming varieties such as Gravenstein. Some varieties, such as Rome Beauty, Newtown, and Transparent, are self-fruitful.

Some sweet cherries and most varieties of apples and pears grown in Oregon and Washington do not set fruit unless they are pollinized by another pollen-compatible variety. The three most commonly grown sweet cherry varieties—Bing, Lambert, and Royal Ann—do not pollinize each other. A fourth variety, such as Corum or Van, must be present to pollinize these varieties. Lapins, Skeena, Sweetheart, and Sandra Rose are self-fruitful sweet cherry varieties. Other examples of self-fruitful crops are tart (pie) cherries and most European plums.

Bartlett pears may set a few seedless pears without cross-pollination, but they set more if pollinized by d'Anjou. Bosc and Comice trees pollinize each other.

Home orchardists should plant pollen-compatible trees within 100 feet of each other to ensure adequate pollination. The act of pollination depends mostly on bees and, to a lesser extent, on other insect activity or, in the case of nuts, wind. The bloom periods of the main and pollinizer varieties must overlap enough to provide at least several days for cross-pollination to take place. Orchards with many pollinizers are more fruitful than those with just one pollinizer.

If no pollinizing varieties are growing nearby, cut a bouquet of blooms from another compatible variety and place it in a pail of water beside your tree while it is in bloom. Or, if you have a single fruit tree that needs a pollinizer, graft a branch of a compatible variety onto the main variety.

Site Selection & Tree Planting

Orchard trees grow best in deep, well-drained soils. To have adequate room for root development, they need at least 4 feet of soil above any impenetrable soil layer or water table. In poor soil conditions, raised beds made with better soil can be helpful. Always choose a location for the home orchard that gets full sun.

Spacing between rows of fruit trees typically ranges from 12 to 24 feet. Apple trees typically are spaced from 4 to 5 feet apart in the row (high density) to more than 20 feet apart. Dwarf trees trained on trellises have the closest spacing. Other fruit trees commonly are spaced farther apart because they often lack growth-controlling rootstocks. True genetic dwarf trees can, of course, be planted closer.

In planning your orchard, compare the amount of space available to the number of trees you want to grow. Spacing trees very close together does push them into earlier production, but tightly spaced trees require more pruning at an earlier age in order to keep them productive. Consider giving the fruit trees as much space as you can within this range, so that you will not have to prune as much to contain the trees to their assigned space.

Fruit trees are usually sold with bare-roots. Be sure to dig a hole large enough to comfortably accommodate the new tree's root system. Do not leave the soil smooth and compacted on the sides of the hole, especially when you are planting in hard-packed soils or soils heavy with clay. Instead, roughen the sides with a shovel so that the roots can grow into surrounding soil and do not get "pot bound" in the planting hole.

Prior to planting, trim off any broken roots and place the root system over a low mound of soil in the hole. Make sure the graft union between the rootstock and the scion wood remains above the ground surface. If the scion wood is below the ground surface it will produce its own root system and the dwarfing impact of the rootstock will be lost. Conversely, any shoots that grow from the rootstock should be pruned as they will produce inferior quality fruit and may out-compete the scion wood.

At planting or prior to the winter season, paint the trunk with a white, water-based latex paint. This precaution will reflect sunlight off the smooth bark of the young tree especially on the southwest side of the tree, and prevent southwest winter injury or trunk sunburn, known as **sunscald**. For ease of application the latex paint can be diluted up to 50 percent with water.

Proper Irrigation

Proper irrigation is of great concern to home orchardists in eastern Washington where rainfall is normally well short of the amount needed to sustain fruit or nut tree growth. The amount of irrigation or drainage needed by fruit trees is highly dependent on soil type and soil profile. The best way to determine whether your irrigation set or the existing soil moisture is adequate is to manually dig down into the soil to the region occupied by the tree roots: 12 to 24 inches deep. Remove a sample of soil with a soil probe or a shovel. Squeeze a handful of soil into a ball. If this soil ball crumbles when released, the soil is too dry and you need to provide more water. If the ball drips water when squeezed, there is more than enough water.

The amount of water needed by a fruit tree will vary over the year. In general, fruit trees will take up water from the onset of growth in the early spring to mid- to late September. Water needs are generally greatest during the summer months when daytime temperatures are highest and tree transpiration rates are the highest. Home orchardists may have to compensate for this greater demand for water by shortening their irrigation set or by supplying supplemental water. During the summer months, even in western Washington, home orchardists should keep an eye out for leaf curling, wilting, or premature leaf drop over the entire tree canopy. These signs of tree stress can indicate either too little or too much soil moisture. Again, the best way to determine soil moisture is to dig down to the tree's root zone and physically assess the moisture in a handful of soil.

Remember that young, newly planted trees typically have an underdeveloped root system and a reduced ability to take up water. Thus watering young trees regularly and frequently in warm weather will help them get off to a better start; however, frequent and light watering will encourage the tree to develop a shallow root system. So as the fruit trees mature, less frequent and deeper watering is preferable. In general, mature fruit trees can use a deep soaking from irrigation or rainfall every 7 to 15 days, depending on the season.

Under-tree or drip irrigation is the preferred means to apply water to fruit trees. Try to keep or minimize water from contacting the tree foliage, flowers at bloom, and fruit. This will reduce the incidence of many tree fruit disease problems. At the same time, avoid over-watering or excessive moisture near the base of the tree trunk as this can lead to crown and root rots.

Tree Pruning & Training

Tree pruning is a necessary part of home orchard care. Prune trees to direct growth, maintain health, and manage fruit-bearing potential. The discussion here covers only guidelines specific to pruning fruit trees.

Your pruning strategy should take into account the fruiting habit of each tree. The type and age of wood that bears fruit varies with the kind of tree. Some fruits bear on more than one kind of wood. For example:

- Walnuts and quince produce fruit on the current season's shoots.
- Hazelnuts, nectarines, peaches, quince, and Japanese plums produce fruit on the previous season's shoots.
- Sour cherries, some apples, and some pears produce fruit on the previous season's spurs and shoots.
- Apples, apricots, sour cherries, sweet cherries, pears, and plums (European and Japanese) produce fruit on long-lived spurs.

Good light penetration is necessary for fruit spur formation and productivity. Trees that fruit on spurs should be maintained in a fairly open form. Those that produce their crop on one-year-old wood (such as peaches and hazelnuts) benefit from pruning because it stimulates new wood formation—and, therefore, more fruit.

Pruning & Training Guidelines

- Prune all fruit and nut trees at planting time. Cut just above the height where you want the lowest branches to grow (usually 30 to 40 inches above the ground).
- Prune young trees very lightly. Heavy pruning will delay tree fruiting.
- Prune mature trees more heavily, especially if they have shown little growth.
- Prune the top portions of trees more heavily than the lower portions.
- Train young trees in the first few years after planting to avoid corrective pruning later. Bend main scaffolds to a 45° to 60° angle.
- To keep trees small, prune moderately every year and do not apply excess fertilizer, manure, or compost. (This does not apply to dwarf trees.)
- Prune during the dormant season (after fall or early winter freezes, but before full bloom in spring). Sweet cherry trees may be pruned in August, when there is less danger of bacterial infection.

- When removing large limbs (Figure 2), first cut part way through from the underside, about 6 inches out from the collar, then make a second cut from the top a little farther out, cutting all the way through until the branch falls away. Finally, cut the stub back to the branch collar. Do not remove the branch collar.
- There is no need to paint pruning wounds. The best protection for a wound is to leave the branch collar intact so the tree is protected from wood-rotting fungi.

Fertilizing Fruit Trees

A fruit tree's need for fertilizer varies according to the amount of available minerals in the soil. Soil types vary within a specific area as well as regionally across the Pacific Northwest. Consult local Extension educators for specific recommendations in your area.

Fruit trees do need nitrogen in all regions. The amount needed varies from fractions of a pound, up to 2 pounds of actual nitrogen per tree each spring, based on the tree size, with fully mature trees getting the higher amounts. The best way to gauge nitrogen needs is to watch the amount of annual growth and check for yellowing of older leaves. If a tree has at least 12 to 18 inches of new growth each year, it is thriving. Over-application of nitrogen may cause excessive tree growth as well as physiological problems in the fruit, such as bitter pit in apples.

Most gardeners use a complete fertilizer (one with nitrogen, phosphorus, and potassium) around the yard and vegetable

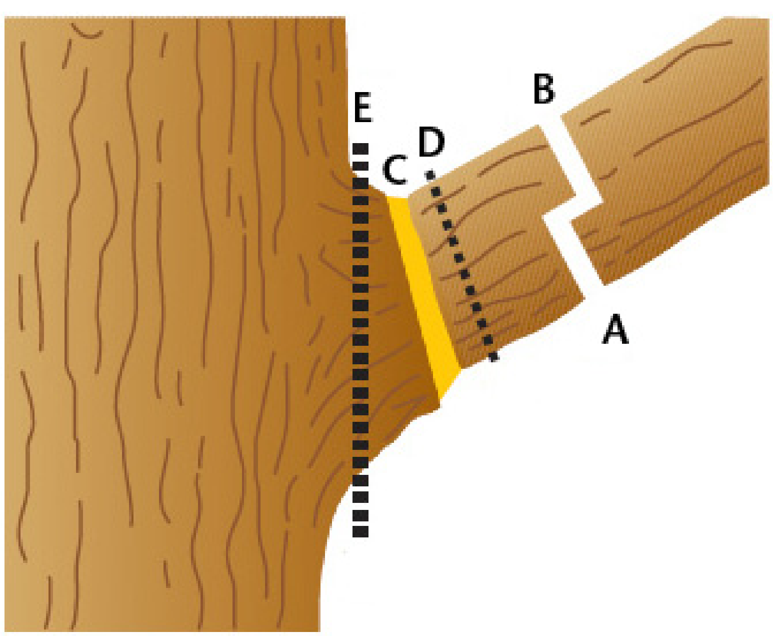


Figure 2.—To avoid bark stripping when removing a large limb, make the first cut at A, below the limb about 12 inches from the trunk. Make the second cut at B, further out on the limb from A. When the limb sags and breaks, it will break to A, leaving a stub. Make the final cut at C, just outside the branch collar to remove the stub. A cut at D would leave too much of a stub, which might rot before the branch collar can grow over it, and a cut at E is a flush cut that would damage the branch collar and inhibit wound healing.

garden. These fertilizers are fine for fruit trees. However, if they are used each year, phosphorus and potassium levels build up far in excess of the tree's actual need.

Most home orchardists do not apply adequate boron to their fruit trees. Although boron is needed only in small amounts (it is a micronutrient), it is essential for plant health and productivity, especially for fruit set. Trees that are low in boron have poor shoot growth and poor fruit set. An easy source of boron for home orchardists is Borax. If you need to apply boron to a fruit tree, add a tablespoon of Borax to 2 gallons or more of water and apply it to the soil within the tree's dripline. It is best to have the soil analyzed for boron deficiency before adding more.

Fruit Thinning

Fruit thinning of apples, Asian and European pears, and peaches is a very important part of orchard management. It improves the size and quality of fruit and helps ensure an adequate crop the next year.

There are three ways to thin fruit. Picking the tiny fruit or blossoms by hand is the most common method. (Home orchardists generally rely on thinning by hand.) Mechanical thinning involves using a tool to knock fruit off the tree. In commercial orchards, plant-growth regulators are sprayed onto apple and pear trees during and after bloom to thin the crop.

Early thinning of blossoms or fruit helps stimulate flower initiation for next year's crop, especially on cultivars that tend toward biennial bearing (bearing fruit every other year). Thinning removes some of the developing embryos that otherwise would produce flowering inhibitors.

Apples initiate flower buds for the following year's crop within 40 days of full bloom, so thinning has a positive effect on next year's bloom if it is done within this period. Pears form buds a little later, so you can thin them within 60 days of full bloom. Attaining adequate return bloom on peaches seldom is a problem, but early thinning generally helps.

Thinning also helps increase the size of harvested fruit by stimulating cell division in the remaining fruit. More cell division means more cells per fruit, thus, larger fruit. The period of cell division for apples lasts 4 to 5 weeks after petal fall. For peaches, it lasts 4 weeks after petal fall, while pears continue cell division for 7 to 9 weeks after petal fall. All fruits continue some cell division in the epidermis layer (the skin) much longer than in the main part of the fruit flesh.

Sometime during the cell-division phase, cell enlargement begins. Enlargement continues throughout the growth of the fruit and often is positively influenced by fruit thinning. The effect is greatest on cultivars that tend to have a heavy fruit set. Determine the size of fruit you want and thin accordingly, with fewer fruit per tree resulting in bigger size individual fruit.

Apples. For apples, first remove the smaller fruit. The relative sizes of the fruit do not change throughout the season. The king bloom is the middle blossom or fruit in the cluster, and it always produces the largest fruit.

Decide how much fruit to leave on the tree based on the vigor and general condition of the tree. In cultivars that tend toward biennial bearing, leaving every other spur without fruit helps ensure adequate return bloom. Leaving more than one fruit per spur is possible except on short-stemmed cultivars, such as Gravenstein, and red cultivars that color poorly. Fruits of short-stemmed varieties tend to push each other off the spur if there are two fruits per spur.

Asian Pears. Asian pears also must be thinned. Each blossom cluster contains several flowers in a row. Save the fruit in the middle and remove the rest. Research has shown that this middle fruit is the roundest. By counting the flowers as they appear, starting from the base of the cluster, you can determine which fruit to remove. For example, if there are seven flowers, save the fourth fruit from the base of the cluster. Thin early to get large fruit.

Depending on the tree's vigor, you might experiment by leaving two fruits per spur and checking the fruit size response.

Peaches. Thin peaches to about 4 to 6 inches from one another. This spacing gives them adequate room to mature to full size.

Other Tree Fruit. European pears seldom over-set their crop, so their thinning needs are not so great. Cherries and plums are seldom thinned, but they could be thinned in heavy set years, if your goal is to produce large size fruit.

Weed management

Proper weed management is important to newly-planted and young fruit and nut trees, especially in Eastern Washington where water can be a limiting resource. Weeds will compete with your trees for water and nutrients. As your trees mature, they will gain the competitive edge to shade out and out-compete many of the weeds. Allowing weeds to grow up at the base of the tree can provide an ideal habitat for several insect pests as well as for pestiferous rodents like voles. Throughout the lifetime of your trees, it is a good strategy and aesthetically pleasing to manage those weeds that grow beneath each tree.

For home orchardists, frequent scouting and hand removal of perennial weeds is the easiest means of managing them. Shallow cultivation under the tree to cut annual weeds just below the soil surface is important for newly planted and young fruit and nut trees. Take care not to damage the trunk of the tree and to minimize the scarring of any shallow roots. Plastic mulches, woven mats, and bark mulches are excellent strategies to prevent weed infestations under young trees. As your fruit or nut tree becomes productive, a dwarf turfgrass ground cover under the tree can be encouraged and managed as a living mulch. Herbicides (including several glyphosate products) may be used to manage weeds under your tree as well. Before using any herbicide product, be sure to verify that the herbicide label allows for use under your fruit or nut tree. Avoid spraying herbicides in windy conditions and avoid applying any herbicide directly to the green tissues of your tree.

Insect Management

There are many arthropods, including both insects and mites that negatively affect tree health and fruit quality. Most are considered indirect pests that may feed on tree leaves, branches, or roots, but do not directly damage the fruit. These pests can be managed through numerous IPM tactics like cultural, behavioral, mechanical, biological, and, occasionally, chemical applications. The most serious pests directly damage the fruit itself. In apples, the most serious pests include apple maggot and codling moth; in pears, the pest of concern is codling moth; and for cherries—western cherry fruit fly. For these fruits, home orchardists will have to practice IPM to prevent these serious pests from infesting a sizeable percent of their harvested fruit. By necessity, these programs will utilize insecticide applications, but other IPM strategies can be used to reduce home orchardist reliance on insecticides.

Two strategies of IPM that home orchardists should consider are pest scouting and pest monitoring. Pest scouting involves periodic visual inspection of the fruit tree for the presence/absence and density of insect pests as well as the damage they cause, and to gauge the overall health of the tree. Pest monitoring involves the use of traps and phenological models to monitor and predict pest development, pest density, and the potential for pest damage.

See chapters on Basic Entomology (Ch. 14), Disease, Diagnosing Problems (Ch. 16), and IPM (Ch. 19)

While scouting and monitoring pest populations, home orchardists should also learn to identify and manage the beneficial arthropods as well as the pests. The proper management of beneficials like lady beetles, predatory mites, spiders, lacewings, and others can help the home orchardists control populations of indirect pests such as spider mites, aphids, caterpillars, and scale insects. While home orchardists may not want to tolerate direct pest populations, they are encouraged to tolerate populations of indirect pests. Indirect pests can be maintained at levels that do not cause fruit damage or impact tree health, but do provide a food source for those beneficial insects that can keep these and other indirect pests in check throughout the growing season.

Please note that in Washington State, home orchardists have a legal responsibility (RCW 15.08.010) to control the horticultural pests and diseases that can plague their fruit trees. The basis of this responsibility is to prevent the buildup of pests in backyard fruit trees that can then spread to adjacent backyard trees as well as to commercial orchard operations. In many counties, especially those whose economies are dependent on agriculture, this responsibility is enforced by County Horticultural Pest & Disease Boards. As a result, home orchardists are often discouraged from planting fruit trees on their property unless they are willing and able to protect these fruit trees from insect pests each and every year. The insect pests of chief concern to most County Horticultural Boards are codling moth, apple maggot, western cherry fruit fly, pear psylla, and San Jose scale.

Pesticides are discussed generally and specifically in the following pest sections. Because labels change you must always read a currently registered label to determine whether that product is registered for use on a specific crop.

Codling Moth

If you grow apples, codling moth will eventually find them and infest the fruit. The larva of this moth is known as the worm in the apple. It is whitish to pinkish in color with a brown head capsule and is ½- to ¾-inch long when mature. Codling moth larvae will also infest crabapples, pears, hawthorns, quince, and sometimes prunes and walnuts. Codling moth is very difficult for home orchardists to control. Satisfactory control is often achieved through the use of several strategies and often necessitates insecticides.

Codling Moth Life Cycle

- There are at least two generations of codling moth each season in Washington. In warmer regions, there can be a partial third generation.
- Codling moth overwinters as mature larvae in cocoons hidden under tree bark or amongst leaf litter and debris at the base of host trees. The mature larvae will pupate in the cocoon in early spring.
- Adult moths emerge from the cocoon in late April to June and the initial moth flight coincides with full bloom of Red Delicious apples. Moths mate almost immediately and egg-laying can start within 2 to 3 days. Eggs are laid singly on leaves adjacent to fruit or on the fruit itself.
- Eggs usually take one to two weeks to hatch into larvae. These larvae immediately enter through the skin and bore to the core of the fruit.
- Larvae can take three to four weeks to complete their development within the fruit.
- Mature larvae exit fruit and drop to the ground on silken

threads. They will seek debris or crevices in tree bark to pupate.

- A second generation of moths will begin emerging and laying in early July to mid-August.
- Second generation larvae can be found infesting fruit from mid-July to September.
- A partial third generation of moths may emerge in mid- to late August. Third generation larvae rarely complete their development, but can cause severe damage to late maturing varieties of apple.

IPM Strategies for Codling Moth

- Plant early-maturing varieties of apples.
- Properly train and prune apple trees to keep the canopy open for pesticide penetration and maintain tree height at 12- to 15-feet tall or as tall as your sprayer can reach.
- Properly thin the fruit on your trees to one fruit per cluster.
- Throughout the growing season, routinely scout your tree for, and remove, any "wormy" fruit. Look for fruit with entry holes that may have a granular, brownish **frass** mound extruding from the hole. Do not just drop wormy fruit on the ground—remove fruit from yard or destroy fruit to prevent larvae from completing their development.
- In early to mid-August, encircle or band the base of the fruit tree with a 4-inch-wide strip of corrugated cardboard. Tightly secure the strip to the tree. Mature codling moth larvae migrating up and down the trunk will cocoon and pupate in these strips. After fruit harvest, remove and destroy these strips. Cardboard strips can also be placed around the base by mid-June, but be sure to remove strips by mid-July.
- "Bag" fruit when fruit are between ½- to 1-inch in diameter. Use standard paper bags or special apple bags available from orchard supply stores to enclose fruit. Cut a small slit in the bottom of bag and slide over fruit. Tightly close both ends of the bag. This strategy can prevent moths from laying eggs on, and prevent any newly hatched larvae from reaching, fruit. Remove those bags about two weeks before anticipated harvest to allow desired color development.
- Insect sex pheromone lures specific to codling moth are available to certified pesticide applicators. Applicators place 2 to 4 traps around the perimeter of the backyard tree at least 25 feet away from the tree. These traps must be placed in the backyard by early April, well in advance of tree bloom. Traps are checked weekly to remove trapped moths, to check trap base for adhesiveness and replace base when adhesiveness is lost, and to replace the lures periodically (usually every 4 weeks). Note that

pheromone lures trap only male moths and this approach works best in backyard trees well isolated from other tree hosts. Commercial attract-and-kill formulations that use pheromones plus insecticides can also help reduce male codling moth populations.

- Set blacklight and molasses traps to intercept and reduce the number of male and female moths that invade a backyard tree.
- Use horticultural oils to reduce codling moth populations by suffocating the moth eggs. Oil applications must be timed to coincide with the presence of codling moth eggs and are most effective early in the season against the first generation of codling moth. It may require 3 to 5 applications spaced 7 to 10 days apart to smother most of the eggs laid each moth generation. Second generation sprays will start in mid-July. Note: prolonged use of the horticultural oils over several seasons can adversely affect fruit quality and tree health.
- Apply kaolin clay (such as Surround at Home, a unique clay product that may deter codling moth egg-laying behavior by acting like a repellant). A thin film of clay must cover the surface of leaves and fruit by the time the moth egg-laying starts. Applications must begin within a week of petal fall and continue every 10 to 14 days. It may take 2 to 4 applications per generation to adequately protect your fruit. Kaolin clay will wash from the fruit, so reapplication after each rain episode may be necessary.
- Use insecticide cover sprays. A limited number of insecticides including carbaryl (in mixtures) and spinosad are available for home orchardists to use against codling moth. These insecticides must be directed towards the newly-hatched larvae before they bore into the fruit. For the first generation, apply the first cover spray about 21 days after petal fall. Depending on the insecticide selected (refer to pesticide label), a second cover spray will be required 10 to 14 days later. For the second generation, begin cover sprays in mid-July and repeat every 10 to 14 days (depending on label) until fruit harvest. Be sure to mind the preharvest interval stated on the pesticide label. It may require 2 to 4 applications per generation to control codling moth.
- Pheromone traps (commercial use only) and degree-day models can be used to monitor and better time pesticide applications.

Apple Maggot

Apple maggot is a serious pest of apples, crabapples, and hawthorns on the west side of Washington State. Apple maggot appears to be spreading to several counties on the east side as well. The apple maggot larvae are white, cylindrical, headless, and legless and ¼- to 3/8-inches long when mature. It is important to distinguish apple maggot damage to apple from codling moth damage. Apple maggots will tunnel in the flesh of the apple often just below the surface while codling moth larvae tunnel to the core of the apple. Often apple maggot damage is associated with a soft rot while codling moth damage is associated with granular frass that lines the tunnels and extrudes from entrance holes. The adult apple maggot is a ¼-inch fly with a distinctive wing pattern. Apple maggot management often necessitates late-season applications of pesticide products.

Apple Maggot Life Cycle

- There is one generation of apple maggot per season throughout the Pacific Northwest.
- Apple maggot overwinters as pupae in the soil beneath host trees. Some pupae may remain in the soil for two consecutive winters.
- Adult flies emerge from the soil in July and may be active in the tree canopy as late as September. Adult flies must feed for one to two weeks before they mate and lay eggs on host fruits.
- Eggs are laid just underneath the surface of the apple. Some dimpling of the fruit may be visible. After hatching, the maggots may take 14 to 30 days to mature.
- Apples infested with maggots drop from the tree, or the mature maggots can bore out of the apple and drop to the ground where they enter the soil to pupate.

IPM Strategies for Apple Maggot

- Properly train and prune apple trees to keep the canopy open for pesticide penetration and maintain tree height between 12- and 15-feet tall (use dwarfing rootstocks) or as tall as your sprayer can reach.
- From mid-July to harvest, routinely scout your tree for, and remove, any fruit infested with apple maggot. Pay close attention to the earlier maturing apple varieties, as this fruit seems to be particularly attractive to apple maggot. Again, do not just drop infested fruit on the ground as maggots will complete their development and pupate in the soil. This fruit must be removed from the orchard or destroyed. Place infested fruit in a black or transparent plastic bag, close the bag, and leave it in the direct sunlight for a couple days to kill maggots.
- Use insect traps. There are several commercially available insect traps developed specifically for mass trapping of apple maggot. These traps may come in the form of yellow, sticky, rectangular cards or as red apple-shaped spheres coated with a sticky insect glue. The traps come with an

ammonium lure that makes it even more attractive to female and male apple maggots. Traps should be in place by late June/early July. Ideally, these traps can be placed in trees adjacent host trees or in the host tree itself (the apple maggot is actually a poor flier). Check the traps every week to make sure it retains its sticky surface.

- Apply kaolin clay (Surround at Home). This clay product has been shown to be very effective in preventing egg-laying behavior by apple maggot. Applications should begin early to mid-July and continue on a 10- to 14-day interval until harvest. It may take 3 to 4 applications to adequately protect your fruit. Kaolin clay will wash from the fruit, so reapplication after each rain episode may be necessary.
- Use insecticide cover sprays. Apple maggot is susceptible to several insecticides available to homeowners including malathion (in a mixture), several pyrethroids, and spinosad. These insecticides must be directed towards the adult fly, but are useless against the immature insect stages in the apple. Begin cover sprays in mid-July and repeat based on label recommendations (every 7 to 10 days for spinosad; every 10 to 14 days for malathion) until fruit harvest. Be sure to mind the preharvest interval stated on the pesticide label. It may require 2 to 4 applications to control apple maggot.
- The yellow sticky card with an ammonium lure is a good tool to help home orchardists reduce their use of insecticides. Hang these traps by late June and check the traps every other day for apple maggot flies. Apply a registered insecticide within one week of your capture of the first apple maggot fly. For home orchardists on the east side of Washington, or for well-isolated fruit trees on the west side, no-trap catching all season long can save on excessive pesticide applications.
- There are a number of molasses-like baits that can be used to enhance fly uptake of insecticides. There is at least one fly bait formulated with spinosad as an active ingredient available for use by **certified pesticide applicators** on backyard fruit and nut trees. These baits are particularly useful in backyard trees that exceed 20 feet in height, as good spray coverage is not critical (the bait attracts flies to the insecticide).

Western Cherry Fruit Fly

Cherry fruit flies are serious pests of sweet and tart cherries throughout North America. The adult fly is about 1/5-inch long with distinctive wing patterns. The fly’s larvae are creamy-white, legless maggots lacking a distinct head capsule and found tunneling in the flesh of the cherry. Since cherry fruit fly is such a poor flier, unsprayed trees may remain uninfested for many years.

But once cherry fruit fly finds your backyard tree, management necessitates multiple applications of pesticides, according to label directions, throughout the cherry season from the point when cherries start to turn from green to yellow color until the pre-harvest interval stated on the product label. If left uncontrolled, cherry fruit fly will eventually infest all the fruit on a tree.

Cherry Fruit Fly Life Cycle

- Cherry fruit fly has only one generation per season here in the Pacific Northwest.
- This insect overwinters as a pupa in the soil under the host tree. Some pupae may remain in the soil for two or even three consecutive winters.
- Adult flies start to emerge from the soil in mid-May through July. Peak emergence of adult flies often coincides with harvest of Bing cherries.
- Adults can live from two weeks to one month. One week after emergence from the soil, these flies will mate and, roughly one week later, the female begins to lay eggs and may continue laying more than 100 eggs over a three-week period.
- Eggs are laid in the cherry fruit just below the skin. Some dimpling of the fruit may be visible.
- Eggs will hatch in about one week and the maggots will bore to the center of the fruit and feed around the pit. At this stage, feeding damage can be difficult to detect without cutting open individual fruits. Maggots can complete their development in 10 to 21 days. When fully developed, maggots will bore their way out of the cherry, drop to the ground, and burrow into the soil to pupate.

IPM Strategies for Cherry Fruit Flies

- Insect traps. These traps come in the form of yellow, sticky, rectangular cards or as red spheres coated with a sticky insect glue. The traps should come with an ammonium lure that make them even more attractive to female and male fruit flies. Traps should be in place by early May. Ideally, these traps can be placed in a tree adjacent to the host trees or in the host tree itself. Check the traps every week to make sure it retains its sticky surface. This strategy can reduce fly numbers, but will not provide satisfactory control on its own.
- Complete harvest. At cherry harvest, be sure all cherries are removed from the tree. Try not to leave any stray cherries on the tree that serve as hosts for next year’s cherry fruit flies.
- Insecticide cover sprays. Cherry fruit flies are susceptible to malathion and spinosad insecticides that are available to home orchardists. These insecticides must be directed towards the adult fly, but are useless against the immature

insect stages shielded inside the cherry. Begin cover sprays in mid-May or when cherry fruit begins to show a little yellow or straw color. Repeat according to label directions (every 7 to 10 days for spinosad and every 14 days for malathion) until fruit is no longer left on the tree. Be sure to mind the preharvest interval stated on the pesticide label. It may require several applications to protect your fruit from cherry fruit fly.

- Adhesive traps. The yellow sticky card with an ammonium lure is a good tool to help home orchardists reduce their use of insecticides. Hang these traps by early May and check the traps every other day for cherry fruit flies. Apply a registered insecticide within one week of your capture of the first cherry fruit fly.
- Baits. There are a number of molasses-like baits that can be used to enhance fly uptake of insecticides. There is at least one fly bait formulated with spinosad as an active ingredient available for use by certified pesticide applicators on backyard fruit and nut trees. These baits are particularly useful in backyard trees that exceed 20 feet in height, as good spray coverage is not critical (the bait attracts flies to the insecticide).

Pear Psylla

Pear psylla is considered a secondary pest in pears since it does not feed directly on the fruit. However, psylla nymphs feed on the phloem of the pear tree and produce copious amounts of honeydew. This sticky, wet honeydew can be a nuisance to home orchardists and can cause russet or surface marking of the pear fruit. When they first hatch from tiny, rice-shaped, yellowish eggs, the nymphs are cylindrical and creamy white. As they mature they grow larger, more oval, and flatter with dark green to brown color. Nymph size varies from 0.02 to 0.09 inches. All nymph stages have distinctive red eyes and are associated with pools or globs of honeydew. Pear psylla can be best managed early in the season with “soft” insecticides that can conserve biocontrol agents later in the season.

Pear Psylla Life Cycle

- Pear psylla has three to four generations per season in the Pacific Northwest.
- This insect has a winter-form winged adult that is dark gray and about 0.1 inch long. The adult is active as pear buds start to open in the spring and egg-laying activity begins immediately.
- In the early spring, eggs are laid at the base of buds and in crevices on small twigs. Later in the spring and summer, eggs are often laid along the midrib on the underside of pear leaves.

- Nymphs can complete their development in about a month and a half. As the season progresses, there will be overlap in the generations and all stages can be found at once by mid-June.
- Summer-form winged adults tend to be light brown to yellowish in color and often jump and fly away when approached.

IPM Strategies for Pear Psylla

- Prune trees moderately each year to avoid excessive vegetative growth. By the end of June, pull all water sprouts at the base of the tree by hand and prune out any upright shoots from center of pear trees.
- Encourage biological control of pear psylla by a number of predacious insects including ladybeetles, lacewings, and several predacious bugs. There are also a couple of wasp species that will parasitize psylla nymphs.
- Horticultural oil applications early in the season will discourage adult psylla from laying eggs. The best timing is in the dormant and the delayed-dormant period before tree buds start showing pink (Figure 3). Apply to the entire tree especially small limbs and shoots.
- Apply kaolin clay (Surround at Home). This clay product has been shown to be very effective in preventing egg-laying behavior by pear psylla early in the season. Apply two to three applications as necessary to cover new growth between dormant, delayed-dormant, and first bloom.
- Use in-season cover sprays. Azadiractin or neem oil, insecticidal soaps, and kaolin clay can be used as in-season sprays on foliage and fruit to control pear psylla. Insecticidal soaps may also help wash honeydew off the fruit. Apply as needed or when lower pear shoots are sticky to touch.

San Jose Scale

San Jose scale is a secondary pest of most fruit and nut trees as well as many ornamental trees and shrubs. It can be most destructive on apples and cherries, especially on large older trees, but young, unsprayed backyard trees can be vulnerable. Adults and older nymphs are immobile and protected under oval, brittle wax scales that are white to gray with a nipple-like bulge. These “barnacle-like” organisms attach themselves to first-year wood and fruit and feed on plant juices. Red spots may form on wood and on fruit. San Jose scale feeding can kill twigs and limbs as well as cause cosmetic damage to the fruit. The best means of controlling San Jose scale is to manage it early in the season, preferably during the dormant and delayed-dormant periods (Figure 3). There are other scale insects that may plague fruit and nut trees, and their management options are similar.

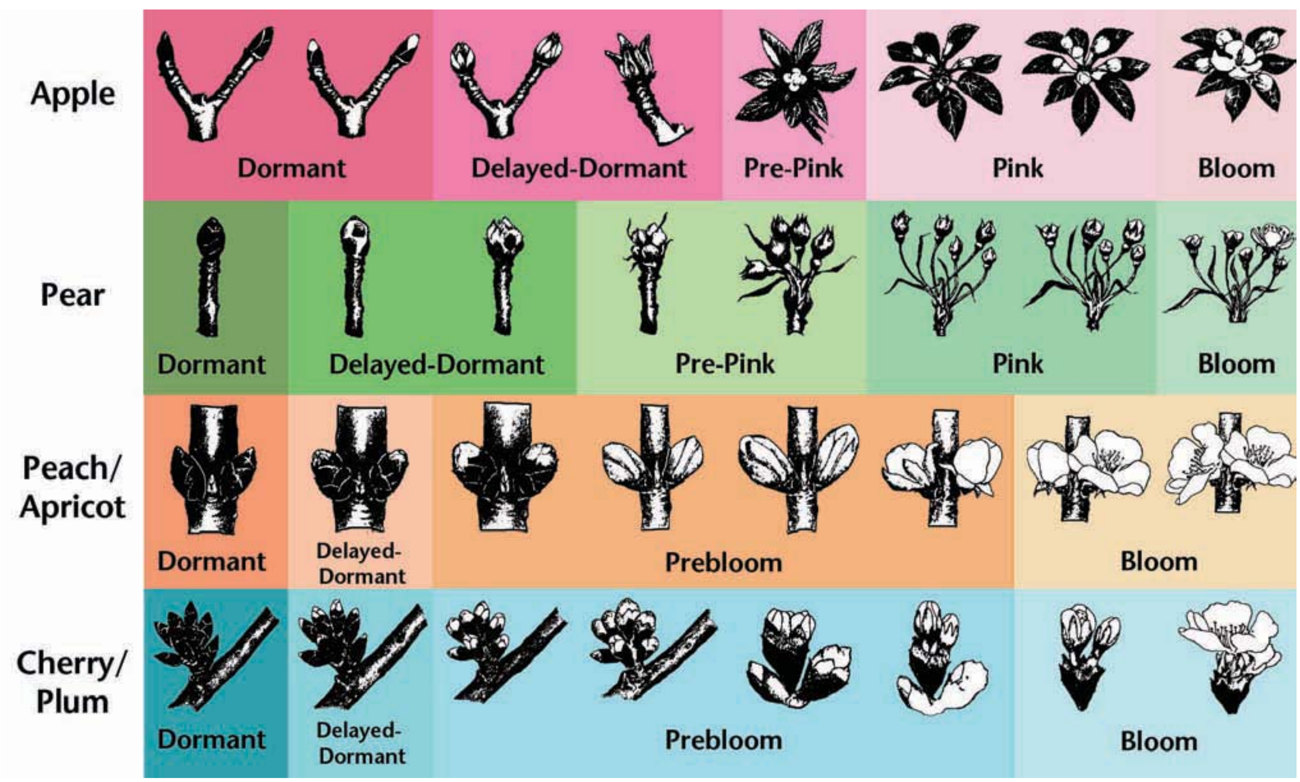
San Jose Scale Life Cycle

- San Jose scale has two generations each year in the Pacific Northwest.
- This pest overwinters as nymphs underneath blackened scales. During the relatively cold winter seasons, only the mature nymphs will survive to spring.
- Nymphs mature in the early spring and emerge as adults from mid-April to May. Adult females remain hidden beneath their scale while adult males develop wings and fly in search of adult females to mate.
- Mated females will give birth to several hundred live nymphs from mid-June through July. These nymphs, also known as "crawlers," will move until they find a suitable feeding site, insert their **stylet**, and immediately produce a waxy scale. The second generation of crawlers will be active from mid-August through October.

IPM Strategies for San Jose Scale

- Avoid planting fruit and nut trees next to older trees or shrubs already infested with San Jose scale.
- There is a fair amount of biological control of scale insects by parasitic wasps, but this control is not enough to keep

Figure 3.—Bud development chart.



scale in check. Conserve these parasites by avoiding summer sprays of insecticides directed towards scales—these sprays are rarely effective on scale anyway.

- Horticultural oil applications early in the season will smother and kill the immobile scale stages. The best timing is in the dormant and the delayed-dormant periods before tree buds start showing pink. Good spray coverage of the first year wood in the small limbs and twigs is critical.
- Use in-season cover sprays such as Azadiractin or neem oil, insecticidal soaps, horticultural oils, and malathion, applied to coincide with the activity of the crawler stage of the nymph to reduce scale population. This strategy works best on the first generation of crawlers.
- Home orchardists can improve the timing of the in-season cover sprays by monitoring the activity of crawlers with dark colored, double-sided sticky tape. The nearly microscopic crawlers are lemon yellow in color and are visible against the dark background. Time in-season spray applications to coincide with crawler activity.

Leafrollers

Most fruit and nut trees have several species of leafroller caterpillars that can become secondary pests. Typically, leafrollers roll and web leaves together for shelter. The caterpillars usually feed on leaf surfaces, but they will sometimes web leaves onto the surface of a fruit and feed directly on the fruit. This damage usually causes superficial fruit scarring; but if the damage is early in the season, scarring can be deep and cause the fruit to be deformed. Leafrollers can be distinguished from other foliar-feeding caterpillars by their behavior when disturbed in their shelter. They will thrash violently, move backwards, and often drop from the leaf suspended on a silken thread.

Leafroller Life Cycles

- Some leafroller species have one generation per season like the fruittree leafroller, while other leafroller species have two generations per season like the obliquebanded leafroller.
- The fruittree leafroller overwinters as egg masses on twigs and branches of the fruit tree. In spring, these eggs will hatch as the leaf and fruit buds begin to open up, through petal fall. These larvae feed for about four to six weeks. They pupate in their webbed leaf shelters from late May to early June. Adult moths emerge mid-June and are active until late July. Peak flight period is in late June. Egg-laying activity occurs primarily during July.
- The obliquebanded leafroller overwinters as late **instar** larvae in silken chambers hidden along cracks and crevices of woody limbs and bark. As a result, these larvae are

active in the spring as fruit buds begin to open. They will bore into opening buds and web together young leaf and fruit clusters, feeding on these tissues. Larvae mature in mid- to late May and pupate in webbed leaf shelters. First adult moths begin to fly in late May to early June. Peak flight activity is around mid-June. During June, eggs are laid in light green, fish scale-like masses on leaves of the host plant and are difficult to find.

- The first generation larvae are active and feeding on leaves and fruit during July and early August. They pupate in silken leaf shelters and adult moths will start emerging early July through September and even into October. Most egg masses will be laid during the month of August and larval feeding activity will continue through September and October until cold temperatures and leaf drop forces larvae to find overwintering areas.

IPM Strategies for Leafrollers

- Horticultural oil applications early in the season will smother and kill egg masses and young larvae of some leafroller species. The best timing is in the dormant and the delayed-dormant period before tree buds start showing pink. Good spray coverage of the small limbs and twigs is critical.
- Horticultural oil applications during the season can control leafrollers that lay eggs during the late spring and summer, but good spray coverage of the tree canopy becomes more difficult to achieve.
- Early season thinning of fruit clusters to a single fruit can discourage leafroller feeding on fruit surfaces.
- There are a number of wasp species that will parasitize leafrollers. Using insecticides sparingly during the growing season can conserve these wasps. Researchers have found that growing wild roses or strawberries in the vicinity of backyard fruit trees can encourage overwintering populations of these wasps.
- Scouting the canopy for, and removing, the rolled leaves that contain leafroller larvae and pupae can reduce populations especially in young, non-bearing fruit trees.
- In-season applications of products containing the natural insecticide *Bacillus thuringiensis* ("Bt") can provide control of leafrollers. Ideally, an application during bloom to petal fall during warm, dry weather can reduce leafroller larvae populations. Products containing Bt are very selective and will only disrupt populations of leafrollers and other leaf-feeding caterpillar larvae in the backyard tree.
- Other in-season applications of insecticides, spinosad, malathion, and carbaryl (in mixtures), can be used to control leafrollers. Use only as needed when tree scouting reveals high populations of larvae and their shelters.

Spinosad is the preferred insecticide as it is the least disruptive to other insect populations.

Walnut Husk Fly

The most troublesome insect pest of walnuts in the Pacific Northwest is the walnut husk fly. The adult fly is about ¼-inch-long with a tawny brown body, a yellow spot on its back, and one pair of wings with a conspicuous wing-banding pattern. The greatest impact comes from the immature stages: the maggots that infest and feed on the husk of walnuts. These white, cream-colored maggots are legless, lack a head capsule, and can reach a size of about ¼ inch. Their feeding damage to the husk will stain the walnut shell and kernel, reducing nut quality.

Walnut Husk Fly Life Cycle

- There is one generation of walnut husk fly per season throughout the Pacific Northwest.
- Walnut husk fly overwinters as pupae in the soil beneath host trees. Some pupae may remain in the soil for two consecutive winters.
- Adult flies emerge from the soil in late July and may be active in the tree canopy as late as September.
- Eggs are laid just underneath the surface of the walnut husk. The larvae hatch in five to seven days and begin feeding on the husk, turning it into a blackened slime mess.
- It takes three to five weeks for the larvae to complete their development, which is usually in early October. The mature larvae tunnel to the outside of the husk and drop to the ground, where they enter the soil and overwinter as pupae.

IPM Strategies for Walnut Husk Fly

- Periodically scout for, remove, and destroy any infested nuts as soon as they drop from the tree.
- In-season applications of pesticides (spinosad) can be applied to the walnut canopy to control the adult fly before egg-laying activities begin. Typically this occurs from late July to mid-August. A second application may be necessary 3 to 4 weeks later.
- Yellow sticky cards with ammonium lures can help home orchardists better time, and even reduce, their use of insecticides. Hang these traps in the host trees in July and periodically (2 to 3 times a week) check the trap for adult fly catch. Apply the first spray within 10 days of capturing multiple husk flies over a 3-day period.
- There are a number of molasses-like baits that can be used to enhance fly uptake of insecticides. There is at least one fly bait formulated with spinosad as an active ingredient

available for use by certified pesticide applicators on backyard fruit and nut trees. These baits are particularly useful in backyard trees that exceed 20 feet in height, as good spray coverage is not critical (the bait attracts flies to the insecticide).

Spider Mites

Mature spider mites are very small (1/50-inch), eight-legged creatures that are just visible with the naked eye. They spin fine webs, often along the mid-rib of leaves, on a wide range of host plants including fruit and nut trees, vegetable crops, houseplants, and ornamental plants. Mites can become secondary pests at high populations because they feed on and suck out the cell contents (including the green pigment chlorophyll) of plant cells, causing a yellow stippling or bronzing of leaf surfaces. In pears, this damage can lead to transpiration burn where the leaves may develop necrotic areas and drop from the tree. Excessive feeding on other trees can cause leaf yellowing and premature leaf drop.

Spider Mite Life Cycles

- There are several species of spider mites in the Pacific Northwest and most of them can complete multiple generation each growing season. During the warmer periods of summer, these mites can complete a life cycle in as little as 10 days.
- Some mite species, such as the two-spotted spider mite, overwinter as mature female adults in the duff and weeds at the base of host trees. Other mite species, such as the European red mite, overwinter as eggs laid in the cracks and crevices of tree bark, small branches, and twigs.
- Spider mites go through egg, larvae, and adult life stages. Due to a short life cycle, all stages can be present in the backyard tree during the growing season.

IPM Strategies for Spider Mites

- Encourage the natural predators of spider mites such as predatory mites, lacewings, ladybeetles, and many other insect predators. Normally, these predators keep spider mites in check and no further control by the home orchardist is necessary. Often, spider mite outbreaks are triggered by in-season applications of certain insecticides that kill off spider mite predators.
- Maintain a tree in proper health, and avoid water stress especially during the drier periods in the summer. Excess nitrogen applications can spark spider mite outbreaks. Dust accumulation on trees along dirt roads can also spark spider mite outbreaks.

- Proper control of broadleaf weeds such as mallow, bindweed, knotweed, and white clover in the area around a backyard tree can reduce spider mite populations by reducing alternate host plants and limiting mite shelters and movement.
- Periodically check your trees for the abundance of spider mites, their associated webs, and feeding damage. Remember their short life cycle and that populations can flare within a week during hot summer weather.
- In-season applications of horticultural oils and insecticidal soaps can reduce spider mite populations. Multiple applications may be necessary.
- Spider mites can even be washed from the tree with a strong stream of water.
- Horticultural oil applications during dormant and delayed-dormant seasons can smother and kill those mites that overwinter as eggs in the fruit tree canopy.
- Horticultural oil applications during the late spring and summer can reduce the survival rates of mite eggs and immature mites, but good spray coverage of the tree canopy becomes more difficult to achieve. Avoid applying horticultural oil to trees that show signs of water stress or during excessively hot weather.

Aphids

A number of aphid species can become pests in nut and fruit trees. In apples, there is the rosy apple aphid and the green apple aphid; in cherries, there is the black cherry aphid; in peaches and nectarines, the green peach aphid; and in walnuts, the walnut aphid. All aphids, both as immature forms and adults, suck plant juices from their host trees and deposit copious amounts of sticky honeydew. Aphids often live in colonies in leaves that curl tightly about them. In addition to honeydew and curled leaves, high populations of aphids can cause fruit deformation, branch death, and premature leaf drop.

Aphid Life Cycles

- In general, most aphids found in fruit trees overwinter as eggs on twigs and branches. Some species can overwinter as adults on weed hosts especially during mild winters.
- Most aphid species alternate host species and will leave their overwintering tree host for a summer host in late spring/early summer.
- In the spring, female aphids reproduce asexually, giving live birth to immature clones of themselves; therefore, aphid populations can build up very quickly in the spring.

- Most fruit aphids will develop winged forms in the late spring and early summer that will leave the tree host in search of a summer host of a different plant species.
- In the autumn, male and female aphids will return to their tree host, undergo sexual reproduction, and the female aphids will lay eggs that overwinter in these trees.

IPM Strategies for Aphids

- Encourage the many natural enemies of aphids, including wasp parasites, lacewings, ladybeetles, and many other insect predators. Normally, these parasites and predators keep aphids in check and no further control by the home orchardist is necessary. Occasionally, aphid populations can reach damaging levels early in the spring before their natural enemies can attack them on their overwintering hosts.
- Maintain your fruit tree in proper health, and avoid practices that can lead to excessive vegetative growth like over-pruning, over-fertilizing, or over-watering.
- Proper control of broadleaf weeds like mallow, bindweed, knotweed, and white clover in the area around a backyard tree can reduce spider mite populations.
- Horticultural oil applications during dormant and delayed-dormant seasons can smother and kill aphid eggs and newly emerged immature forms in the fruit tree canopy.
- In-season applications of insecticides can also reduce aphid populations. The best time to apply azadirachtin (neem oil), insecticidal soaps, and malathion is just before tree bloom and before aphid damage causes leaves to become severely curled, enclosing and protecting the aphid colonies from contact with pesticides. In-season application of the fungal insecticide *Beauveria bassiana* is an effective control of aphids and other soft-bodied insect species.
- Aphids can even be washed from the tree with a strong stream of water.

Disease Management

The key to disease prevention is reducing the duration and amount of leaf moisture in the canopy of your home orchard.

Eastern Washington may be considered America's fruitbasket since it leads the country in the production of apples, pears, and sweet cherries. One key factor that makes this status possible is the dry climate and abundance of sunshine that hampers the spread of plant diseases. It is necessary for residents in western Washington to be much more vigilant and proactive in disease management in tree fruits. Nevertheless, the basic fundamentals of disease management on both sides of the state remain the same.

The key to disease prevention is reducing the duration and amount of leaf moisture in the **canopy** of your home orchard.

Fruit trees should be located in areas of the home landscape that receive plenty of sun and adequate air circulation. Avoid planting fruit trees next to homes, hedgerows, and fences that not only restrict air movement, but also provide excess shade and inhibit quick leaf drying conditions. Proper pruning and training reduces the density of the tree canopy allowing for better air circulation, spray, and sunlight penetration into your tree. Proper weed management under your tree will also enhance canopy-drying conditions. Avoid irrigation systems that direct water into or over the fruit tree canopy.

Home orchardists need to scout their fruit trees throughout the growing season for signs and symptoms of diseased tree tissues. Most diseases in home orchards can be controlled through orchard sanitation or prompt pruning and destroying of infected tree tissues to prevent the spread of the pathogen throughout the tree. Signs and symptoms of diseased tissues include branches with wilting, dying or dead leaves; tree limbs with visible cankers; and rotting fruit in the tree or on the ground beneath the tree.

Keep in mind that a healthy tree is better able to resist plant diseases than a stressed tree. Excessive or inadequate watering practices can stress a tree and leave it susceptible to soil-borne and air-borne pathogens. Insect damage, wind, hail, or mechanical damage to the trunk or branches, or even pruning in the growing season during wet conditions can provide pathogens an opportunity to circumvent the natural bark barrier and infect the tree.

Powdery Mildews

Different species of fungi cause powdery mildew in apples, cherries, and soft fruits. Often the fungus overwinters in infected buds and vigorous new shoots of various hosts. Early in the season, the fungus spreads and infects new tissues especially leaves and young vigorous shoots. Initially, leaves or shoots are covered with a white, dusty or powdery coating of fungal mycelium and spores. These affected tissues will become curled, distorted, and brittle, and may die. Prune out and destroy these infected or newly infected tissues early in the spring or as soon as you see them. Later in the season, secondary spread of powdery mildew can infect more leaves, twigs, and fruit. Infected fruit will often develop a netlike russet on the surface of the fruit.

Powdery mildew control must start early in the growing season to be effective. Home orchardists can use sulfur fungicides to reduce powdery mildew. These fungicides should be applied before bloom and continuing every 7 to 10 days until the trees are fully leafed out. Fruit varieties vary in their susceptibility to powdery mildew, and relatively resistant varieties of apples and cherries exist. Powdery mildew is often the biggest disease problem faced by home orchardists on the east side of the state.

Apple & Pear Scab

Apple and pear scab are caused by different fungi, but their symptoms and management are similar. Apple scab is considered one of the most serious diseases of fruit on the west side of the state. It is less common on the east side. The fungus overwinters on dead apple leaves and fruit on the ground. Raking up fallen leaves and fruit in the autumn can be helpful in managing scabs. Early in the spring, rainfall initiates spore formation and air currents can carry these spores to young, developing tissues. Apple and pear scab is worse during wet springs. Avoid irrigation that wets the tree canopy especially when warm spring temperatures exceed 60°F. Black, sooty lesions form on infected leaves and flowers in the early spring. After petal fall, fruit can become infected, resulting in superficial pinpoint scars, scabby lesions, and fruit distortion.

There are some fungicides available to home orchardists for scab control including lime sulfurs, wettable sulfurs, and captan (in mixtures). The control sprays are applied at the following stages: prepink, pink, calyx, and first cover (when the leaves are out). The primary scab infection period typically ends by June 1. In dryer climates, the scab control program can be minimized.

Fire Blight

Fire blight is a serious bacterial disease of apples and pears and even affects many of the newer varieties of apples. The bacterium appears to overwinter in tree cankers caused by infections during the previous year. When possible, scouting for, and removing, all tree cankers during the dormant season is the best means to keep this disease from spreading. Early in the spring, fire blight bacteria will ooze from these cankers and can be carried by blowing rain or insects to adjacent trees or new tissues on the same tree. The environmental conditions that promote fire blight are warm, wet weather during the bloom period, and so this disease is much more prominent on the west side of the state.

To infect a new tree, the bacteria must enter the tree through fruit blossoms or fresh wounds that can be caused by wind damage to young shoots. Infected apples tissues will develop a “watersoaked” appearance, then wilt, turn brown, and die. Infected pear tissue will appear to melt and tissues will turn black as if scorched by fire. Currently, there are no effective fungicides available to home orchardists for treating trees infected with fire blight.

If weather conditions are wet and warm during flower bloom, home orchardists should routinely inspect their trees for symptoms of tree infection. If an infection occurs in your apple or pear trees, the best thing to do is to cut out the infected tissue as soon as possible—at least a foot back from the visible signs of infection. Be sure to sterilize your pruning shears with a registered household disinfectant such as Lysol® spray or a chlorine solution between cuts, to avoid spreading the bacteria. Apple varieties and apple rootstocks vary considerably in their resistance to fire blight. Fire blight bacteria can quickly circulate through the tissues of young, vigorous non-bearing apple trees, killing the apple rootstock far in advance of symptom development in the tree itself.

Coryneum Blight or "Shot Hole"

This fungus affects peaches, nectarines, apricots and sometimes cherries. Coryneum blight overwinters in infected tree buds and twig lesions and can be spread by splashing water during warm weather in the early spring months. Bud and twig infections appear as small purplish spots that rupture, releasing gum and fungal spores. Infected leaves develop small, round, tan to purplish spots that will drop from the leaf when tree conditions dry out (hence the name "shot hole"). Infected fruit can develop small red spots and exude gummy material. Fruit buds can be killed off, while large cankers can form and girdle older fruiting wood. To control Coryneum blight, copper sprays should be applied in the fall at 50% leaf drop, and again at shuck fall in the spring. (The **shuck** is the papery sheath surrounding the newly developing fruit. As the new fruit expands, the shuck first splits, then falls.)

Peach Leaf Curl

This is a fungus disease that affects peaches and nectarines during wet springs and is prevalent on the west side of the state. Fungal spores overwinter on tree bark and twigs, and infection occurs just as the leaf buds begin to swell in the early spring. Later in the spring, infected leaves turn yellow and reddish, leathery, puckered, and tightly curled. Entire shoots can become affected and fruit can develop reddish wart-like growths. Two applications of copper-based fungicide sprays are recommended for peach leaf curl control; one application at 50% leaf fall in October, and another application at the delayed-dormant stage in February.

Bacterial Canker

While bacterial canker affects all stone fruits, it is most serious on sweet cherries. The most frequently encountered symptoms are branch and trunk cankers and excessive gum exudates. In the early spring, infected buds will fail to open, then turn brown and exude gum. Bacterial cankers can grow and girdle entire limbs and young trees. Bacterial canker is spread by wind and water, and in the late fall may infect trees through leaf scars. During hot summer weather, the bacteria dies back and the cankers do not resume growth until cool weather returns. Home orchardists should prune out infected and visibly affected branches in August when the bacteria are less likely to be spread through pruning tools and wounds. To control bacterial canker, copper fungicide sprays are recommended in October at 50% leaf fall, and again in January.

Vertebrate Pests

Birds

A number of bird species like starlings, robins, and several song birds can become pestiferous when they feed directly on ripe, or nearly ripe, tree fruit. Visual and audio scare tactics (like mylar tape, shiny pie tins, ceramic predatory birds, distressed bird calls) or bird netting draped over fruit trees are the only methods available to home orchardists to suppress bird damage. None of these methods alone will work for extended periods of time. It is best to alternate two or more methods.

Rodents

Voles (field or meadow mice) and rabbits will feed on the bark at the base of fruit and nut trees during the winter months and can sometimes girdle and kill young trees. Gophers can gnaw and feed on the root systems of fruit and nut trees to the point of removing the entire root system. The best management is to remove as much of the vertebrate's habitat as possible. Weed management at the base of the tree and throughout the yard can reduce vole populations. Remove mulches or grass thatches from the base of fruit trees particularly in late fall and during the winter. Home orchardists can disrupt rodent habitat by tilling the soil around the tree periodically to destroy their tunnels. Home orchardists can also place a cardboard or plastic mesh tree collar around the trunk to protect the young trees from the feeding damage and girdling caused by voles and rabbits. Be sure to bury the collar a couple inches below the ground surface to discourage voles from tunneling under the collar. In Washington, the use of all body-gripping traps is illegal, although mousetraps are exempted. When baited with fruit or peanut butter, mousetraps set in underground tunnels can trap voles. There are some gopher baits registered for home use. They must be applied according to label directions to be effective and to reduce accidental poisonings of other non-target vertebrates.

Deer

Deer are herbivores and naturally feed on the succulent vegetative growth on fruit and nut trees. They can completely defoliate young trees in the winter and early spring. Thus, protection is important for trees that are adjacent to wooded lots that harbor deer. In these situations, approved deer fencing is the best method to exclude deer from your trees. Erecting a wire cage around individual trees also works to prevent deer damage. Hanging soap, human hair, animal scents, or other deer repellents can help prevent damage for a short time. It is best to utilize several methods at the same time.

Harvest & Handling

Nursery catalogs, Extension publications, and other sources give a general idea about when given varieties ripen. However, ripening times may vary from year to year depending on the weather. Apples with codling moth damage drop about 1 to 1 ½ weeks before the crop is ripe.

The best and most time-tested method of judging when to pick fruit is the taste method. When enough starch has been converted to sugar and the flavor is developed, the fruit is ready to eat. Remember, fruit continues to ripen in cold storage, so pick fruit before it is ripe if you intend to store it.

Fruit changes color as it ripens. The *base color*, or ground color, is the color underneath the red striping or blush of peaches, apples, pears, and cherries. In most fruits, the fruit is ripening when the ground color turns from greenish to yellowish. The surface color may develop before the fruit actually is mature.

If storing fruit, cool it as soon as possible after picking. The sooner heat is removed from freshly picked fruit, the longer the fruit will keep in decent condition. Handle fruit intended for storage very gently. Bruises and wounds allow pathogens to infect the fruit.

Further Reading

WSU Extension Publications available at: http://cru84.cahe.wsu.edu/

Aphids in Apples (EB1075)

Apple Cultivars for Puget Sound (EB1436)

Apple Scab (PNW0582)

Backyard Filbert Production (EB0967)

Cherry Fruit Flies (EB1068)

Coryneum Blight of Stone Fruits (EB1266)

Disease and Insect Spray Schedule for Home Orchard Apples, Pears in Western Washington (EB0918)

Disease and Insect Spray Schedule for Home Orchard Peaches, Nectarines, Apricots, Plums, Cherries, Flowering Prunus (EB0918)

Fire Blight (EB1352)

Fruit Handbook for Western Washington: Varieties and Culture (EB0937)

Growing Tree Fruit at Home in Eastern Washington (EB1694)

Hortsense: Home gardener fact sheets for managing plant problems with IPM. *http://pep.wsu.edu/hortsense/*

Insect and Mite Control in Home Orchard Tree Fruits and Nuts (EB0932)

Pacific Northwest Landscape Integrated Pest Management (IPM) Manual (MISC0201)

Pear Psylla Detection and Control (EB1230)

PNW Insect Management Handbook (MISC0047)

PNW Weed Management Handbook (MISC0049)

PNW Plant Disease Management Handbook (MISC0048)

Powdery Mildew of Cherry (EB1539)

Protecting Backyard Apple Trees from Apple Maggots (EB1928)

Sweet Cherry Varieties for Western Washington (EB0882)

Training and Pruning Your Home Orchard (PNW400)

Using Horticultural Spray Oils to Control Orchard Pests (PNW0328)

Berries and Small Fruits

8

Topics covered:

Blueberries

Raspberries

Blackberries

Strawberries

Kiwi

Currants & Gooseberries

Miscellaneous Small Fruits

Learning Objectives

- Know the common types of berries and selected small fruits suited for growing in Washington State
- Know basics of site selection, soil preparation and planting techniques for berries and small fruits
- Understand common plant maintenance, pruning, harvesting, and pest management practices for berries and common small fruits

Adapted from Growing Small Fruits for the Home Garden, by Charles A. Brun. WSU Extension publication EB1640.

Illustrations by Pat Green and Charles Brun.

Blueberries

Highbush blueberries (*Vaccinium corymbosum*) are both an ideal fruit producing plant and an ornamental specimen plant for Pacific Northwest gardens, especially those west of the Cascades.

Plants can grow to a height and circumference of 5 to 6 feet. During the spring blooming period of late April to early May, plants usually produce abundant white to pinkish urn-shaped flower clusters, followed by a bountiful crop of tasty berries from early July through mid-September, depending on the cultivar. In autumn, some cultivars display striking yellow-to-scarlet foliage before the leaves fall.

As members of the plant family Ericaceae, blueberries share the same soil and climatic preferences as rhododendrons and azaleas. The plants thrive in areas of moderate summer temperatures and acidic soils. Cold hardiness is not a major factor. The plants can survive midwinter temperatures as low as -20°F and -25°F. An open site with air drainage reduces spring frost injury to flower blossoms. While blueberries survive the warmer summers of eastern Washington, yields there rarely match those from west of the Cascades. A growing season of at least 140 days produces the best fruit.

Young plants generally do not begin to bear fruit until they are between 4 and 5 years old. Once a bush is established, life expectancy can be unlimited. Young plants, between 5 and 7 years, may bear 4 to 5 pounds of fruit per plant; mature plants can yield as many as 20 to 25 pounds.

Blueberries are self-fertile, but plant at least two different cultivars near one another to ensure optimum fruit set and size. When honey bees visit the blossoms in their search for nectar, the plants yield the most fruit.

Cultivars

All commercial blueberry cultivars (Table 1) released by the U.S. Department of Agriculture and state universities over the past 60 years have resulted from crosses with wild blueberry species indigenous to the eastern United States. These cultivars have performed very well in the Pacific Northwest. Season of ripening (early July through mid-September), yield, plant-growth habit, fruit size, color, flavor (sugar/acid ratio, aromatic components), and susceptibility to pathogens distinguish one cultivar from another. Home gardeners may wish to plant three to four different cultivars having varying ripening periods to extend the harvest season.

Dwarf Blueberries. In the last 5 years, researchers have developed dwarf, or so-called half-high blueberries, by crossing the standard highbush blueberry, noted for its large fruit size and productivity, with the lowbush blueberry, *Vaccinium angustifolium*, low in stature and cold-hardy. This cross produces a winter-hardy plant that can survive the extremely low winter temperatures of the upper Midwest. In the Pacific Northwest, these plants have become desirable landscape plants that require only minimal care and produce edible fruit. Popular cultivars are Northcountry, Northblue, and Northsky. While the yield of these cultivars will never match that of standard highbush types, these cultivars do have a place in the small or container garden.

Site Selection and Preparation

An acid soil with a pH of 4.0 to 5.0 is the most important condition for growing blueberries successfully. Plants often become yellow and stunted due to iron deficiency where the soil pH is greater than 6.0. If you plant blueberries where lime has been used during the previous 3 years, or in areas east of the Cascades, send a soil sample to a soil testing laboratory to determine its pH. Use soil amendments such as garden sulfur, dusting sulfur, or flowers of sulfur to lower the soil pH. Incorporate sulfur, at the rate of 1 to l.5 pounds per 100 square feet into the top 8 inches of the soil profile 12 months before planting. During the life of the plant, make yearly spring applications of ammonium sulfate fertilizer to lower the soil pH. If the pH falls below 4.0, use lime to raise the pH back to the recommended range.

Heavily compacted soils, or those low in organic matter, greatly benefit from the addition of rotted manure, compost, sawdust, or peat moss. Amendments improve the soil texture and increase the water holding capacity. Blueberry plant roots are relatively fine and shallow (14 to 18 inches), and prefer an open, porous soil. Add 4 to 6 inches of sawdust initially, and 1 inch each year to maintain depth, or mix half a gallon of peat moss with the soil in the planting hole.

Blueberries do not demand as much soil depth for rooting as caneberries and strawberries, but gardeners should still select a site with at least 18 inches of free-draining soil. Install drain tile in areas that may flood during winter months.

Grow blueberries in full sun for optimum fruit production and quality. They will perform adequately, however, in a location that receives partial sun, although yield will be less. In areas of high summer temperatures, partial shade prevents soil moisture loss and keeps fruit from shriveling. Prepare the planting site in the fall before planting in the spring. Eliminate all weed growth through cultivation. In areas west of the Cascades, use of a fall cover crop of rye or barley (2 to 2.5 pounds of seed per 1,000 square feet) reduces fall germination of weed seeds, protects the prepared site from erosion, and helps build up organic matter. East of the Cascades, use a fall planting of winter rye or early spring plantings of Austrian winter peas or clover and plow under in early summer.

Table 1. Blueberry cultivars

Cultivar	Harvest period	Fruit characteristics	Plant characteristics
Earliblue	Early	First to ripen; excellent dessert quality; large fruit size.	Upright bush; avoid frost pockets and poorly drained soils.
Ivanhoe	Early	Large fruit.	Upright bush; winter hardy.
Spartan	Early	Very large, light blue; excellent dessert quality.	Upright bush; productive; prefers light, well-drained soils.
Patriot	Early	Large fruit, firm, very good flavor, high yield	Vigorous, upright, winter-hardy; performs well on sites with less than perfect soil drainage.
Bluejay	Early to mid-season	Medium size, light blue, mild, tart flavor; fruit will drop from bush.	Bush vigorous, moderate yield; winter-hardy to zone 4; some resistance to mummyberry fungus.
Northland	Early to mid-season	Medium size, high sugar; excellent for jams.	Compact size; hardy to zone 3
Bluecrop	Mid-season	Most widely planted cultivar in world. Large, light blue fruit; medium fresh quality, firm.	Very productive, vigorous bushes bear fruit over a 1-month harvest season.
Blueray	Mid-season	Large, sweet; good dessert quality.	Dense upright growth; adapted to areas with hot summers and cold winters; hardy to zone 4.
Berkeley	Mid-season	Large fruit; mild flavor (sweet); medium blue color.	Bush is open and spreading; high yields in the Pacific Northwest; more susceptible to spring frost.
Darrow	Late	Largest of fruit size; tart flavor.	Vigorous, upright bush.
Elliott	Very late	Medium yields; mild flavor.	Suitable to areas south of Puget Sound.

Establishment and Cultivation

Planting

Most blueberry bushes are set out during the dormant season from January to March (March to April in eastern Washington) as either 2-year-old bareroot stock, or as 3-year and older container stock. While the smaller stock is less expensive, do not allow it to bear fruit for 2 years to assure strong plant development. More expensive container stock often bears fruit the year it is planted. In a landscape setting, allow at least 4 to 5 feet between the plants and 5 to 6 feet between the rows, since plants become quite large at maturity. Dig a hole large enough to spread out the roots carefully.

Fertilizing

Fertilizing blueberries during the first 3 to 4 years encourages development of a number of well-spaced, stocky canes with many branches. On plants showing little or no shoot growth during the spring, use the maximum recommended amount of fertilizer. Give plants that grow more than 1 foot little or no fertilizer. On mineral soils, apply fertilizer at leaf bud break and again during late spring. Use a balanced fertilizer such as 5-10-10 in early spring. Follow up with ammonium sulfate in May, and again in June if needed. Home gardeners may use commercially packaged evergreen and azalea fertilizer for blueberries. Table 2 gives recommended rates for using common commercial fertilizers on blueberries.

Delay fertilizing young, newly transplanted blueberries for at least a year to avoid burning the developing root systems. Keep inorganic fertilizer away from the crown of the plants, but work in thoroughly within the dripline of the bushes. Apply extra nitrogen when you use sawdust mulches to prevent leaf yellowing and plant stunting.

Table 2. Blueberry fertilization: quantity of fertilizer per plant in ounces and approximate equivalents. (For organic equivalents, see Table 4 in Chapter 5: Plant Mineral Nutrition & Fertilizers.)

Age of plants (from transplant)	5-10-10 ounce (cup) March 15 to April 15	Ammonium sulfate ounce (Tbsp) May 20	Ammonium sulfate ounce (Tbsp) June 15
Newly set	0	0	0
1 year	2 (1/4 cup)	1 (2 Tbsp)	1 (2 Tbsp)
2 years	4 (1/2 cup)	1-2 (2-4 Tbsp)	1-2 (2-4 Tbsp)
3 years	6 (3/4 cup)	1-2 (2-4 Tbsp)	1-2 (2-4 Tbsp)
4 years	8 (1 cup)	2-3 (1/4 cup + 1 Tbsp)	1-2 (2-4 Tbsp)
5 years	10 (1 1/4 cup)	2-3 (1/4 cup + 1 Tbsp)	1-2 (2-4 Tbsp)
6 years and older	12 (1 1/2 cup)	2-3 (1/4 cup + 1 Tbsp)	1-2 (2-4 Tbsp)

There are organic fertilizers for your small fruit crops as well. Organic fertilizers such as composted poultry manure and organic blends with 4-4-4 or similar N-P-K ratios are good balanced fertilizers that can be used in place of 5-10-10 or 10-20-20.

Where a recommendation calls for 1 lb of 5-10-10, use 2 to 3 lb of chicken compost or organic 4-4-4. Use the 3-lb conversion if it is the first year applying organic fertilizers, and reduce to 2 lb after one or two years. You can reduce the amount of organic fertilizer you apply over time because of the cumulative benefits of past applications.

Nitrogen-rich organic fertilizers such as feather meal, fish products, or high-nitrogen blends can be used in place of 21-0-0. Adjust the rate needed based on the amount of nitrogen in the organic fertilizer compared with 21-0-0. For instance, if you have a feather meal fertilizer with 12% N, you will need 21÷12 or roughly twice as much feather meal compared with 21-0-0.

For more information on choosing and using organic fertilizers and amendments, see Plant Mineral Nutrition and Fertilizer (Ch. 5).

Composts are excellent soil amendments to increase soil organic matter, improve permeability, and create a better rooting environment for small fruit plantings. Some composts are also a source of nutrients, and can be used when establishing or amending small fruit plantings. Many yard debris composts supply small amounts of plant nutrients, and a yearly 1-inch application could meet the nutrient needs of some small fruit crops. Other composts, such as those made from separated dairy solids or largely woody materials, will tie up nitrogen in the short run, and you will need to supplement with extra fertilizer. Composts also tend to raise the pH of the soil, so you should specifically check for signs of pH-related iron deficiency if you use compost when growing blueberries.

Watering

Supplemental watering from June to August is needed for successful production of blueberries in the Pacific Northwest. Shallow-rooted plants require close attention to maintain a uniformly moist environment around their base. They require 1 or possibly 2 inches of water each week, in the absence of any rainfall. Be sure the entire root zone is wet after irrigating. Drought symptoms include reddened foliage; weak, thin shoots; and reduced fruit set. A drip system, set on a timer, works especially well in keeping soil moist on a daily basis. Keep watering the plants through August to ensure good fruit bud development for the following season's crop. Maintain a 2-inch mulch layer to preserve soil moisture.

Weed Control

If you have controlled the perennial weeds prior to planting, add 2 inches of mulch each year to control the new germination of annual and broadleaf weeds. Hand cultivate carefully within the dripline of the bushes to avoid severing shallow roots.

Bird Control

Robins, starlings, and finches can strip ripening blueberry plants totally clean of fruit if plants are left unprotected. Drape plastic bird netting over the bushes as the berries begin to turn blue, or string plastic streamer tape between the bushes to frighten the birds away.

Pruning

Young plants need little if any pruning during their first 3 years in the ground. Flower buds form from late summer to early fall, then overwinter, bloom, and set fruit the following spring. On 2- and 3-year-old plants, strip the blossoms off in spring to promote plant vigor.

As the plants mature, prune out low, spreading branches near the ground, and head back branches that lack vigor to a strong upright lateral. When the branch tips become twiggy, carefully thin them out with hand shears. Flower buds form nearer the tips of the branches and are fatter and less pointed than leaf buds. Remove any broken or diseased branches.

On older bushes, production often declines as canes age and produce fewer fruit buds. To renovate the planting, use loppers to remove canes with a basal diameter of more than 1 inch at the ground line. This will not affect subsequent yield but ensures strong return bloom and larger fruit size. Prune in the dormant season. Pruning during the fall, as opposed to the winter and spring, tends to delay spring bloom and reduces possible spring frost damage.

Harvest and Storage

Harvest fruit approximately 4 or 5 days after the first berries turn blue so fruit size and sugar levels are the greatest. From then on, continue harvesting at 3- to 5-day intervals since all the berries in a cluster do not ripen at the same time. Use your thumb to gently roll berries from the fruiting cluster into the palm of your hand, then transfer them to a picking container. Fresh berries have a 2-week shelf life if they are kept in a refrigerator. To freeze blueberries, simply rinse them in water, then place in freezer in a single layer on a tray. When frozen, transfer to freezer containers.

Disease and Insect Problems

Diseases

Mummyberry is the most serious fungal disease of highbush blueberries. It leaves affected fruit hard, white, and inedible. During a prolonged wet spring, this disease can be quite common. In late March, mummified fruit on the ground from the previous summer sprout minute, brown, mushroom-like cups that release fungal spores. The spores infect new flower clusters and leave them blackened and withered. Spores produced on these blighted tissues infect new opening flower blossoms, which subsequently produce infected fruit. Infected berries appear normal until the onset of ripening. They then turn a tan to salmon color. Mature fruit turn white, drop to the ground, and restart the cycle. Control mummyberry by raking the soil or mulch layer beneath the plants in early March as leaf buds swell. Raking destroys spore cups. Pick off and remove infected berries from the patch before harvest. Pick up and throw away infected berries that fall to the ground. A fungicide that can be sprayed on developing blossoms to protect them from the fungal spores is available to home gardeners. An integrated program of spring raking, blighted shoot removal, mummy removal, and use of protective fungal sprays will contribute significantly to mummyberry control.

Botrytis blossom blight can also be a problem during a prolonged, wet spring. Gray fungal spores distinguish Botrytis infection from frost injury. If rains occur before harvest, Botrytis fruit rot can infect maturing berries. Reduce the incidence of this gray mold by keeping the plants well pruned to improve air circulation. Apply protective fungicide spray applications during bloom, and do not let the berries become overripe on the bushes.

Insects

Blueberries have relatively few insect pests. Aphids can reduce plant vigor and leave a buildup of sticky honeydew on the leaves and fruit. Ladybird beetles are effective against aphids in commercial settings. On small plots of land, however, they are not as effective because they disperse before feeding on very many aphids.

Cherry fruitworm larvae destroy blueberries by feeding on the inside of the fruit. The 1/2-inch conspicuous pink worms are the progeny of small, dark gray moths. The larvae burrow into and feed within berries, leaving frass and webbing; often the damage is noted shortly before harvest. Apply appropriate insecticides at blossom drop, and 2 weeks later, if cherry fruitworm is a perennial problem.

A heavy infestation of lecanium scale stunts blueberry bushes and leaves them sticky and sooty with honeydew and mold. Prune out stems encrusted with high scale populations and apply dormant oil spray to the plants when the temperature is above freezing.

Root weevil larvae can damage blueberries as well as other small fruits. The c-shaped larvae, from 1/5 to 1/3 inch long, are legless, having white bodies and brown heads. They feed on the root systems and on the lower portion of the bush crown. Adult root weevils are rarely seen during the day. They feed on leaves in the evening, leaving the bush with characteristic leaf notching. While not harmful to the plant, the presence of notching is a good indication that larvae are present in the soil. No pesticides are available to home gardeners for use on larvae.

Raspberries

Red raspberries (*Rubus idaeus*) thrive in most areas of Washington. A raspberry planting may live and produce fruit for more than 30 years if it is planted in well-drained soil and cared for properly. In all locations, shelter raspberry plantings from winds to prevent desiccation of the canes.

Since all raspberry flowers are considered self-fertile, no additional cultivar is needed for pollination. Pollen is transferred by bees that visit raspberry flowers because of the high nectar level. Spring frost injury is generally not a problem because flowers appear relatively late in the spring.

Cultivars

Two types of raspberries are available to the home gardener. Summer-bearing (June-bearing types, Table 3) initiate flower bud on first-year canes, or **primocanes**, from late August to early September. The canes overwinter, bloom, and fruit the following spring and summer, then die. While the fruiting canes, or **floricanes**, are bearing, new green primocanes emerge for the next year's crop and continue the life of the planting. Root systems are perennial.

The second kind, fall fruiting types, are also known as everbearing or primocane fruiting types (Table 4). They bear fruit on the top half of first-year-canes from early August through late September. They overwinter and produce a second crop on the lower half of the canes the following June through July.

No single cultivar can be universally recommended. June-bearers have ample plant vigor, but they produce fruit with different flavors. The earliest ripening cultivars usually produce mature fruit by the second week in June in the southern parts of the state, and 1 or 2 weeks later in the northern parts of the state. The potential harvest season lasts 4 to 6 weeks. The earliest ripening fall-fruiting types usually have fruit by the first week in August in the southern districts and can produce fruit until the start of the fall rains. In fact, later ripening, fall-fruiting types have had limited acceptance in the past because they bear late in the season.

Black raspberries (*Rubus occidentalis*) ripen around the beginning of August. The two most commonly recommended cultivars are Cumberland and Munger. Both of these cultivars suffer from virus diseases and anthracnose. Black raspberries, or blackcaps, are commonly used for jam. Black raspberries differ from blackberries in that, when picked, they do not bring the fruit receptacle, or core of the berry, with them and therefore are "hollow" like other raspberries.

Table 3. June-bearing red raspberry cultivars

Cultivar	Harvest season	Fruit characteristics	Plant characteristics
Willamette	Early, short	Dark, red fruit, low in sugar, tart flavor; leading commercial cultivar.	Vigorous plants with numerous spines; adaptable to well-drained sites throughout western WA and OR; avoid hot, dry climates east of the Cascades.
Algonquin	Mid-late season	Small to medium red berries; excellent flavor.	Cold hardy; tolerant of Phytophthora root rot.
Meeker	Mid-season, long	Higher in sugar, excellent flavor; standard for fresh market production.	Fruit softens in fresh storage; not as winter-hardy; not suitable for wet, poorly drained sites.
Sumner	Later season, average	Fruit has bright color; lacks flavor and sugar; yields well.	Best performing cultivar for wetter sites; some winter hardiness for east of the Cascades.
Chilliwack	Later season, short	Newest cultivar; best fruit flavor, color, and size.	Better winter hardiness than other cultivars; better root rot resistance than Willamette or Meeker.
Centennial	Mid-season, long	Higher yields and better fruit size than Meeker.	A new, fresh-fruit cultivar suited to the southern portions of the Pacific Northwest; better root rot resistance than Willamette or Meeker.

Table 4. Fall fruiting raspberry cultivars

Cultivar	Harvest season	Fruit characteristics	Plant characteristics
Amber	Early	Medium size, firm, yellow fruit; excellent flavor.	Very productive, winter hardy.
Autumn Bliss	Early	Larger and firmer than Heritage; very nice flavor.	Canes short and sturdy, needing minimal support.
Summit	Early	Equal in size and firmness to Heritage; difficult to pick under hot conditions.	Plants not as vigorous as Heritage; has resistance to root rot.
Fall Gold	Early	Yellow-fruited cultivar with mild, sweet fruit.	Bushes are only moderately vigorous; average yield.
Heritage	Late	Large, dark fruit; mild flavored.	Vigorous canes need support; winter-hardy for sheltered areas east of the Cascades.

Site Selection and Preparation

Site Selection

Raspberries are the most demanding of all small fruits in their preference for well-drained, sandy loam soil at least 24 inches deep. Check the future planting site after a heavy rain in the winter for the presence of standing water. On sites that are slow to drain, install drain tile 24 inches deep, or plant the raspberries on mounds of soil 1 foot high. Excessive soil moisture during late winter when new roots are growing leads to root rot development (see Disease section, below).

Select a site that receives full sun all day long. Plants grown in the shade remain small and produce tart fruit. Cultivate on either side of the rows to allow for primocane growth.

Soil Preparation

Plan to control weeds and build up the soil tilth a year before planting. Consider seeding a fall crop of cereal rye or barley to the planting site to build up organic matter. For that, use between 2 and 2.5 pounds of seed for each 1,000 square feet. Do not allow rye to head out the following spring before tilling it in and planting the raspberries. Amend the soil with lime when the pH is less than 5.5. For raspberries, the ideal pH range is between 6.0 and 6.5. If the soil needs lime, apply the fall before planting.

Establishment and Cultivation

Planting

Dormant raspberry plants are usually available in nurseries from mid-January to March in western Washington and a month or two later in eastern Washington. From March to early April stock is available for immediate planting. Do not use any planting stock that already has started to bud out appreciably; it generally does not perform well. Purchase virus-free, certified nursery stock. Caution: Sucker plants dug from an old, established planting during the winter when the plants are dormant often have virus diseases that can survive during transplanting.

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The generally accepted planting distance for red raspberries in the Northwest is 30 inches between plants within the row, in rows spaced 8 to 10 feet apart. This **stool method** of planting, which maintains canes as discrete bushes, permits more ease in controlling weeds and excess primocane growth. Hand plant the row, then cut down the canes to a stem or “handle” of three to four buds above ground level. This practice encourages early development of basal shoots without promoting production of fruiting laterals during planting. In subsequent years, allow 10 to 12 primocanes to grow from each original stool. Maintain the row at a width of 12 inches; remove excess primocanes using a hoe or rototiller. In the **English hedgerow** planting system, growers set out plants at 30-inch intervals, but allow new primocanes to fill in the row to a width of 8 inches (Figure 1).

Fertilizing

Raspberry primocanes normally grow an average of 8 to 9 feet during the spring and summer. Adjust fertilizer rates annually to achieve this amount of growth. Apply fertilizer in the late winter (March) as bud swell begins. Either broadcast fertilizer over the entire row, or band it 1 foot on either side of the row. West of the Cascades, apply 2 to 3 pounds of a 5-10-10 fertilizer to each 100 feet of row. East of the Cascades, in areas of relatively high phosphorous and potassium, use only nitrogen. Consider an application of 3/4 to 1 pound of ammonium sulfate per 100 feet of row.

Watering

The raspberry plant is fairly deep rooted but can still suffer from a shortage of summer rainfall. Moisture is critical during the fruit ripening stage in early June, and the late August to September period, when flower buds form for the following year's crop. Apply an inch of water per week when rain does not fall. Overhead irrigation during the ripening stage can encourage fruit rot if the weather is cool and cloudy; consider using a trickle or soaker hose irrigation system.

Weed Control

To control weeds, apply an organic matter mulch 4 to 6 inches deep in the spring after new canes are more than 4 inches tall. Hand pull weeds that appear later in the season or cultivate lightly being careful to not damage roots.

Trellising and Training

Raspberry canes lack sufficient strength to remain erect. Plant against a fence that they can be tied to or install a post and wire trellis support. Erect the trellis the first summer the new plants are in the ground. If the newly planted canes grow vigorously the first summer, tie them to a wire support to ensure a crop the second year.

The first step in building a trellis involves placing secure, 6-inch-diameter end posts, preferably ones that have been treated with an environmentally safe wood preservative. Within the row, space 3-inch-diameter wooden posts every 25 to 30 feet, or place metal posts every 20 feet. Use 12-gauge or stronger wire to support a heavy fruit-laden canopy (Figure 1). A three-wire trellis is the universally accepted design. Place the top wire 54 inches above the soil line, and run two detachable training wires to be set 30 inches above the soil line. During the late summer renovation process, tie primocanes to the top wire, leaving the lower two wires on the

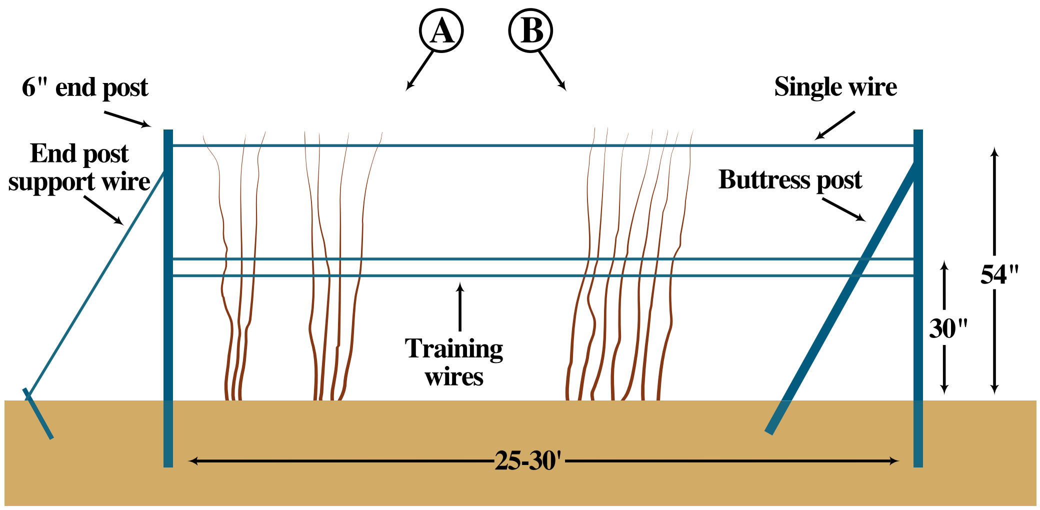


Figure 1. Three-wire raspberry training system: A.) Scottish stool system with stools spaced 30 inches apart, and B.) English hedgerow system with canes allowed to grow continuously within the row.

ground. In the Scottish stool system canes are gathered together in upright bundles and tied to the top wire with binder twine. For the English hedgerow system, canes are spaced and tied individually along the top wire.

The following spring, when new primocanes attain a height of 3 to 4 feet, bring up the training wires to collect the primocanes. Fasten the training wires to the intermediary posts, or hook them together with wire loops. Secure primocanes to the top wire with twine or metal loops of wire every 3 to 10 feet. In the late summer, repeat the renovation process.

Also acceptable is a four-wire trellis with two wires at 54 inches, and two training wires below. A four-wire cross-arm trellis incorporates an 18- to 36-inch-wide wooden cross-arm attached at the top of each post within the row. During August, secure primocanes to these two top wires with twine. During the following spring, allow new primocanes to grow up through the center of the canopies to prevent them from interfering with picking of fruit from the floricanes.

Pruning and Cane Vigor Control

On summer-bearing cultivars, prune out spent fruiting canes any time after harvest. These will be brown and appear dried. Retain 10 to 12 of the healthiest primocanes, which are green, and secure these to the top trellis. Leave primocanes long during the fall and early winter; topping canes in early fall makes them more susceptible to cold injury. In late January or February of the following winter, tie top canes trained to either the Scottish stool or English hedgerow system to the uppermost trellis wire and then trim to 6 inches above that. You also can leave canes long and bow them over the top wire in a semi-circle. Either method of pruning forces lateral branches to grow in the spring at a convenient picking height.

Remove the first flush of primocane growth by hoeing in spring when growth is 7 to 8 inches high on vigorous plantings where cane growth is greater than 9 feet. New primocane growth follows shortly. This practice substantially increases yields, reduces fruit rot, and makes picking easier. Remove the top half of the cane from fall-bearing cultivars after fruiting is over, or remove the entire cane at the ground line. Leave the lower half of the cane for a summer crop the following June; remove canes entirely for only a fall crop each year. Because the fall crop on fall-fruiting cultivars is superior to the summer crop, most growers advise cutting all canes to the ground in mid-October.

Harvest and Storage

Collect dry, firm fruit as it reaches the peak of color and sugar development. Avoid picking wet fruit, as it deteriorates soon after harvest. Berries will not ripen further in storage. Frequent harvesting greatly reduces the incidence of fruit rot disease. Fresh berries have a shelf life of only 2 to 3 days in the refrigerator. Raspberries freeze well for later use and are good for making tasty preserves.

Disease and Insect Problems

Phytophthora root rot. The most limiting disease problem of red raspberries is a fungal disorder known as Phytophthora root rot. This soil pathogen is the primary agent that causes a planting to decline when the soil is imperfectly drained or exhibits a high water table. Symptoms include wilting of primocanes in the spring and yellowing, drying, and premature death of fruiting canes during harvest. Affected plants also have deteriorated root systems. Unhealthy root tissue is brick red in color, while healthy tissue is creamy white. Little can be done to control root rot in an established planting. Relocate the planting to better soil, consider planting the raspberries on raised beds, or select a cultivar that has greater genetic resistance to this pathogen.

Botrytis. Berries with fruit rot (Botrytis gray mold) appear water-soaked; in the latter stages of rot, tufts of gray fungal strands grow on the surface, covering the fruit. Promptly remove spent fruiting canes in August, and control excessive primocane growth as outlined under the cane vigor control section.

Viruses. A number of virus diseases attack raspberries. Symptoms include stunted plants; leaves that are small, yellowish, mottled, crinkled or have bright veins, and berries that are small and crumbly. Be sure of the cause before taking action, as these conditions can result from many other factors, including poor pollination, drought, and soil boron deficiency. Dig out virus infected plants and replace them with certified stock. Since the virus can spread to other parts of the plant before symptoms show, it is necessary to remove the entire plant, not just infected canes. The virus cannot live in the soil, so growers can place new plants in the same area. Since the virus requires raspberry plants as a host to survive, growers may replant in the same area if all infected plants have been removed.

Cane diseases. Diseases such as anthracnose, spur blight, and crown gall are occasional problems that affect the canes of raspberries. Anthracnose appears as small purple spots with gray centers forming on new growth. Canes can become girdled and cracked. Spur blight results in brown or purple spots appearing at buds along infected canes; often these buds are killed, resulting in the absence of fruiting spurs the first 18 inches from the ground. Affected leaves display brown wedge-shaped lesions. Field sanitation and properly applied fungicides, used at the green-tip stage of bud breaking in late winter, control these two diseases. A bacterial disease called crown gall causes rough outgrowths to appear on canes, crowns, and roots. Be careful when pruning affected plantings—accidentally wounding healthy plants encourages entrance of this pathogen. Dig out galled canes from the planting.

Crown borer. The crown borer is the chief insect problem for red raspberries. Clear-winged larvae tunnel to the basal portions of the canes and crowns, resulting in a gradual decline of the stand. A moth that looks like a black and yellow wasp produces the larvae. Digging out and removing infested canes helps control this pest.

Other minor insect pests include root weevil larvae that feed on the roots, leafrollers that roll leaves and feed on the fruit, and spider mites that cause speckled, bronzed leaves.

Blackberries

Blackberries and raspberries are members of the same genus, *Rubus*. Unlike raspberries, however, picked blackberries retain the fruit receptacle, or core, of the berry with the fruit. As is the case with raspberry, blackberry flowers are self-fertile, eliminating the need for an additional pollinizer cultivar.

Well-known blackberry cultivars, such as Marionberry or Boysenberry, do best in areas west of the Cascades and south of Puget Sound. Even in mild areas, however, winter injury is a constant concern. Near 5°F, canes can suffer freeze injury that results in poor bud emergence in spring. East of the Cascades, growers can keep vines of the trailing types on the ground and mulch them during the winter. Nonetheless, high summer temperatures and low relative humidity often result in small yields and poor fruit.

Cultivars

Western trailing types, often called dewberries *(Rubus ursinus)*, are the most widely planted commercial cultivars, exhibiting vigorous growth. You can train them by tying trailing canes to a post and wire trellis. These biennial plants form nonbearing primocanes the first year and fruiting floricanes the second year. Canes die shortly after fruiting, turning dry and brown—at which point they should be cut and removed. The earliest bearing cultivars generally produce fruit by the first week of July in southwest Washington; the latest cultivars bear fruit in late August.

Cold-hardy, erect thorny cultivars (e.g., Cherokee), developed in the southern Midwest are more suited to eastern Washington. These plants produce much stiffer canes that will stand erect with proper pruning techniques. Erect types are cold-hardy enough for most of Washington.

Semi-erect thornless (e.g., Chester Thornless) cultivars were developed in Illinois. The new thornless types are significantly sweeter than older cultivars, such as Smoothstem and Black Satin. Newer Pacific Northwest thornless blackberry cultivars are hardy to approximately 0°F.

A number of different raspberry-blackberry hybrids are available. The Tayberry, from Scotland, has thorny trailing canes that bear large, narrow reddish-black fruit with a sweet flavor (Table 5). The Tummelberry and Sunberry are also thorny; each has a distinctive flavor. Hybrids often are more suitable for processing than for eating fresh because of their unusual flavor.

Table 5. Northwest blackberry cultivars

Cultivar	Harvest season	Fruit characteristics	Plant characteristics
Loganberry	Early	Large, elongated, dusky red berries; juicy and acidic; may be used for fresh-eating, frozen, or preserves.	Thorny canes of moderate vigor; needs winter protection for eastern Washington.
Kotata	Mid-season	Large, firm berries, good flavor.	Canes not brittle; heavy yields; hardy to zone 5.
Boysenberry	Mid-season	Very large reddish-black fruit; soft and sweet-tart in flavor (suggestive of raspberries); excellent fresh or frozen.	Thorny, vigorous canes; hardy to approximately 10°F without winter protection.
Marionberry	Mid-season	Black, shiny fruit of medium firmness; sweet flavor.	Very productive, vigorous canes with numerous large spines; needs winter protection in many parts of Washington.

Cultivar	Harvest season	Fruit characteristics	Plant characteristics
Tayberry	Mid-season	Large, long, reddish-black berries; less acidic than Loganberries.	Extremely thorny; moderate vigor; canes need winter protection in eastern Washington.
Cherokee	Mid-season	Medium-large black fruit similar to Marionberries but firmer; excellent flavor.	Canes erect, thorny; hardy to -10°F. Very vigorous and productive west of the Cascades.
Hull	Late	Large berries; good flavor; retains color on hot days.	Vigorous, thornless canes; hardy to zone 5.
Chester Thornless	Late	Similar in size and shape to Thornless Evergreen.	Canes erect; winter-hardy for most of Washington.

Site Selection and Preparation

Blackberries generally are more tolerant of varying soil conditions than are red raspberries. They can tolerate heavier soil textures. Even so, avoid planting sites that have standing water in the winter, or tile drain sites before planting. Provide a shelterbelt around sites that receive considerable wind during the winter months to avoid cane damage. Prepare the planting site as you would for red raspberries. Ensure that the planting site receives full sun exposure.

Establishment and Cultivation

Planting

Dormant blackberry planting stock is available for immediate planting in nurseries from mid-January to March in western Washington and a month or more later in eastern Washington. You also may obtain rooted cuttings from established plantings through a propagation method known as tip layering: bury the last or top 6 inches of primocanes during late summer. A root system and a new shoot then develop in the fall for late winter or spring transplanting. Perform this operation only with healthy, disease-free propagating stock.

Planting distances vary according to the vigor of the cultivar. Set Boysenberries 4 feet apart within a row. Set more vigorous cultivars such as Marion, 5 to 6 feet apart. Space rows 8 to 10 feet apart. Maintain plants in this stool system for the life of the planting. Since relatively few sucker canes arise from each of the stools, retain all primocanes for later training. Plant erect types 3 to 4 feet apart within rows, keeping rows 8 to 10 feet apart.

Fertilizing

Calculate fertilizer application rates based on the length of primocane growth made each year. Apply fertilizer in the late winter or early spring as the plants begin to break dormancy. Fertilize as recommended for raspberries: either broadcast fertilizer over the entire row, or band it 1 foot on either side of the row. West of the Cascades, apply 2 to 3 pounds of a 5-10-10 fertilizer to each 100 feet of row. East of the Cascades, in areas of relatively high phosphorous and potassium, use only nitrogen. Consider an application of 3/4 to 1 pound of ammonium sulfate per 100 feet of row. (For organic equivalents, see Table 4 in Chapter 5: Plant Mineral Nutrition & Fertilizers.)

Trellising and Training

A trailing-type blackberry trellis consists of stout end posts, wooden or metal intermediary posts, and two 12-gauge wires set 18 inches apart. Place the top wire 5 feet above the ground (Figure 2) and the bottom wire 42 inches above the ground. Leave new canes to trail along the ground within the row as they elongate during their first summer.

Blackberry primocanes (new green canes) grow for one year, overwinter, set fruit the following summer, and then die. Cut out spent floricanes (canes that bore fruit during the summer) at ground level. Then train the new primocanes singly in a spiral, fan-shaped wrap on the two wires. Put the longer canes on first. Train each cane over the top wire, then under the bottom wire in succession, taking care not to crease or break the canes. Separate the canes along the wires to ensure good air circulation.

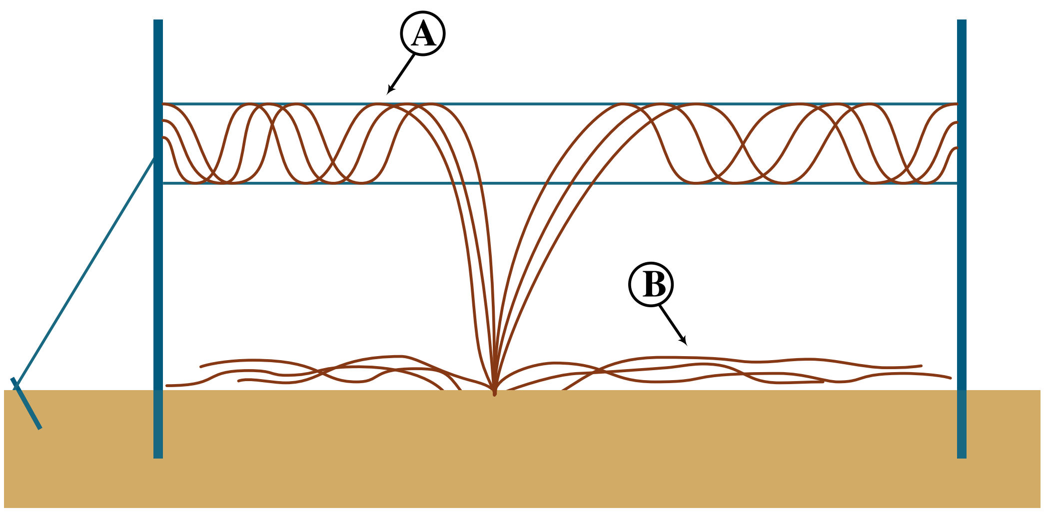


Figure 2. Training system for trailing blackberries where fruiting canes A) are woven upon the trellis wires and primocanes B) are allowed to run freely upon the ground.

Train trailing types during August in the warmer regions of western Washington. If canes suffer from winter desiccation, and in eastern Washington, delay training them until the following spring. However, disease and insect problems are usually worse when you train canes in the spring.

Cut back primocanes of erect blackberry cultivars to 36 inches as they develop during the summer to promote lateral branching. After harvest, retain only three to four of the strongest primocanes. During the following spring, cut back lateral branches on floricanes from 12 to 18 inches (Figure 3); this practice improves fruit quality.

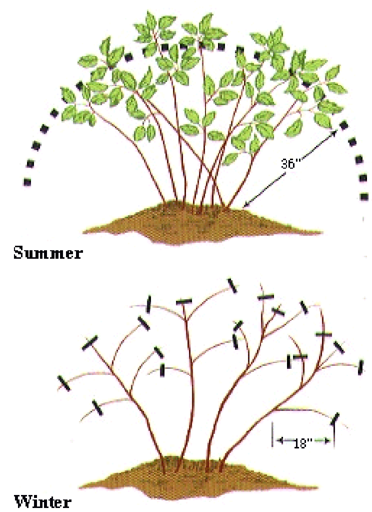


Figure 3. When pruning erect blackberries, cut back primocanes in the summer to 36 inches. During the following winter, cut laterals back to 12–18 inches.

Disease and Insect Problems

Blackberries suffer from many of the same pathogens that attack red raspberries. Root rot is often a lesser problem on blackberries because the fruit is more tolerant of heavier soil types. Fruit rot is often less severe as well, since blackberries mature during the drier portion of the summer. Minimize fruit rot by keeping the primocanes well separated during training to ensure good air movement through the canopy, and by harvesting regularly.

Septoria cane spot. The most notable disease on trailing blackberries is commonly called "leaf and cane spot." This fungal disease causes 1/8-inch leaf spots that vary from light to dark brown and take on whitish centers with brown to red borders. In the spring, canes of Marion and Evergreen blackberry also display irregular elongated purple blotches that can develop into cankers and girdle the canes. To control the disease, promptly remove spent fruiting canes, train primocanes in August, and apply fungicide in the spring and fall.

Other cane diseases of blackberries are anthracnose and crown gall. Refer to the raspberry section for further details.

Redberry mites. Infestation of Redberry mites results in fruit that do not ripen uniformly. Infected fruit form bright red or hard green druplets that spoil fruit flavor. Microscopic mites overwinter in cane bud scales. Train canes in August, and apply miticides thoroughly in the fall and prior to spring budbreak to control red mite damage.

Strawberries

All Northwest edible fruit gardens should include a healthy bed of strawberries producing large, sweet, brightly colored berries for fresh eating, freezing, or preserves. Strawberries (*Fragaria ananassa*) adapt better than any other small fruit crop to Washington climates. Cultivars released from regional breeding projects of Oregon, Washington, and British Columbia are noted throughout the United States for their excellent flavor, and for their superior internal red color for processing in the jam, preserves, and yogurt industries. Northwest berries may lack the size and appearance of California strawberries, but they more than make up for those characteristics with their flavor.

The strawberry is considered an herbaceous perennial. It sends up new shoots, leaves, and runners each year from a crown and root structure that generally lives for 4 to 5 years. Home gardeners often try to extend the life of the planting for more than 5 years. It is generally best to start anew with dormant, certified virus-free nursery stock when the original planting has declined in vigor, or become choked with runners or perennial weeds.

The strawberry fruit itself is the swollen receptacle of the flower. The individual achenes or seeds on the berry's surface result from bee pollination and fertilization. A strong, vigorous plant that has escaped spring frost injury during bloom will produce a bountiful crop of large berries.

Cultivars

Two types of strawberries are available for planting in the Northwest: June-bearing and day-neutral or everbearing. June-bearing cultivars, often referred to as single-cropping cultivars, initiate flower buds when the days become shorter in late August and September (Table 6). The following May, blossoms appear, with ripe fruit following about 30 days later. June-bearing cultivars from other regions of the United States generally perform poorly in the Northwest.

Flower bud initiation of day-neutral cultivars, often referred to as everbearing or double-cropping cultivars (Table 7), is not governed by day length. Flowers and fruit occur simultaneously from June through October, although production normally declines during the hotter days of late July and August.

Table 6. June-bearing strawberry cultivars for the Northwest.

Cultivar	Harvest season	Fruit characteristics	Plant characteristics
Totem	Early	Large, good color inside and outside fruit.	Very winter hardy; intolerant of soils with pH>7 without acidifying amendments.
Earliglow	Early	Firm, good color and flavor; size decreases later in season.	High yields; resistant to Red Stele and Verticillium diseases.
Hood	Early	Moderate yield; attractive, bright fruit of average size; excellent for preserves.	Good runner capacity; average winter hardiness; very susceptible to virus diseases and fruit rot.

Cultivar	Harvest season	Fruit characteristics	Plant characteristics
Benton	Mid-season	Bright glossy fruit of good size; excellent for fresh eating and preserves, poor texture frozen.	Vigorous plants produce high yields; good winter hardiness; good virus resistance.
Cavendish	Mid-season	Large fruit; good flavor.	Resistant to Red Stele and Verticillium diseases; hardy; ripens unevenly in hot weather.
Honeoye	Mid-season	Large, firm; can be tart.	High yields; hardy; not disease resistant.
Shuksan	Mid-season	Large fruit size; bright, attractive; best cultivar for freezing.	Most winter-hardy of all cultivars; good vigor; good winter hardiness; good virus resistance.
Allstar	Late	Sweet, mild flavor.	High yield; hardy.
Rainier	Late	Very attractive fruit; excellent for fresh, frozen, and preserve uses.	Vigorous plants but poor runner capacity; good virus resistance; average winter hardiness; moderate fruit rot resistance.

Table 7. Day-neutral strawberry cultivars.

Cultivar	Harvest season	Fruit characteristics	Plant characteristics
Tillikum	June-October	Excellent flavor, but poor fruit size and firmness.	Plants do not runner well; may offer virus resistance.
Selva	June-October	Best day-neutral for large fruit size, and firmness; lacks flavor.	Vigorous plants, but low yields; may lack winter hardiness.
Tristar	June-October	Good flavor, firmness, and color; average fruit size.	Average vigor and yield; winter-hardy east of Cascades.
Tribute	June-October	Med size berry, good quality.	Productive and hardy.

Site Selection and Preparation

Strawberries share the same growing requirements as raspberries: they like well-drained ground that receives full sun all day long. Avoid frost-prone areas where a freeze can occur during early May.

Before planting, carefully remove all perennial weeds from the planting site. Only hand hoeing or cultivation controls perennial weeds once the strawberries plants are established. Raising a cover crop the fall prior to planting will help control weeds during the establishment year. Incorporate compost or aged animal manure the fall prior to planting, to improve soil texture. The optimum soil pH for strawberries is 6.0 to 6.5.

Establishment and Cultivation

Planting

Certified virus-free planting stock is available from nurseries after the first of the year. Plants are sold bareroot, so keep them cool until planting. Trim roots back to 4 or 5 inches before planting. Plant so the crown—the swollen growing region that gives rise to leaves and roots—is at soil level.

June-bearers are normally grown in a matted row system where plants are set 15 to 24 inches apart within the row, and rows are 36 to 42 inches apart. Allow runner plants to fill in the spaces until the row is 14 to 18 inches wide.

Day-neutral cultivars often are grown in a hill system. They seldom form runners. Space plants 10 to 18 inches apart: at 10 inches remove all runners through the season; while at 18 inches, hand set one runner between mother plants. Best results occur when no two plants are closer than 7 to 8 inches apart. After planting, remove the first blossoms appearing on day-neutrals to encourage strong leaf and root development. Retain flowers appearing after the middle of June for later fruit.

Fertilizing

Strawberries are not heavy nutrient feeders. Apply 2 pounds of a 10–20–20 fertilizer, or 4 pounds of 5-10-10 per 100 square feet prior to planting. (For organic equivalents, see Table 4 in Chapter 5: Plant Mineral Nutrition & Fertilizers.)

Watering

Supplemental watering during dry summer months results in a vigorous, productive strawberry bed. Most of the plant roots are in the top 18 inches of the soil. Irrigate the planting in the most crucial times in its life: before and during harvest to ensure good fruit size, and in late summer as flower buds form. Do not use excessive overhead watering during the bloom period. This can encourage fruit rot later.

Weed Control

To control weeds, apply an organic matter mulch a few inches deep after planting. As runners form, nestle them through the mulch to make contact with soil. Hand pull weeds that appear later in the season or cultivate lightly being careful to not damage roots.

Renovation

After June-bearers finish producing fruit for the season, cut or mow all leaves to stimulate vigorous new growth. Avoid damaging the crowns of the plants in the process. Dig up and replant rooted runners in bare areas. Use rooted runners to replace weak areas of day-neutrals. Maintain the hill systems for June-bearers.

Next, apply fertilizer, control weeds, and irrigate adequately. Apply fertilizer to established June-bearing beds to stimulate late summer plant growth and flower bud initiation for the following season's crop. One-half of the pre-plant fertilizer amount is adequate.

Growers often replace day-neutral beds after 2 fruiting years, as plant vigor and fruit size become marginal.

Harvest and Storage

Fruit is ready for harvesting when its entire surface area becomes a bright red. The color indicates berries have reached the maximum in flavor, sweetness, and aroma. Fresh berries keep in the refrigerator for 24 to 48 hours. They last little more than overnight at room temperature. Pick strawberries with their green calyxes left on. Handle them carefully to reduce bruising. Cool fresh berries promptly (32°F to 45°F) to extend their shelf life. Clean and process fruit destined for the freezer or for use in preserves soon after harvest.

Disease and Insect Problems

Viruses. Infection by virus diseases is the most important factor limiting plant life span of home garden strawberries. The presence of virus leads to a gradual loss in vigor in plant height and spread, as well as a marked reduction in the yield. Leaves become cupped, small, yellow, or streaked, depending upon which virus has infected the plant. Planting noncertified nursery stock can spread viruses. The most common control measure is to dig out infested plants and replace them with certified nursery stock. Since the virus requires strawberry plants as a host to survive, (rather than surviving in the soil), growers may replant in the same area if all infected plants have been removed.

Root rot. Root rot can be a problem in poorly drained soils. Several different soil fungi, some of which can survive in the soil for many years, are responsible for characteristic symptoms including leaf reddening and stunted and discolored root systems. No registered fungicides are available to home gardeners for the control of root rot. Remove infected plantings. Reestablish new beds on better drained ground to avoid root rot.

Verticillium. Verticillium wilt spreads by a soil-borne pathogen, similar to the one that causes wilt and decline in tomatoes and potatoes. Older, outer leaves wilt, while newer, inner leaves remain green and erect. Eventually, wilt can kill the entire plant. Generally, do not plant strawberries in an area where tomatoes or potatoes have been grown previously.

Botrytis. Strawberries, like other small fruits, are highly susceptible to flower and fruit deterioration caused by Botrytis gray mold. Infected blossoms turn brown and wither, and exhibit the characteristic gray fungal growth. Control fruit rot with fungicidal spray applications during early bloom, restrict use of overhead irrigation from bloom through harvest, maintain good air circulation in the planting, and harvest fruit every day.

Root weevil. The root weevil is the most common insect pest of strawberries. Adult weevils notch leaf margins when they feed. The larvae or grubs, however, are the most damaging: they feed on plant roots and cause the plant to wilt and die. No insecticide is available for home gardeners to use to control the grubs. Fall plowing a future planting site will protect the newly established plants. Controlling root weevil adults on adjacent ornamentals also helps.

Other pests. Use insecticidal soaps to control aphids on a planting to reduce the incidence of viruses. Spider mite infestations, although infrequent, can result in leaf speckling and bronzing. Masses of foam on stems or fruit characterize spittlebug infestations. A strong spray of water is usually enough to control spittlebugs. Slugs feed on both leaves and fruit, especially during cool, moist weather. Slime trails accompany slug feeding damage. Control slugs by smashing adults, or by setting out insecticidal baits between the rows, but do not apply bait to foliage or fruit.

Kiwi

Kiwi (*Actinidia deliciosa*), a relative newcomer to the Pacific Northwest, is native to the Yangtze River Valley of China. The popular kiwi is a subtropical vine that grows up to 30 feet long and produces numerous, fuzzy brown, berrylike fruit the size of large eggs. The fruit have a tough skin that must be peeled off before eating. The flavor resembles a combination of strawberry and melon.

Kiwi vines are normally winter-hardy to 0°F or 10°F, depending upon degree of plant dormancy. Avoid sites prone to early fall freezes or late spring frosts. Expect fairly consistent crops in western Washington if the crop is in a sheltered field. The lower trunk of the kiwi is the most sensitive to cold. Growers have used craft paper or plastic-coated foam insulation to protect the vines.

Kiwi is a **dioecious** plant: male and female flowers are produced on separate plants. For pollination, interplant male vines with the female fruit-producing vines. Pollen from one male vine can pollinate up to eight surrounding female vines. Male vines flower profusely, but do not produce fruit. Numerous stamens and lack of styles characterize male flowers. Female flowers have styles but sterile stamens. Honey bees pollinate kiwis. Open flower clusters are not very attractive to bees; a shortage of bee activity results in small, misshapen fruit.

Vines do not begin to bear fruit until they have been in the ground for 4 years. Maximum production is not attained until 8 years. Growers in the north Willamette Valley report vine yields of up to 200 pounds of fruit per plant.

The hardy kiwi (*Actinidia arguta*) differs from the fuzzy kiwi in that the fruit are smaller (1 inch across), shiny green, and can be eaten without peeling. Nurseries report that hardy kiwi vines are cold-hardy to -25°F.

Cultivars

Nurseries recommend Hayward, the popular commercial fuzzy kiwi cultivar available in supermarkets, for the Pacific Northwest. Other notable cultivars are Blake and Saanichton 12. Select either the cultivar Matua or Tomuri as the pollinizer; nurseries often simply refer to them as the male plant.

The recommended hardy kiwi female is Ananasnaja. Once again the pollinizer is simply referred to as the male vine. This male vine can also be used to pollinate the fuzzy female kiwi. A self-fertile female cultivar, Issai, has recently been introduced.

Establishment and Cultivation

Select a sunny, wind protected, well-drained site for kiwi plantings. Kiwi plants are vigorous vines that produce a considerable weight of fruit. Erect a sturdy arbor or trellis to support the plants. The best trellis for ease of harvest and pruning for the home gardener is a 6-foot T-bar trellis made of treated posts set in concrete. Space three to five 12-gauge horizontal wires at 1- to 1.5-foot intervals and space plants 15 to 20 feet apart within the trellis.

The New Zealand Renewal system (Figure 4) is the preferred training system for kiwis on a T-bar. After planting, allow the vine to grow straight up to the middle wire. Pinch the terminal bud to stop its growth. Select two buds that will grow to become permanent leaders in opposite directions along the middle wire.

During the second growing season, select fruiting arms spaced at 2-foot intervals along the permanent leaders. These developing fruiting arms will grow at right angles to the permanent leaders

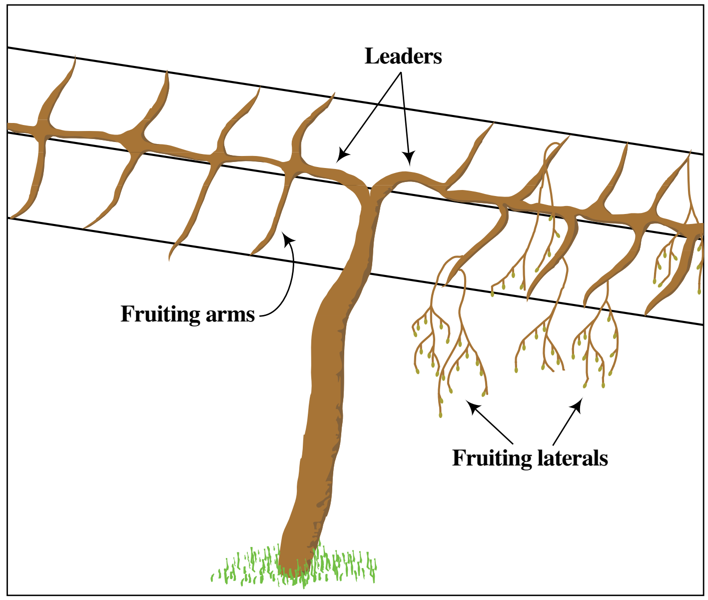


Figure 4. New Zealand Renewal System for training kiwi vines.

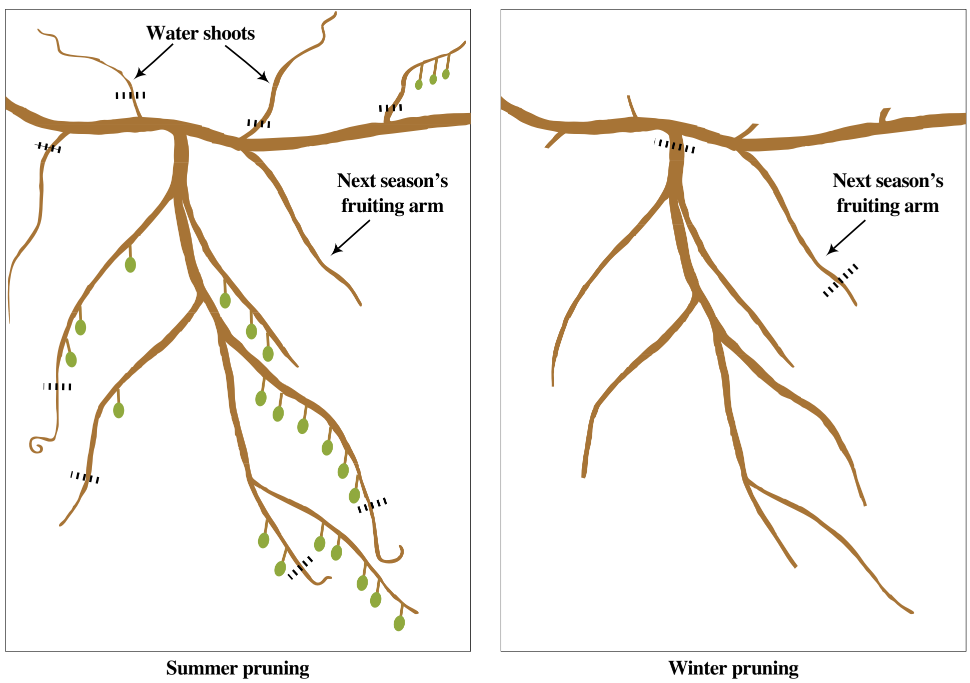


Figure 5. Winter and summer pruning cuts on kiwi vines.

and will bear for 2 to 3 years. Fruit will develop on shoots from these arms and hang down below the trellis wires. In the spring, pinch back the developing fruiting shoots to six leaves. Pinch off near the wire any erect water shoots on top of the trellis. During the summer, continue to pinch off the majority of developing arms. Leave only a number sufficient to serve as replacements for shoots that are no longer fruitful. During the winter, cut 2-year-old arms back severely (Figure 5); leave only two or three fruiting shoots that bore fruit the previous summer. These shoots will bear new shoots and fruit the next spring and summer.

Harvest and Storage

In western Washington, harvest fuzzy kiwi in late October. Pick fruit while still hard; a slight depression on the surface of the fruit when pressed hard with the thumb serves as a good indicator. The surface color of the fruit will have turned from green to full brown. Pick vines three or four times; harvest the larger fruit and leave the smaller ones to swell. Fruit can be left on the vine through a light freeze and even after the leaves have fallen, but it will shrivel if exposed to a hard frost. Snap the fruit off the vines but leave the fruit stalks intact.

Fruit can be held for 1 to 2 months in cold storage (32°F) before setting it out at room temperature to ripen. Once ripe, the fruit should last 10 to 14 days. Refrigerated ripe fruit may last up to 4 months. Do not store kiwi fruit with apples—apples give off ethylene gas which hastens kiwi ripening. Therefore, a ripe apple can be used to speed ripening of kiwi brought out of cold storage.

Disease and Insect Problems

Neither home nor commercial growers of kiwi in the Pacific Northwest have reported any serious insect or disease problems.

Currants and Gooseberries

Currants (*Ribes sativum*) and gooseberries (*Ribes grossularia*) are considered shrubby bush fruits. They bear colorful spring flowers and abundant berries that are tasty when processed. Unlike blueberries, they do well on almost any soil of average fertility, whether it is slightly acidic or alkaline. In addition, they can grow in soil that does not drain adequately to support strawberries or raspberries. Both currants and gooseberrics flourish in areas of partial shade where soil stays moist.

Currants and gooseberries are hardy in eastern Washington. They bloom fairly early in the spring, so avoid frost prone sites. They are considered drought tolerant, but irrigate them well during the summer. Because the plants can suffer under high temperatures, consider planting in a field with a northern exposure, or under the shade of a deciduous tree.

Gooseberry plants can reach 5 to 7 feet at maturity. They generally have thorny, arching canes borne singly along the stems. The fruit is too tart to be eaten out of hand and must be cooked for use in pies, jams, jellies, and preserves.

Currants are more erect than gooseberries and are thornless. Fruit are borne in grapelike clusters. Red-colored currants, while not as tart as gooseberries, are best when used in pies and preserves.

Gooseberries ripen from mid-June through early July. Both currants and gooseberries ripen on 2-year-old wood, but generally do not bear heavily for 3 to 4 years.

Widespread adoption of both fruits has been slow because they serve as alternative hosts for white pine blister rust (*Cronartium ribicola*) a disease that attacks five-needle pines, including western white pine and eastern white pine, in addition to attacking *Ribes* species. In the past, planting currants and gooseberries was illegal because of the potential damage to pines. Restrictions in the United States were dropped in 1966 after researchers determined that many wild *Ribes* species also serve as alternative hosts. Nonetheless, if five-needle pines do occur in the local landscape, consider planting other small fruits.

Cultivars

Recommended red currant cultivars are Red Lake, Perfection, and Wilder. A good white cultivar is White Imperial. Black currant cultivars include Consort and Crusader, both of which are considered rust resistant. Currants ripen in late July in western Washington.

For gooseberries, consider Poorman (red), Pixwell (pink), Oregon Champion (green, thornless bushes), or Captivator (pink).

Establishment and Cultivation

Planting

Dormant stock is available for mid-winter planting in January and February in western Washington, later in eastern Washington. Set plants 5 feet apart. A thick layer of mulch or well-rotted manure keeps roots surrounding the plants evenly moist during the dry summer months. The root systems are as shallow as those of blueberries.

Training

Grow gooseberries and currants as free-standing bushes, in hedgerows, or as fan-shaped bushes up against the side of a wall. The last method allows for easier picking when thorns are present. Diseases usually cause fewer problems because air can circulate through the foliage.

The objective in pruning free-standing bushes is to develop an open vase-shaped bush with equally spaced branches. In general, use more thinning cuts (removal of an entire branch back to the base) than heading cuts (shortening a branch). Failure to keep a bush pruned usually results in a brushy, unthrifty bush. The 2-, 3-, and 4-year-old branches are the most productive; at maturity a healthy bush probably has no more than six to eight branches.

Harvesting and Storage

Harvesting currants and gooseberries is a slow process, especially when gooseberry cultivars have thorns. Currants ripen over a 2-week period. Once mature, however, they hold on the bushes for a week without spoiling. Do not bother removing stems from red currants intended for juice or jelly, as the products are strained. Black currants are prized for their distinctive flavor in preserves and juices; in France, one cultivar is used for the manufacturing of brandy.

Gooseberries mature over a 4- to 6-week period. Pick them individually when the fruit attain full size. Juice, preserve, or freeze the fruit. All *Ribes* fruits are high in vitamins A, B, and C.

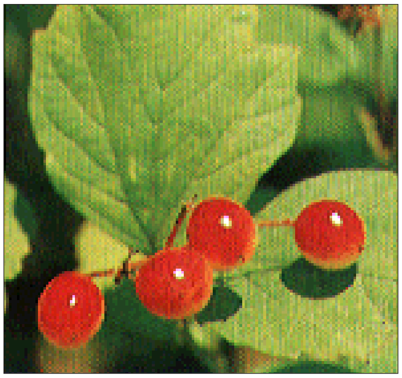
Disease and Insect Problems

Powdery mildew. The principal disease problem on both currants and gooseberries is powdery mildew. The disease is characterized by a whitish, powdery growth that occurs on leaves, shoots, and fruit. During fruit maturation, heavily infested fruit take on a brown, rough coating that makes them unusable. Humid conditions and crowded plantings that reduce airflow through the canopy favor powdery mildew. Prune to increase air circulation.

Currant fruit fly. Currant fruit flies, also known as gooseberry maggot, are one of the principal insect pests of currants and gooseberries. Currant fruit flies emerge as adults from the soil beneath the bushes in April, and soon lay eggs in developing berries. Resulting white maggot larvae feed within the berries, causing them to turn red and drop from the bushes. Apply foliar insecticides to gooseberry bushes in mid- to late April when adult flies are first noted. (Note: No home insecticides were registered for use on currants at the time of publication.)

Currrantworm. Imported currantworm larvae can defoliate *Ribes* bushes in a matter of days if left unchecked. Larvae, 1/2-inch long, are green with distinctive black spots.

Aphids. Aphids, another main insect pest, can devitalize currant and gooseberry plants and leave the fruit with a sticky, undesirable coating. Use a harsh water spray or insecticidal soaps to control aphids when necessary.



Miscellaneous Small Fruits

A number of minor small fruit crops that have ornamental and food uses are suitable for the home garden.

Elderberry

The common or American elderberry (*Sambucus canadensis*) forms a moderately tall shrub (6 to 16 feet) that bears large, flat-topped flower clusters. These produce an abundant quantity of purplish black berries approximately 1/4 inch in diameter. Plants grow on soil types that range from very moist to fairly dry. It takes 2 to 3 years for full production (10 to 15 pounds of fruit per bush). To promote good growth of elderberry bushes, every year prune any canes older than 3 years of age and leave a total of seven to nine canes on each bush.

Fruit grow principally on 2-year-old canes, although smaller flower clusters occur on 1-year-old canes. Fruit usually mature from late August to mid-September. For easiest harvesting, remove entire fruit clusters for later cluster stripping before processing. Make berries into sauces or use for pies or tarts, juice and wine, either alone or in combination with other berries. In the past, tannin in the bark and roots was used for tanning and dyeing leather. A cousin of the common elderberry is the Pacific red elderberry (*Sambucus callicarpa)*, a bush that bears bright red berries. The bushes are attractive as ornamentals, but fruit are edible by birds only.

Juneberry, Serviceberry

In the genus *Amelanchier* (Rose family), the Juneberry (*Amelanchier alnifolia*) known variously as serviceberry, saskatoon, sarvisberry, and shadbush, is a widely distributed slender shrub that can be 6 to 15 feet tall at maturity. Plants prosper in a wide range of soil types and pH and are very cold hardy. Drooping white flowers give rise to dark purple blueberry-like berries that mature in midsummer. Flowers are borne on 2-year and older wood. Prune a mature bush so five to seven shoots remain.

In the past, North American Indians prized the fruit for making pemmican, a dry mixture of fruit, meat, and suet. Today, people eat the berries fresh, use them in preserves, and make them into wines. Fruit harvested at an early stage of maturity have a higher pectin content and are more suitable for preserves, while more mature fruit, having a higher sugar content, are better suited for wine. Juneberries have no serious insect or disease problems; birds feeding on ripe berries can quickly strip the bushes.

Highbush Cranberry

Highbush cranberry (*Viburnum trilobum*) also called the American cranberrybush, forms an open, spreading bush that grows 6 to 13 feet tall; a dwarf type grows to half that height. Highbush cranberry shrubs display showy white flowers in the spring. Bright scarlet fruit mature in late July. You can use the berries as a substitute in cranberry sauce if you strain the large seeds out first. Particularly high in pectin, the fruit is suitable for preserves. While cooking, add shavings of lemon or orange peel to eliminate the odor the berries give off. Highbush cranberries have no reported serious insect problems. Powdery mildew may occur in times and places with limited air movement. The plants are hardy enough to grow anywhere in Washington.

Evergreen Huckleberry

Evergreen huckleberry (*Vaccinium ovatum*) is an evergreen shrub that can grow to 2 to 3 feet tall in full sun (twice as tall in the shade). Its blackish berries, covered by a white bloom, make the evergreen huckleberry a strikingly attractive ornamental. The fruit are used in preserves, and cut branches often are used in flower arrangements. Like other *Vaccinium* species, this one thrives in acidic soil. A closely related species, the red huckleberry (*Vaccinium parvifolium*) produces small, clear red berries on a slow-growing, spreading bush that prefers partial shade and an acidic, humus-rich soil.

Lingonberry

Lingonberry, also known as the mountain cranberry or foxberry (*Vaccinium vitis-idea*) is a low-growing, evergreen groundcover, producing red new growth that later turns a glossy green. It grows to a height of 6 to 12 inches and prefers partial shade and a large amount of water during the summer. Clusters of white, urn-shaped flowers produce bright red, tart berries that mature in August and September, but may persist on the bushes all winter. Berries are tart to bitter when first picked, but their flavor improves when picked after the first frost. Fruit are highly regarded for use in preserves and syrups; use them as substitutes for the true cranberry. The plants are hardy enough to grow anywhere in Washington State.

Further Reading

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9

Lawns

Topics covered:

- Introduction
- Biology of Grass
  - Identifying Turfgrass Species
- Choosing a Grass Variety or Mix
  - Site Considerations
  - Types of Turfgrass
  - Cultivars
- Establishing a New Lawn
  - Soil Requirements
  - Surface Preparation
  - Seeding
  - New Lawn Care
- Lawn Maintenance
  - Mowing
  - Watering
  - Fertilizing
  - Aeration
  - Thatch Control
  - Weed Control
  - Disease Control
  - Insect Control
- Lawn Renovation

Learning Objectives

- ✿ Recognize the types of turfgrass and their suitability for different site conditions
- ✿ Know cultivars for Eastern and Western Washington
- ✿ Know principles of soil and site preparation for healthy lawns
- ✿ Know basic practices for the establishment, maintenance, and renovation of lawns
- ✿ Recognize common lawn problems, diseases, and pests, and methods of managing them

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With additional material adapted with permission from EB0482: *Home Lawns* by Gwen K. Stahnke, Stanton E. Brauen, Ralph S. Byther, Arthur L. Antonelli, and Gary Chastagner.

Introduction

Grasses cover a lot of ground – both literally and figuratively. In this chapter we will be discussing lawns which, traditionally, are expanses of turfgrass, as opposed to ornamental, bunch, or cereal grasses.

Lawns serve important functions in a landscape. They can be aesthetically pleasing and provide a playing or walking surface while covering erodible soil and producing oxygen. Lawns can fill areas where otherwise more problematic weeds might get established. Turfgrasses are most commonly chosen for lawns because they are hard wearing and attractive. They can be repeatedly cut or mown low because the growing point is at the base of the plant. Turfgrasses are even used as roofing material (Figure 1) because of their insulating quality and other environmental benefits, but we will consider them only for lawns in this chapter.

Establishing a healthy turfgrass lawn requires choosing the right cultivars for the site and expected usage, plus good ground preparation. Once the turfgrass is properly established, continued maintenance—moderate watering and mowing, with fertilizing, dethatching, and aeration when needed—will keep it healthy for years to come. This chapter discusses each of these topics in detail.

Figure 1. Turfgrass can be used as a roofing material. Here it is part of the roof of the Holland Library on the Pullman campus of Washington State University. (Photo courtesy of Gerald Steffen.)

Biology of Grass

Grasses have adapted to conditions ranging from rain forests to deserts and even intertidal habitats and are the most widespread plant form on earth. Formerly in the family Gramineae, but now known as Poaceae, this family is considered by some to be the most important plant group because it includes the staple food grains and cereal crops (Table 1) that feed much of the world.

True grasses (family Poaceae) are monocots and usually have round, hollow stems. Reeds and sedges are considered grass-like but are classified in different families. Flowers of true grasses are usually arranged in spikelets.

Table 1. Economically important grasses (not all of which will grow in the Northwest).

Grain crops	Leaf & stem crops	Turfgrasses
Barley	Bamboo	Bentgrass
Corn (maize)	Bluegrass (meadow grass)	Bermuda grass
Millet	Reeds	Bluegrass (meadow grass)
Oats	Ryegrass	Fescue
Rice	Sugarcane	Ryegrass
Rye		St. Augustine grass
Sorghum		Zoysia
Wheat		

Scientific classification of grasses

Kingdom: Plantae

Order: Poales

Family: Poaceae

Subfamilies: (6 of 12):

- Bambusoideae (bamboo)
- Danthonioideae (pampas grass)
- Ehrhartoideae (rice)
- Panicoideae (corn, sorghum, sugarcane, millet)
- Poaceae (turfgrasses)
- Pooideae (wheat, barley, brome-grass, reed grass)

Identifying Turfgrass Species

Vegetative parts of a grass plant (Figure 2) are useful for identifying a grass species. Always use more than one plant and identifying structure for identification, since vegetative characteristics can vary depending on environmental conditions or cultivar. Plant aspects to consider for identification include:

- Leaf blade
- Ligule
- Auricle
- Leaf sheath
- Leaf bud
- Collar
- Vernation
- Growth habit

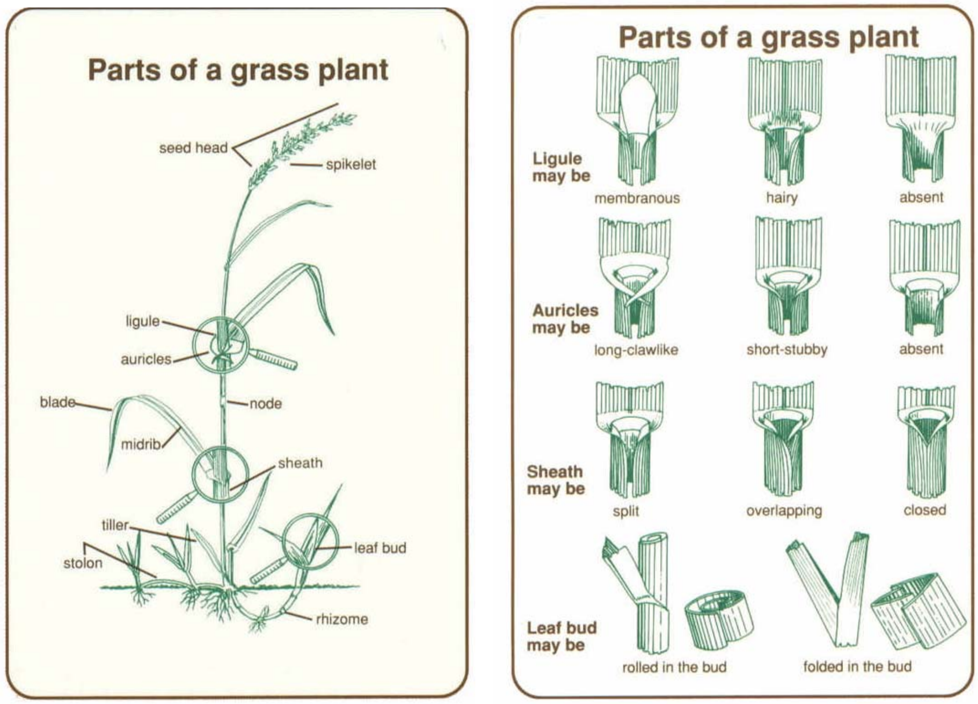

Figure 2. The basic anatomical parts of a grass plant (left) and hints on what to look for when identifying different types of grass (right). (Images courtesy of the USDA Soil Conservation Service.)

Figure 2 illustrates some of these plant parts, and below are hints on what to look for when identifying a type of grass.

Leaf Blade. The blade is the upper flattened portion of a turfgrass leaf.

- Is the leaf texture fine, medium, or coarse?
- Are veins prominent?
- What shade of green is the blade?
- Is the blade smooth (glabrous) or hairy (pubescent)?
- Is the tip of the blade sharply pointed, boat-shaped, or blunt and round?

Ligule. The ligule is an appendage on the inner side of a grass leaf at the junction of the blade and sheath. Not all grasses have ligules.

- Is the ligule absent, membranous, or hairy?
- If present, what is the size and shape of the ligule?
- What does the upper edge of the ligule look like? Is it smooth, notched, or hairy?

Auricles. Auricles are appendages occurring in pairs at the base of the blade. Not all grasses have auricles. If present, auricles vary in size and shape from barely noticeable knobs to long, clasping arms.

- Are auricles present or absent?
- If present, are auricles small (rudimentary) or prominent (claw like)?

Leaf Sheath. The sheath is the lower portion of a leaf—the part that encircles the stem.

- Is the sheath cylindrical or compressed?
- Is the sheath closed or open, or do the margins overlap?

Vernation. Vernation refers to the arrangement of new, young leaves within the older leaf sheath or the leaf bud.

- Is the new leaf folded or rolled when it emerges?

Collar. The collar is a band or line where the leaf blade and the leaf sheath meet.

- Is the collar divided, broad, or narrow?

Growth Habit. Growth habit refers to the orientation of shoots.

- Is the plant erect or lying down (decumbent)?
- Are there lateral shoots such as rhizomes, stolons, or tillers?

Choosing a Grass Variety or Mix

Several kinds of grasses are used for turf in the Northwest. There is not one ideal grass to plant. Many cultivars of each have been developed through selection and breeding. Cultivars differ primarily in leaf color, texture, disease resistance, and stress tolerance, including the amount of traffic and wear they can tolerate (Table 2).

There are advantages and disadvantages to any kind of grass. It's important to choose a turfgrass that is suited to your site's soil, light, and drainage conditions, as well as the expected use. Kentucky bluegrass, fine fescues, and turf-type tall fescues are best for areas east of the Cascades. Turf-type perennial ryegrasses, fine fescues, and bentgrasses are well adapted to conditions west of the Cascades. Specific cultivars of Kentucky bluegrass can be used west of the Cascades in seed mixtures, especially in high traffic areas. Tall fescues can be used in shady, wet areas, but will go off-color in winter on the west side of the state.

Table. 2. Turfgrass descriptive identification features.

Turfgrass Type	Characteristics
Bluegrasses	Boat-shaped blade tips, short ligules. Distinctive rhizomes on established plants. Annual bluegrass (a weed) is yellow green with a long ligule and prolific seed heads.
Fine fescues	Very narrow, somewhat rounded leaves, heavy veining. Fibrous-rooted (sometimes rhizomatous). Thatchy. Bunch-type or clumping growth habit.
Tall fescues	Wider leaf blade, pointed tip, heavy veining on upper side and somewhat shiny on the underside. Usually has auricles and hook like appendages on leaf margins. Bunch-type growth habit. Some cultivars are weakly rhizomatous with a more spreading growth habit than other bunch grass cultivars. Can be purple at the base of the sheath, like ryegrasses.
Bentgrasses	Continuous parallel veins, fine leaf blades, and pointed leaf tips. Fibrous-rooted (sometimes rhizomatous), stolons present. Thatchy.
Ryegrasses	Upper sides of leaves heavily veined, shiny/waxy-appearing lower leaf surfaces, pointed leaf tips. Fibrous-rooted. Often have purple sheath bases. Bunch-type growth habit.

Site Considerations

Shade or Sun. If many evergreen trees are on your site, select grasses that withstand shade. If there are so many trees that no grass will perform adequately (greater than 50 percent shade), consider groundcovers or just mulching around the trees.

Seed mixes for moderate shade should include high proportions of fine-leaved fescues, such as creeping red, Chewings, or hard fescue. Tall fescue also withstands partial shade. In dense shade or wet, shady sites, add roughstalk bluegrass (*Poa trivialis*) to the seed mix. It is the most shade-tolerant grass we can grow in the Northwest. Consider tall fescues on sites with both shade and moderate traffic because fine fescues and roughstalk bluegrass do not withstand intense traffic. Turf-type perennial ryegrasses and Kentucky bluegrasses are not very shade-tolerant.

Drainage. Fine fescues and turf-type perennial ryegrasses do not perform well on soils that are saturated for long periods. Bentgrasses and turf-type tall fescues perform better on these soils.

Expected Use. Any of the recommended grasses can be used for lawns that receive only moderate foot traffic and no heavy play from children. For lawns that receive a considerable amount of heavy play, use primarily turf-type perennial ryegrasses on the west side of the Cascades, with selected Kentucky bluegrasses and fine fescues in the seed mixture. For lawns with heavy traffic east of the Cascades, use primarily Kentucky bluegrass and blend three cultivars that have performed well for your area.

Types of Turfgrass

Kentucky Bluegrass. Kentucky bluegrass is well adapted to areas east of the Cascades in Washington and is one of the best choices for a home lawn there. It does well in high pH soils (7 to 8) and needs full sun. Most cultivars are susceptible, however, to necrotic ring spot disease. Table 3 shows susceptibility of some Kentucky bluegrass cultivars.

We do not recommend a **monostand** (pure stand) of any turfgrass cultivars. There is no problem having Kentucky bluegrass as part of a mixture, but many cultivars generally do not persist for more than 3 to 5 years. Table 4 lists the Kentucky bluegrass cultivars best suited for use west of the Cascades (in seed mixes for turf longevity). Kentucky bluegrass is included in seed mixes, mostly on sports fields, to add stability to an area: it grows via rhizomes, which hold turf together and help damaged areas fill in quickly. This is a definite advantage on athletic fields.

Fine Fescues. Fine fescues for lawns include creeping red, Chewings, and hard fescues. These grasses require little fertilizer compared with other types. They are reasonably drought-tolerant (especially hard fescues) and are shade-tolerant both east and west of the Cascades. Most fine fescues are very susceptible to red thread disease, but are moderately resistant to other diseases. Hard fescues are resistant to red thread disease. All fine fescues have a tendency to develop thatch, so a good cultural program is important.

Fine fescues tolerate only light wear and are not suitable for play areas or sports fields. They can be planted with colonial bentgrasses for golf course fairways, tees, and some greens. The Chewings fescues tend to germinate quickest and blend with the colonial bentgrasses most successfully in mixtures west of the Cascades.

Turf-type Tall Fescues. These types of tall fescue are well adapted to sites that remain somewhat wet for extended periods. They also withstand drought conditions (because they have deep roots) and moderately high salt concentrations. They must have deep soil in order to develop and take advantage of deep roots. Tall fescues have moderate fertility requirements, moderately good shade tolerance, and moderate wear tolerance.

These grasses can be slow to germinate and fill in when soil temperatures drop below 55°F. As a result, annual bluegrass may invade during lawn establishment. If a solid stand is achieved, tall fescues make a good lawn, although they can be overrun rapidly by invading grass species west of the Cascades due to their slow growth in the winter months. Applications of a growth regulator can be made by professionals to limit the growth of annual bluegrass, while the tall fescue will continue to grow and crowd out the annual bluegrass from the grass stand.

Table 3. Kentucky bluegrass varieties and their susceptibility to necrotic ring spot in Eastern Washington.

Kentucky bluegrass variety	Susceptibility to NRS*
A-34	I
Able I	R
America	I
Asset	I
Blacksburg	I
Challenger	I
Chateau	I
Cheri	S
Conni	I
Destiny	I
Eclipse	R
Estate	I
Glade	S
Gnome	I
Julia	R
Kelly	I
Lofts 1757	I
Majestic	R
Marquis	I
Midnight	R
Princeton	R
RAM I	S
Sydsport	I
Touchdown	R
Victa	S
Wabash	R

*R = resistant; I = intermediate; S = susceptible

Turf-type tall fescue leaves are coarser than leaves of other commonly planted grasses. New cultivars have been developed with finer leaf blades and a slower rate of growth. They can be used in the western parts of Washington, but some people find the olive green to brownish color in the winter undesirable.

Turf-type Perennial Ryegrasses. These grasses are extremely wear-tolerant, produce beautiful lawns with little thatch, and blend well with other grasses for west of the Cascades. They require moderate to high nitrogen fertility. Under low-fertility conditions, perennial ryegrass is rapidly out-competed by invading grass species.

Seeds germinate very rapidly (5 to 7 days under ideal conditions) and quickly out-compete weeds. Like fine fescues, ryegrasses are highly susceptible to red thread disease. Perennial ryegrasses may suffer some cold injury during severe winters east of the Cascades. When purchasing perennial ryegrass seed, be sure to ask for turf-type, since otherwise common pasture ryegrasses might be substituted.

Bentgrasses. In western areas of Washington, use only colonial-type bentgrasses, which have shorter stolons for lawns (for example, Bardot, Tracenta, SR 7100, Tiger, or Astoria). Do not use creeping bentgrasses. Colonial bentgrasses perform well under low fertility, on acid soils, and in moderate shade. Thatch development is the worst problem with bentgrasses; they require semiannual dethatching. They are susceptible to fusarium patch and take-all patch, and are slightly susceptible to red thread. Bentgrass is a prominent weedy grass in lawns in Central and Eastern Washington, and should not be part of any seed mix purchased.

Well-maintained bentgrasses produce the most professional-looking lawns (such as on golf courses), since they can be mowed to very low heights. Bentgrasses are at their best when maintained at 3⁄8 to 3⁄4 inch high and using a reel mower. When mowed above 1 1⁄2 inches, they tend to produce excess thatch and are prone to scalping.

Other Types of Grasses. Do not include Zoysia, St. Augustine, Bermuda, dicondra, centipede, carpetgrass, or mondograss in Washington lawns. These grasses are not adapted to Washington's climate.

White clover is sometimes included in lawn seed mixtures. It is not a grass and is usually considered and treated as a lawn weed. It can be killed by most common broadleaf herbicides sold for home lawn use.

Cultivars

Tables 4 and 5 list adapted varieties for Western and Eastern Washington. Not all varieties are listed, since information is not always available for every one. If insufficient or inconsistent observation is the only information available for a variety, that variety may not appear on the list.

"Best Choice" cultivars have the best test performance records during recent years in Washington. We suggest use of these cultivars where they are available. Certainly use them if you want high-quality turf. "Next Best" cultivars have the next best records and provide good to excellent turf, but may be more susceptible to local diseases or may become discolored and thin more often than the best cultivars.

Kentucky bluegrass is not well-adapted to Western Washington, so use only the best cultivars there. Other cultivars of Kentucky bluegrass may disappear quickly from the turf. Turf-type tall fescues have been inconsistent in different locations, so use the best cultivars listed for each region.

Table 4.— Turfgrass cultivars for Western Washington (2009). The list of varieties included below is in constant revision as new varieties are released or become available on the market. The letter following each cultivar is a general designation for color. VD = very dark; D = dark; MD = medium dark; M = medium; L = light.

Perennial Ryegrass

Best Choice		*Next Best*		*Third Choice*	
Kokomo II	D	Silver Dollar	D	Nexus XR	D
Uno	MD	Amazing GS	D	Goalkeeper II	M
Zoom	M	Primary	M	Wind Dance 2	D
Apple GL	D	1G Squared	M	Brea	M
Fiesta 4	D	Transformer	ML	Inspire	L
Homerun	M	Cutter II	D	SRX 4682	M
Cabo II	VD	Mach I	M	Quicksilver	M
Derby Extreme	D	Brightstar SLT	M	Gray Fox	M
Palmer IV	D	Grand Slam 2	M	Monterey 3	M
Fiji	VD	Keystone 2	M	Premier II	L
Stellar GL	VD	Citation Fore	M	Barlennium	M
Protégé GLR	D	Cutter II	D	Palmer III	L
Allstar 3	M	Line Drive GLS	M	ASP6006	VD
Attribute	MD	Edge II	D	Firebolt	VD
Defender	M	Paragon GLR	D	Accent II	M
Palace	D	Pianist	MD	Presidio	D
Buena Vista	MD	Repell GLS	M	Hawkeye 2	M
Charismatic II GLSR	MD	Secretariat II GLSR	ML	ASP6004	D
		Harrier	M	ASP6001	D
Exacta II GLSR	VD	Regal 5	D	Premier	VL
Calypso 3		Panther GLS	M	Affinity	VL
OverDrive	M	Dasher 3	M		
Sunshine 2	D	Fusion	MD		
		Gray Star	M		
		Phenom	M		
		Top Gun II	MD		
		Delaware XL	VD		
		Ringer II	L		
		Revenge GLX	D		
		Pinnacle II	MD		
		Pleasure Supreme	MD		
		Galatti	MD		
		Manhattan 5 GLR	M		

Fine Fescue, Strong Creeping Red

Best Choice		Next Best		Third Choice	
Epic	MD	Celestial	MD	Shademaster	M
Cardinal	M	Class One	M		
Fortitude	D	Razor	M		
Wendy Jean	M	Oracle	M		
Garnet	MD	Splendor	D		
Pathfinder	MD	CO3-4676	M		
Jasper II	MD	Boreal	MD		

Fine Fescue, Slender Creeping (SR)

Best Choice		Next Best		Third Choice	
Dawson E+	MD	Comfort	MD	(none)	
Shoreline	D	Smirna	MD		
Barcrown	MD				
Marker	M				
Napoli	MD				
Barskol	MD				
Seabreeze	L				

Fine Fescue, Chewings

Best Choice		Next Best		Third Choice	
Treazure II	MD	LaCrosse	D	(none)	
Musica	L	Cascade	M		
Zodiac	D	Culumbra II	D		
Compass	D	J-5	MD		
Tiffany	MD	Longfellow II	D		
Shadow II	MD	7 Seas	MD		
Weekend	D	Banner III	D		
Tamara	MD	Beauty	MD		
Ambassador	D	Waldorf	MD		
SR 5130	MD	Highlight	M		

Fine Fescue, Hard/Sheep

Best Choice		Next Best		Third Choice	
Berkshire	MD	Predator	D	(none)	
Reliant IV	MD	Scaldis	M		
Spartan II	D				
Oxford	MD				
Gotham	D				
Bighorn (Sheep)	VD				
Aurora w/Endo	D				
Biljart	D				
Discovery	D				
Firefly	MD				
SR 3000	MD				
Quatro (Sheep)	MD				
Nordic E	D				
Osprey	D				

Tall Fescue

Best Chioce		*Next Best*		*Third Choice*	
Traverse SRP	M	Firecracker LS	ML	Biltmore	M
Faith	M	Bullseye	M	Toccoa	D
3rd Millennium SRP	M	Spyder LS	M	Darlington	D
		Turbo RZ	M	Plato	ML
Essential	M	Talladega	M	Lindbergh	M
Padre	D	Skyline	M	Reunion	M
Firenza	M	Cezanne	M	Aristotle	ML
Wolfpack II	MD	Falcon IV	L	Tahoe II	M
Speedway	M	Turbo	ML		
Hemi	M	Escalade	ML		
Van Gogh	M	Renovate	D		
SR 8650	D	AST9002	D		
Rhambler SRP	M	AST9003	D		
Rebel IV	M	Justice	M		
Mustang 4	M	Titanium LS	ML		
		Compete	D		
		Gazelle IV	M		
		Magellan	M		
		Silverado	L		
		Einstein	M		
		AST9001	D		
		Rembrandt	M		

Kentucky Bluegrass

Best Choice		*Next Best*		*Third Choice*	
Champagne	M	Boomerang	D	(none)	
Blackstone	M	SR2284	MD		
Bariris	MD	Shamrock	M		
Washington	M	Brooklawn	M		
Freedom II	D	Cynthia II	M		
Champlain	MD	Julius	MD		
Princeton 105	MD	Freedom III	MD		
Baritone	D	Avalanche	M		
Odyssey	MD	Chelsea	MD		
Barzan	M	Blacksburg II	M		
Serene	M	Everglade	MD		
		Langara	MD		
		Limousine	M		
		Bodacious	MD		
		Lakeshore	ML		
		Cheetah	L		

Bentgrass, colonial
(Note: only colonial bluegrass is recommended for use in lawns and similar areas.)

Best Choice		*Next Best*		*Third Choice*	
SR 7100	L	(none)		Greentime	M
				Tiger II	M

Table 5.—Turfgrass Cultivars for Eastern Washington (2007).

The commercially available cultivars listed here have performed well in the National Turfgrass Evaluation Program (NTEP, www.ntep.org) trials located in Pullman, WA, over the past several years. This list is not a ranking and does not contain all cultivars, but is a sampling of cultivars to look for when selecting a seed mixture. Colors are: VD = very dark green, D = dark, MD = medium dark, M = medium and L = light green.

Kentucky Bluegrasses							
Chicago II	VD	Blue-Tastic	MD	Diva	M	Mallard	M
Ginney	D	Everest	MD	Freedom II	M	Perfection	D
Moon Shadow	MD	Impact	VD	Liberator	D	Ulysses	MD
Everglade	VD	North Star	MD	Midnight II	VD	Showcase	M
Blue Velvet	D	Rugby II	VD	Total Eclipse	VD	Skye	M
Bluestone	VD	Award	VD	Alexa	VD	Sonoma	M
Courtyard	VD	Awesome	MD	Bedazzled	M	Voyager II	M
Excursion	VD	Barrister	VD	Freedom III	VD	Princeton 105	MD
Moonlight	D	Midnight	M	NuDestiny	VD		
Tsunami	D	NuGlade	VD	Blue Knight	D		
Odyssey	MD	Quantum Leap	D	Bordeaux	MD		
Arcadia	MD	Bluemax	D	Botique	M		
Beyond	D	Boomerang	M	Glenmont	M		
Perennial Ryegrasses							
Gray Star	D	Pizzazz	M	Sunshine 2	M	Kokomo II	MD
Protégé GLR	M	ASP6002	MD	Line Drive GLS	M	Attribute	M
Halo	D	Headstart 2	M	Exacta IIGLSR	M	Regal 5	MD
MS2	M	Mach I	M	Palace	M	Monterey 3	M
Delaware XL	M	Palmer IV	M	All*Star 3	MD	ASP6006	M
PM 102	VD	Paragon GLR	M	$ilver Dollar	M	Fiesta 4	L
SR 4600	M	PM 101	M	Buena Vista	L	Quicksilver	M
Phenom	M	PM 103	M	Presidio	MD	ASP6001	MD
Amazing GS	M	Harrier	M	ASP6004	MD	ASP6003	MD
Fineleaf Fescues							
Compass	VD	Reliant IV	M	7 Seas	M	Culumbra II	MD
Jasper II	M	Spartan II	M	Predator	D	Ambassador	M
Gotham	M	Longfellow II	M	Oxford	M	SR 5130	M
Fortitude	VD	Zodiac	M	Berkshire	D	Celestial	MD
Razor		Epic	L	Splendor	MD	Audubon	M
Wendy Jean	M	Scaldis	M	SR3000	MD	J-5	M
Cascade	L	Seabreeze	L	Pathfinder	MD	Quatro	M
Tall Fescues							
Justice	MD	Avenger	M	Hunter	VD	Cochise III	M
Inferno	M	Coyote II	MD	Lexington	M	Falcon IV	M
Firebird	VD	Forte	MD	Guardian-21	M	Raptor	D
SR 8550	D	Blackwatch	MD	Escalade	MD	Gremlin	MD
Padre	M	Quest	M	Rebel Exeda	MD	Rebel Sentry	M
DaVinci	D	Fidelity	MD	Finelawn Elite	MD	Focus	D
Ultimate	M	Barrington	M	Bingo	VD	Cayenne	M
Constitution	M	Covenant	M	Five Point	D	Kalahari	M
Magellan	MD	Millenium	M	Innovator	M	Signia	D
Titanium	MD	Tracer	MD	2nd Millenium	M	Scorpion II	M
Corgi	M	Dominion	M	Matador	MD	Penn1901	MD
Serengeti	MD	Apache III	M	Barlexas	M	Barrera	M

Establishing a New Lawn

Regardless of whether you establish a new lawn by sodding or seeding it, the lawn will have the same basic requirements. Use the methods described in this chapter to prepare and maintain a new lawn.

Soil Requirements

One of the most important factors affecting a lawn's health is the soil or root zone. Consider the following soil characteristics before planting a lawn.

Texture. It is not always possible, or even necessary, to have beautiful topsoil to establish a new lawn or landscape area. Lawns can grow in essentially any soil texture from sand to clay, and there are trade-offs with each texture. Consider that the lighter the texture (for example, sandy soil), the more difficult it is to hold nutrients and water in the root zone, but sandier soil will not compact much under heavy traffic. Conversely, the heavier the texture (for example, a clay soil), the more water the soil holds so drainage can become an issue, as will compaction from heavy traffic. Heavier textured soils will require less frequent fertilization and watering. In general, a moderate-textured soil works best for lawns and other garden purposes in terms of holding adequate water and nutrients with minimal compaction.

Depth. When new homes are built, 2 to 4 inches of imported soil or sand are often placed over cemented hardpans or other obstructions. Since the majority of grass roots are in the upper 2–4 inches of the soil, a lawn planted on that shallow imported soil is doomed to failure because of drainage problems, principally during winter or whenever the heaviest rainfalls occur. There must be some oxygen in the soil for the roots to be able to function properly.

It is best to have at least 1 foot of permeable soil over hardpan, dense clay, or very gravelly subsoil to allow for gravitational drainage. Six inches of topsoil over a well-drained base is the minimum recommended for a good-quality lawn. Sandy subsoils work quite well, provided you follow appropriate fertility recommendations.

Drainage. Construct beds and lawns so they grade away from the house with a 1 to 2 percent slope if possible. Using surface drainage in this way is always best, since this is far less expensive than installing subsurface drainage. If your soil contains cemented hardpans or extremely heavy clay layers, then drain lines or pipes may need to be installed in the root zone during construction, before the lawn is planted.

For subsurface drainage in a home landscape, usually 4-inch diameter drain tile (perforated pipe) is used. Place pipe at least 16 inches below the finished surface and 10 to 15 feet apart. Put about 2 inches of pea gravel below the pipe and then cover the pipe with at least a 4-inch layer of pea gravel, then add sand or sandy soil to the surface. Note: do not cover the drain lines with a sod that has been grown on a heavy clay-based soil, since the attached soil that comes with the sod can restrict the downward flow of water to the drainage lines.

Fertility. It always is best to do a soil test before finishing soil preparation for a new lawn. Test for phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), organic matter, and pH. County Extension offices can provide information on soil testing facilities, or see http://www.puyallup.wsu.edu/analyticallabs/ for database of soil-testing laboratories serving the Northwest. See Chapter 3: Soil Science, for details on how to collect soil samples for testing.

If phosphorus (P) or lime (Ca and Mg) is needed, incorporate it into the soil before establishing a lawn. Nitrogen and potassium, both of which are water-soluble, will find their way into the root zone with rainfall or irrigation, so you can add them later, at the time of seeding or sodding.

In Western Washington, if it's not possible to test your soil, apply 10 pounds of a starter fertilizer such as 10–20–20 (N–P–K) before planting, to get the lawn off to a good start. This rate provides 1 pound of nitrogen (N) per 1,000 square feet and 2 pounds each of P and K per 1,000 square feet. Establishing a lawn from seed or sod is the only time a starter fertilizer should be used. After that, a fertilizer with a 3–1–2 or 6–1–4 formulation should be used for maintenance of the turfgrass, since much less phosphorus is required by the grass after it is established. In Eastern Washington, there is usually more than enough P, K, and Ca present in the soil and they are not necessary for establishment.

Surface Preparation

After the lawn area is graded, it must be rolled, raked, and smoothed out. The smoother the bedding surface and lawn, the easier it is to mow without scalping and to use for outdoor activities. After grass roots lock soil particles together, minor surface irregularities become very difficult to remove. Loosen compacted soil to the point that a 160-pound person walking across the surface leaves footprints approximately 1⁄2 inch deep. If soil is thoroughly rototilled, you will need to roll the area with a landscape roller in order to get the soil to this firmness.

Seeding

Seeding rates for various grasses are given in Extension publications PNW 299: Turfgrass Seeding Recommendations for the Pacific Northwest, and EB0482: Home Lawns.

Always store seed in a cool, dry place to keep the seed viable for several years. To achieve best coverage, distribute half of the seed over the site in one direction, then apply the other half at a 90-degree angle to the original direction. Save a few ounces of seed to patch up thin areas or to have analyzed if you later suspect you received poor-quality seed. It is best to buy **certified seed** (seed with a blue tag on the bag) to guarantee the germination rate, minimal weed seed content, and the proper improved cultivars of seed for the area you are planting. Certified seed is more expensive, but it is very much worth the extra cost over the years of your lawn maintenance.

After distributing the seed, lightly rake it into the top 1⁄4 inch of soil, then roll the surface with a lawn roller half full of water. Use sprinklers to maintain constant surface moisture, without constant puddling, until the seeds germinate (usually about 7 to 10 days). The best method is to use several light irrigations daily. Do not let the bedding surface dry out before the seed has germinated because the rate and percentage of germination may be severely reduced. For information on sodding, see Oregon State University publication EC 966: Establishing Lawns by Sodding.

Seeding Rates

Detailed seeding rates for turfgrasses in Washington can be found in the following publications from WSU Extension:

PNW0299—Turfgrass Seeding Recommendations for the Pacific Northwest

Available in hard copy:

https://cru84.cahe.wsu.edu/Default.aspx

EB0428—Home Lawns

Available in hard copy or electronically:

http://cru.cahe.wsu.edu/CEPublications/eb0482/eb0482.pdf

New Lawn Care

Generally, a lawn is considered "new" for its first growing season. Mow the new lawn as soon as there is enough grass to cut, usually after 4 to 6 weeks of new growth.

Watering. After the grass seed sprouts, reduce the watering frequency. In general, new grass can go approximately 2 days without water (an exception would be for grass grown on pure sand). After you mow the grass the first time, you can irrigate even less frequently. Mature lawns on soils approximately 1 foot deep can go as long as a week without irrigation. When most of the soil moisture is gone, replenish the total amount at one time by watering slowly and deeply. Avoid watering more than two or three times per week.

Pest Control. Diseases generally are not a problem on new lawns except during fall establishment in western parts of Washington. Microdochium (Fusarium) patch is the major disease problem. If it is severe enough, fungicides can be applied.

Establishing a lawn in summer and watering excessively may create conditions favorable to the development of damping off (*Pythium*) and brown patch.

Good Lawn Management Practices

- Mow at the proper height. Don't increase the mowing height at any time during the season.
- Maintain adequate fertilization for normal growth. Nitrogen is important to stimulate populations of bacterial organisms, but do not over-fertilize. A balanced program is essential.
- Water thoroughly and infrequently. Avoid light, frequent irrigations. Do not over-water.
- Check soil depth and moisture content frequently during the irrigation season, and irrigate properly to maintain correct soil moisture levels.
- Aerate the soil with hollow-tined aerifiers if soil becomes compacted or if water does not penetrate.
- Use soil tests to determine the pH. Maintain proper pH levels. If the soil becomes too acidic (below 5.0), a light application of lime may help.
- Never use creeping bentgrass varieties for home lawns because of the proliferation of creeping stems (stolons). Creeping bentgrasses are recommended only for specialized areas such as golf putting greens.

Do not spray weeds in a new lawn until the lawn is at least 6 weeks old. Use the lowest recommended rate on the herbicide label if it says it is appropriate. Other pests usually are not a severe problem in Washington.

Fertilizing. If you applied a starter fertilizer, there usually is little need to fertilize a lawn before it is approximately 4 to 6 weeks old. At that time, begin a fertilization program as discussed under "Lawn Maintenance," below. Note, however, that lawns on extremely sandy soils may require some nitrogen 3 to 4 weeks after establishment. To prevent leaching, apply about 1/2 pound of available N at the time of lawn establishment and another 1/2 pound of available N after about 3 weeks later.

Lawn Maintenance

A good lawn should last a long time if properly mowed, watered, fertilized, aerated, dethatched, and over-seeded as needed. Control pests when they are diagnosed at levels harmful to the turf.

Mowing

Use a mower with sharp blades to cut grass sharply, keeping a lawn looking neat and well trimmed (Figure 3). Do not reduce or lower the mower's cutting height more than ½ inch (one notch or setting on a rotary mower) per mowing or you will scalp the lawn, causing brown patches. Normally this will not kill a lawn, but if the lawn is thatchy, the scalping and browning will further stress

Figure 3. Mowing injury: frayed, straw-colored leaf tips from a dull mower.

the lawn, making it more susceptible to bugs and disease. Mow at regular intervals to promote a healthier lawn.

Mowing height can influence a lawn's appearance and life span. Table 6 lists recommended mowing heights for grasses in Eastern and Western Washington. Do not remove more than 30 percent of the leaf blade in a single mowing.

Table 6. Suggested mowing heights for turfgrasses.

Grass	Mowing Height (inches)	
	West of Cascades	East of Cascades
Kentucky bluegrass	1 to 2 1/2	1 to 3
Fine fescue	1 to 2 1/2	1 to 3
Perennial ryegrass	1 to 2 1/2	1 to 3
Tall fescue	2 to 3	2 to 3
Bentgrass	1/2 to 1	—

Removing grass clippings is optional. Research shows that mulched clippings (finely chopped clippings left on the lawn) can be beneficial, although some thatch may accumulate under extremely cool, moist conditions and with turfgrasses with high lignin content such as fine fescues. If the lawn has excessive weeds, seeds are also returned with mulched clippings. Remove excessive clippings, mulched or not, so they do not smother the lawn and encourage disease.

Watering

Over-watering can cause many problems, most notably leaching of nutrients out of the root zone. Also, saturated soils suffocate roots because saturated soils are very low in oxygen. Roots prefer to develop where oxygen supplies are high, so saturated soils tend to discourage deep rooting and induce surface rooting. Shallow rooted lawns cannot withstand sudden changes in temperatures or soil moisture.

Thorough, infrequent watering generally is more desirable than light, frequent applications, which tend to result in over-irrigation. Monitor turf closely and water before wilting or browning occurs. Use a soil probe or shovel to check soil moisture content. Here are some tips to help you know when to water:

- Know your soil's texture and depth in order to understand its moisture-holding capacity. This will help you know what to expect in terms of the lawn's watering requirements.
- On hot, dry summer days, lawns may consume more than 1⁄4 inch of water. Average consumption is 1⁄8 inch per day in Western Washington and 1⁄4 inch per day in Eastern Washington.

When watering a lawn:

- Apply only enough water to adequately wet the root zone.
- Apply water slowly to achieve better infiltration and to prevent runoff.
- Place straight-sided, flat-bottomed containers within the sprinkler pattern to determine the rate of water output.
- Use soil-wetting agents (surfactants) to make dry spots accept water if needed.
- Water early in the morning or very late at night to minimize evaporation.
- Water early in the morning to minimize disease problems such as mildew.

- The surest ways to determine when to water a lawn are to feel the soil in the root zone and to observe the appearance of the grass. Signs of excessive dryness include blue-green to grey-green leaf color, failure of leaves to spring back when pressed down, and lack of dew formation.

Fertilizing

A good nutritional program can reduce weeds, moss, and certain diseases such as rust, take-all patch, and red thread in home lawns. Refer to Chapter 5: Plant Mineral Nutrition and Fertilizer for a complete discussion of plant nutrition and how to calculate and use fertilizers.

Have a soil test done to determine what nutrients are needed. Nitrogen may be the only nutrient needed if phosphorus and potassium levels are adequate. You can save money by not buying nutrients you don't need.

An ideal fertilizer contains a small amount of quick-release fertilizer plus a slow-release fertilizer to supply N between fertilizer applications.

For a moderately maintained established lawn, apply 4 pounds of nitrogen per year per 1,000 square feet in four applications: 1 pound each about May 1, June 15 to 30, September 15, and in November (early November east of the mountains and late November west of the mountains). Do not fertilize during hot weather.

On healthy lawns, never apply more than 1 pound of quick-release N per 1,000 square feet in a single application. If the soil is sandy, do not apply more than 1⁄2 pound N per 1,000 square feet in a single application, in order to prevent leaching. Instead, apply two separate 1⁄2-pound applications 2 to 3 weeks apart.

Improved cultivars of perennial ryegrass and Kentucky bluegrass are an exception to the above rates. For new lawns and lawns on sandy soils, apply at least 6 pounds of N per 1,000 square feet to maintain green color throughout the growing season. If P and K are needed, use a fertilizer with a 3–1–2 or 6–1–6 ratio of N, P, and K (for example, 12–4–8 or 15–5–10). The nutrient levels should average out to this ratio over the year.

Granular or pelleted fertilizer is best applied over large areas with a cyclone (broadcast) spreader. Note that quick-release fertilizers can burn grass if they aren't watered in thoroughly after application.

The nitrogen in all fertilizers is converted to nitrate in the soil in order for the plants to take up the nutrient in solution. (See Figure 1 in Chapter 5: Plant Mineral Nutrition and Fertilizer for an illustration of how nitrogen moves within the soil.) Most people apply more than one type of fertilizer at different times of the year. The ideal fertilizer is a "bridge" fertilizer containing a small amount of quick-release fertilizer plus a slow-release fertilizer to supply N between fertilizer applications.

Natural organic fertilizers can also be used, but should not be applied in late fall to prevent any possible leaching of nutrients over the winter. The best time to apply them within your maintenance schedule is in June and/or September. Most natural organics are applied at a rate of 2 pounds of N per 1000 square feet to get an adequate response.

Table 7 lists common fertilizer materials. A soil test will tell you whether lime is needed. If it is, apply 25 to 50 pounds per 1,000 square feet in fall or early spring. Note: lime does not remove moss. Agricultural lime supplies calcium, while dolomitic lime supplies calcium and magnesium. Liming usually is not necessary in Eastern Washington.

Table 7.—Common sources of N, P, and K nutrients.

Nutrient	Nutrient content (%)	Comment
Nitrogen		
Ammonium nitrate	33 1/3	Can burn.*
Ammonium sulfate	21	Can burn.*
Urea	46	Can burn.*
Urea formaldehyde	38	
Calcium nitrate	15	Can burn.*
Methylene ureas	varies	
Sulfur-coated urea	31–36	
IBDU	31	
Milorganite	6	A brand of processed sewage sludge.
Human and animal wastes	varies	Check local regulations.
Animal and vegetable by-products	varies	
Phosphorus		
Single superphosphate	20	Usually nonburning.
Treble superphosphate	44	Usually nonburning.
Potassium		
Muriate of potash	60	Can burn.
Potassium sulfate	50	Less burn potential than muriate.

*Quick-release nitrogen sources can cause burning of plant tissues if not watered in immediately.

Aeration

Aeration is the process of making holes in the ground in order to improve soil oxygen. Aeration of a lawn benefits the lawn in several ways:

- Increases soil oxygen and water penetration
- Encourages grass root growth

- Reduces soil compaction
- Increases germination of over-seeded grasses
- Increases fertilizer and lime movement into the soil
- Reduces thatch

Methods to Increase Soil Oxygen. Use an aerifier with hollow tines to remove soil cores. You can leave these cores on the surface if the soil is good and you do not have too much thatch. The cores will be broken up by normal lawn mowing or can be raked apart.

Spikers (machines that punch holes without removing cores) are of less value for aerating because they compact the soil around the holes and do not increase flow of water and nutrients into the root zone. Deep-tine aerifying (8 to 10 inches) can be done by a professional service, which will help break through a problem layer for better drainage.

Thatch Control

Thatch is a layer of living and dead grass stems, roots, and leaves that develops at the soil surface beneath actively growing grass (Figure 4). Stems and roots are the main contributors to thatch; grass leaves contribute very little. A thin layer of thatch (1⁄2 inch) is desirable for adding greater impact absorption, improving wear tolerance, and insulating soil from extreme temperatures.

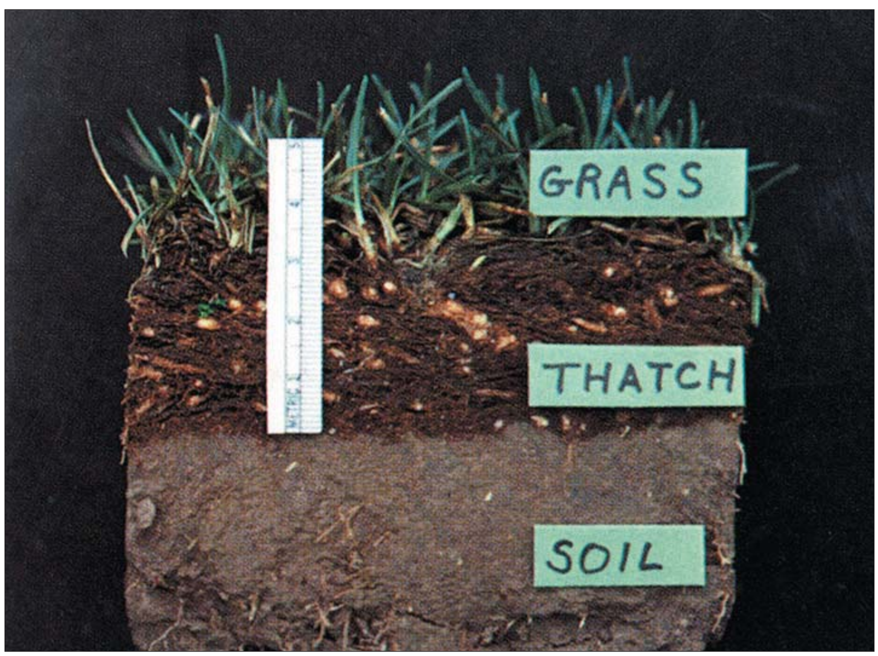

Figure 4. Thatch is a thick layer of undecomposed organic matter between the soil surface and green grass blades. Large irregular areas of dead turf can occur in spite of attempts to water and fertilize because overly thick thatch prevents penetration of water and nutrients into the root zone.

Thatch-induced Problems. Excessive thatch (more than 3⁄4 inch thick) is undesirable for several reasons.

- Too much thatch restricts the movement of air, water, plant nutrients, and other applied materials into the soil.
- During wet periods, thatch may act as a sponge and hold excessive amounts of water, thus reducing the oxygen supply to roots.
- During hot, dry weather, thatch may get too dry and become very resistant to wetting, thereby losing its moisture-moderating ability.
- Thatch can harbor turfgrass disease organisms and insects.
- Thatch can act as a barrier that reduces fungicide and insecticide effectiveness since the chemicals may not reach target pests.
- Thatch may cause abnormal development of grass plants. Thatch accumulation usually is greater when grass is mowed high; hence, stems may become elongated with the leaves forming at the top. Frequently, when these leaves are mowed off, the lawn can appear brown, scalped, or off-color.
- Thatch also affects mowing height. As undecomposed material builds up, a mower tends to ride on the thatch and does not cut at the desired height. If you lower the cutting height to overcome this problem, scalping can occur and brown areas can develop.

Thatch Development. Thatch accumulation in lawns is influenced by the following factors:

- *Too little or too much nitrogen.* Nitrogen stimulates bacterial decomposition of thatch. Other essential plant nutrients, such as phosphorus, calcium, magnesium, and potassium, also must be present in proper proportions. However, too many nutrients can stimulate excessive grass growth and thatch production.
- *Excessive wetness or over-watering.* Too much water reduces soil oxygen and inhibits bacterial activity needed for thatch decomposition. Also, extended periods of saturation in the root zone induce surface rooting and greater thatch accumulation.
- *Mowing height.* In general, the higher the mowing height, the greater the tendency to produce thatch. Mow the grass at recommended heights.
- *Grass type.* Stolon-producing colonial-type bentgrasses, which are persistent and dominate older lawns, tend to develop thatch. Kentucky bluegrass (rhizome producing) and fine fescues also often are heavy thatch formers. High lignin content in fine fescues slows decomposition, which increases thatch accumulation. Perennial ryegrasses and tall fescues do not produce much thatch.

- *Grass parts.* Crown tissues, stems, and roots are more resistant to decay than leaves. They contribute most to thatch development in all grass varieties.
- *Soil pH.* Acid soil conditions (pH 5 or below) reduce bacterial activity, which may result in slow stem and root decay, especially if calcium is deficient.

Removing Thatch. Remove thatch annually, if necessary, so that it doesn't build up to more than 3⁄4 inch thick. If thatch becomes too thick (more than 2 inches), renovation or repeated core aeration may be the only answer.

Spring is the best time to remove thatch, particularly if there are large amounts. At this time, you can remove all dead surface debris that accumulated the previous year. Turfgrasses are partially dormant at this time and suffer the least amount of injury. If only light thatch removal is required, you can dethatch almost any time of the year. Normal thatch removal will not injure the lawn severely enough to require reseeding. If properly dethatched, grasses recover quickly and exhibit their normal beauty when conditions are suitable for growth.

Considerable force is necessary to slice or scratch into a thatch mat and remove all of the dead material. Power rakes or other mechanically driven dethatching machines are superior to hand rakes. Run dethatchers across the turf in two directions, offset at 90 degrees. Remove loosened material before changing direction. You should not be bringing up any soil. If soil comes up, the dethatching unit is set too deep and you might burn out the engine on the machine. Although lots of fluffy material is pulled up, you will only be removing about 1⁄4 inch of thatch by going over the lawn in two directions. Mow immediately after removing debris, at the recommended mowing height.

If thatch becomes unmanageable (more than 2 inches thick), it is best to remove all grass with a power sod cutter, cultivate the soil, and reseed with desirable grasses.

Weed Control

By using good fertilization, mowing, and watering practices, you'll minimize weed problems. If you do need to control weeds, the first step is to identify the weed so you can choose the correct herbicide for the weed and its stage of growth, as well as plan the correct timing of herbicide application. See Chapter 17: Weeds and Weed Management for complete discussions of weeds and their control, and Chapter 20 for information on how to legally and safely use pesticides.

Mid-spring (early May) or anytime in September are the best times to treat lawn weeds. Grass and weeds should be growing vigorously when treated. If your lawn is dormant (from lack of water), but the weeds are green during the summer, do not apply an herbicide. The weeds will not take up the herbicide so you will waste product and get no effect. Also, do not apply selective herbicides when air temperatures are expected to exceed 80°F because efficacy will be reduced. Always read and follow the label directions.

Be cautious of herbicide drift (particles) and volatility (fumes). Use proper equipment and never use excessive pressure. Lower pressure increases droplet size, thus reducing drift. Try to spray when wind is less than 2 to 3 miles per hour.

Disease Control

Numerous diseases can occur in lawns in the Northwest, but there are only six really common lawn disease problems: fusarium (*Microdochium*) patch, take-all patch, fairy ring, red thread, rusts, and necrotic ring spot. Table 8 is a more comprehensive list with detailed descriptions and solutions for many of the possible problems. For a thorough discussion, see Diseases of Turfgrass (EB0713), a WSU Extension publication.

Insect Control

Various insect pests attack lawns. Insecticides will control most species commonly encountered. Always read and follow label instructions for any pesticide. Keep children and pets off the lawn for 1 day, or as label instructs, after applying insecticides.

Because insecticides must penetrate the turf to control root-feeding insects, it may be several days or longer before insects are killed and the grass begins to recover from the injury. In a lawn with heavy thatch, aerating first may help insecticide penetration.

Due to the continual change of home insecticide products, specific product names are not listed here. Current pesticide recommendations can be found in HortSense (http://pep.wsu.edu/hortsense/), which is revised annually.

Ants. Ants are more of an annoyance than a pest when they take up residence in a lawn. Controlling them is difficult. Broadcast treatments with the more commonly available short residual materials are usually ineffective or, at best, only temporary in effect. If the nest can be located, however, then treatments can be effective if the nest is thoroughly and totally saturated.

Billbugs. Lawn billbugs damage lawns both as grubs and adults. The grubs cut off the roots just below the ground while the adults rip and shred grass stems. Kentucky bluegrass lawns are severely damaged while bentgrass has not been damaged. This is an Eastern Washington lawn problem exclusively since it has not yet been detected in Western Washington. You can obtain some

Table 8.—Lawn diseases. (Adapted from EB0938: Disease Management in Home Lawns (http://cru.cahe.wsu.edu/CEPublications/eb0938/eb0938.html)

Disease/symptom	Conditions favorable for development	Presence in Washington	Management	
			Cultural	Fungicidal
Brown patch (*Rhizoctonia solani*) Brown, irregular-shaped or circular patches	Moist, warm (above 80°F)	Common in Eastern Washington; not common in Western Washington	Avoid excessive irrigation and high nitrogen fertility.	triadimefon
Fairy ring (*Marasmius oreades*) Rings of dark green grass up to several feet in diameter; sometimes dead zones, with or without 1–2 inch tan mushrooms	Mild, moist. Mushrooms appear mostly in spring and fall.	Common on all turfgrasses in Western Washington; fairly common on turfgrasses in Eastern Washington	Open soil mechanically. Soak rings with water daily for 1 month. Keep turf well fertilized.	
Fusarium patch (*Microdochium nivale*) See also Pink snow mold. Browning and thinning of turf in large indefinite spots (1–8 inches)	Cool, wet.	Very common on bentgrass and annual bluegrass in Western Washington; common in Eastern Washington.	Promote air and soil drainage. Avoid excessive nitrogen. 2 lb sulfur per 1,000 sq ft per year may help.	triadimefon Use twice in spring and twice in fall.
Gray snow mold (*Typhula* spp.) Irregular, dead, bleached areas (2–24 inches) with gray mold, usually under or near melting snow.	Cold, wet; worse under prolonged snow cover.	Not common in Western Washington; very common in northeastern Washington. Occurs wherever there is prolonged snow cover.	Avoid late-season, heavy nitrogen fertilization.	triadimefon Apply before snowfall.
Helminthosporium diseases *Bipolaris, Drechslera,* and *Exserohilum* species (*Helminthosporium* spp.) Root and crown rot; yellowing and thinning of turf or tan to purple spots on leaves.	Moist	Common on bluegrasses and ryegrasses.	Water in morning. Pick up clippings. Do not let grass get matted. Avoid excess nitrogen.	
Necrotic ring spot (*Leptosphaeria korrae*) Dead circles, arches, and patches several inches to several feet in diameter.	Spring and fall in Eastern Washington and in Western Washington.	On seeded and sodded bluegrass. Most common on sodded turf 2 to 3 years after establishment.	Promote deep-rooted turf by proper fertilizer and water management.	fenarimol Spring through fall.
Pink snow mold (*Microdochium nivale*) See also Fusarium patch. Circular, light brown to dark brown patches (2–12 inches across). Patches commonly bleached under snow and covered with pink fungus.	Cold, wet; worse under prolonged snow cover.	Not common in Western Washington; very common in northeastern region and wherever there is prolonged snow cover.	Avoid heavy, late-season nitrogen fertilization.	triadimefon Apply before snowfall.

Table 8.—Lawn diseases. (Adapted from EB0938: Disease Management in Home Lawns (http://cru.cahe.wsu.edu/CEPublications/eb0938/eb0938.html)

Disease/symptom	Conditions favorable for development	Presence in Washington	Management	
			Cultural	Fungicidal
Red thread (*Laetisaria fuciformis, Corticium fuciforme*) Bleached or tan-colored irregular areas (2–24 inches) with red fungus strands.	Cool, moist	Very common in Western Washington; occasional in Eastern Washington.	Use adequate nitrogen in a balanced N-P-K nutritional program. Late fall fertilizer applications are especially important.	triadimefon
Rust (*Puccinia* spp.) Leaves turn yellow; yellow to orange to reddish-brown powdery growths on leaves.	Variable	Most common on certain bluegrasses, especially Merion. Also on perennial ryegrasses.	Increase nitrogen. Water during dry periods. Mow frequently.	Usually not necessary.
Slime molds (various fungi) White to yellow slimy growth, usually turning to masses of small, dark, powdery "pinheads" on large leaves; occasionally large, gray, powdery mounds (1–3 inches). Not parasitic.	Mild, moist	Periodically observed in areas west of the Cascades in spring and fall; not common east of the Cascades.	Mow, rake, or wash off with water. Usually disappears after 1–2 weeks.	Common turf fungicides may prevent reappearance.
Take-all patch (*Gaeumannomyces graminis* var. 'graminae') Thinning and/or dying of turf in circles (4–36 inches) followed by invasion of weeds and annual bluegrass in center.	High moisture favors disease development, but symptoms do not show until turf is under moisture stress.	Common on bentgrasses in Western Washington; occasional in Eastern Washington.	Use ammonium sulfate in balanced N-P-K nutrition program (3-1-2 ratio). Avoid high lime. 3 lb of sulfur per 1,000 sq ft per year may help.	
Yellow patch (*Rhizoctonia cerealis*) Light brown to yellow patches and rings.	Prolonged moisture at 40–60°F.	Common on bentgrasses, bluegrasses, and fescues.	Avoid excessive irrigation and fertilization to ensure deep rooting.	

control by applying insecticide when the damage is first noted and when grubs are present, but for best results, make the application in late May or early June to kill the overwintering adults before they have laid eggs.

Chinch Bugs. Chinch bugs suck juices from the grass plants and inject a toxin into them, turning the turf yellow and killing large areas. Damage is associated with summer drought and may be confused with drought damage or damage from excessive thatch accumulation. Shaded turf areas are less damaged. Areas damaged by chinch bugs will not green up again after rains or irrigation, whereas drought-damaged turf will. Proper watering reduces turf stress and also encourages development of the fungus which parasitizes chinch bugs.

To test for chinch bugs, dig a section of turf at the edge of the damaged area where the grass is becoming discolored. Place the turf in a plastic bag, seal the bag, and place in a warm area. Any bugs present will soon leave the turf and be seen on the plastic. Or, place the turf section in a container of water. The bugs will shortly float to the surface. Positively identify any bugs found before considering treatment

Cutworms. Cutworms are not usually a lawn problem, but they may move in as an overflow from resident or surrounding weeds. Weeds are their preferred host, so good weed management will prevent most cutworm problems. Insecticide control is usually effective only when cutworms are younger than half-grown. Mature cutworms are virtually impossible to kill with insecticides and you are limited to killing them mechanically when and if you can find them.

Crane Fly. The European crane fly, *Tipula paludosa*, has become established in Western Washington and is documented in Eastern Washington. Although originally a turf and pasture pest, it has also been found feeding on annual and perennial flowers and several types of vegetables and small fruits. More recently another crane fly, *Tipula oleracea*, the common crane fly has also been found to damage turf. Damage to lawns is caused when larvae feed on root crowns. Damage is usually temporary and lawns re-grow easily. With extensive lawn damage, weed invasion is a threat, however, so chemical treatment may be advisable after monitoring larval populations.

The adult crane fly has very long legs and looks like a large mosquito. Its body is about 1 inch long, excluding the legs. They are especially drawn to the color white and homeowners are alarmed when thousands of these large flies gather on the sides of homes. The cranefly does not bite or sting, nor does it damage houses.

Adult European crane flies emerge from the soil in grassy areas from late August to mid-September. The adult common crane flies emerge twice per year, at approximately the same time as the European adults in the fall and again in February or March. Females of both crane fly species mate and lay eggs in the grass within 24 hours after emergence. Crane fly eggs hatch into small, gray-brown, worm-like larvae, which develop a tough skin; they commonly are called leatherjackets. Leatherjackets feed on the root crowns of clover and grass during the fall. They overwinter in the leatherjacket stage, and feed during this time as long as the ground is not frozen.

Damage may become especially noticeable in March and April. In warm years, damage can be severe as early as December thru February. During the day, leatherjackets mostly stay underground, but on damp, warm nights they come to the surface to feed on the above-ground parts of many plants. Leatherjacket feeding stops about mid-May for both species. They spend July and August in a nonfeeding pupal stage just below the soil surface. From late August through September, pupae wriggle to the surface, and adult craneflies emerge. The same cycle occurs for the common crane fly again in February, when the pupae stop feeding in the soil and they emerge as adults in March/April to lay eggs.

To monitor crane fly populations, survey the turf area in early spring (February or March) or when temperatures are consistently warmer. Select three or four random spots 6 inches by 6 inches (0.25 sq. ft.) in the lawn. Dig up the top layer (1 to 2 inches) and tear apart these samples to count the larvae. Larvae will usually be located at the base of the vegetative layer (thatch) or in very shallow spots in the soil. Multiply the number of crane fly larvae you find in any one sample by 4 to get the number of larvae per square foot. If this number exceeds 25 and the turf is thin, consider a chemical control. If the lawn is generally unhealthy, treatment at lower levels (10–15 larvae per square foot) may be necessary. Healthy lawns have been known to have 40 larvae per square foot and still not show any damage.

When unusually warm weather occurs early in the year, watch for early crane fly feeding. (See http://pep.wsu.edu/hortsense/ and click on "Lawn and Turf.") Biological control with insect-eating nematodes will suppress populations, but will not eliminate them. If well established lawns are properly cared for, chemical treatment is rarely needed.

If you do need to control craneflies, use a registered insecticide as soon as damage has been confirmed and the population identified. Spray timing is important. Applications after mid-April may be ineffective since damage already has been done and larvae may already have stopped feeding. Note: these application dates reflect normal years and, as such, are generalizations. Since European craneflies undergo a weak hibernation, prolonged unseasonably warm periods in December or January can allow them to feed, leading to serious damage. Therefore, if a warm winter occurs, watch your lawn carefully for damage, particularly if your region has a history of cranefly problems.

Fall spraying is not recommended because it suggests spraying without knowing whether a pest problem will occur in spring. Research has shown that, as often as not, natural controls largely eliminate high autumnal cranefly populations by the following spring, thus eliminating the need for sprays.

Consult HortSense (http://pep.wsu.edu/hortsense/) for recommended pesticides and rates. Several registered pesticides are available in granular form for crane flies. Be careful when spreading granules so children and pets cannot come in contact with them. Make sure to apply at least 1/8 inch of water after spreading the granules. Avoid spills and keep products off areas such as walks and patios. Be sure to read and follow all label instructions.

Bee Warning

Many insecticides are highly toxic to honey bees, bumble bees, and other wild bees. Sevin is particularly hazardous to bees. It should not be used where bees are obviously foraging on blooming weeds or flowers.

Simple steps like removing (mowing) blooming clover should always be taken before applying materials hazardous to bees. Avoid using dusts if possible. Sprays are preferred for bee safety.

Webworm. Sod webworm or lawn moths are a problem in many grasses of Eastern Washington. It is not normally a problem west of the Cascades unless it becomes very dry and watering programs diminish. It can also become a problem where bentgrass is prevalent. This is related to the stress of thatch associated with bentgrass.

White Grubs. White grubs are the larvae of small scarab beetles related to June beetles. Grubs feed on grass roots to the extent that large pieces of lawn can be lifted free from the ground. Grubs can be very destructive to golf courses and lawns. Fortunately, they are not very common at pest levels.

Yellowjackets. These pests do not harm a lawn, but are ground dwellers that may reside in a lawn area. There are aerosol insecticides which can be propelled for distances of 20 feet to control yellowjackets. Use according to label instructions. These products rapidly kill subterranean colonies. After treating an area, do not plug the entrance hole of yellowjacket nests. Returning foragers will enter the nest and be killed by the insecticidal residue.

Lawn Renovation

Lawns severely damaged by insects, diseases, or uncontrolled weeds may have to be renovated. Renovation includes a variety of corrective procedures to restore health to an old lawn. Partial renovation can be as simple as over-seeding a thin turf area, or can include power raking and core aeration if thatch is thicker than 1⁄2 inch or the soil is compacted. Power raking is a much more severe treatment than normal dethatching, which should be done to lawns as needed. Total renovation involves killing existing turf and reseeding.

Ninety percent of turfgrass renovation attempts do not succeed in changing turfgrass species, because the lawn areas are sprayed once, over-seeded, and rapidly recolonized by weedy grasses as they recover. If renovation is not done properly, the site will look good to begin with, but eventually will return to the conditions (with the same weed species) existing before renovation. Favorable spring and fall growing (cool, wet) weather favors lawn recovery following renovation. Mid-summer renovation may result in slow recovery and generally is not recommended. However, total kill, sod removal, and reestablishment can be accomplished during late summer, especially west of the Cascades.

Partial Renovation

Follow these steps to renovate a lawn without totally removing existing vegetation:

1. Adjust the mower to approximately 3⁄4 inch (slightly lower for bentgrasses) and mow the lawn thoroughly.
2. Power-rake the lawn as many times as necessary to remove accumulated thatch. It is best to dethatch in opposite directions. Thoroughness is important.
3. Rake and remove material brought to the surface by the de-thatching process. (Add it to the compost pile.)
4. Mow the turf again at approximately 3⁄4 inch high.
5. Remove sod from all high and low spots, adjust these areas to the proper grade, and replace the sod to obtain a uniformly smooth surface.
6. If grass stems and crowns were thinned excessively by power raking, over-seed the lawn. Over-seed at a rate of one-half the recommended establishment rate, using varieties recommended for your area. Growth will initiate quickly both from the remaining grass stems and crowns and from the new seed.
7. Maintain constant surface moisture for seed germination.
8. Although the turf may be somewhat thin, it's important to mow regularly at the recommended mowing height.

Total Renovation

Total renovation involves killing all weeds and undesirable grasses with a nonselective herbicide. This is the best approach for lawns having large patches of coarse, weedy grasses such as velvetgrass, quackgrass, unimproved tall fescue, orchardgrass, or non-turf-type perennial ryegrasses. Apply glyphosate (for instance, Roundup®) in mid-spring or late summer. It probably will take more than one application to kill creeping perennial grasses, which have rhizomes.

After killing the grass, you have a choice of either removing the dead sod or following steps 1 through 5 given above for partial renovation. If you remove all sod and cultivate the soil, follow procedures for establishing a new lawn. It is advisable to use the full seeding rates recommended for the type of seed you are using, for new lawns.

After seeding, use a starter-type fertilizer to apply 1 pound of actual nitrogen per 1,000 square feet to hasten establishment. If the soil is extremely sandy, and you are using a quick-release fertilizer, make two applications of 1⁄2 pound N each, 2 to 3 weeks apart, instead of a single 1-pound application to avoid the possibility of nutrient loss by leaching and overgrowth of the turfgrass.

Close-up view of Kentucky bluegrass and clover. (Photo courtesy of John D. Byrd, Mississippi State University; Bugwood.org.)

Further Reading

WSU Extension Publications available at: http://cru84.cahe.wsu.edu/

WSU Extension Publications

Annual Bluegrass Control in Turfgrass for Homeowners (EB1600)

Chemical Weed Control for Home Grounds (EB1214)

Disease Control in Home Lawns (EB0938)

Diseases of Turfgrass (EB0713)

Establishing a Lawn in Eastern Washington (EB1153)

Home Lawns (EB0482)

La Siembra del Césped en el Este de Washington (Seeding Turfgrass in Eastern Washington) (EM3888A)

Lawn Renovation (EB0924)

Lawn Weed Control (EB0607)

Managing Necrotic Ring Spot on Turfgrass in the PNW (EB1734)

Moles (EB1028)

Saving Water: Lawns and Other Turf (EB0684)

Turfgrass and Soil-Water Relationship (EB1280)

Turfgrass Diseases Supplement (EB0713S)

Turfgrass Management (VT0063)

Turfgrass Seeding Recommendations for the Pacific Northwest (PNW0299)

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WSU Puyallup Turfgrass Science website. http://www.puyallup.wsu.edu/turf/

Herbaceous Landscape Plants

10

Topics covered:

Learning Objectives

- Understand life cycles of annuals, biennials, and perennials, and how those life cycles affect a plant's garden usefulness.
- Understand how climate and hardiness affect success of plants.
- Understand principles of basic care and maintenance realities.
- Identify and manage common garden problems.
- Understand garden requirements and maintenance techniques for several specific types of herbaceous perennials.

By

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Herbaceous Plants in the Landscape

Trends and styles in gardening may vary from year to year, but the basic delight gardeners find in the details and presence of plants remains constant. The phrase 'ornamental' gardening now seems out-dated; plants are often chosen for their contribution to the ecology of the garden as well as for their appearance: they help conserve water; they attract and feed beneficial insects; they are suited to the individual garden microclimate. Edibles may be combined with the landscape. As you wander nurseries and plant sales looking at choices, you'll be considering much more than the plant's form and color.

Tucked under trees and shrubs, or edging a small lawn, brightening an entryway, or acting as an elegant ground cover, herbaceous plants give the garden its texture. Without them, gardens lack interest. Gardeners often comment about seeing 'sterile' landscapes composed of large square footage of bark, a few shrubs, and one tree—a style often seen around newly-constructed houses. The missing element is the softening of foliage and added color given by herbaceous plants from hardy ferns to wispy annual poppies. The most monotonous garden can leap into year-round interest when these plants are properly chosen.

Know your plants' species

Learn the species of plants you have or that you wish to grow. *Iris germanica*, the common German 'bearded' iris, grows well in full sun, requires little extra irrigation in summer, and prefers a pH of 6.5–7.5. However, *Iris ensata,* the Japanese iris, grows best in acid soil (pH 5.5–6.0) with continuous moisture. Japanese iris can thrive on the edges of ponds in partial shade. These two iris share a genus but the two different species require nearly opposite garden conditions.

Herbaceous Plant Life Cycles

Herbaceous plants are those that do not retain woody stems and add to that growth each year. These plants may increase in size by adding new leaves and stems, but do not increase the diameter of their stems each year. Herbaceous plants may have a life cycle that is perennial, biennial, or annual. Knowing the basic life cycles of herbaceous plants helps in planning for the seasonal progression of a garden.

Perennials

Herbaceous perennials are defined as plants that go dormant in cold weather and return with seasonal warming temperatures.

They exist, world-wide, in great variety in temperate zones. The key to their life cycle is the seasonal change in temperatures, resulting in varying growth habits.

Herbaceous Perennials

- generally go dormant during cold weather—the current season's foliage dies.
- do not form a permanent woody structure.
- may be grown for foliage only (*Hosta* spp.) or for bloom.
- have a limited bloom period: short, (less than one week, as with some peonies) to long (six weeks or more, as with yarrow, *Achillea* spp.).
- may be short-lived (three years, as with wallflowers, *Erysimum* spp.) or long-lived (decades, as with *Peonia lactiflora* and hybrids).

Perennials take time to establish, at least two years. There's an often-quoted saying: "The first year, they sleep; the next year, they creep;.the third year, they leap." Plants may be small initially, but a 4-inch-pot plant will expand after 2 to 3 years to cover 2 or more square feet, depending on the plant.

If you have time to allow for growth, buying smaller herbaceous perennials is more economical. For plants with fibrous roots like asters (*Aster x frikartii*) and Shasta daisies (*Leucanthemum x superbum*) that will eventually form mats, it's good form to plant three of a type in a triangle with about 18 inches between plants. Other types that will be sculptural or add a spot of height, such as biennial mullein (*Verbascum* spp.), may be planted singly. Perennial gardens have no "end date," but are constantly being planted, redesigned, and replanted.

This chapter will concentrate on plants hardy even in the colder zones of Washington, zones 4–6. These plants will also thrive in zones 7–8. In milder zones you will be able to use plants such as tender salvia (*Salvia guarantica)* which do not survive winters in the coldest areas.

Biennials

Biennials develop small plants the first year; after going through a cold dormant period (winter), they bloom and set seed the next year.

Planning gardens to include biennials requires allowing them space during the first year for their necessary development.

Biennials are easy to forget during their first season as they may lack garden presence, forming rosettes or other small ground-level plants which disappear behind taller plants. Their second year brings colorful flowers, often in tall spikes such as with foxglove

Extending the definition:

Some garden writers confine the definition of herbaceous perennials to those growing from fibrous roots, thus excluding bulbs, tubers, rhizomes, and corms. In this book, we consider herbaceous perennials to include plants grown from rhizomes (German iris), bulbs (true lilies, tulips), corms (crocus, gladiolus), and tubers (dahlias). This will provide a wider view of plants available and often chosen for Northwest gardens.

Some vegetables and other edibles may also be considered herbaceous perennials, such as rhubarb (*Rheum* sp.) and asparagus (*Asparagus officinalis.*)

(*Digitalis purpurea*). If you do not wish a flurry of new plants from seed, remove blooms from biennials before they mature. Foxgloves, for instance, produce thousands of seeds per plant.

Annuals

Annual plants complete their life cycle in one year, from seed germination to maturity. Annuals often produce ample seeds and reappear yearly from seed, leading gardeners to mistake them for herbaceous perennials (California poppy, *Eschscholzia californica)*.

Annuals provide long periods of bloom color, longer than most herbaceous perennials, if the fading flowers are picked off so that the plant does not set seed. They are often featured in landscape situations requiring eye-catching, persistent summer color. See Table 1 for a list of common annuals for your garden in Washington State.

Some plants, such as tender geranium (*Pelargonium* spp.), act as perennials in warmer zones such as 9–10. Gardeners in Washington State consider them annuals because they are killed by frost, but if sheltered throughout winter they may live for years, gradually growing larger. Gardeners often over-winter plants such as rose-scented geraniums (*Pelargonium capitatum*) by bringing them inside and treating them as houseplants. These plants are not strictly annuals because they do not mature in one season.

Table 1. Common annual species, weeks from seeding to transplant, mature height, and flower color.

Common name	Scientific name	Time for sowing seeds indoors to transplanting (weeks)*	Mature plant height (inches)	Flower color
Ageratum	*Ageratum houstonianum*	8-10	6-12	Blue, white, lavender, pink
Annual phlox	*Phlox drummondii*	6-8	6-18	White, pink, purple, red, blue
Begonia, wax leafed	*Begonia x semperflorens-cultorum*	12-16	6-8	Red, white, pink
Black-eyed Susan vine	*Thunbergia alata*	6-8	72 (vine)	Orange, yellow, white
Blanket flower	*Gaillardia pulchella*	6-8	12-24	Red, yellow, orange
Celosia, crested	*Celosia cristata*	6-8	12-24	Yellow, orange, pink, red
Celosia, plumed	*Celosia plumosa*	6-8	10-12	Yellow, orange, pink, red
China aster	*Callistephus chinensis*	6-8	12-24	Pink, red, blue, white, purple
China pink	*Dianthus chinensis*	8-10	6-12	Pink, white, red
Coleus	*Coleus x hybridus*	8-10	8-20	Red, pink, cream yellow foliage

Common name	Scientific name	Time for sowing seeds indoors to transplanting (weeks)*	Mature plant height (inches)	Flower color
Cornflower	*Centaurea cyanus*	4-6	12-30	Pink, blue, white
Cosmos	*Cosmos bipinnatus*	4-6	36-48	Pink, white, rose
Cosmos, yellow	*Cosmos sulphureus*	4-6	12-36	Yellow, orange, pink
Dahlia	*Dahlia hybrids*	8-10	12-36	White, red, orange, pink, purple, cream
Dusty miller	*Senecio cineraria*	10-12	8-16	Silvery-white foliage
Flowering cabbage/kale	*Brassica oleracea*	6-8	12-18	Pink, purple, cream foliage
Flowering tobacco	*Nicotiana alata*	8-10	18-36	Red, pink, white, purple
Forget-me-not	*Myosotis sylvatica*	6-8	12-18	Blue, white
Four o'clock	*Mirabilis jalapa*	6-8	24-36	Pink, white, yellow, red
Gazania	*Gazania rigens*	6-8	6-12	Red, yellow, orange, white, pink
Geranium	*Pelargonium x hortorum*	10-12	12-18	Red, white, salmon, pink
Globe amaranth	*Gomphrena globosa*	8-10	12-18	White, pink, purple, red
Godetia	*Clarkia amoena*	6-8	24-36	White, pink, red
Heliotrope	*Heliotropium arborescens*	8-10	12-24	White, blue, purple
Impatiens	*Impatiens wallerana*	8-10	8-24	Red, pink, white, orange, lavender
Larkspur	*Consolida ambigua*	6-8	18-30	Blue, pink, white, rose
Lisianthus	*Eustoma grandiflorum*	10-12	12-24	Blue, pink, white, cream, rose
Lobelia	*Lobelia erinus*	8-10	6-8	Blue, violet, white, pink
Love-in-a-mist	*Nigella sp.*	4-6	8-20	Blue, white, pink, purple
Love-lies-bleeding	*Amaranthus tricolor*	3-4	36-60	Red, red and green
Lupine	*Lupinus hartwegii*	6-8	24-36	White, rose, red, purple
Marigold, African	*Tagetes erecta*	4-6	12-36	Yellow, orange, red
Marigold, French	*Tagetes patula*	4-6	6-18	Yellow, orange, red
Mexican sunflower	*Tithonia rotundifolia*	6-8	48-72	Orange
Monkey flower	*Mimulus x hybridus*	8-10	6-8	Yellow, red, orange
Moss rose	*Portulaca grandiflora*	6-8	6-8	Yellow, white, rose, orange, pink, red
Nasturtium	*Tropaeolum majus*	6-8	12	Yellow, orange, red, cream
Nigella	*Nigella damascena*	6-8	12-18	White, blue, purple
Painted tongue	*Salpiglossis sinuata*	8-10	24-36	Pink, yellow, red, purple , white

Common name	Scientific name	Time for sowing seeds indoors to transplanting (weeks)*	Mature plant height (inches)	Flower color
Pansy	*Viola x wittrockiana*	8-10	6-8	Blue, purple, white, yellow, orange, pink
Petunia	*Petunia x hybrida*	10-12	6-12	White, pink, purple, white, red
Ponytail grass	*Stipa tenuissima*	6-8	30	Ornamental grass with cream plumes
Poppy, California	*Eschscholzia californica*	2-3	12	Red, yellow, pink, red, white
Poppy, Iceland	*Papaver nudicaule*	6-8	12-18	White, yellow, pink, orange, red
Pot Marigold	*Calendula officinalis*	8-10	12-24	Yellow, orange
Sage, mealycup	*Salvia farinacea*	8-10	18-24	Blue, white
Sage, scarlet	*Salvia splendens*	8-10	12-24	Red, white, purple, salmon
Snapdragon	*Antirrhinum majus*	10-12	6-18	Yellow, orange, red, white, pink
Spider flower	*Cleome hassleriana*	6-8	48	White, purple, rose
Statice	*Limonium sinuatum*	6-8	12-24	Yellow, pink, white, blue, purple, apricot
Strawflower	*Helichrysum bracteatum*	6-8	18-36	White, red, pink, yellow, rose, orange
Stock	*Matthiola incana*	4-6	30-45	White, yellow, apricot, blue, pink, red
Swan River daisy	*Brachycome iberidifolia*	6-8	12-18	Blue, purple, pink, white
Sunflower	*Helianthus annuus*	2-3	24-108	Yellow, red, bronze, orange
Sweet alyssum	*Lobularia maritima*	6-8	4-8	White, purple, pink
Sweet pea	*Lathyrus odoratus*	6-8	72 (vine)	Orange, yellow, rose, purple, white
Sweet William	*Dianthus barbatus*	8-10	12-18	Red, pink, white
Torenia	*Torenia fournieri*	8-10	8-12	Blue, purple, pink
Verbena	*Verbena x hybrida*	10-12	8-24	White, pink, blue, red
Vinca	*Catharanthus roseus*	10-12	12-18	White, pink, red
Zinnia, narrowleaf	*Zinnia angustifolia*	4-6	8-12	Orange, white, yellow
Zinnia, common	*Zinnia elegans*	4-6	12-36	Red, pink, yellow, orange, white

** Contact your county WSU Extension office for information on the last average frost date in your area.*

Table 1 Courtesy of Teresa Cerny-Koenig, Washington State University, Pullman WA, and Richard and Jo Cerny, Spring Valley Farm, Cobden, IL.

Climate and USDA Temperature Zones

Two factors primarily influence plant growth and survival in Washington State: temperature variations from season to season and available rainfall. Of these two, it's somewhat easier to plan for temperature variations, because plants can be chosen to suit temperature ranges by understanding the zone of the garden and matching it to available plant hardiness information. Occasionally, a winter with below-average temperatures, such as that experienced in western Washington in 2008–09, will confound the best zonal planning and result in plant losses.

Table 2, the USDA list of temperature zones is a guide, not a set of absolutes. Personal experience and record-keeping will help you relate this guide to your own garden conditions.

Table 2. USDA Temperature Zones

Zone	°Fahrenheit
1	Below -50
2a	-50 to -45
2b	-45 to -40
3a	-40 to -35
3b	-35 to -30
4a	-30 to -25
4b	-25 to -20
5a	-20 to -15
5b	-15 to -10
6a	-10 to -5
6b	-5 to 0
7a	0 to 5
7b	5 to 10
8a	10 to 15
8b	15 to 20
9a	20 to 25
9b	25 to 30
10a	30 to 35
10b	35 to 40
11	above 40

Available rainfall, in all parts of Washington State, limits plant growth and results in necessary garden management choices. West of the Cascade Mountains, Seattle averages about 35 inches per year and Olympia about 51 inches. In the east, Spokane has about 16 inches, and Yakima only 8 inches (Western Regional Climate Center data, 1971–2000). These are averages that cover decades, so rainfall can and does vary from individual year to year.

The basic reality for gardeners is that rainfall in all areas of the state falls most heavily from October through February. Rainfall is lightest from March through September when most herbaceous perennials, biennials, and annuals are in active growth. A gardener's task is to know the region's water availability realities and plan for sensible water use in the landscape. Consider, when selecting plants, "How will this plant be watered throughout the year?" Hardy spring-blooming bulbs (*Narcissus, Tulipa*) require water during their fall, winter, and spring seasons but are dormant during summer. Their life cycle coincides with the local water patterns throughout our region.

Light levels—both seasonal and daily—also affect plant growth profoundly. Photograph the garden regularly, noting where light strengthens and wanes across the seasons. A series of photographs on the first of January, first of April, first of July, and first of October, showing the garden space from various angles, will be helpful in seeing where sun-loving or shade-requiring plants can thrive. Learning the movement of light across the garden will be as important in choosing plants as studying the soil.

Pictorial records also help as time passes and trees and shrubs grow. Herbaceous perennials may bloom less as they become shaded by taller plants, and a garden's sunny spots may gradually alter into part-sun or even shade. Perhaps the loss of a large tree or trees to storms may bring shade plants into unwelcome full sun.

Gardens require planning and then revising as time changes them. Fortunately, gardeners enjoy changing the scene by adding and subtracting plants. One particular advantage of plants discussed in this chapter is their ease of handling and transplanting. Their root structures generally don't present the transplanting challenges of established trees and shrubs.

Microclimate

Localized land forms and structures can influence the climate of even a very small piece of land, so that its growing conditions vary from the surrounding area, creating a **microclimate**. As you garden, you will notice the difference between a southern slope that thaws readily, and a north-facing slope or wall that retains frost. The individual microclimates of any garden will be affected if the garden is near a large body of water (which will moderate both summer and winter temperatures somewhat). Altitude can affect the general climate, but a feature as uncomplicated as a hill can demonstrate different growth patterns at its top and in the low area below it. Cold air flows downhill, pooling in low spots, and may reduce survival of tender plants there. An individual garden's warming trend may result from nearby pavement, buildings, or rock walls that retain and slowly release heat. Prevailing winds may also require fencing or plantings for windbreaks to protect flowers and vegetable crops.

Winter hardiness

A garden's microclimate is not the only factor affecting a plant's winter survival. Genetic hardiness is built into the physiology of every plant, and it is for this hardiness that plants are rated for certain zones.

The age of a plant also counts. If it's newly planted, with small roots, or if it's weakened by age, chances of survival may be lower. Check on the general health of the roots—they must not be soggy from being over-watered or sitting in a wet spot in the garden. Finally, soil moisture going into winter makes a difference. Gardeners in zones 3–6 should water plants before the first hard freeze. In all zones, gardeners should check plants tucked under building overhangs to be certain they are not dry.

Plant selection

With thousands of possible choices, it's necessary to focus both on the purpose of the plant and its climate needs.

Choose plants adapted to your zone, then group them in the garden according to water and light needs.

A Japanese-influenced garden design, with conifers and other plants providing shade, might include ferns and mosses.
A billowing flower garden in full sun could feature flowers blooming in sequence over several months, with April narcissus, May peonies, late May German iris, June Siberian iris, late June daylilies, July and August, true lilies. The adaptability of herbaceous perennials allows these to tuck against each other, even in a few square feet of space. By choosing for foliage color and texture as well as flowers, your garden design will have multi-season interest.

Maintenance

Caring for herbaceous perennials means being sensitive to, and responding to, the rhythm of their growth with the seasons. Observation will tell you that the plants demonstrate what is needed: dead stems in spring with new growth beneath? Trimming is the action needed. Taller plant growth in May, falling sideways? You'll know staking is required.

The individual maintenance tasks aren't difficult, but because gardeners bring so many different genera of plants into the garden, they will require action individually throughout the season. In early summer, you may be cutting away foliage of dormant poppies (*Papaver* spp.) while tying up delphinium (*Delphinium elatum* and cultivars) that are in their most vigorous growth.

Mulching

Like many tasks in gardening, how and when mulching occurs can vary without harming the plants. Some gardeners mulch in both spring and late fall; others apply mulch only once in late fall. The garden will benefit whatever the timing.

As spring growth starts, mulch requires renewing. Research what's available in your area, because mulches differ regionally. Choose mulch with a fine texture such as composted yard waste or shredded leaves or needles mixed with composted sawdust, or finely chipped tree trimmings.

'Fertile' mulch with some animal manure in it, such as aged dairy manure mixed with compost, supplies some nutrients to the plants. Choose composted materials rather than fresh manures, which can damage plants. These finer-textured mulches are pleasant to spread and look "finished" when tucked around plants. They also break down as the season progresses and add to soil tilth. Their disadvantage is that seeds dropped or blown onto their surface will germinate rapidly. This may be a help if you want extra plants from your own perennials or biennials, but it's bothersome when the newly emerging plant proves to be a weed. Coarser mulches reduce, but do not eliminate, weed intrusion.

In the late fall, clip back spent plants and remove dead annuals before applying mulch. This fall clean up is particularly necessary in the coldest regions where the mulch will provide some protection against winter frost-heaving. Gardeners east of the Cascades sometimes use pine needles for winter mulch. Some gardeners in zones 3–6 also lay evergreen boughs loosely over perennial plants after the ground freezes.

Always spread mulch over damp ground. If rain has been scarce in either spring or late fall, weed the area and water deeply before mulching.

Watering

Many herbaceous perennials require more water during their growing season than our natural rainfall provides anywhere in the region. Biennials and annuals also need extra irrigation to support small plants in active growth. The more rapidly a plant is growing, and the smaller its roots, the more water, in general, it will require. An annual petunia (*Petunia x hybrida*) planted from a 1-inch start may become a plant 3 feet wide and 2 feet tall by the end of the season; this growth cannot occur without water. Seedlings are also vulnerable to drought and can easily be killed if watering is neglected.

When planting, group plants according to their individual water needs. Keeping them watered will be the main task of the summer season. Check reference sources when selecting plants to determine their exact requirements.

Apply enough water to wet plant roots thoroughly, then allow soil to dry an inch or two down. The best way to determine whether plants need water is to probe the root zone with a trowel to gauge moisture. Plants will lose less moisture on overcast days; a calm, cloudy 70-degree day causes far less water loss than a windy, sunny 70-degree day. Light rain, even though it may seem to dampen the garden, may fail to reach the plant roots: moisture lands on leaves or mulch but roots stay thirsty.

When adding plants to an established garden, check the soil moisture before planting. Soil often dries between rains. It’s helpful to excavate the hole for a new perennial or annual plant, then fill the hole with water and allow it to drain before planting. This supplies moisture at and below the root level—moisture that would be difficult to provide by watering from above. After planting, water thoroughly again. This technique especially gives fall-planted bulbs a good start, because their roots need to emerge into damp soil.

Irrigation systems are installed more easily when plants are still small. Place them early enough in the spring that plants have not covered the soil. Soaker hoses, properly laid out, can make watering chores much easier. They work best if loops of hose are fairly close together, about 12 to 16 inches, and if the hose is pinned to the ground. Placing a light mulch over the installed hose also aids in both attractiveness of the hose and its effectiveness.

If an automatic irrigation system is included in the plans, make sure there is careful positioning of sprinkler or bubbler heads so that no group of plants gets skipped.

Winter watering. Some plants, even if rated hardy for their region’s lowest temperatures, may suffer from winterkill if the ground freezes around dry roots. Especially in our coldest regions, gardeners must water plants deeply before freezing occurs. Also, double-check plants under overhangs and eaves which will have sheltered them from rainfall.

Waterwise plants. Some plants can manage with little irrigation once established. ‘Establishment’ means that the root system of a plant has expanded into the surrounding soil and takes up water efficiently. This process may take up to 2 years for herbaceous perennials.

‘Establishment’ means that the root system of a plant has expanded into the surrounding soil and takes up water efficiently.

If watering occupies too much of your summer time or to conserve water, add waterwise plants in the next planting season. Sedums (*Sedum* spp.) and sempervivums ‘hens and chicks’ (*Sempervivum tectorum*), in dozens of fascinating color combinations, tuck in nicely along walkways, in among rocks, and in containers, requiring almost no auxiliary watering. They do need protection from soggy winter soil conditions and should be sited to ensure year-round good drainage. Waterwise and environmentally sensible gardening now extends to 'green roofs' planted with hardy selections like sedums. (See Figure 1.)

Figure 1. This rooftop garden is a whimsical addition to the retail building at Living in the Garden, a small garden shop north of Pullman, WA. (photo courtesy of Therese Harris)

Many perennials suit these conditions, with excellent species and cultivars available to enhance the waterwise garden. Look for yarrow (*Achillea* spp), various artemesias (*Artemesia* ' Powis Castle'), coreopsis (*Coreopsis verticillata* 'Moonbeam'), coneflower (*Echinacea purpurea* and others), and sun rose (*Helianthemum* sp). See Chapter 25: Waterwise Landscaping for more information on this topic.

Moist or damp conditions. Some gardeners are fortunate to have a spot that stays damp year-round, or perhaps even a pond. If you're able to provide sufficient water to keep an area thoroughly moist throughout the summer, your plant choices include some beauties. Ferns, astilbes in red, pink, or white (*Astilbe* spp), filipendula—sometimes called Queen of the Prairie (*Filipendula rubra venusta*), ligularia (*Ligularia dentata 'Desdemona'*), and globe flower (*Trollius europaeus*) will suit moist conditions. If these plants are selected for a place that becomes and stays dry, they will not thrive.

Stress from lack of water. All newly-planted herbaceous perennials, even those quite accustomed to dry conditions, such as yarrow, will need water during their first growing season. In addition, regular watering is needed at root depth, to help all perennial gardens look their best. Thirsty plants may not expire, but they will grow more slowly and stay smaller. For some plants and some gardeners, slow growth is acceptable. Herb gardens, for instance, can produce more intensely flavorful foliage if plants do not produce well-watered, fast-growing leaves.

Some herbaceous perennials, such as Shasta daisies *(Leucanthemum maximum*,) are tough and recover well even after leaf wilt. Others, especially the water-lovers like astilbe and ligularia, will show stem as well as leaf wilt with entire parts of the plant drooping to the ground. Bee balm (*Monarda didyma*) has showy flowers that attract bees and hummingbirds, but is susceptible to water stress. If any plants wilt in the evening and do not perk up by morning, water is definitely needed. Repeated water stress can kill plants.

Stress from too much water. Certain categories of plants, notably sedums, sempervivums, and woody herbs, will seldom show signs of water stress. They require relatively little water during dry periods—sedums can endure an entire summer gardening season without supplementary water in all but the most arid regions. Winter conditions, especially in western Washington, present these types of plants with another difficulty: soggy roots during winter rains. If planted where drainage is poor, these plants can be killed by drowning, not by freezing, in winter.

Fertilizing

If you are starting a completely new garden, a soil test can help determine specific nutrient and pH levels and possible needs. If you are working in an previously-established garden, or adding a few plants at a time to a border, a soil test may be more difficult to implement, but it is better to start with one if possible.

For herbaceous perennials, which store nutrients in roots, rhizomes, or bulbs over winter, fertilizer in some form is needed when they begin active growth in spring. Some nutrients will be available in the first season if organic components, such as compost, were added when the bed was prepared A 1-inch mulch of fertile material such as composted dairy manure can also supply nutrients.

For an in-depth look at fertilizers, see Chapter 5: Plant Mineral Nutrition and Fertilizers

Many gardeners use one spring fertilization a year, with a light application of 5–10–10. Many water-wise plants such as artemesia, sedum, sempervirens, and yarrow become floppy and unattractive if fertilized. As for herbs, if the herb garden grows well and plants have normal color, no fertilizer is needed.

Special cases in fertilizing. Fertilize all spring-blooming bulb clumps (crocus, tulip, narcissus, etc.) when shoots have emerged 1 to 2 inches, and then once more just after bloom to help with formation of flower embryos for next year. Use a bulb fertilizer with analysis of 9–6–6 or close to that, following instructions on the package. Water granular fertilizers into the soil using a gentle spray.

A few herbaceous perennials need summer fertilizing. Dahlias (*Dahlia x hybrida*) and delphiniums (*Delphinium* spp.) are considered heavy feeders and benefit from a low-nitrogen fertilizer at planting time, then a boost 6 weeks after the first fertilizing, and another 6 weeks after that. Side-dressing these plants with a 5–10–10 fertilizer and then watering it in will help their growth. For individual plants, you can also use a liquid fertilizer.

On the west side of the state, plants growing better in pH of 6.5 to 7.5 prefer added lime in their soil: dahlia, dianthus, delphinium, and German iris (*Iris germanica*). Addition of lime is rarely needed in eastern Washington.

Grooming/Pruning

Grooming or pruning herbaceous perennials goes more easily when you understand the way different types grow. Herbaceous perennials with fibrous root systems die to the ground and come back from a 'crown' just above the roots (native columbine, *Aquilegia formosa.).* During winter their stems become brittle, stop growing, and don't show a 'green' inner core when broken. When pruning, remove these old stems, being careful not to chop into any emerging new stems beneath the dead bits.

Deadhead your flowers, that is, remove spent flower heads as they finish blooming. Many plants bloom longer and stay more attractive if they aren't allowed to go to seed. Removing the first spent flower will result in new side shoots and more bloom on perennials such as campanulas, coreopsis, daylilies, lupine, lavender, and some sages—as well as many others.

Some perennials, when cut back just after bloom, will produce new stems with secondary flowers later in the summer: Penstemon (*Penstemon* spp.), foxgloves, and delphinium will offer fresh flowers on new stems. Often the repeat flower isn't as tall as the original, but is still attractive.

Fall-blooming plants in the composite family, including asters and chrysanthemums, grow sturdier flowers and more compact bushes if merely pinched back. Remove about 3 inches of growing tips in mid-May and again in early July.

Some spring-blooming perennials disappear in early summer. You'll discover foliage dying back on true poppies (*Papaver orientale*), and on native and cultivated bleeding heart (*Dicentra formosa, Dicentra spectabilis*) –the plants simply stop growing and go dormant. Remove the foliage gently when it is completely browned.

At winter's end, trim back or groom all ornamental grasses. Cut down tall grasses such as 6-foot *Calamagrostis acutifolia*, and *Micanthus sinensis*, to about 1 foot. Huge clumps are better managed if lassoed with rope to hold them together in a pillar shape before cutting below the tied area. Shorter grasses can be taken down to 4–5 inches before spring growth begins.

Some plants set attractive seedpods. Species peonies, many poppies, and Siberian iris (*iris siberica)* produce intriguing stalks of seedpods that dry well and can add to winter garden interest or dried flower arrangements. Prune out these old stalks before spring growth begins.

Staking

Staking or support is needed for plants that grow tall, like the larger lilies *(Lilium* spp.), or grow weak stems (*Ligularia* spp.), or have top-heavy, multi-petal flowers that might fall in rain, as with peonies or dahlias. Dahlias and delphiniums have hollow stems; once broken, they cannot be re-staked. Other plants, such as compact hardy geraniums (*Geranium macrorrhizum* and many others), may never require staking. If your garden is windy, you'll need to stake susceptible plants. In addition, you can look for shorter, tougher cultivars of plants: Asiatic lilies grow shorter, (2–4 feet) than Oriental lilies (6–8 feet) when established, so Asiatics lilies are wise choices for windy gardens.

Use single uprights for plants with single stems. Bamboo poles, slender wood poles, metal poles, or plastic stakes work. The stake should be about 3/4 the height of the plant's final size. Tie the plant stem as it grows, using flexible plastic or cloth ties. In some cases, you may wish to set the stake when planting, as is often done with dahlia tubers. With large lilies, you also place the stake when planting to avoid later piercing the vulnerable bulb.

Bushy or floppy plants require either twiggy brush placed to hold up the plant or short stakes surrounding it. Three or four short stakes with crisscrossed string will support well. Commercial wire hoops and supports also work, especially for heavy plants like peonies.

Common Problems of Herbaceous Landscape Plants

Powdery mildew

This fungal disease results in an obvious gray, disfiguring layer of spores on a plant, sometimes in spots but often covering an entire leaf so that it looks fuzzy. Powdery mildew is present in Washington in many different species, some of which affect only one plant while other species have a wide range of hosts.

Common where summer produces warm days and cooler nights, powdery mildew is present in nearly all gardens somewhere during the season. This disease can cause leaf drop, deformation or simply reduce the leaf's efficiency at photosynthesis.

Powdery mildew is common on roses, zinnias, dahlias, pansies, begonias, squash and many other plants.

Hortsense, the WSU guide to plant problems and their control, has photographs of common powdery mildew. (http://pep.wsu.edu/Hortsense) Be sure to check Hortsense for its recommendations on plant problem management, for each plant problem you encounter.

Planting in a sunny spot with good air circulation helps reduce powdery mildew. Even plants that are seldom bothered by powdery mildew can be affected if they are planted too closely and crowded against other plants.

Prune out affected leaves. Some growers, particularly those confronted with a powdery mildew infection that covers the entire plant, as may be the case with dahlias late in the season, allow the plant to end its growth naturally and then discard the entire top growth after frost. Do not add the mildewed leaves to compost piles. Review Hortsense for other management tips.

Some plants show resistance to powdery mildew, such as the bee balm *Monarda didyma* 'Jacob Kline.' Resistance is not equivalent to immunity. The plant may develop fewer symptoms but it can still be affected.

Aphids

Aphids, with many different species present in Washington gardens, hatch in the spring just as plants begin growth. Once active leaf formation starts, aphids are vigorous and hungry. As their leaves mature plants can endure a certain amount of aphid activity but the insects can be damaging on the youngest leaves, causing curling and reducing photosynthesis. Because they reproduce prolifically, aphids can cover an entire plant.

Wash them off with a gentle stream of water, encourage beneficial insects, and use mild insecticidal soap for the worst infestations. Check Hortsense (http://pep.wsu.edu./Hortsense) for specific current recommendation. Avoid insecticides that harm ladybugs, lacewings, and other beneficial predators that will come to eat the aphids. Many birds, including hummingbirds, also eat aphids.

Slugs and snails

Gardeners sometimes cope with their slug invasions by joking; the imported European garden slugs may qualify as the most discussed and disgusting of garden pests. Slugs and snails, both classified as mollusks, can rapidly damage plants, especially those with new, tender growth. Two common types in Washington are the European black garden slug (*Arion ater*) and the great gray garden slug (*Linax maximus.)* Note that some native slugs, such as the banana slug (*Ariolimax columbianus*) are valuable recyclers in forests, especially in western Washington, and should be protected. The imported garden slugs also recycle plant materials, but they unfortunately do not always wait for the material to die before munching it.

Plants favored by slugs and snails includes many favorite garden choices: delphinium, iris, pulmonaria, dahlia, brunnera, hosta, iris, all lilies, spring blooming narcissus, and tulips. Vegetable starts can be decimated just as they germinate, or chomped when they have a few true leaves. Damage may be most serious in late spring when weather is moist and cool and plants begin their growth. Slugs, however, stay active throughout the growing season.

Slugs and snails reproduce by eggs. Look for small patches of translucent or pearly eggs, less than 1/4 inch in diameter, in clumps of a few to more than 50. They will be tucked into mulch, under the edges of rotting wood, or even down in the soil. You will probably find them by accident more often than by hunting. Scoop them out with a trowel, drop them on a piece of newspaper, and crush them. Slug eggs may be visible throughout the year but the heaviest mating periods are in August and September.

If you've planted handsome perennial ground covers, they offer great hiding places for slugs. Trim foliage so it clears the ground a bit, and avoid laying fresh mulch until plants finish their spring growth and just the top of the soil dries a bit.

Handpicking—or glove-picking if you prefer—reduces the population somewhat when done regularly. If your plants hang down over brick or rock walls, lift the dangling foliage to find more slug hiding spots. Also try placing a wet board or wet newspaper on the ground and checking under it in early evening or morning for slug invaders. Lift or tip container plants to check because slugs hide underneath pots, even those placed up on decks and patios. Vigilance and patience helps, because no single system will manage slugs.

Check with Hortsense (http://pep.wsu.edu/Hortsense) for current chemical control recommendations. Use the least toxic control available.

Specific Garden Styles

Container gardens

Growing plants for portability has a long history, as gardeners have long appreciated the convenience and practicality of putting plants into pots. Pots may be nearly any size and any material—including old sneakers, kitchen colanders, and perforated teacups, to name a few seen locally. The one firm, definite requirement is that the container, no matter its type, must drain well. Plants left sopping without drainage will rapidly succumb to rot, unless they are among the relatively few adapted to wet conditions. If the container lacks drainage holes, add holes or use another container.

Table 3. Vegetatively propagated annuals for containers

Bacopa
Bidens
Calibrachoa hybrids (Million bells)
Diascia
Nemesia
Osteospermum hybrids
Petunia hybrids
Scaevola (Fan flower)

Choose a potting soil that has gritty texture, with perlite or pumice or vermiculite incorporated for drainage. Some gardeners use basic commercial potting soils, but add 1/4 pumice by volume and a few scoops of screened compost.

When potting, cover the drainage holes with a simple piece of screen, a bit of broken crockery, a piece of wall board tape, or even a coffee filter. You want the water to drain well but not to carry the potting mix with it. Do not add gravel, rocks, piles of pottery, or any other lower layer to the pot. Fill it completely with thoroughly dampened potting soil. Settle the plants in the potting mix and water well.

Annuals, especially those planted from seed or from small 1-inch starts, require time; annuals started at 1 inch fill out in around 6 to 7 weeks. Keep soil evenly moist for annuals and vegetables. If the pot is in hot afternoon sun or is a hanging basket, daily watering or more may be needed. Hanging baskets require particular care; if they dry out, take them down and immerse the entire basket in water to rewet the dried-out soil.

Fertilize container plantings every 2 weeks with a liquid fertilizer. Choose one with trace elements and a fairly low nitrogen level, such as a 5–10–10. Excess nitrogen in container plantings will result in foliage rather than blooms. Some gardeners prefer to use 1/2 strength fertilizer weekly. Do not fertilize a dry pot. Water thoroughly one day and fertilize on the next.

Dead-head all container plants to encourage continuous bloom or food production.

Some annuals such as sweet alyssum, lobelia, begonia, and coleus can be started from seed and do well in containers. Table 3 lists some recommended annuals for containers that are harder to start from seed, thus are vegetatively propagated.

Herb gardens

Centuries of gardeners have cherished plants for their culinary and medicinal properties. Herb gardens may be elaborately formal, planted in circular or maze patterns, but simple beds of plants provide kitchen supplies just as readily. Even the smallest landscape has room for a few edible herbs—many just require full sun and only moderate water.

Thyme *(Thymus* spp.*),* chives (*Allium schoenoprasum*), and oregano (*Origanum vulgare*) will survive at least zone 5 winters. Peppermints (*Mentha* sp.) can be so invasive that confining them to a deep pot makes sense. Cat lovers can grow true catnip, *Nepeta cateria,* which has handsome blue flowers that may not be obvious when it is draped with a cat.

Some familiar herbs are **sub-shrubs**, meaning they have a woody structure that persists, including lavender and rosemary. These often retain leaves through winter in zones 7–9, although many are too tender for zones 4–6. Common English lavender (*Lavandula angustifolia*) will, however, take zone 5 winter temperatures, although it can look battered by spring. Sub-shrubs don't recover if they are chopped to the ground or if the branches are cut back too deeply. Trim them gently after bloom or in earliest spring in colder areas, removing about 1/3 of the growth.

Cutting gardens

Choosing plants to harvest for bouquets engages many gardeners; the combination of shrubs and smaller plants can yield texture and nearly year-round flowers or foliage. Table 4 lists some of the common annuals grown for flower bouquets.

For gifts or for sharing at community events, home-grown bouquets reward gardening. Donations of food to community food banks can include flowers as cheerful extras.

Butterfly gardens

Flowers can attract not only butterflies, but many beneficial insects. In general, the greater the variety of plants grown, from many different genera, the more assistance the garden gives to beneficial insects. Flowers with umbel-shaped blooms, such as angelica, fennel, dill, and yarrow can feed many types of insects. See Table 5 for a partial list of annuals that help attract beneficial insects.

A water source also helps insects during drier months. Even wasps and bees will sip at the edges of birdbaths, while many butterflies prefer muddy spots.

Table 4. Annuals commonly grown for cut flowers

Annual phlox
Blanket flower
Celosia
China aster
China pink
Cornflower
Cosmos
Dahlia
Globe amaranth
Heliotrope
Larkspur
Lisianthus
Love-in-a-mist
Lupine
Marigold
Painted tongue
Pot marigold
Salvia
Snapdragon
Spider flower
Statice
Strawflower
Stock
Sunflower
Sweet pea
Sweet William
Verbena
Zinnia

Table 5. Annuals to attract beneficial insects and hummingbirds

Blanket flower
Four o'clock
Globe amaranth
Heliotrope
Mexican sunflower
Petunia
Scarlet sage
Spider flower
Verbena
Common zinnia

Bird-friendly gardens

Water, even in a small container—no tumbling waterfalls needed—and a variety of plants can help attract and succor birds year-round. Check with your local Audubon chapter to determine which plants best serve the birds in your particular region: http://wa.audubon.org/chapters_websites.html.

In general, scarlet runner bean (*Phaesolus coccineus*) brings hummingbirds during the summer, while sunflowers, cosmos, and zinnias encourage the American Goldfinch, Washington's State Bird. Chickadees feed on sunflower and dahlia seeds in the autumn garden. Many different birds will visit a varied garden.

Native plant gardens

Native plants suit many different types of landscaping, such as prairie restoration where appropriate. Streamside plantings can help retain banks and prevent erosion. Incorporating native plants such as the familiar trillium (*Trillium ovatum*) into your own landscape can help build native plant populations and teach people about threatened or scarce plants. Shrubby native currant (*Ribes sanguinea*) is often added to landscapes for spring bird feeding as well as for its beauty.

If given extra water and fertilizer, native plants will grow larger than they do in their undisturbed habitat. Altering their desired conditions may not be ideal. In addition, fertilizing native plants will sometimes result in soft, unhealthy growth. After the first two years of adaptation, reduce watering to allow native plants to respond to normal summer water conditions.

Some gardeners assume that native plants guarantee a low-water use garden; keep in mind that native plants differ as much in their needs as do introduced plants.

Grouping native plants according to their water needs is vital: salal (*Gaultheria shallon*), ground cover mahonia (*Mahonia nervosa*), and sword fern (*Polystichum munitum*) require identical conditions. Learn the exact requirements of native plants: some thrive in moist conditions, such as Western tiger lily (*Lilium occidentale*) and red columbine (*Aquilegia formosa)*.

In conjunction with conservation groups, gardeners may be able to salvage plants in the path of land clearing. Check local garden centers or with your local County Conservation District for sources of native plants. Many counties have spring sales of native plants. Do not remove plants from "natural" areas without proper permission.

Edible landscape gardens

Consider using fruit and vegetable plants throughout the landscape where appropriate. Alpine strawberries (*Fragraria vesca*) make good garden edging in sunny spots. Artichokes (*Cynara* spp., in zones 7–8) offer striking leafy punctuation as well as a food source. Investigate choices and look into new resources on the "munchable" garden as it becomes one of the primary interests of the 21st century gardener.

If using flowers for garnish or for edible petals, be certain the chosen plant isn't toxic, and if in doubt, Do Not Eat It! Some of the many common but toxic plants include daffodils (*Narcissus* spp. and cultivars) monkshood(*Aconitum napellum*) and foxglove (*Digitalis* spp.). Reliably edible flowers include calendulas, daylilies, nasturtiums, pansies, roses, and violas, but even these may present problems for people with allergies. Never eat any plant from a yard where dogs and cats are allowed to roam free. If you have applied any kind of pesticide (any insecticide, herbicide, fungicide, etc.) to a plant, do not eat any part of that plant unless the pesticide label allows use on that specific plant, gives directions on how long you must wait between application and harvest, and you have followed all label directions.

Specific Garden Plants

Spring-blooming hardy bulbs

Spring's arrival coincides with the emergence of hardy bulbs and corms that come up while temperatures are still cool. The pleasure of seeing daffodils (*Narcissus* spp.), crocus (*Crocus* spp.), and tulips (*Tulipa* spp.) starts the garden year.

These hardy plants have specific timing requirements. They must be planted in the fall, from September in coldest zones through November in zones 7–8, after soil cools and before hard freezing occurs. Their growth begins at planting; during the winter their roots grow slowly. Most need 11 to 14 weeks of cold temperatures (below 45° F) to prepare them for flowering. Choose a sunny spot with good drainage for best performance.

Do plant on time. Gardeners commonly find unplanted hardy bulbs in bags or boxes, forgotten, as late as February; these can be planted but they will have small or absent blooms. Narcissus can recover and may bloom the next year; tulips seldom do.

Fertilize bulbs when planting and again in spring when plants are up about 2 inches. Use a granular 5–10–10 fertilizer, watered in well, or a bulb fertilizer (about 9–6–6).

When blooming finishes, allow foliage to die back without interference. Snowdrops (*Galanthus nivalis*), crocuses, hyacinths, and tulips need thoroughly brown leaves, indicating that the bulb has received as many nutrients as possible from the leaves. All daffodils may be cut back 6 to 7 weeks after bloom finishes even if the leaves remain slightly green. Spring-blooming hardy bulbs are fully dormant during the summer months, returning to root growth in September and October with fall rains.

Lilies, true lilies, and day lilies

Many plants have 'lily' in their common names, but the true lilies are bulbs in the genus *Lilium*. They add color to summer gardens and return reliably season after season when they are well-established.

True lilies have bulbs like tulips and alliums, but their bulbs do not have a permanent protective coat. The botanical term for this is **imbricate**, whereas bulbs like tulips are **tunicate**, that is, they have an outer layer or tunic. Because true lilies lack this protection, and because they seldom go fully dormant, you will find them packed with a layer of sawdust, wood shavings, or other protection when shipped. Plant lilies as soon as you receive them and take care to avoid bruising the unprotected outer scales.

Good drainage means good lily growing; they require regular water during active growth, but they cannot endure soggy ground conditions. If your garden is primarily clay soil, your lilies will grow best in containers or prepared raised beds.

One peculiarity of some lilies, such as the familiar 'Casablanca,' (*Lilium hybrida* 'Casablanca') is stem-rooting. The bulbs develop numerous fine roots along the stem as it emerges. To provide enough space for these stem roots, plant bulbs sufficiently deep—most need at least 8 inches of friable soil above the bulb. These stem roots help the plant receive enough water and nutrients and are essential for a plant's health. After bloom, remove as little of the stem as possible; just cut off the spent flower then allow the rest of the stalk to go completely brown before trimming it back.

Lily species vary in their needs. Some, such as the Oregon native *Lilium pardalinum,* require ample moisture throughout the growing season. Be sure you check the specific planting needs when selecting.

Daylilies, often confused with true lilies (*Lilium* spp.) are actually in the genus *Hemerocallis*. These valuable landscape plants flower from mid-summer for about 6 weeks. They open flowers one at a time, with today's flowers withered by tomorrow, thus their "day lily" name. Their toughness can be seen in older plantings of the common lemon-colored *Hemerocallis flava*, which has been grown since the sixteenth century and carries on well even in neglected spots. But modern hybrid daylilies (*Hemerocallis* 'Mary Todd,' for example) bloom best when they receive supplementary summer water.

Peonies

With glorious flowers worth waiting for, herbaceous peonies (*Peonia lactiflora* and hybrids) have been grown for centuries in landscape gardens. These lush plants can grow for decades without disturbance, and once they settle in and begin to bloom, they are best left alone.

Peony growth stalls when they are newly planted or transplanted. Choose a sunny site but check the pH of the soil, because peonies grow best at a pH of 6.0–7.0. They can, however, endure a range both toward acid and toward alkaline. They do particularly well east of the mountains in Washington State, because they require significant winter chill for best bloom. Fertilize in early spring with a 5–10–10 or equivalent.

If peonies fail to bloom but produce healthy leaves, they may just be too young. Herbaceous peonies take at least 2 to 3 years to settle into bloom after planting. But check the depth of the planting: if the 'eye' or growing point, which is roughly pointed and pinkish-white, is planted deeper than 1 to 2 inches, the plant will look fine but will not bud. If the peony is planted too deep, dig it and reset it when its leaves drop in the fall.

Peony hybridizers have, during the last 40 years, developed 'intersectional' peonies, resulting from crosses between the herbaceous *P. lactiflora* and the woody tree peony *P. lutea* (other crosses have also been made.) These peonies, called 'Itoh' in honor of their first breeder, Toichi Itoh, offer vigorous blooms that open over several weeks. They are robust and some evidence exists that they can bloom without as much winter chill as others. Yellow tones predominated at first, but they are now available in most peony tones, white through red. Look for future additions in this newer category of garden peonies.

Sometimes as peonies develop their large flower buds, ants wander onto the plants. People sometimes say "the ants make the peonies bloom," but the ants have just arrived for food, in the form of a sticky sweet residue on the buds. When picking peonies for bouquets, swish the flowers in a bucket of water to remove ants. The ants do not harm the peonies but they alarm dinner guests.

Ground cover plants

Practical necessity governs the planting of ground covers, a rather dull term for what can be elegant, hard-working, and invaluable plants. Their mission in the landscape can be 1) as slope-holding erosion preventers; 2) as lawn replacements where lawns fail to thrive; 3) for creating a lower layer of uniform texture if planted in large quantities; or 4) for adding texture and interest to paving or shrub and tree plantings. A ground cover can also be a 'mass planting' used for landscape effect.

In general, ground covers top out at about 18 inches in height. As with everything in gardening, there are exceptions. When a ground cover is created using small shrubs, such as Bearberry cotoneaster (*Cotoneaster dammeri),* a planting may grow to 2 feet. Some valuable choices, often planted between stones or in pathways, might be only 3–6 inches tall when fully mature. The herb thyme (*Thymus* spp.) fills in when given good drainage and sun, sometimes standing only 2 inches tall. The balance and design of the landscape will dictate height of the acceptable ground cover. The larger the landscape acreage, the taller the ground cover it may use. Generally, plants of approximately the same height are chosen to cover one area.

Choosing an evergreen ground cover versus one that goes dormant in the winter will also result from overall choices about how the landscape is to look and function year-round. Simply being short does not necessarily make a plant an effective ground cover. Attractive texture and sturdy evergreen foliage helps the overall usefulness of choices. Two tidy, classic choices are Japanese spurge (*Pachysandra terminalis*) and bunchberry (*Cornus canadensis*), both suited to plantings in acidic soils and shady areas under trees and shrubs. Kinnikinnick and wooly thyme are suited for alkaline soils and sunny sites.

As with all plant choices, match the groundcover to your specific garden conditions. A sunny slope may be ideal for the familiar shrub, carpet juniper (*Juniperis horizontalis* and its cultivars.) They are often drought-tolerant once established, but cannot be left alone to sprawl for decades without attention. When they become crowded, junipers are susceptible to disease problems and can develop dead areas in their centers. Like all garden plants, those grown as groundcovers must be properly maintained.

Groundcovers may also control or minimize weed infestations, though this effect does not occur when the plants are newly installed and have not spread thoroughly. A frequently-used ground cover in Washington state, the native kinnikinnick, (*Arctostaphylos uva-ursi*), develops excellent weed resistance after 2–3 years of care. When first planted, though, it has many open spaces between branches, providing good shelter for weeds and weed seeds. Maintenance for all newly planted ground covers is often focused on weeding for the first few years until the soil is fully shaded by the desired plants.

Avoid ‘thuggish’ or invasive plants as you choose groundcovers. While it may be helpful to have a plant that covers territory with speed, this trait can be a sign of future difficulties. Lamium (*Lamium maculatum*) roots wherever a stem touches soil; in some gardens it’s manageable, in others, a complete pest. The individual garden conditions affect plant vigor. Another one that can be tricky to manage is sweet woodruff (*Galium odoratum*), a determined spreader. Check with experts and nurseries in your area to determine which plants have colonized local gardens too enthusiastically. Most important, review the noxious weed list for your particular county; several cultivars of English ivy (*Hedera helix*) are listed as noxious weeds in Washington State. In spite of this, recommendations for using it persist.

Learning More

The best approach to gardening is doing it. Read catalogs, attend classes on perennials, or check newest information on line. New cultivars come up for sale, developed as plant breeders work. Or exotic plants found world-wide—where plant hunters still gather seeds internationally—may survive local trials and become newly available. Your best results will come from your own study and experience in your specific garden conditions.

Further Reading

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11

Trees & Woody Landscape Plants

Topics covered:

- Benefits of Trees and Shrubs
- Tree Selection
- Buying Quality Trees and Shrubs
- New Tree and Shrub Planting
- Trees and Turf
- Mulching
- Mature Tree Care
- Tree Hazards
- Treatment of Damaged Trees
- Landscape Plant Values
- Certified Arborists

Learning Objectives

- Understand the environmental, economic, and aesthetic benefits of trees in communities
- Know basics of tree selection, purchasing, planting, and maintenance practices
- Recognize problems associated with poor plant selection and placement, construction damage, and improper maintenance practices
- Know of the International Society for Arboriculture and its research-based resources

By

The International Society of Arboriculture

This chapter has been adapted with permission from the International Society of Arboriculture's consumer education brochures. All information is current and research-based.

The International Society of Arboriculture (ISA) is a nonprofit organization supporting tree care research around the world. For more information, contact a local ISA Certified Arborist or visit www.isa-arbor.com.

Benefits of Trees and Shrubs

Most trees and shrubs in cities or communities are planted to provide beauty or shade. Woody plants also serve many other purposes, and it often is helpful to consider these other functions and benefits when selecting a tree or shrub for the landscape (Figure 1). The benefits can be grouped into social, communal, environmental, and economic categories.

Social Benefits

Most of us respond to the presence of trees beyond simply observing their beauty. We feel serene, peaceful, restful, and tranquil in a grove of trees. Hospital patients have been shown to recover from surgery more quickly when their hospital room offered a view of trees. The strong ties between people and trees are most evident in the resistance of community residents to removing trees to widen streets or in the heroic efforts of individuals and organizations to save particularly large or historic trees in a community.

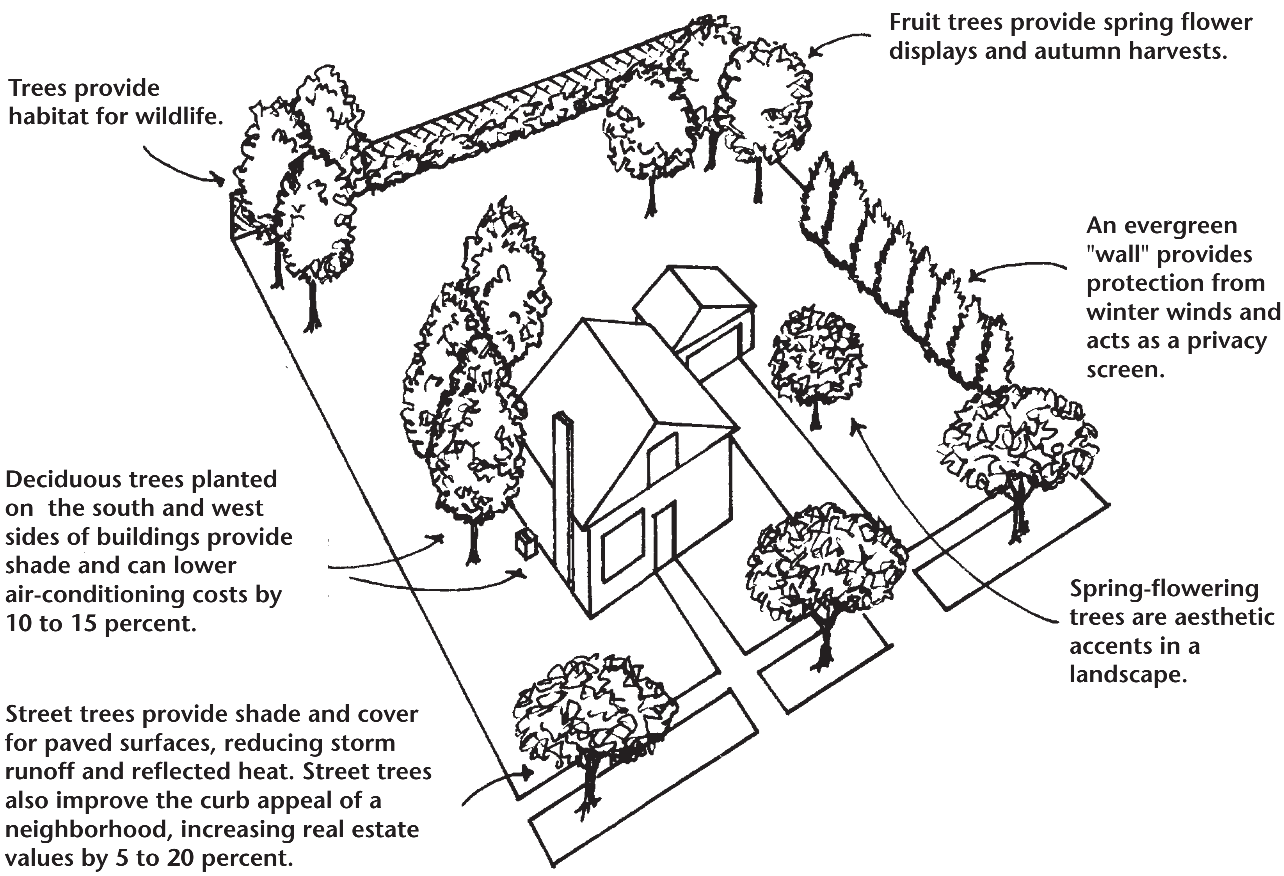


Figure 1. Trees and shrubs provide a wide variety of benefits to people, wildlife, and the environment.

The stature, strength, and endurance of trees give them a cathedral-like quality. Because of their potential for long life, trees frequently are planted as living memorials. We often become personally attached to trees that we or those we love have planted.

Community Benefits

Even though trees may be private property, their size often makes them part of the community as well. Trees often serve several architectural and engineering functions. They provide privacy, emphasize views, or screen out objectionable views. They reduce glare and reflection. They direct pedestrian traffic. They provide background to and soften, complement, or enhance architecture.

Environmental Benefits

Trees alter the environment in which we live by moderating climate, improving air quality, conserving water, and harboring wildlife. Climate control is obtained by moderating the effects of sun, wind, and rain. Radiant energy from the sun is absorbed or deflected by leaves on deciduous trees in the summer and is only filtered by branches of deciduous trees in winter. We are cooler when we stand in the shade of trees and are not exposed to direct sunlight. In winter, we value the sun's radiant energy. Therefore, we should plant only small or deciduous trees on the south side of homes.

Wind speed and direction can be affected by trees. The more compact the foliage on the tree or group of trees, the greater the influence of the **windbreak**. Falling rain, sleet, and hail are initially absorbed or deflected by trees, providing some protection for people, pets, and buildings. Trees intercept water, store some of it, and reduce storm runoff and the possibility of flooding. Dew and frost are less common under trees because less radiant energy is released from the soil in those areas at night.

Temperatures in the vicinity of trees are cooler than temperatures away from trees. The larger the tree, the greater its cooling effect. By using trees in cities, we are able to moderate the heat-island effect caused by pavement and buildings in developed areas.

Air quality can be improved through the use of trees, shrubs, and turf. Leaves filter the air we breathe by removing dust and other particulates. Rain then washes the pollutants to the ground. Leaves absorb carbon dioxide from the air. In this process, leaves also absorb other air pollutants—such as ozone, carbon monoxide, and sulfur dioxide—and give off oxygen.

Economic Benefits

Individual trees and shrubs have value, but the variability of species, size, condition, and function makes determining their economic value difficult. The economic benefits of trees can be both direct and indirect. Direct economic benefits are usually associated with energy costs/savings. Air-conditioning costs are lower in a tree-shaded home. Heating costs are reduced when a home has a windbreak. Trees increase in value from the time they are planted until they mature. Trees are a wise investment of funds because landscaped homes are more valuable than non-landscaped homes. The savings in energy costs and the increase in property value directly benefit each homeowner.

The indirect economic benefits of trees are even greater. These benefits are available to the community or region. When power companies are able to use less water in their cooling towers, build fewer new facilities to meet peak demands, use reduced amounts of fossil fuel in their furnaces, and use fewer measures to control air pollution, customers get lower energy bills. Communities also can save money if fewer facilities must be built to control storm water in the region. To the individual, these savings are small, but to the community, reductions in these expenses are often in the thousands of dollars.

Tree Selection

Tree selection is one of the most important investment decisions a homeowner makes when landscaping a new home or replacing a tree. Considering that most trees have the potential to outlive the people who plant them, the impact of this decision is one that can influence a lifetime. Match the tree to the site, and both lives will benefit.

Before selecting a tree for a particular site, consider these factors:

- Why is the tree being planted? Do you want the tree to provide shade, fruit, or seasonal color, or act as a windbreak or screen? Maybe more than one reason?
- What is the size and location of the planting site? Does the space lend itself to a large, medium, or small tree? Are there overhead or belowground wires or utilities in the vicinity? What clearance is needed for sidewalks, patios, or driveways? Are there other trees in the area? Are there barriers to future root growth, such as building foundations?
- Which type of soil conditions exist? Is the soil deep, fertile, and well drained, or is it shallow, compacted, and infertile?
- Which type of maintenance are you willing to provide? Do you have time to water, fertilize, and prune the newly

planted tree until it is established, or will you be relying on your garden or tree service for assistance?

Asking and answering these and other questions before selecting a tree will help you choose the "right tree for the right place."

Landscape Function

Trees and shrubs make our surroundings more pleasant. A large shade tree provides relief from summer's heat and, when properly placed, can reduce summer cooling costs. A tree that drops its leaves in the fall allows the sun to warm a house in the winter. An ornamental tree provides beautiful flowers, leaves, bark, or fruit. Evergreens with dense, persistent leaves or needles can provide a windbreak or a screen for privacy. A tree or shrub that produces fruit can provide food for the owner or attract birds and wildlife into your home landscape. Street trees decrease the glare from pavement, reduce runoff, filter out pollutants, and add oxygen to the air we breathe. Street trees also improve the overall appearance and quality of life in a city or neighborhood.

Trees and shrubs planted close to buildings reduce wind currents that otherwise would chill or heat the outside surfaces (Figure 2). These foundation plantings can create a dead air space which slows the escape of heat from a building in the winter. That same dead air space helps insulate buildings from the heat of summer, thus reducing the need for air conditioning.

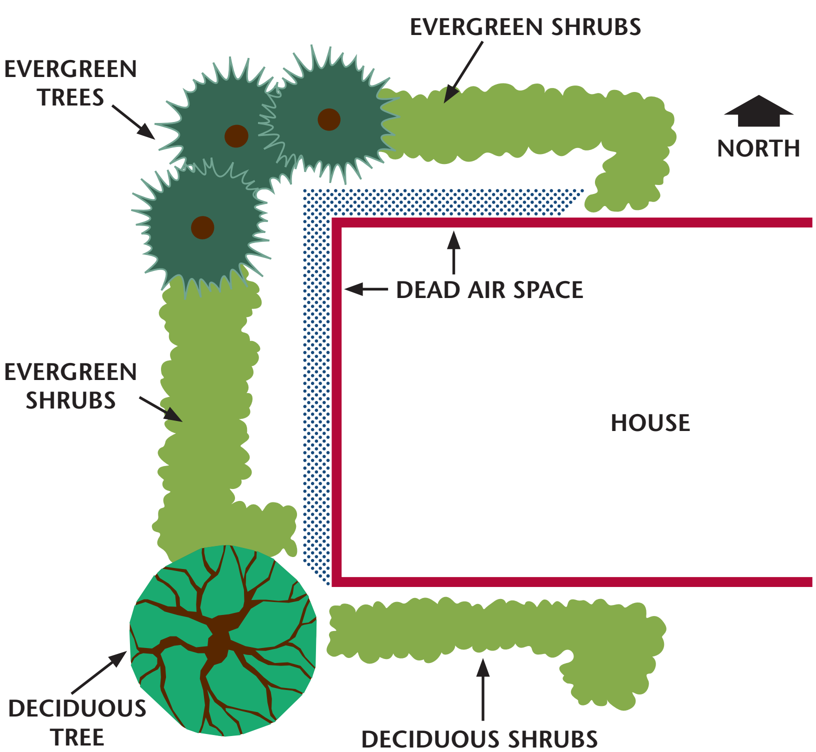


Figure 2. Select foundation plants with the full, mature size of those trees and shrubs in mind. See "Avoiding Tree–Utility Conflicts" for more details on plant size concerns.

Form and Size

A basic principle of modern architecture is “form follows function.” This is a good rule to remember when selecting a tree or shrub. Selecting the right form (shape) to fit the desired function (what you want the tree to do) can significantly reduce maintenance costs and increase the tree’s value in the landscape (Figure 3). Trees grow in a variety of not only shapes, but sizes. They can vary in height from a few feet to several hundred feet. Select both a form and size that will fit the planting space available.

Depending on your site restrictions, you can choose from among hundreds of combinations of form and size. You may choose a small-spreading tree for a location with overhead utility lines. You may select a narrow, columnar form to build a hedge that provides a screen between two buildings. You may choose large, vase-shaped trees to create an arbor over a driveway or city street. You may even determine that a site just does not have enough space for a tree of any kind.

Site Conditions

Selecting a tree that will thrive in a given set of site conditions is the key to long-term tree survival. Before selecting a tree for planting, consider the following list of major site conditions:

- soil conditions
- exposure (sun and wind)
- human activity
- drainage
- dimensional space
- hardiness zone

Soil Conditions. The amount and quality of soil present in a planting site can limit plant success. In urban sites, the topsoil

Figure 3. Trees can be classified according to their form.

often has been disturbed and frequently is shallow, compacted, and subject to drought. Under these conditions, trees are continuously under stress. For species that are not able to handle these types of conditions, proper maintenance designed to reduce stress is necessary to ensure adequate growth and survival.

Exposure. The amount of sunlight available will affect tree and shrub species selection for a particular location. Most woody plants require full sunlight for proper growth and flower bloom. Some do well in light shade, but few shrub or tree species perform well in dense shade. Exposure to wind is also a consideration. Wind can dry out soils, causing drought conditions and damage to branches and leaves during storms. Wind can also dessicate leaves and can actually uproot newly planted trees that have not had an opportunity to establish their root systems. Special maintenance, such as staking or more frequent watering, may be needed to establish young trees on windy sites.

Human Activity. The top five causes of tree death are actually the results from things people do. Soil compaction, underwatering, overwatering, vandalism, and planting the wrong tree (the number one cause) account for more tree deaths than all insect- and disease-related tree deaths combined.

Drainage. Tree roots require oxygen to develop and thrive. Poor drainage can remove the oxygen available to the roots from the soil and kill the tree. Before planting, do a percolation test: dig some test holes 12 inches wide by 12 inches deep in the areas you are considering planting trees. Fill the holes with water and time how long it takes for the water to drain away. If it takes more than 6 hours, you may have a drainage problem and should choose a different site.

Space Constraints. Many different factors can limit the planting space available to the tree: overhead or underground utilities, pavement, buildings, other trees, visibility requirements, etc. The list goes on and on. Make sure there is adequate room for the tree you select to grow to maturity, both above and below ground.

Hardiness. Hardiness is a plant's ability to survive the extreme temperatures of a particular geographic region. Make sure the plant you have selected is hardy in your area. See Chapter 10: Herbaceous Landscape Plants for more discussion of climate and hardiness zones.

Pest Problems. Insects and diseases affect almost every tree and shrub species. Every plant species has its own particular pest problems, and the severity varies geographically. These pests may or may not be life threatening to the plant. It is best to select plants resistant to pest problems for your area.

Right Plant—Right Place

The notion of planting the right plant in the right place is drilled into Master Gardener volunteers over and over again. What exactly does it mean? Getting plants, including trees, in the right place means considering all of a plant's traits and requirements—cold hardiness; light, soil, and water requirements; and mature size—before purchasing and planting something.

For trees, knowing the mature size is critical. Planting a tree in a space that is too small for its ultimate size will only result in frustration and extra work later on. No amount of pruning will keep a large tree from trying to fulfill its genetic destiny and reach its full size. Continuous trimming both weakens the tree and leaves it vulnerable to pests and disease. Continuous trimming also encourages rampant regrowth (which will require yet more trimming) as the tree tries to recover what it lost; after all, the tree's roots were not trimmed and they are still following their genetic blueprint and growing to support a canopy of ultimate size.

If space is limited, look for smaller varieties of the species you want to plant—many new hybrids have been developed for smaller planting spaces such as city or suburban lots. Save both yourself and the tree a lot of frustration and wasted energy.

Buying Quality Trees and Shrubs

When you buy a quality tree or shrub, then plant it correctly and treat it properly, you and your landscape plant will benefit greatly in many ways for many years. When you buy a low-quality tree, you and your tree will have many costly problems even if you take great care in planting and maintenance.

Defining Plant Quality

A high-quality tree or shrub has

- a large enough and healthy root system to support growth;
- trunks free of mechanical wounds and wounds from incorrect pruning; and
- a strong form with well-spaced, firmly attached branches.

A low-quality tree or shrub has

- crushed or circling roots in a too-small root-ball or container;
- a trunk with wounds from mechanical impacts or incorrect pruning; or
- a weak form in which multiple stems squeeze against each other or branches squeeze against the trunk.

Any of these problems alone or in combination with the others will greatly reduce a plant's chances for a long, healthy, and productive life.

When buying a tree or shrub, inspect it carefully to make certain it does not have problems with roots, injuries, or form. Remember the acronym RIF; it will help you remember **R**oots, **I**njuries, and **F**orm.

Here are some details on potential problems and some other considerations that you should be aware of when buying landscape plants.

Root Quality

Roots specifically on trees and shrubs for sale are available as one of three types:

- bare-root: no soil; typically for small trees or roses that are dormant (Figure 4A)
- root-balled: roots in soil held in place by burlap or some other fabric; the root-ball may be in a wire basket (Figure 4B)
- container-grown: roots and soil in a container (Figure 4C)

Figure 4 (A—bare-root plant, B—root-balled plant, and C—container-grown plant). Quality trees and shrubs can be purchased with a variety of root treatments. When grown and treated properly, all of these plants can successfully establish in a landscape.

Bare-root Stock. Bare-root plants should be dormant with buds that have not opened. Roots should not be crushed or torn. The ends of the roots should be clean-cut. If a few roots are crushed, use sharp tools to re-cut them to remove the injured portions. Make straight cuts. Do not paint the ends. The cuts should be made immediately before planting and watering. Handle the bare roots gently and keep them moist; do not let them dry out before they get into the ground.

Root-balled Stock. You should be able to see the basal **trunk flare**. The flare is the spreading trunk base that connects the trunk with the roots and signals the change from stem tissue to root tissue. Root-balls should be flat on top. Roots in soil in round bags often have many major woody roots cut or torn during the bagging process. Avoid trees with many crushed or torn roots.

The diameter of the root-ball should be at least 10 to 12 times the diameter of the trunk as measured 6 inches above the trunk flare.

At the time of planting, cut the root-ball ties or the wire on any wire baskets and carefully pull away the burlap or other fabric. Examine any roots that protrude from the soil. If many roots are obviously crushed or torn, the tree may have severe growth problems. If only a few roots are injured, use a sharp tool to cut away only the injured portions. Be careful not to break the soil ball around the roots.

If the trunk flare has been buried, gently expose it with a stream of water before planting the tree, taking care not to damage the bark.

Container-grown Stock. Roots should not twist or circle in the container. Remove the root-ball from the container. Inspect the larger exposed roots carefully to see whether they are twisting or turning in circles. Circling roots often girdle and kill other roots. If only a few roots are circling, cut them away with a sharp tool.

The trunk flare should be obvious. Be alert for trees planted too deeply in containers or “buried” in fabric bags. As with root-balled stock, you should be able to see the trunk flare on container-grown plants. If the trunk flare has been buried, gently expose it before planting the tree, taking care not to damage the bark. Plant the tree so the trunk flare is at the ground surface (not buried).

Injuries

Never buy a tree without thoroughly checking the trunk. Beware of injuries beneath trunk wraps. If the tree is wrapped, remove the wrap and inspect the trunk for wounds, incorrect pruning cuts, and insect injuries. Wrap can be used to protect the trunk during transit but should be removed after planting.

Incorrect pruning cuts are major problems. Incorrect pruning cuts that remove or injure the swollen branch collar at the base of branches can start many serious tree problems, cankers, decay, and cracks.

Form

Good, strong form starts with branches evenly spaced along the trunk. Branches should have firm, strong attachments with the trunk.

Squeezed branches portend problems: weak branch unions occur where the branch and trunk squeeze together. Because branches and trunks increase in diameter as they grow, the squeezing increases and dead spots or cracks will begin to form where the branch is attached to the trunk. Once this problem starts, the weak branch attachment could lead to branches cracking or breaking during mild to moderate storms.

When several branches are at the same position on the trunk, the likelihood of weak attachments and cracks increases greatly. As the branches grow larger and squeeze tighter together, the chances for splitting increase.

Avoid trees with two or more vertical stems squeezing together. As stems squeeze together, cracks will form down the trunk. The cracks could start from squeezed multiple leader stems or where the two trunks come together, pinching the bark between them (Figure 5).

If you desire a tree with multiple trunks, make certain that the trunks are well separated at the ground line. Remember, trunks expand in diameter as they grow. Two trunks may be slightly separated when small, but as they grow in girth, the trunks will squeeze together.

Look for early signs of vertical trunk cracks. Examine branch unions carefully for small cracks below the unions. Cracks are major starting points for fractures of branches and trunks. The small cracks can be present for many years before a fracture happens. Always keep a close watch for vertical cracks below squeezed branches and squeezed trunks.

If your tree has only a few minor problems, corrective pruning may help. Start corrective pruning one year after planting. Space major pruning over several years. Remove broken or torn branches at the time of planting. After a year, start corrective pruning by removing any branches that died after planting.

Figure 5. Acute angles between tree branches can result in the bark getting pinched between them. This leads to cracking and splitting of the branches so that one eventually breaks off and falls. In this example, one of the branches should have been eliminated when they were small to avoid this problem, and one should be cut now before it breaks off and falls.

New Tree and Shrub Planting

Planning before plant selection and planting can help ensure that the right tree is planted in the right place. Proper tree selection and placement enhance your property value and prevent costly maintenance, trimming, and damage to your home or property.

Timing and Preparation

The ideal time to plant trees and shrubs is during the dormant season, which is in the fall after leaf drop or early spring before budbreak. Weather conditions are cool and allow plants to establish roots in the new location before spring rains and summer heat stimulate new top growth. However, plants properly cared for in the nursery or garden center and given the appropriate care during transport to prevent damage can be planted throughout the growing season, provided that sufficient water is available. In either situation, proper handling during planting is essential to ensure a healthy future for new trees and shrubs. Before you begin planting your tree or shrub, be sure you have had all underground utilities located prior to digging.

If the tree you are planting is balled or bare-root, its root system has been reduced by 90 to 95 percent of its original size. As a result of the trauma caused by the digging up and root reduction process, many plants exhibit what is known as transplant shock. Containerized trees may also experience transplant shock, particularly if they have circling roots that must be cut. Transplant shock is indicated by slow growth and reduced vigor following transplanting. Proper site preparation before and during planting, coupled with good follow-up care, reduces the amount of time the plant remains in transplant shock and allows the plant to quickly establish in its new location.

Steps for Planting

Following these steps can significantly reduce the stress placed on a plant at the time of its planting.

1. **Dig a shallow, broad planting hole.** Make the hole wide, as much as three times the diameter of the root-ball but only as deep as the root-ball. It is important to make the hole wide because the roots on the newly establishing tree or shrub must push through surrounding soil in order to establish. On most planting sites in new developments, the existing soils have been compacted and are unsuitable for healthy root growth. Breaking up the soil in a large area around the tree provides the newly emerging roots room to expand into loose soil to hasten establishment.
2. **Identify a tree's trunk flare.** The trunk flare is where the roots spread at the base of the tree. This point should be partially visible after the tree has been planted (Figure 6). If the trunk flare is not partially visible, you may have to remove some soil from the top of the root-ball. Find it so you can determine how deep the hole needs to be for proper planting.
3. **Remove the container from containerized trees.** Carefully cutting down the sides of the container may make this easier. Cut or remove any circling roots in the root-ball. Expose the trunk flare, if it isn't already showing.
4. **Place the tree at the proper depth.** Before placing the tree in the hole, check to see that the hole has been dug to the proper depth and not deeper. The majority of the roots on a tree will develop in the top 12 inches of soil. If a tree is planted too deeply, new roots will have difficulty developing because of a lack of oxygen. It is better to plant the tree a little shallow, 2 to 3 inches above the base of the trunk flare, than to plant it at or below the original growing level. This planting level will allow for some settling. To avoid damage when setting the tree in the hole, always lift the tree by the root-ball and never by the trunk.
5. **Straighten the tree in the hole.** Before you begin backfilling, have someone view the tree from several directions to confirm that the tree is straight. Once you begin backfilling, it is difficult to reposition the tree.
6. **Fill the hole gently but firmly.** Fill the hole about one-third full and gently but firmly pack the soil around the base of the root-ball. Then, if the root-ball is wrapped, cut and remove any fabric, plastic, string, and wire from around the trunk and root-ball to facilitate growth (Figure 6). Be careful not to damage the trunk or roots in the process.
7. Firmly pack the soil as you fill the remainder of the hole to eliminate air pockets that may cause roots to dry out.

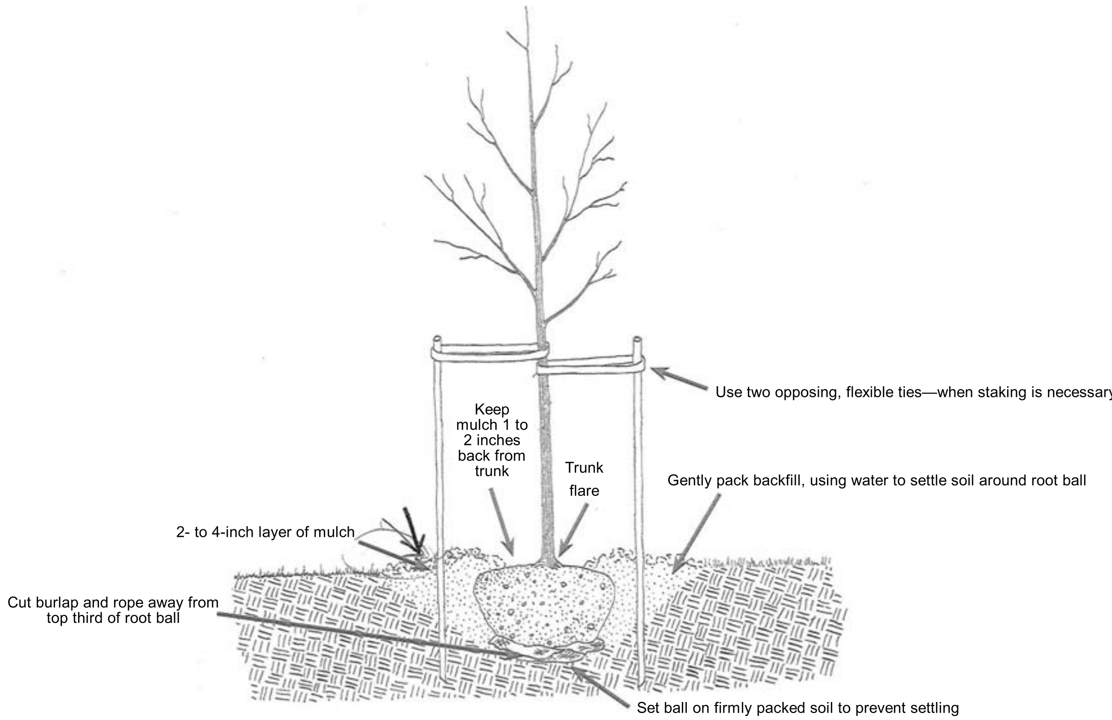


Figure 6. Good tree planting practices include removing the plant root container, backfilling the hole and settling the soil, mulching, and staking the new tree if necessary.

To best avoid this problem, add the soil a few inches at a time and settle with water. Continue this process until the hole is filled and the tree is firmly planted. Do not apply fertilizer at the time of planting.

8. **Stake the tree, if necessary.** If the tree was grown and dug properly at the nursery, staking for support will not be necessary in most home landscape situations. Studies have shown that trees establish more quickly and develop stronger trunk and root systems if they are not staked at the time of planting. However, protective staking may be required on sites where lawn mower damage, vandalism, or windy conditions are concerns.

   If staking is necessary for support, two stakes used in conjunction with a wide, flexible tie material on the lower half of the tree will hold the tree upright, provide flexibility, and minimize injury to the trunk. Remove support staking and ties after the first year of growth.

9. **Mulch the base of the tree.** Mulch acts as a blanket to hold moisture, moderates soil temperature extremes, and reduces competition from grass and weeds. Some good choices are leaf litter, pine needles, shredded bark, or composted wood chips. A 2- to 4-inch layer is ideal. More than 4 inches may cause problems with oxygen and moisture levels. When placing mulch, be sure that

the actual trunk of the tree is not covered. Covering the trunk may cause decay of the living bark at the base of the tree. A mulch-free area, 1 to 2 inches wide at the base of the tree, is sufficient to avoid moist bark conditions and prevent decay.

10. **Provide follow-up care.** Water newly planted trees at least once a week, barring rain, and more frequently during hot weather. Keep the soil moist but not soaked; overwatering causes leaves to turn yellow or fall off. When the soil is dry below the surface of the mulch, it is time to water. Continue until mid-fall, tapering off at times of lower temperatures that require less-frequent watering.
11. **Limit pruning.** Only remove branches damaged during the planting process. Prune sparingly immediately after planting and wait to begin necessary corrective pruning until after a full season of growth in the new location.

Trees and Turf

Trees and turf grasses provide many of the same environmental benefits including:

- processing carbon dioxide and releasing oxygen into the air we breathe
- cooling the air by changing water into water vapor
- stabilizing dust
- entrapping air polluting gases
- controlling erosion

However, we've all seen poor, thinning grass under large shade trees, large surface tree roots that cause safety hazards and mowing obstacles, young trees that don't seem to grow, and tree trunks badly damaged by lawn mowers or string trimmers. All of these undesirable effects can be caused by trees and turf growing together.

When trees and turf are used in the same areas, an effort should be made to make the trees and lawn compatible. Grass is generally a sun-loving plant. Most grass species will not grow well in areas that get less than 50 percent open sunlight; however, there are varieties with improved shade tolerance. Refer to the discussion of shade-tolerant grasses in Chapter 9: Lawns.

In areas where the lawn is the primary design feature, select woody plants that compete least with grass growth and maintenance. These woody plants should be small, have an open canopy (to allow sunlight to penetrate to the ground), or have a high canopy. Select trees that do not root near the soil surface. Spruce, Norway maples, poplars, and aspens all have shallow root systems, but surface rooting on any tree can be serious where shallow topsoil or composted clay soils are present. Remember, tree roots get larger as the tree gets older, so surface roots will only become bigger problems later.

Competition

Each plant in the landscape competes with neighboring plants for available sunlight, water, nutrients, and rooting space for growth. Because woody plants increase in size each year, they require even more space over time. A landscape design should provide adequate space for these plants to mature.

While shade is the biggest, most obvious problem trees create for turf growth, a tree's roots also contribute to poor turf performance. Most tree roots are in the top 2 feet of soil. More importantly, the majority of fine, water-absorbing roots are in the top 6 inches of soil. Grass roots ordinarily occupy a much greater percentage of the soil volume than tree roots do and so outcompete them for water and nutrients, especially around young trees. However, grass root density is often much lower in areas where trees were established first. In these situations, tree roots compete much better for water and nutrients and can prevent or reduce the success of establishing new turf.

The newest plant in a landscape must be given special treatment and must receive adequate water, nutrients, and sunlight. This frequently means that competing sod should be removed from around transplanted trees and shrubs, or that some of the lower branches should be removed from existing trees above a newly sodded lawn. In any case, do not do any rototilling around trees.

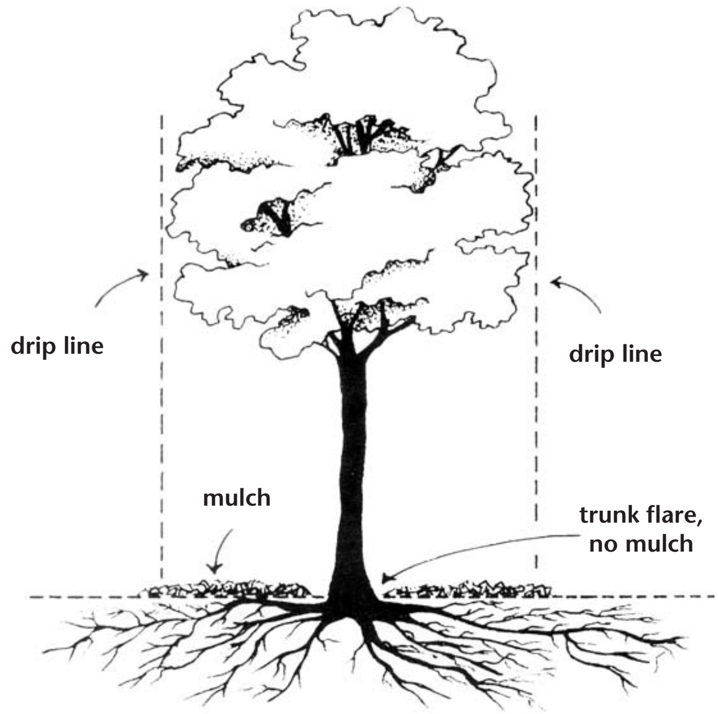
Mulching is an alternative to growing turf around trees, and its use eliminates potential competition. A 2- to 4-inch layer of wood chips, bark, or other organic material over the soil within the **drip line**—the outermost reaches of the tree canopy—is recommended (Figure 7).

Maintenance Practices

Maintenance practices for trees and turf are different and because tree and grass roots exist together in the upper 6 to 8 inches of the topsoil, treatment of one may damage the other. Fertilizer applied to one plant will also be absorbed by the roots of any nearby plant. Normally that is good, but excessive fertilizing of either trees or turf can result in tree crown or grass blade growth greater than desired.

Many herbicides or weed killers that are used on turf can cause severe damage to trees when misapplied. Misapplication can occur on windy days, causing the drift to fall on non-target plants, or on hot days when the herbicide may vaporize and diffuse into the air. While most herbicides do not kill tree roots, some, such as soil sterilants and a few others, do. Herbicides that can cause tree

Figure 7. The drip line of a tree or shrub marks a rough circle on the ground around the plant where rain shed by the plant would land. The drip line is defined by the outer reaches of the plant's branches. At a minimum, mulch should cover all the ground within the drip line, but not pile up against tree trunks or plant stems.



damage have statements on their labels warning against using the product near trees.

Watering of lawns is beneficial to trees too, if the watering is done correctly. Trees need, on average, one inch of water every seven to ten days, depending on the species. Frequent, shallow watering does not properly meet the needs of either trees or turf and can be harmful to both.

Special Situations

Placing fill dirt around existing trees. Fill dirt may be desired around existing mature trees so that a level or more visually desirable lawn can be established. The added fill dirt changes the ratio of oxygen to carbon dioxide around tree roots and, as a result, the roots may die. Consult a tree care expert before adding fill or constructing soil wells around tree trunks.

Establishing lawns around existing trees. Preparation of a seedbed for lawns requires disruption of the upper 4 to 6 inches of topsoil. This soil contains the feeder roots of trees. Damage to tree roots often results in declining tree tops.

Lawn watering in arid sites. In arid regions, the watering that is required to maintain grass is especially damaging to dryland trees. Excess water at the tree trunk encourages growth of fungi that can kill trees.

Mulching

Mulching is one of the most beneficial things a home owner can do for the health of landscape plants. Mulches are materials placed over the soil surface to maintain moisture and improve soil conditions.

Benefits of Mulching

Trees growing in a natural forest environment have their roots anchored in a rich, well-aerated soil full of essential nutrients. That soil is blanketed by **humus**, derived from rotting leaves, needles, and organic materials, that replenishes soil nutrients and provide an optimal environment for root growth and mineral uptake. Urban landscapes, however, are typically a much harsher environment with poor soils, little organic matter, and large fluctuations in temperature and moisture. Applying a 2- to 4-inch layer of organic-matter mulch can mimic a more natural environment and improve plant health.

Although the guideline for many maintenance practices is the drip line the roots can grow many times that distance. In addition, most of the fine, absorbing roots are located within inches of the soil surface. These roots, which are essential for taking up water and minerals, require oxygen to survive. A thin layer of mulch, applied as broadly as practical, can improve the soil structure, oxygen levels, temperature, and moisture availability where these roots grow.

Types of Mulch

The two major types of mulch are inorganic and organic. Inorganic mulches include various types of stone, lava rock, pulverized rubber, geotextile fabrics, and other materials. Inorganic mulches do not decompose and do not need to be replenished often. On the other hand, they do not improve soil structure, add organic materials, or provide nutrients. For these reasons, most horticulturists and arborists prefer organic mulches.

Organic mulches include wood chips, pine needles, hardwood and softwood bark, leaves, compost mixes, and a variety of other products usually derived from plants. Organic mulches decompose in the landscape at different rates depending on the material and climate. Materials that decompose faster must be replenished more often. Because the decomposition process improves soil quality and fertility, many arborists and other landscape professionals consider decomposition a positive characteristic, despite the added maintenance.

Benefits of Mulching

- Evaporation of water from the soil is reduced, and the need for watering can be minimized.
- A 2- to 4-inch layer of mulch will reduce the germination and growth of weeds.
- Mulch serves as nature's insulating blanket, keeping soils warmer in the winter and cooler in the summer.
- Many types of mulch can improve soil aeration, structure, and drainage.
- Some mulches can improve soil fertility.
- A layer of mulch can inhibit certain plant diseases.
- Mulching around trees and shrubs makes maintenance easier and can reduce the likelihood of damage from string trimmers or lawn mowers.
- Mulch can give planting beds a uniform, well-cared-for look.

Mulching Techniques

Both the choice of mulch and the method of application are important to the health of landscape plants. Following are some guidelines to use when applying mulch.

- Inspect plants and soil in the area to be mulched. Determine whether drainage is adequate. Most commonly available mulches work well in most landscapes.
- If mulch is already present, check the depth. Do not add mulch if there is a sufficient layer in place. Rake the old mulch to break up any matted layers and to refresh the appearance.
- Do not pile mulch against stems or tree trunks; pull it back several inches so that the base of the trunk and the trunk- or root-flare remain exposed.
- Organic mulches usually are preferred to inorganic materials because of their soil-enhancing properties. If organic mulch is used, it should be well aerated and, preferably, composted. Avoid using sour-smelling mulch.
- Composted wood chips can make good mulch, especially when they contain a blend of leaves, bark, and wood. Fresh wood chips also may be used around established trees and shrubs, but they may tie up available nitrogen while they decompose.
- For well-drained sites, apply a 2- to 4-inch layer of mulch. If there are drainage problems, a thinner layer should be used. Spread mulch out to the tree's drip line or beyond.

Mulch Problems

Improperly applied mulch can lead to problems in a landscape.

- Mulch applied too thickly can lead to excess moisture in the root zone, which can stress the plant and cause root rot.
- Mulch piled high against the trunks of young trees may create habitats for rodents that chew the bark and can girdle the trees. Mulch placed right against tree trunks can stress stem tissues and may lead to insect and disease problems.
- Some mulches, especially those containing cut grass, can affect soil pH. Continued use of certain mulches over long periods can lead to micronutrient deficiencies or toxicities.
- Thick blankets of finely textured mulch can become matted and may prevent the penetration of water and air. In addition, a thick layer of fine mulch can decompose and become like potting soil that supports weed growth.
- Anaerobic "sour" mulch may give off pungent odors, and the alcohols and organic acids that build up may be toxic to young plants.

Mature Tree Care

Tree care is an investment: a healthy tree increases in value with age, paying big dividends by increasing property values, beautifying our surroundings, purifying our air, and saving energy by providing cooling shade from summer's heat and protection from winter's wind. Regular maintenance, designed to promote plant health and vigor, ensures their value will continue to grow.

Preventing a problem is much less costly and time-consuming than curing one once it has developed. An effective maintenance program, including regular inspections and the necessary follow-up care, can detect problems and correct them before they become damaging or fatal. Considering that many tree species can live as long as 200 to 300 years, including these practices when caring for your home landscape is an investment that will offer enjoyment and value for generations.

Tree Inspection

Tree inspection is an evaluation tool to assess any change in the tree's health before a problem becomes too serious. By providing regular inspections of mature trees at least once a year, you can prevent or reduce the severity of future disease, insect, and environmental problems. During tree inspection, examine four characteristics of tree vigor: new leaves or buds, leaf size, twig growth, and absence of **crown dieback** (gradual death of the upper part of the tree).

A reduction in the growth of shoots, buds, or new leaves is a fairly reliable cue that the tree's health has recently changed. To evaluate this factor, compare the growth of the shoots over the past three years. Determine whether there is a reduction in the tree's typical growth pattern.

Further signs of poor tree health are trunk decay, crown dieback, or both. These symptoms often indicate problems that began several years before. Loose bark or growths such as trunk conks (mushrooms) are common signs of stem decay.

Any abnormalities found during these inspections, including insect activity and spotted, deformed, discolored, or dead leaves and twigs, should be noted and watched closely.

Mulching

Mulching of established trees can reduce environmental stress by providing trees with a stable root environment that is cooler and contains more moisture than the surrounding soil. Mulch can also prevent mechanical damage by keeping machines such as lawn mowers and string trimmers away from the tree's base. Further, mulch reduces competition from surrounding weeds and turf.

To do all this, mulch should be placed 2 to 4 inches deep and cover the entire root system, which may extend as far out as 2 or 3 times the diameter of the branch spread of the tree. If the area and activities happening around the tree do not permit the entire area to be mulched, mulch as much of the area under the drip line of the tree as possible.

Plastic sheet mulch should not be used because it interferes with the exchange of gases between soil and air, thus inhibiting root growth. Thicker mulch layers, 5 to 6 inches deep or greater, may also restrict gas exchange.

Fertilizing

Fertilizing a tree can improve growth; however, if fertilizer is not applied wisely, it may not benefit the tree at all and may even harm the tree. Mature trees with satisfactory growth may not require fertilization. When considering supplemental fertilizer, it is important to know which nutrients are needed and when and how they should be applied. Especially when dealing with a mature tree that provides considerable benefit and value to your landscape, it is worth the time and investment to have the soil tested for nutrient content.

Mature trees have expansive root systems 2 to 3 times wider than the diameter of their canopies. A majority of the actively growing roots are located outside the tree's drip line. It is important to understand this when applying fertilizer to your trees as well as to your turf.

Lawn fertilizers that contain weed-and-feed formulations may be harmful to your trees. When you apply a broadleaf herbicide to your turf, remember that tree roots coexist with turf roots. The same herbicide that kills broadleaf weeds in your lawn is picked up by tree roots and, if incorrectly applied, can harm or kill your trees. Understanding the actual size and extent of a tree's root system before you fertilize is necessary to determine how much, what type, and where to best apply fertilizer.

The same herbicide that kills broadleaf weeds in your lawn is picked up by tree roots and, if incorrectly applied, can harm or kill your trees.

Pruning

Pruning is the most common tree maintenance procedure next to watering. Pruning is often desirable or necessary to remove dead, diseased, or insect-infested branches and to improve tree structure, enhance vigor, or to maintain safety. Because each cut has the potential to change the growth of (or cause damage to) a tree, no branch should be removed without a reason.

Removing foliage from a tree has two distinct effects on its growth. Removing leaves reduces photosynthesis and may reduce overall growth. That is why pruning should always be performed sparingly. Over-pruning is extremely harmful because without enough leaves, a tree cannot gather and process enough sunlight to survive. However, after pruning, the growth that does occur takes place on fewer shoots, so they tend to grow longer than they would without pruning. Understanding how the tree responds to pruning should assist you when selecting branches for removal.

Pruning mature trees may require special equipment, training, and experience. If the pruning work requires climbing, the use of a chain or hand saw, or the removal of large limbs, then personal safety equipment, such as protective eyewear and hearing protection, must be used. Arborists can provide a variety of services to assist in performing the job safely and reducing risk of personal injury and damage to your property. They also are able to determine which type of pruning is necessary to maintain or improve the health, appearance, and safety of your trees. See Chapter 21 "Pruning Woody Landscape Plants" for details on how and when to prune trees and other woody landscape plants.

Tree Removal

Although tree removal is a last resort, there are circumstances when it is necessary. An arborist can help decide whether or not a tree should be removed. Professionally trained arborists have the skills and equipment to safely and efficiently remove trees. Removal is recommended when a tree:

- is dead, dying, or considered irreparably hazardous;
- is causing an obstruction;
- is crowding and causing harm to other trees and the situation is impossible to correct through pruning;
- is to be replaced by a more suitable specimen; or
- should be removed to allow for construction.

Pruning or removing trees, especially large trees, can be dangerous work. It should be performed only by those trained and equipped to work safely in trees.

Tree Hazards

While trees provide significant benefits to our homes and cities, when trees fall and injure people or damage property, they are liabilities. Recognizing and reducing tree hazards not only increases the safety of your property and that of your neighbors but also improves the tree’s health and may increase its longevity.

It is an owner's responsibility to provide safety from trees on his or her property. However, evaluating the seriousness of tree defects is best done by a professional arborist. Once a hazard is recognized, steps may be taken to reduce the likelihood of the tree falling and injuring someone or causing more damage.

Trees that fall into utility lines have additional serious consequences. Hitting a line may cause power outages, surges, fires, and other damage. Downed lines still conducting electricity are especially dangerous. A tree with the potential to fall into a utility line is a very serious situation.

A severely leaning tree is an obvious hazard. The following are less obvious defects or signs of possible defects in urban trees that can become hazards (Figure 8):

1. regrowth after topping, line clearance, or other pruning
2. utility lines adjacent to tree
3. broken or partially attached branch
4. open cavity in trunk or branch
5. large dead or dying branches
6. multiple branches arising from a single point on the trunk
7. mushrooms and other signs of decay and rot present in old wounds
8. recent change in grade or soil level, or other construction

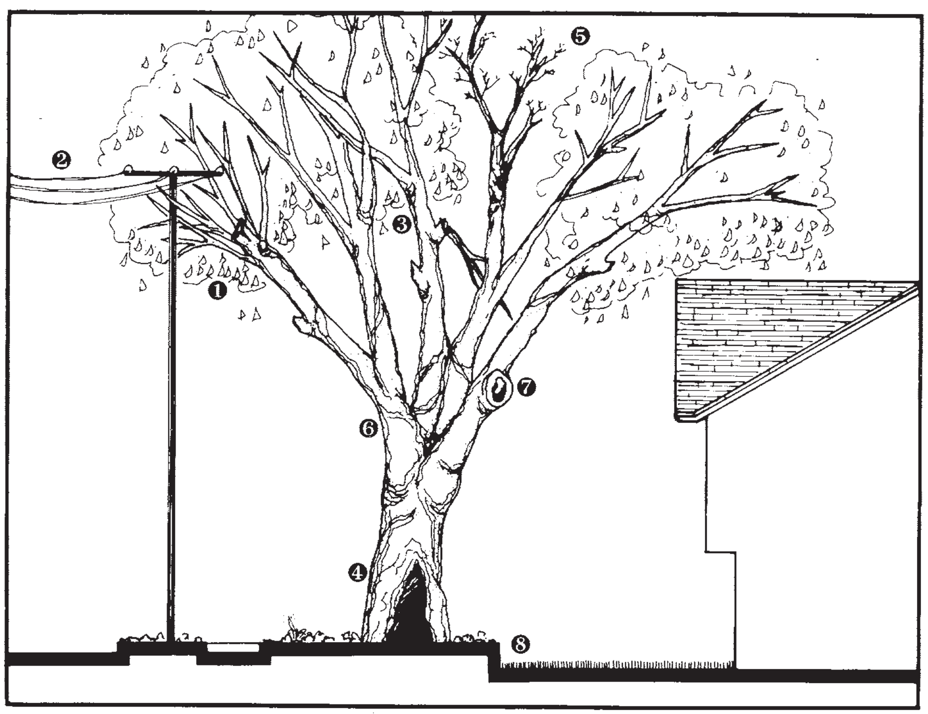


Figure 8. Common defects in urban trees can make them a hazard in the landscape. Refer to the text for details on each numbered defect.

Managing Tree Hazards

An arborist familiar with hazard tree evaluation may suggest one or more of the following:

- **Remove the target.** While a home or a nearby power line cannot be moved, it is possible to move picnic tables, cars, landscape features, or other possible targets to prevent them from being hit by a falling tree.
- **Prune the tree.** Remove the defective branches of the tree. Because inappropriate pruning may weaken a tree, pruning work is best done by an ISA Certified Arborist.
- **Cable and brace the tree.** Provide physical support for weak branches and stems to increase their strength and stability.
- **Provide routine care.** Mature trees need routine care in the form of water, fertilizer (in some cases), mulch, and pruning as dictated by the season and the tree structure.
- **Remove the tree.** Some hazardous trees are best removed. If possible, plant a new tree in an appropriate place as a replacement. And remember "right tree, right place." Don't plant a future problem for someone else.

Some hazardous trees are best removed. If possible, plant a new tree in an appropriate place as a replacement.

Avoiding Tree–Utility Conflicts

When planning what type of tree to plant, remember to look up and look down to determine where the tree will be located in relation to overhead and underground utility lines. For us to enjoy the convenience of reliable, uninterrupted utility service, distribution systems are required to bring utilities into our homes. These services arrive through overhead or underground lines. Overhead lines can be electric, telephone, or cable television. Underground lines include those three plus water, sewer, and natural gas.

The location of these lines should have a direct impact on your tree and planting site selection (Figure 9). The ultimate mature height of a tree to be planted must be within the available overhead growing space. Just as important, the soil area must be large enough to accommodate the particular rooting habits and ultimate trunk diameter of the tree.

Overhead Lines. Overhead utility lines are the easiest to see and probably the ones we take most for granted. Planting tall-growing trees under or near these lines eventually requires your utility company to prune them to maintain the required safe clearance from the wires. This pruning may result in the tree having an unnatural appearance and can also lead to a shortened life span for the tree. Trees that must be pruned away from power lines are under greater stress and are more susceptible to insects and disease. Small, immature trees planted today can become problem trees in the future.

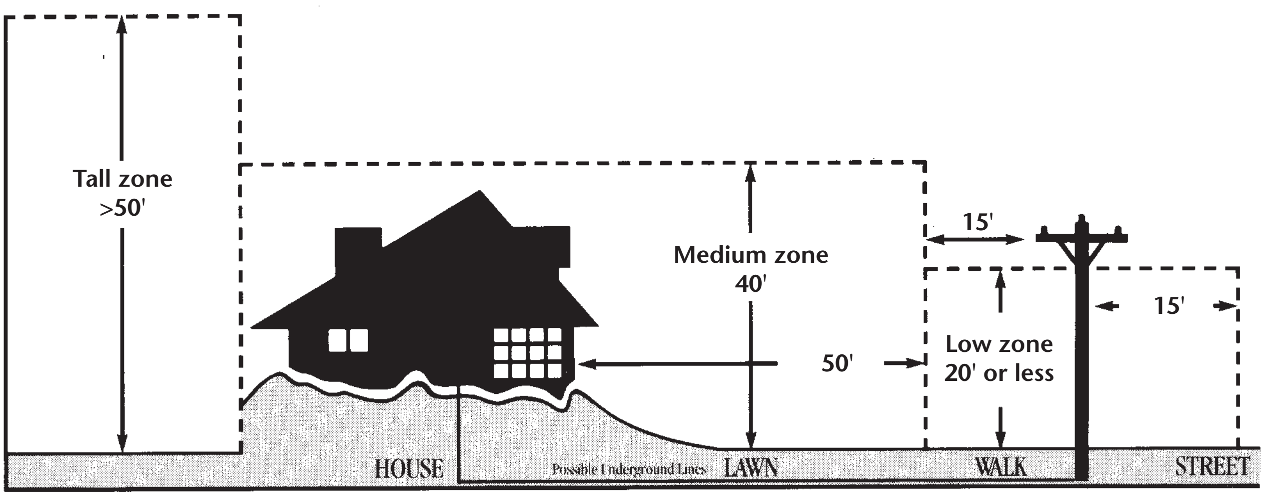


Figure 9. Trees should be placed within a landscape so that their mature size will not interfere with overhead or underground utility lines or other buildings and structures.

Call before you dig! Visit www.callbeforeyoudig.org

Tall trees near overhead lines can cause service interruptions when trees contact wires. Children or adults climbing in these trees can be severely injured or even killed if they come in contact with the wires. Proper selection and placement of trees in and around overhead utilities can eliminate potential public safety hazards, reduce expenses for utilities and their rate payers, and improve the appearance of landscapes (Figures 10, 11).

Underground Lines. Much of the utility services provided today run below ground. Tree roots and underground lines often coexist without problems. However, trees planted near underground lines could have their roots damaged if the lines need to be dug up for repairs.

The biggest danger to and from underground lines occurs during planting. Before you plant, make sure that you know the location of any underground utilities. To be certain that you do not accidentally dig into any lines and risk serious injury or a costly service interruption, call your utility company or utility protection service first. In Washington State, the law requires anyone doing an excavation to call for a utility locate service first. Visit www.callbeforeyoudig.org for more information and phone numbers of utility notification centers.

Never assume that utility lines are buried deeper than you plan to dig. In some cases, utility lines are very close to the surface.

Siting Urban Trees

Different size trees have different roles and places in the landscape. Trees that grow as tall as 60 feet need to be in large, open areas away from contact with any overhead wires. Before planting a tree that will grow large, consider whether the mature tree will interfere

Figure 10. This fir tree was probably less than 5 feet tall when it was planted more than 40 years ago. Pruning to keep it away from overhead utility lines has ruined its natural shape. Its near-surface roots have also cracked and lifted the adjacent sidewalk, creating a hazard.

with your neighbors' views and their existing trees. Plant large trees at least 35 feet away from a house for proper root development and to minimize potential damage to the house or building. Street planting sites for large trees must have no overhead wires and have wide planting areas or medians (wider than 8 feet) to allow for a large root system, trunk diameter, and trunk flare. Large trees are recommended for parks, meadows, or other open areas where their large size, both above and below ground, will not be restricted and not cause damage or become a liability.

Trees that grow up to 40 feet tall can be used to accent or frame your house or provide a park-like setting. Select your trees first, then plant shrubs to complement the trees. Medium-size trees are recommended for planting anywhere the available above- and below-ground growing space will allow them to reach a mature height of 30 to 40 feet. Appropriate soil spaces are wide planting areas or medians (4 to 8 feet wide), large planting squares (8 feet square or greater), and other open areas of similar size or larger.

Trees with a mature height of less than 20 feet are recommended when the growing space is limited, including within 15 feet of utility lines. These trees are appropriate as well for narrow planting areas (less than 4 feet wide); planting squares or circles surrounded by concrete; large, raised planting containers; or other locations where underground space for roots will not support tall- or medium-size trees.

*Figure 11. The short stature (20 feet tall at maturity) of these 'Crimson Sentry' Norway maples (*Acer platanoides*) will prevent them from growing up into the overhead power lines.*

Treatment of Damaged Trees

Despite the best intentions and most stringent tree preservation measures during a construction project, trees still might be injured. There are some remedial treatments that may save some construction-damaged trees, but immediate implementation is critical.

Treating Trunk and Crown Injuries

Pruning. Branches that are split, torn, or broken should be removed. Also remove any dead, diseased, or rubbing limbs from the crown of the tree. Sometimes it is necessary to remove some lower limbs to raise the canopy of a tree and provide clearance below. After such extensive pruning, it is best to postpone other maintenance pruning for a few years. It used to be recommended that tree canopies be thinned or topped to compensate for any root loss. There is no conclusive research to support this practice. In fact, thinning the crown can reduce a tree's food-making capability and may stress the tree further. It is better to limit pruning in the first few years to removal of damaged branches and dead wood. Do not top trees, ever.

Cabling and Bracing. Trees growing in wooded areas are usually not a threat to people or structures. Trees that are close to houses or other buildings must be maintained to keep them structurally sound. If branches or tree trunks need additional support, a professional arborist may be able to install cables or bracing rods. If cables or braces are installed, they must be inspected regularly. The amount of added security offered by the installation of support hardware is limited. Not all weak limbs are candidates for these measures.

Bark and Trunk Wounds. Often the bark may be damaged along the trunk or major limbs. If that happens, remove any loose bark. Use a sharp knife to cut away jagged edges. Take care not to cut into living tissues.

Wound dressings were once thought to accelerate wound closure, protect against insects and diseases, and reduce decay. However, research has shown that dressings generally do not reduce decay or speed closure and rarely prevent insect or disease infestations. Most experts now recommend that wound dressings not be used. If a dressing must be used for cosmetic purposes, use just a thin coating of a nontoxic material.

Irrigation and Drainage

One of the most important tree maintenance procedures following construction damage is to maintain an adequate, but not excessive, supply of water to the root zone. If soil drainage is good, be sure to keep trees well watered, especially during the dry summer months. A long, slow soak over the entire root zone is the preferred method of watering. Keep the top 12 inches moist, but avoid overwatering. Avoid frequent, shallow watering. Make sure surface water drains away from the tree. Proper irrigation may do more to help trees recover from construction stress than anything else you could do.

If a drainage problem has developed due to soil compaction or grade change, the trees will decline rapidly. Improper drainage must be corrected if the trees are to be saved.

Drilling Holes/Vertical Mulching. Both compaction of soil and increases in grade have the effect of depleting the oxygen supply to tree roots. If soil aeration can be improved, root growth and water uptake can be enhanced.

A common method of aeration of the root zone involves drilling holes in the ground. Holes are usually 2 to 4 inches in diameter and are made about 3 feet on center throughout the root zone of the tree. The depth should be at least 12 inches but may need to be deeper if the soil grade has been raised. Sometimes the holes are filled with peat moss, wood chips, pea gravel, or other materials that maintain aeration and support root growth. This process is called **vertical mulching**.

Radial Aeration. Some research has shown promising results with another method called **radial aeration**, in which narrow trenches are cut with a compressed air gun in a radial pattern throughout the root zone. These trenches are placed like the spokes of a wheel, with the tree trunk as the hub. It is important to begin the trenches 4 to 8 feet out from the trunk of the tree to avoid cutting any major support roots. Trenches should extend at least as far as the drip line of the tree. If the primary goal is to reduce compaction, the trenches should be about 8 to 12 inches in depth. They may need to be deeper if the soil grade has been raised.

The narrow trenches can be backfilled with topsoil or compost. Root growth will be greater in the trenched area than in the surrounding soil. This treatment can give a tree the added boost it needs to adapt to the compacted soil or new grade.

Vertical mulching and radial aeration are techniques that may improve conditions for root growth. If construction-damaged trees are to survive the injuries and stresses they have suffered, they must replace the roots that have been lost.

Fertilizing

Most experts recommend not fertilizing trees the first year after construction damage. Water and mineral uptake may be reduced because of root damage, so excessive soil salts (from fertilizer) can draw water out of the roots and into the soil. In addition, nitrogen fertilization may stimulate top growth at the expense of root growth.

It is a common misconception that applying fertilizer gives a stressed tree a much-needed shot in the arm. Fertilization should be based on the nutritional needs of trees on a site. Soils should be tested to determine whether any of the essential minerals are deficient. If soil nutrients are deficient, supplemental fertilization may be indicated. It is advisable to keep application rates low until the root system has had time to adjust.

Monitoring for Decline and Hazards

Despite your best efforts, you may lose some trees from construction or other damage. Symptoms of decline include smaller and fewer leaves, dieback in the crown of the tree, and premature fall color. If a tree dies as a result of root damage, it may be an immediate falling hazard and should be removed right away.

Examine trees regularly for signs of possible hazards. Look for cracks in the trunk, split or broken branches, and dead limbs. Watch for indications of internal decay such as cavities, carpenter ants, soft wood, and mushroom-like structures growing on the trunk, root crown, or along the major roots. If you detect any defects or suspect decay, consult an arborist for a professional assessment.

Landscape Plant Values

Almost everyone knows that trees and other living plants are valuable for all the things they do. Many people don't realize, however, that plants have a dollar value of their own that can be measured by competent plant appraisers in a process known as **tree valuation**.

Valuating Trees and Shrubs

Professionals in this industry have developed a set of guidelines for valuation. Such guidelines have been widely adopted in the field and are recognized by insurance companies, the courts, and, in some cases, the Internal Revenue Service (IRS).

A casualty loss is defined by the IRS as "… a loss resulting from an identifiable event of sudden, unexpected, or unusual nature." This definition can include such events as vehicular accidents, storms, floods, lightning, vandalism, or even air and soil pollution.

If you incur damage to trees or landscaping from any type of casualty, first consult your home owner's insurance policy to determine the amount and kind of coverage in place. Contact the insurance company to have an appraisal made by a competent tree and landscape professional who is experienced in plant appraisal. Have the appraisal made right after your loss or damage.

The appraiser will establish the amount of your loss in financial terms, including the costs of removing debris and making repairs as well as replacements. All of these steps are wise investments and well worth the cost you may incur for the inspection.

Value Factors

Size. Sometimes the size and age of a tree are such that it cannot be replaced. Trees that are too large to be replaced should be assessed by professionals who use a specialized appraisal formula.

Species or Classification. Trees that are hardy, durable, highly adaptable, and free from objectionable characteristics are most valuable. They require less maintenance and they have sturdy, well-shaped branches and pleasing foliage. Tree values vary according to your region, the “hardiness” zone, and even state and local conditions.

Condition. Obviously, a healthy, well-maintained plant has a higher value. Roots, trunk, branches, and buds all need to be inspected.

Location. Functional considerations are important. A tree in your yard may be worth more than one growing in the woods. A tree standing alone often has a higher value than one in a group. A tree near your house or one that is a focal point in your landscape tends to have greater value. The site, placement, and contribution of a tree to the overall landscape help determine the total value of the plant attributable to location.

All of these factors can be measured in dollars and cents by professional plant appraisers. They can determine the value of a tree, specimen shrubs, or evergreens, whether for insurance purposes, court testimony in lawsuits, or tax deductions.

Value Checklist

You can improve the value of your landscape investment and prevent financial loss should it be damaged by taking these steps:

- Plan your landscaping for both beauty and functional value.
- Protect and preserve landscape elements to maintain the total value.
- Take pictures of trees and other landscape plants now while they are healthy and vigorous. Pictures make before-

and-after comparisons easier and expedite the processing of insurance claims or deductions for losses on federal tax forms.

- Check your insurance. In most cases, the amount of an allowable claim for any one tree or shrub is a maximum of $500.
- For insurance, legal, and income tax purposes, keep accurate records of your landscape and real estate appraisals on any losses.

Certified Arborists

Generally, an arborist is a specialist in the care of individual trees. An arborist by definition is an individual who is trained in the art and science of planting, caring for, and maintaining individual trees.

ISA arborist certification is a nongovernmental, voluntary process by which individuals can document their base of knowledge. It operates without mandate of law and is an internal, self-regulating device administered by the International Society of Arboriculture. Certification provides a measurable assessment of an individual's knowledge and competence required to provide proper tree care. Certification is not a measure of standards of practice. Certification can attest to the tree knowledge of an individual but cannot guarantee or ensure quality performance.

Certified Arborists are individuals who have achieved a level of knowledge in the art and science of tree care through experience and by passing a comprehensive examination developed by some of the nation's leading experts on tree care. Certified Arborists must also continue their education to maintain their certification. Therefore, they are more likely to be up to date on the latest techniques in arboriculture.

Arborist Services

An arborist can determine the type of pruning necessary to maintain or improve the health, appearance, and safety of trees. These techniques include

- eliminating branches that rub each other
- removing limbs that interfere with wires, building facades, gutters, roofs, chimneys, or windows, or that obstruct streets or sidewalks
- removing dead or weak limbs that pose a hazard or may lead to decay
- removing diseased or insect-infested limbs

- creating better structure to lessen wind resistance and reduce the potential for storm damage
- training young trees
- removing limbs damaged by adverse weather conditions
- removing branches, or thinning, to increase light penetration
- improving the shape or silhouette of the tree

Tree Removal. Although tree removal is a last resort, there are circumstances when it is necessary. An arborist can help decide whether a tree should be removed. Arborists have the skills and equipment to safely and efficiently remove trees (Figure 12).

Figure 12. Special tools and skills are important for safely and effectively working in, or removing, trees.

Emergency Tree Care. Storms may cause limbs or entire trees to fall, often landing on other trees, homes and other structures, or cars. The weight of storm-damaged trees is great, and they can be dangerous to remove or trim. An arborist can assist in performing the job in a safe manner, while reducing further risk of damage to property.

Other Services. Many arborists also provide a variety of other tree care services, including

- recommending and planting trees
- Plant Health Care, a concept of preventive maintenance to keep trees in good health, which will help the tree better defend itself against insects, disease, and site problems
- fertilization
- cabling or bracing for added support to branches with weak attachment
- aeration to improve root growth
- installation of lightning protection systems
- spraying or injecting to control certain insect and disease problems

When selecting an arborist, ask for these 5 conditions:

1. ISA certification
2. Licensed in the state
3. Has evidence of liability insurance
4. Current list of references
5. If spraying or injecting materials to control insect and disease problems, evidence of a current Washington State pesticide license

Further Reading

WSU Extension Publications available at: http://cru84.cahe.wsu.edu/

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Backyard Forest Stewardship

12

Topics covered:

- Introduction
- Forest Health
  - Environmental Factors
  - Diseases
  - Insects
  - Human Activities
  - Animal Damage
  - Noxious and Invasive Weeds
  - Hazard Trees
- Forest Health Care
  - Thinning
  - Pruning
- Wildlife and Wildlife Habitat
  - Habitat Diversity
  - Snags
  - Nest Boxes
  - Bird Feeders

Learning Objectives

- Be able to identify common long-term objectives and goals for timber property or woodland.
- Understand the basic care required for trees in a woodland setting to ensure long-term forest health.
- Know ways to improve wildlife habitat in and around timber properties and woodlands.

This chapter is adapted from EM026: Backyard Forest Stewardship in Western Washington by Janean Creighton and Amy Grotta, and tailored for Master Gardener volunteers who advise people about the health of the trees in their wooded lots.

Master Gardener volunteers should refer questions about commercial forest management, Christmas tree production, and timber sales to an Extension forester or a Department of Natural Resources stewardship forester. Funding for the development of EM026 provided by the US Forest Service.

Introduction

Owning a home in the woods is a dream come true for many people (Figure 1), but living in a forested setting presents unique challenges because there are so many, and often conflicting, objectives for the land use. Improving habitat for wildlife is often an important objective for many small acreage owners, but what species are most desired? Is hunting an important consideration or bird watching? Perhaps improving the access in the forest for walking or other activities, or improving the overall visual aesthetic is what is desired. There may be more than one objective for the land. Managing for combined objectives can be challenging but often can be fairly easy to accomplish.

Develop a plan. Having a plan of work for the property will help property owners reach their goals, as well as save time and money. Worksheet 1 (at the end of this chapter) provides a framework for starting to plan.

Begin by assessing the property and dividing it into levels of use: heavy use, intermediate use, and natural areas. Then decide

Figure 1. A home in the woods. (Photo by Kristi McClelland)

whether to retain an area in its current use or change it. For example, perhaps there is a large lawn to convert to a more natural area, or some hiking trails could be added in an area that has a lot of brush or is thick with a lot of small diameter trees. There may be areas in which to reduce the level of human use in order to encourage more wildlife, or perhaps there is a small stream or wetland area on the property to restore for fishing.

Identify objectives. Objectives are intended to help landowners meet their goals. To begin developing a plan, identify and prioritize the objectives. There may be dozens of management activities desired for the property, and prioritizing them will help complete them successfully. Worksheet 2 (at the end of this chapter) helps identify potential objectives and then rank them in order of importance.

Forest Health

The health of trees on a property is important to maintain regardless of the objectives for that property. Healthy trees live longer, present fewer hazards, and contribute to the overall value of a property. Many factors can influence the health of trees and forests in Washington. Following are some of the most common factors.

Environmental Factors

Drought. Extended periods of drought during the growing season can kill or damage trees. Trees on gravelly or sandy soils and species such as western hemlock and western redcedar are particularly susceptible to drought. Whole branches or tree tops whose needles have turned bright red may be symptomatic of drought damage. Sometimes the damage may not be apparent until the next growing season after the dry conditions occurred. Western redcedar trees often exhibit patches of red foliage throughout their crowns in the fall (Figure 2). If the pattern of this

Figure 2: An cedar showing typical "flagging" caused by drought. (Photo by Dan Omdahl)

discolored foliage is in older foliage, not the current year's growth, this is a normal occurrence and is not a concern.

High winds. Storms periodically damage or blow down trees. Check for root disease and hazard trees before the next wind storm. Stands of trees suddenly exposed to wind, such as those at the edge of newly cleared land or recent timber harvest areas are especially susceptible to wind throw. Thinning of stands beginning when trees are young will help individual trees to resist wind throw.

Dry, easterly winds on sunny winter days can severely dehydrate foliage and may kill tree tops.

Temperature extremes. Sudden heat waves or deep freezes often cause damage. Small trees may be killed. Large trees usually show damage but recover.

High water. Poor soil drainage and high water tables during the winter can suffocate tree roots. Flooding can also damage or kill trees if water stands for an extended period. Planting species that can thrive under these conditions is the best approach. Avoid planting Douglas fir in wet sites. Shore pine (lodgepole pine), grand fir, and western redcedar are better choices, or, encourage deciduous alder to grow in these areas.

Ice and snow. Periodically, large loads from freezing rain and heavy snow cause excessive damage to trees and forests. Tree tops and branches are often broken and whole trees can be bent over or uprooted. Thinning forest stands starting when trees are young will help trees withstand ice and snow breakage.

Overcrowded forests. Many forest stands are too dense. Competition between trees results in small crowns, poor diameter growth, and reduced tree health and vigor. One way to assess whether a stand is overcrowded is to examine the understory. A healthy forest will have a variety of shrubs growing throughout, whereas an overcrowded stand will be dark with little to no live vegetation on the ground. Thinning will help to keep trees healthy and growing vigorously and allow a healthy understory to develop. (See the section on Thinning, below, for specific information on improving stand density.)

Diseases

Root diseases are caused by native fungi that persist in soil and tree roots. Laminated Root Rot is a particular problem, primarily in Douglas fir stands. The root rot fungus spreads by root-to-root contact. Conifer trees of all ages and sizes may be killed or blown over in high winds. Sparse or yellow foliage, short top growth, and excessive cone crops may be signs of root diseases (Figure 3). Trees blown down with few or no roots attached usually indicate root disease (Figure 4). Look for forest openings or groups of affected trees called "root rot pockets." Trees near the center of such pockets will be most severely affected, perhaps dead or blown down. Trees on the edge of the root rot pocket will be infected before visible signs appear. Once trees are infected, there is no direct control. Remove affected trees, especially if they are near structures or other areas of heavy human activity. Avoid replanting with Douglas fir. Good choices for replanting include Western white pine, western redcedar, or hardwoods such as alder and maple species.

Foliage diseases. Foliage diseases can weaken trees but rarely kill them. Thinning and pruning to increase air circulation is helpful. Preventive applications of fungicides may be needed for landscape trees. However, this is rarely an option in forest stands. Periodic fertilizer applications can sometimes help trees maintain sufficient foliage and grow out of disease-susceptible stages.

Insects

Bark Beetles. These insects are usually not the primary damaging agent in Washington. They typically attack trees already under stress from some other factor such as drought, root damage, or overcrowding. Bark beetle-infested trees normally cannot be saved.

Foliage Insects. Several species of insects can cause foliage damage or loss. Aphids, adelgids, tent caterpillars, sawflies, leaf beetles, and loopers are just a few common examples. Direct control may be possible for landscape trees but is rarely feasible or necessary in forest stands. Damage is often cyclic, that is, worse in some years than others. Most trees will recover from this type of insect attack.

Figure 3. (At left) A typical crown of a tree affected by root disease. (Photo by G.W. Wallis, Bugwood.org)

Figure 4. (Above) A wind-thrown tree. (Photo by G.W. Wallis, Bugwood.org)

In general, if many trees of different species exhibit common symptoms, the cause is probably environmental or human. If damage is limited to an individual species, the problem may be insects or disease. Most insects and diseases are specific to individual tree species or closely related groups of species, and will not spread to others in the forest.

Human Activities

Human activities such as excavating, filling, road construction and timber harvesting can damage trees directly or indirectly by affecting root function or changing soil drainage. Heavy equipment traffic near trees can compact the soil, which is also damaging to roots. Plan to protect trees and their root zones during development or construction activities (and be aware that the root zone extends well beyond the drip line of the tree). Damaged trees may die suddenly or deteriorate slowly. Trees stressed by human-caused damage are often highly susceptible to secondary damage-causing agents such as bark beetles.

People also sometimes unknowingly introduce exotic pests and weeds that can cause extensive damage to Washington trees and forests. One pest example is the European Gypsy Moth, which "hitchhikes" on vehicles and possessions and moved here from the eastern U.S. Personal alertness and cooperation with Washington State Department of Agriculture pest monitoring programs will help minimize the potential for damage from exotic pests. People are often responsible for the introduction of noxious weeds as well. Noxious weeds are common and may influence the development of the forest floor vegetation. See Noxious and Invasive Weeds, below, for more information.

Animal Damage

Figure 5. Elk damage on a birch tree trunk. (Photo by Thomas E. Hinds, USDA Forest Service)

Both wildlife and domestic animals can damage trees, shrubs, and young seedlings especially. Use fences to keep horses and cattle away from trees and forest vegetation, particularly along streams. Paper or fabric bud caps, rigid plastic tubing, and repellents can help control feeding damage done by deer, elk, mountain beaver, rabbits, and rodents. See Figure 5 for an example of damage by elk.

Livestock left to graze in forested areas for prolonged periods can cause damage to both mature and young trees. Forest soils are easily compacted by animal traffic that may, in turn, lead to root damage. Horses and cattle may also rub against trees, causing bark damage. Horses or other livestock should be kept out of a forest, especially during wet months.

Noxious and Invasive Weeds

Many non-native plants have spread into Washington's forests and natural areas. They get introduced in a variety of ways including human activity or from droppings of livestock and birds or other native wildlife.

Some non-native plants are invasive—they spread rapidly and are difficult to control. These **invasive weeds** threaten ecosystems and wildlife by displacing native plants. Invasive weeds such as

Japanese knotweed (Figure 6) can create soil erosion problems on slopes and along streams if they displace native woody plants with more developed root systems. **Noxious weeds** may be toxic to wildlife or domestic animals, and some weeds such as Scotch broom and gorse pose a serious fire hazard.

Figure 6. Japanese Knotweed growing along a stream. (Photo by Amy T. Grotta)

Invasive weeds may or may not be on the noxious weed list, but are, nevertheless, a problem. In western Washington, some of the most common invasive weeds in forests include Himalayan blackberry, English ivy, English holly, and Scotch broom. In eastern Washington, some of the most common invasive weeds in forests include knapweed, Dalmatian toadflax, and skeleton weed.

You can improve your property's aesthetic value and ecological health by controlling noxious and invasive weeds. Here are some suggestions for success:

- Educate yourself on how to identify noxious and invasive weeds. See "Further Reading" at the end of this chapter for some Web sites with good weed photos and descriptions.
- Don't buy invasive plants at nurseries. Most regulated noxious weeds cannot legally be sold at retail nurseries, but many nurseries carry highly invasive plants. Learn which are which and purchase accordingly. Garden Wise is an excellent guide to non-invasive plant choices for landscaping: http://www.nwcb.wa.gov/education/Western_Garden_Wise_Web.pdf.
- Don't dump potted plants in the forest. Many forests are invaded because landowners unintentionally introduce weedy plants in this way. Dispose of unwanted plant material in a hot compost pile or through a local yard waste disposal program. Invasive plants are best disposed of through a local yard waste program since home composting may not get hot enough to destroy seeds and roots.
- Control weeds with integrated pest management techniques. Hand pulling, mowing, and chemical application each have their place for managing weed populations. Consult your local Noxious Weed Control

From Chapter 17.10.010 of the Revised Code of Washington (RCW):

"Noxious weed" means a plant that when established is highly destructive, competitive, or difficult to control by cultural or chemical practices.

"State noxious weed list" means a list of noxious weeds adopted by the state noxious weed control board. The list is divided into three classes:

(a) Class A consists of those noxious weeds not native to the state that are of limited distribution or are unrecorded in the state and that pose a serious threat to the state;

(b) Class B consists of those noxious weeds not native to the state that are of limited distribution or are unrecorded in a region of the state and that pose a serious threat to that region;

(c) Class C consists of any other noxious weeds.

See Chapter 17: Weeds and Weed Management for more information on controlling weeds.

Board for specific recommendations for your area and weed of concern.

- Control small, isolated patches of weeds first. Early detection and control are critical to keep newly invaded areas from becoming a larger problem. It requires much less effort and time to eradicate a small infestation than a large one.
- Replant areas where weeds have been removed and monitor for reinvasion. Nature abhors a vacuum, and weeds will re-establish on cleared ground quickly, either from root sprouts or newly germinating seeds. Plant native ground covers and shrubs, and check regularly for re-sprouting weeds.

Landowner Responsibility. In order to reduce the spread of harmful plants in Washington, state law requires landowners to control certain noxious weeds, generally those that are not yet widespread in an area. The Washington State Noxious Weed Control Board determines which plants are designated as noxious weeds and specifies regions where different species are required to be controlled. Current lists of noxious weeds are available at: http://www.nwcb.wa.gov/weed_list/weed_list.htm.

Hazard Trees

Figure 7. A hazard tree threatening power lines, buildings, and human activities. (Photo by Joseph LaForest, University of Georgia, Bugwood.org

Dead, dying, or damaged trees may be hazards if they are within range of structures, parking areas, or other areas with heavy human activity (Figure 7). Trees or parts of trees which are structurally weakened may pose a threat to people and structures. Check the trees near your home and yard for hazard signs such as:

- Dead or dying, poorly attached limbs
- Old wounds and obvious signs of decay (fungal conks, hollow trunks)
- Leaning trees
- Cracks in soil (indicating root movement)
- Shortened height growth
- Sudden large crop of cones
- Signs of root damage (including excavation in the root zone or compaction, pavement, or fill over the root zone)
- Yellowing, reddening, or thinning foliage out of season.

Some of these indicators may be signs of normal change or environmental challenges such as drought. But some, such as shortened height growth or unexpectedly large crops of cones, may be indicators of root disease that can make a tree a windfall hazard.

Some foliage discoloration and loss of older foliage is normal—most conifers lose some foliage between the tree trunk and the current year's growth. These older needles turn yellow or reddish and drop from the tree each fall. This condition may be more pronounced in drought years. It is particularly noticeable in pines and cedars. If an entire branch has discolored foliage, corrective pruning may solve the problem. However, if all or most of the tree is affected, removal of the entire tree is likely necessary. Trees that exhibit symptoms of overall decline can rarely be saved.

If you have a hazard tree, consider converting the tree to a short snag or wildlife tree as an alternative to complete removal. Cut the tree back to a height short enough that it will not pose a threat if it falls. As the tree decays, many species of birds and mammals may use the tree for forage and shelter. See Tips for Creating Snags, below. Another alternative is to have the tree felled and left in place. The downed woody debris will provide additional wildlife habitat.

WSU Extension foresters, Department of Natural Resources Stewardship foresters, or professional consulting foresters can help you with diagnosing problems on forest trees. A professional arborist can determine whether a tree near a home or other structures must be removed. Check the yellow pages and look for individuals or firms that employ ISA Certified Arborists.

Forest Health Care

Thinning

Thinning is one of the most beneficial tasks property owners can perform to improve the health and vigor of their woodlands and reduce the potential for damage from catastrophic wildfire (Figure 8). Trees growing too close together causes them to be stressed and unhealthy. When trees compete for sunlight, nutrients, and moisture there are numerous ill effects, including:

- Poor growth and health. Overcrowded and stressed trees have poor diameter growth and small crowns. Stressed trees are more susceptible to health problems than vigorous trees.
- Poor wildlife habitat. If too little sunlight reaches the forest floor, shrubs and forbs, which are beneficial to wildlife, are shaded out.
- High wildfire hazard. When crowns of adjoining trees touch, fire can spread quickly. For more information on wildfire hazards, see Chapter 23: Fire-resistant Landscaping.

When to Thin. When branches of adjoining trees touch, it is time to thin. Short tree crowns are also a sign of overcrowding. Healthy trees should have approximately 40% of their total height in live, green branches.

How to Thin. Here are some guidelines for thinning forested properties.

- Save the biggest and best. Retain the tallest trees with larger diameters and large, healthy crowns.

Figure 8. A stand of trees before thinning (left of the center tree) and after thinning (to the right of the center tree). (Photo by P. Duniho)

- Remove competitors. Trees with below-average diameters, shorter crowns, or disease, insect, or other problems should be removed to benefit their more desirable neighbors. Do not make the mistake of trying to release poorer quality, lower level trees by removing larger, better trees growing above them.
- Remove enough trees. Most forest landowners really love their trees, but a common error is to remove too few of them, resulting in a thinned stand which is still stressed and overcrowded. After thinning, branches in the crowns of adjoining trees should be several feet apart with open sky visible between trees.
- Variable density thinning. Leave some dense clumps of un-thinned, un-pruned trees to provide places for animals to hide from predators and the elements.
- Retain trees for wildlife. Dead or hollow trees should be retained unless they are hazardous or within the defensible space for buildings. (See Chapter 23: Fire-resistant Landscaping). Consider variable density thinning to provide habitat diversity.
- Watch out for fire hazard. Debris (slash) left where it falls from thinning and pruning may result in a fire hazard if a significant accumulation occurs. Slash may need to be piled, burned, or chipped.

Check local regulations regarding permit requirements and “burn ban” restrictions. Since 2007, outdoor burning has been banned within urban growth areas throughout Washington. For more information, check with the Washington Department of Ecology. Outside the urban growth areas, burning is usually regulated by local clean air agencies, and regulations vary by location.

Pruning

Proper pruning keeps trees healthy, safe, and attractive. In forested areas, pruning can reduce fire risk while improving aesthetics and timber quality. Tree removal and replacement with a more appropriate species may be preferable to excessive pruning.

When to prune. Prune at the right time. Hardwoods are best pruned during the dormant season. Avoid pruning forest trees from January through July to minimize the potential for bark beetle infestation because bark beetles are actively seeking freshly downed material then.

Remove the right amount of branches. With forest conifers, all limbs are normally removed from the trunk up to a height of about 18 feet from the ground. This height is good for aesthetic enhancement as well as fire hazard reduction, and will improve timber quality in the first 16 feet of the tree.

Avoid "flush cuts" which remove the branch bark collar or "stub cuts" which leave branch stubs protruding. Make the cut at the branch bark collar (Figure 9). See Chapter 21 on Pruning Woody Landscape Plants for more information and details on pruning techniques.

Smaller trees should be pruned in stages yearly, retaining approximately 40 percent of the total height in live green branches after pruning.

Do not top trees. Tree topping is not pruning! Topping trees is an unnecessary and damaging practice. When necessary, reduce the height of hardwood trees by selectively removing upper branches. For view enhancement, tree crowns can be thinned by removing selected branches.

Use proper pruning tools. Use shears or a saw designed for pruning and keep them sharpened. Use a chainsaw only for limbs too large for hand tools. Always use recommended safety equipment such as eye protection, hard hat, gloves, and sturdy footwear.

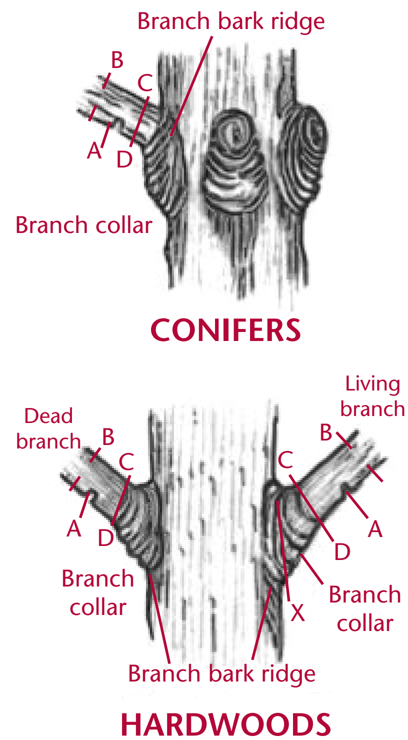

Figure 9. Diagram of the series of cuts required to remove large limbs without damaging the tree. Make partial undercut A first, then, cuts B and C–D.

Wildlife and Wildlife Habitat

Most people enjoy watching wildlife in their yards and forests. Wildlife cannot distinguish between private and public lands, and they depend on both for food, living space, shelter from predators and adverse weather, and a place to rear their young. There are a number of things people can do to help improve wildlife habitat on their own property.

Habitat Diversity

Encourage habitat diversity. A wider variety of plant species (with varying sizes) will attract a wider variety of wildlife species (Figure 10). Therefore, diversify the plants on the property.

Retain understory vegetation and downed logs. Woody debris and shrubs should be retained unless they pose an excessive fire hazard. Downed wood that is 4 inches in diameter or larger contributes very little to fire spread, but is helpful for habitat creation. Maintain trees and shrubs along stream banks. If your property is too tidy and park-like it will probably not attract a large variety of wildlife.

Figure 10. Variable density thinning provides a variety of habitat with areas of unthinned trees bordered by thinned areas. (Photo by Dave Powell, USDA Forest Service, Bugwood.org)

Plant a variety of supporting grasses, forbs, shrubs and trees. A good overall seed mix (spread along trails, roads, and in openings) for supporting wildlife is:

Fine fescue-17 lbs/acre

Big trefoil-2 lbs/acre

Annual rye grass-1 lb/acre

White Dutch clover-2 lbs/acre

Snags

Retain and maintain dead or dying trees as snags. Snags are essential habitat for cavity-nesting species such as woodpeckers (Figure 13). But other species such as bats, songbirds, and some small mammals also utilize dead trees as important habitat (Figure 14). If too few snags exist on a property, more can be

Plants to attract wildlife

For upland sites:

Blue elderberry*
Cascara
Bitter cherry
Pacific dogwood
Hawthorn
Serviceberry
Wildrose
Mountain ash
Kinnikinnick

**Figure 11. Blue elderberry provides shelter and food for a variety of wildlife. (Photo by Dave Powell, USDA Forest Service, Bugwood.org)*

For riparian and wet sites:

Willow
Cottonwood**
Oregon ash
Red-osier dogwood

***Figure 12. Black cottonwood is a native riparian species that grows quickly and provides shelter and nesting for birds and food for butterflies, beaver, deer, elk, and more. (Photo by Dave Powell, USDA Forest Service, Bugwood.org)*

created by killing live trees that should be thinned or removed anyway. Snags should only be retained or created in places where they will not pose a safety hazard. You can provide additional habitat for cavity-dependent species by providing wooden nesting boxes and bat-roosting boxes. Make sure you place the boxes in areas that are protected from heat and wind.

Create Snags. Snags may be created from living trees if there is a shortage of safe natural snags. Created snags can be expected to last for a long time. Poor quality or deformed trees, such as those with broken tops or large branches, make excellent snags.

Word of caution! Snags can become hazardous. Site them well away from trails, roads, buildings, and other structures.

Figure 13. Evidence of woodpecker activity in a tree trunk. (Photo by James E. Johnson)

Figure 14. A snag showing evidence of multiple users and residents, including shelf fungi. (Photo by James E. Johnson)

Tips for creating snags. Select conifers for snag creation because they normally last longer as snags than deciduous trees do. Snag trees should be at least 14 inches in diameter, but smaller diameter snags are used by many cavity nesters and foragers.

Top or girdle a live tree at or above the first whorl of branches, if possible, and at least 14 feet high (ideally, much higher). Shorter trees are useful for some cavity nesters and especially for foraging birds, as are stumps that are at least 3 feet tall. A jagged top will decay faster and supply more habitat than a smooth-topped tree.

Jagged cuts, grooves, and cavity starts can be added to the trunks of trees when they are topped or girdled for snag-dependent wildlife. These additional cuts allow decay-causing fungus to enter the stem of the tree and accelerate the creation of structure for many species of birds and mammals including many bat species. Cuts should angle upward and be at least 2 inches wide and at least 6 inches deep. A shelf or cavity can be initiated by cutting a hole or opening at least 6 inches deep and about 4 inches in diameter.

Large branches, extending at least 2 feet out from the trunk, can be cut to create foraging habitat on live trees not intended to be used as snags.

Nest Boxes

Nest boxes do not replace the need for snags, but they can be erected in most forest stands, depending on target species and stand characteristics. Nest boxes of varying sizes will host many species, such as wood ducks and swallows. Note: Do not put nest boxes on existing snags, as they are unnecessary – the snag itself provides nesting space.

Bird Feeders

Use bird feeders only if you are committed to taking care of them. If you commit to feeding birds you must keep the feeders clean and filled, especially during the harsh winter months. Thoroughly clean all feeders weekly to reduce the spread of disease from bird to bird. If you notice dead birds, take the feeders down immediately, clean them thoroughly, and stop feeding. Follow these simple health and safety precautions:

1. Do not handle wild birds that are obviously sick or found dead.
2. Wear rubber gloves while filling or cleaning bird feeders.
3. Disinfect bird feeders periodically with a 10% solution of chlorine bleach and dry thoroughly.
4. Clean up seed waste and bird droppings beneath feeders.
5. Wash hands with soap and water or alcohol wipes immediately after filling or cleaning bird feeders.

Further Reading

WSU Extension Publications available at: http://cru84.cahe.wsu.edu/

Technical and Education Resources

Washington State University Extension. http://ext.wsu.edu/forestry/index.htm.

Washington Department of Natural Resources. http://www.dnr.wa.gov/Pages/default.aspx.

Washington Dept. of Fish and Wildlife. http://wdfw.wa.gov/.

Planning

Trees of Washington. An easy-to-use tree identification guide. Available at: http://cru.cahe.wsu.edu/CEPublications/eb0440/eb0440.pdf, or through your local WSU Extension forestry educator.

Landscape Design for Wildlife. A publication available from Washington Department of Fish and Wildlife Mill Creek office, 425-775-1311.

The woods in your backyard : Learning to create and enhance natural areas around your home. Kays, Jonathan, J. Drohan, A. Downing, and J. Finley. Natural Resource, Agriculture, and Engineering Service. NRAES-184. Order on line: http://www.nraes.org/nra_order.taf?_function=detail&pr_booknum=nraes-184.

Forest Health

WSU forest-health on-line diagnostic. Diagnose sick trees with this on-line tool from Washington State University. http://nrs.wsu.edu/forestHealth/.

Common insect and disease problems. On-line diagnostic tool from Oregon State University. Although it focuses on SW Oregon, it has information pertinent to the Inland Northwest. http://extension.oregonstate.edu/sorec/sick-tree-information.

On-line catalog of western forest insects and disease. Very in-depth on-line resource from the US Forest Service. http://www.fs.fed.us/r6/nr/fid/wid.shtml.

Field guide to diseases and insect pests of Northern and Central Rocky Mountain Conifers. http://www.fs.fed.us/r1-r4/spf/fhp/field_guide/.

WSU Forest Health Notes. Fact sheets organized by insect/pathogen species. http://ext.wsu.edu/forestry/foresthealth/foresthealthnotes.htm.

Hazard Trees

The Hazard Tree Prevention Web page. Produced by the Pacific Northwest Chapter of the International Society of Arboriculture (ISA). http://pnwisa.org/media/htp/index.html.

Thinning

Guidelines for thinning Ponderosa Pine for improved forest health and fire prevention. Applied research results from the University of Arizona. http://cals.arizona.edu/pubs/natresources/az1397.pdf.

Variable density thinning for wildlife and wood production. Fact sheet from the Washington Department of Natural Resources. http://snohomish.wsu.edu/forestry/documents/VDT.pdf.

Planting Trees and Shrubs

Small trees for the home landscape. WSU Extension publication with recommendations for suitable trees in urban landscapes. http://cru.cahe.wsu.edu/CEPublications/EB2036/eb2036.pdf.

Wildlife

Woodland, Fish and Wildlife. A series of publications covering many species of wildlife and fish. http://www.woodlandfishandwildlife.org/.

Wildlife Ecology and Forest Habitat. WSU Extension publication on managing woodlands for wildlife. EB1866. http://cru.cahe.wsu.edu/CEPublications/eb1866/eb1866.pdf.

WDFW Backyard Wildlife Sanctuary Program. A program for landowners with small acreages and/or big backyards. http://wdfw.wa.gov/wlm/backyard/index.htm.

Crossing Paths. An on-line newsletter from the Washington State Department of Fish and Wildlife with news and information about urban and suburban wildlife. http://wdfw.wa.gov/living/crossing_paths/.

Build nest boxes for wild birds. Nest box plan from Oregon State University. EC1556. http://extension.oregonstate.edu/catalog/pdf/ec/ec1556.pdf.

Create roosts for bats in your yard. Oregon State University publication on bats with plans for building bat houses and roosts. EC1555. http://extension.oregonstate.edu/catalog/pdf/ec/ec1555.pdf.

Streams and Wetlands

Stream*A*Syst. An on-line tool from Oregon State University to help examine stream conditions on a property. http://extension.oregonstate.edu/catalog/html/em/em8761/.

Taking care of streams in Eastern Washington, Eastern Oregon, and Idaho: A homeowner's guide. http://extension.oregonstate.edu/catalog/pdf/pnw/pnw557.pdf.

Taking care of streams in Eastern Washington, Eastern Oregon, and Idaho: A landowner's guide. http://extension.oregonstate.edu/catalog/pdf/pnw/pnw559.pdf.

Worksheet 1. Property Description and Goals[1]

Complete the form below for your property.

Total # of acres owned	Heavy use (buildings, driveways, carports, etc.)	Intermediate use (lawns, gardens, orchards, pasture)	Natural areas (forested areas and/or unmowed areas with small trees, shrubs, grass)
________ acres*	% total property _________%	% total property _________%	% total property _________%

**An acre is a square ~ 210 ft. on each side; 44,100 square feet.*

When did you buy or acquire your land? ____________________

Why did you purchase your land? ____________________

____

____

Have your reasons for owning land changed since you bought or acquired it? If so, how? ____________________

____

____

What do you enjoy most about your land? ____________________

____

____

What do you enjoy least about your land? ____________________

____

____

What do you want from your woodland now? (Examples: protect wildlife, pay for college, protect view)

____

____

In 10 years? ____________________

How much land (if any) would you like to convert to a natural area? Where is it ? ____________________

____

[1] Adapted from The Woods in Your Backyard : Learning to Create and Enhance Natural Areas around Your Home. Kays, et al.

Worksheet 2. Identify and Rank Property Objectives[2]

Suggested Objectives	Potential objective (Yes/No)	Rank selected objective
Natural area improvement		
I have a grassy lawn/pasture I want to plant in trees		
I want to control exotic/noxious weeds		
I want to improve the health of my forest		
I want to improve forest regeneration		
I want to remove hazard trees		
Other:		
Other:		
Wildlife habitat		
I want to create snags for woodpeckers and other cavity-users		
I want to provide more food and cover for wildlife		
I want to discourage deer		
I want to have more amphibians and reptiles on my property		
I want to attract more wildlife Species of interest: ______________________________		
Other:		
Other:		
Forest products		
I want to cut firewood for myself and others		
I want to start a forest products enterprise for fun and profit Forest products of interest: ______________________________		
Riparian and water resources		
I want to create or enhance a riparian buffer		
I want to protect water quality in my streams/spring/seep		
Other:		
Other:		
Recreation		
I want to build recreational trails		
I want to create a special place in the woods for reflection, campfires, etc.		
I want to create a place for nature study		
I want to build a blind for wildlife viewing		
I want to build a tree stand for hunting		
Other:		
Other:		

2 Adapted from "The Woods in Your Backyard: Learning to Create and Enhance Natural Areas Around Your Home." Kays et. al.

Suggested Objectives	Potential objective (Yes/No)	Rank selected objective
Aesthetics		
I want to block an unpleasant view or have more privacy		
I want to create a scenic view		
I want to protect some special trees or a special place		
Other:		
Other:		

13

Houseplants

Topics covered:

- Introduction
- Selecting an Indoor Plant
  - Transporting Houseplants
  - Acclimatization
- Environmental Factors
  - Light
  - Water
  - Temperature
  - Humidity
  - Ventilation
  - Fertilization
  - Soluble Salts
- Planting Media
- Containers
- Repotting
- Training & Grooming
- Care of Special Potted Plants
- Propagating Houseplants
  - General Propagation Instructions
  - Instructions for Specific Types of Cuttings

Learning Objectives

- ✿ Understand basic care of tropical plants grown indoors.
- ✿ Know the common ways to propagate houseplants.

Excerpted with permission from the Texas Master Gardener Handbook

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Samuel D. Cotner, Extension Horticulturalist
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Introduction

This chapter is designed to familiarize you with the basic aspects of tropical plant care, rather than attempting to acquaint you with specific cultural requirements of the more than 250 commonly grown plants in the foliage industry. Bear in mind that in most cases, homes and offices are environments poorly suited to the needs of tropical plants. Thus the task of the houseplant owner/enthusiast is to select plants that can best withstand indoor conditions of a specific location.

Note: A searchable database of common houseplants and other interior foliage plants can be found at http://aggie-horticulture.tamu.edu/interiorscape/tamuhort.html.

Selecting an Indoor Plant

Select only those houseplants which appear to be insect- and disease-free. Check the undersides of the foliage and the axils of leaves for signs of insects or disease. Select plants that look sturdy, clean, well potted, shapely, and well-covered with leaves.

Choose plants with healthy foliage. Avoid plants that have yellow or chlorotic leaves, brown leaf margins, wilted or water soaked foliage, spots or blotches and spindly growth. In addition, avoid leaves with mechanical damage, and those which have been treated with “leaf shines” which add an unnatural polish to the leaves. Plants that have new flowers and leaf buds along with young growth are usually of superior quality.

Remember that it is easier to purchase a plant which requires the same environmental conditions your residence has to offer than to alter the environment of your home or office to suit the plants.

Transporting Houseplants

When transporting plants, remember the two seasons of the year that can cause damage to the plants: the hot summer and the cold winter months. In the summer, avoid placing plants in a car and leaving the car shut up, because the temperature inside the car will rise and destroy the plant in a short period of time. And if you have to travel for any distance at all, the plant can be burned by the sun shining on it even though the air conditioner is on and the temperature is comfortable in the car. Shade the plant from direct sun while it is in the car.

During winter months, wrap plants thoroughly before leaving the store to carry them to your car. A short run from the store to the car in very low temperatures can severely damage or even kill plants. Wrap plants thoroughly with newspaper or paper bags, and place in the front seat of the car and turn on the heater. The trunk of most cars is too cold to carry plants safely during winter months.

On an extended trip make special arrangements so that plants will not be frozen or damaged by cold weather. Many foliage plants will be damaged considerably if the temperature drops much below 50°F, so maintain as warm a temperature as possible around these plants when transporting them from one location to another.

Acclimatization

Research done in Florida in the late 1970s revealed an interesting phenomenon. Tropical plants grown in full sun have leaves (so called sun leaves) which are structurally different from the leaves of plants grown in shade (shade leaves). Sun leaves have fewer chloroplasts and thus less chlorophyll. Their chloroplasts are located deep inside the leaves and the leaves are thick and small, but large in number. Shade leaves have more chloroplasts and thus more chlorophyll, and are thin, large, and few in number. When plants are grown in strong light they develop sun leaves which are photosynthetically very inefficient. If these same plants are placed in low light, they must either remake existing sun leaves or drop their sun leaves and grow a new set of shade leaves which are photosynthetically more efficient.

To reduce the shock which occurs when a plant with sun leaves is placed in shade, gradually reduce the light levels the plant is exposed to. This process is called acclimatization. (Hardening off is a type of acclimatization.) The homeowner should acclimatize plants when placing them outdoors in summer by gradually increasing light intensities, and reverse the process before bringing plants back indoors in the fall. For newly purchased plants, acclimatize them by initially locating them in a high light (southern exposure) area of your home and gradually moving them to their permanent darker location over a 4- to 8-week period.

Environmental Factors

Light, water, temperature, humidity, ventilation, fertilization, and soil are chief factors affecting plant growth, and any one of these factors in incorrect proportions will prevent proper plant growth indoors.

Light

Light is probably the most essential factor for houseplant growth. The growth of plants and the length of time they remain active depend on the amount of light they receive. Light is necessary for all plants because they use this energy source to photosynthesize. When examining light levels for tropical plants, consider 3 aspects of light: (1) intensity, (2) duration, and (3) quality.

Light intensity influences the manufacture of plant food, stem length, leaf color, and flowering. A geranium grown in low light tends to be spindly with pale green leaves. The same kind of plant grown in very bright light would tend to be shorter, better branched, and have larger, dark green leaves. Houseplants can be classified according to their light needs, such as high, medium and low light requirements.

The intensity of light a plant receives indoors depends upon the nearness of the light source to the plant (light intensity decreases rapidly as you move away from the source of light). The direction the windows in your home face will affect the intensity of natural sunlight that plants receive. Southern exposures have the most intense light, eastern and western exposures receive about 60% of the intensity of southern exposures, and northern exposures receive 20% of a southern exposure. A southern exposure is the warmest, eastern and western are less warm, and a northern exposure is the coolest. Other factors which can influence the intensity of light penetrating a window are the presence of curtains, trees outside the window, weather, season of the year, shade from other buildings, and the cleanliness of the window. Reflective (light-colored) surfaces inside the home/office will increase the intensity of light available to plants. Dark surfaces will decrease light intensity.

Day-length or duration of light received by plants is also of some importance, but generally only to those houseplants which are photosensitive. Poinsettia, kalanchoe, and Christmas cactus bud and flower only when day-length is short (11 hours of daylight or less). Most flowering houseplants are indifferent to day-length.

You can compensate for low light intensity by increasing the length of time the plant is exposed to light, as long as the plant is not sensitive to day-length. Increased hours of lighting allow the plant to make sufficient food to survive and grow. However, plants require some period of darkness to develop properly and thus should be illuminated for no more than 16 hours. Excessive light is as harmful as too little light. When a plant gets too much direct light, the leaves become pale, sometimes sunburn, turn brown, and die. Therefore, during the summer months, protect plants from too much direct sunlight.

Additional lighting may be supplied by either incandescent or fluorescent lights. Incandescent lights produce a great deal of heat and are not very efficient users of electricity. If artificial lights are to be used as the only source of light for growing plants, the quality of light (wavelength) must be considered. For photosynthesis, plants require mostly blues and reds, but for flowering infrared light is also needed. Incandescent lights produce mostly red and some infrared light, but are very low in blues. Fluorescent lights vary according to the phosphorus used by the manufacturer. Cool white lights produce mostly blue light and are low in red light. Foliage plants grow well under cool white fluorescent lights and these lights are cool enough to position quite close to plants. Blooming plants require extra infrared which can be supplied by incandescent lights, or special horticultural-type fluorescent lights ("grow lights").

Water

Over- and under-watering account for a large percentage of tropical plant losses. The most common question home gardeners ask is, "How often should I water my plants?" There is not a good answer to this question. Some plants like drier conditions than others. Differences in soil or potting medium and environment influence water needs. Watering as soon as the soil crust dries results in overwatering.

Houseplant roots are usually in the bottom two-thirds of the pot, so do not water until the bottom two-thirds starts to dry out slightly. You can't tell this by looking. You have to feel the soil. For a 6-inch pot, stick your index finger about 2 inches into the soil (approximately to the second joint of your finger). If the soil feels damp, don't water. Keep repeating the test until the soil is barely moist at the 2-inch depth. For smaller pots, 1 inch into the soil is the proper depth to measure.

Water the pot until water runs out of the bottom. This serves two purposes. First, it washes out all the excess salts (fertilizer residue). Second, it guarantees that the bottom two-thirds of the pot, which contains most of the roots, receives sufficient water. However, don't let the pot sit in the water that runs out. After a thorough watering, wait until the soil dries at the 2-inch depth before watering again.

When you test for watering, pay attention to the soil. If your finger can't penetrate 2 inches deep, you either need a more porous soil mix, or the plant is becoming root-bound.

Temperature

Most houseplants tolerate normal temperature fluctuations. In general, foliage houseplants grow best between 70° and 80°F during the day and from 60° to 68°F at night. Most flowering houseplants prefer the same daytime range but grow best at night-time temperatures from 55° to 60°F. The lower night temperature induces physiological recovery from moisture loss, intensifies flower color, and prolongs flower life. Excessively low or high temperatures may cause plant failures, stop growth, or cause spindly appearance and foliage damage or drop. A cooler temperature at night is actually more desirable for plant growth than higher temperatures. A good rule of thumb is to keep the night temperature 10 to 15 degrees lower than the day temperature.

Humidity

Atmospheric humidity is expressed as a percentage of the moisture saturation of air. Two ways to provide increased humidity are by attaching a humidifier to the heating or ventilating system in the home or placing gravel trays (in which an even moisture level is maintained) under the flower pots or containers. Wet gravel trays will increase the relative humidity in the vicinity of the containers. As the moisture around the pebbles evaporates, the relative humidity is raised.

Another way to raise humidity is to group plants close together. You can also spray a fine mist on the foliage, although this is of doubtful effectiveness for total humidity modification. Do this early in the day so that the plants will be dry by night. This lessens the chance of disease since cool dampness at night provides an ideal environment for disease infection.

Ventilation

Houseplants, especially flowering varieties, are very sensitive to drafts or heat from registers. Forced air dries the plants rapidly, overtaxes their limited root systems, and may cause damage or plant loss. Houseplants are sensitive to natural or blended gas. Some plants refuse to flower, while others drop flower buds and foliage when exposed to gases. Blended gases are more toxic to houseplants than natural gases. Tomato plants are extremely sensitive to gas. They will turn yellow before the escaping gas is detected by household members and are sometimes used in greenhouses as indicator plants for excessive ethylene gas resulting from incomplete combustion in gas furnaces.

Fertilization

Houseplants, like most other plants, need fertilizers containing three major plant food elements: nitrogen (N), phosphoric acid (P), and potassium (K). They are available in many different combinations and under a multitude of brand names. Each brand should be analyzed on the label, indicating specifically how much water-soluble elemental nitrogen, phosphate, or potash (in that order) is available in every pound of the product. The majority of these fertilizers are about 20–20–20. Commercial fertilizers used for houseplants are sold in granular, crystalline, liquid, or tablet forms. Each should be used according to instructions on the package label or even more diluted. Frequency of fertilizer application varies somewhat with the vigor of growth and age of each plant. Some need it every 2 weeks, while others will flower well for several months without needing any supplement. As a general rule, use a fertilizer recommended every 2 weeks from March to September. During the winter months no fertilizer need be added at all because reduced light and temperature result in reduced growth. Fertilizing at this time could be detrimental to some houseplants.

When applying fertilizer in a solution, make sure that some runs out of the bottom of the pot. This prevents root burn and the buildup of soluble salts or excess fertilizer and reduces the chance of burning the plant.

Soluble Salts

Reduced growth, brown leaf tips, dropping of lower leaves, small new growth, dead root tips, and wilting are all signs of soluble salts build-up. These salts will accumulate on top of the soil forming a yellow to white crust. A ring of salt deposits may be formed around the pot at the soil line or around the drainage hole. Salts will also build up on the outside of porous clay pots.

Soluble salts are minerals dissolved in water. Fertilizer dissolved in water becomes a soluble salt. When water evaporates from the soil, the minerals or salts stay behind. As the salts in the soil become more and more concentrated, plants find it harder and harder to take up water. If salts build up to an extremely high level, water can be drawn out of the root tips causing them to die.

High soluble salts damage the roots directly, and because the plant is weakened, it is more susceptible to attack from insects and diseases. One of the most common problems associated with high salt levels is root rot.

The best way to prevent soluble salt injury is to stop the salts from building up. Water correctly. When you water, allow some water to drain through and then empty the drip plate. Water equal to one-tenth the volume of the pot should drain through each time you water. **DO NOT ALLOW THE POT TO SIT IN WATER.** If you allow the drained water to be absorbed by the soil, the salts that were washed out are taken back into the soil. Salts can be reabsorbed through the drainage hole or directly through a clay pot.

Plants should be leached every 4 to 6 months. You should leach a plant *before* you fertilize so that you don't wash away all the fertilizer you just added. Leaching is done by pouring a lot of water on the soil and letting it drain completely. The amount of water used for leaching should equal twice the volume of the pot. A 6-inch pot will hold 10 cups of water, so 20 cups of water are used to leach a plant in a 6-inch pot. Keep the water running through the soil to wash the salts out. If a layer of salts has formed a crust on top of the soil, you should remove the salt crust before you begin to leach. Do not remove more than 1/4 inch of soil. It is best not to add more soil to the top of the pot. If the soluble salt level is extremely high or the pot has no drainage, repot the plant.

The level of salts that will cause injury varies with the type of plant and how it is being grown. A plant grown in the home may be injured by salts at concentrations of 200 ppm. The same plant growing in a greenhouse where the light and drainage are good will grow with salts at 10 times that level, or 2000 ppm. Some nurseries and plant shops leach plants to remove excess salts before the plant is sold. If you are not sure that has been done, leach a newly purchased plant the first time you water it.

Planting Media

The potting soil or medium in which a plant grows must be of good quality. It should be porous for root aeration and drainage but also capable of water and nutrient retention. Most commercially prepared mixes are termed "artificial" which means they contain no soil. High quality artificial mixes generally contain slow-release fertilizers which take care of a plant's nutritional requirements for several months. Commercial mixes are often misleading as to content and, therefore, are unsatisfactory. It is better to mix your own if possible.

Preparing Artificial Mixes

Artificial mixtures can be prepared with a minimum of difficulty. Most mixes contain a combination of organic matter, such as peat moss or ground pine bark, and an inorganic material, such as washed sand, vermiculite, or perlite. Materials commonly used for houseplants are the peat-lite mixtures, consisting of peat moss and either vermiculite or perlite. Artificial mixtures are usually very low in trace or minor elements, therefore, it is important to use a fertilizer that contains these trace elements.

Here are some details on the ingredients for these mixes.

Peat Moss. Readily available baled or bagged sphagnum peat moss is recommended. Materials such as Michigan peat, peat humus, and native peat are usually too decomposed to provide necessary structural and water-drainage characteristics. Most sphagnum peat moss is acidic, with a pH from 4.0 to 5.0. It usually has a very low fertility level. Do not shred sphagnum peat moss too finely.

Vermiculite. This is a sterile, light-weight mica product. When mica is heated to approximately 1800°F, it expands its plate-like structure. Vermiculite will hold large quantities of air, water and nutrients needed for plant growth. Its pH is usually in the 6.5 to 7.2 range. Vermiculite is available in four particle sizes. For horticultural mixes, sizes 2 or 3 are generally used. If at all possible, the larger-sized particles should be used since they give much better soil aeration. Vermiculite is available under a variety of trade names.

Perlite. This is a sterile material produced by heating volcanic rock to approximately 1800°F, resulting in a very lightweight, porous material that is white in color. Its principal value in soil mixtures is aeration. It does not hold water and nutrients as well as vermiculite. The pH is usually between 7.0 and 7.5. Perlite can cause fluoride burn on some foliage plants. Fluoride damage is usually seen on the tips of the leaves. The burn progresses from the tip up into the leaf. Fluoride burns can be prevented by adding 1 1/2 times the recommended amount of lime when mixing the soil.

Here is a recipe for a good artificial mix containing no outside garden soil. The following materials will make three bushels of mix:

- 1 bushel shredded peat moss
- 2 bushels perlite or vermiculite
- 1/2 cup 8–8–8 or similar analysis mixed fertilizer
- 1 level teaspoon chelated iron

Containers

There are many types of containers from which to choose. A good container should be large enough to provide room for soil and roots, have sufficient head room for proper watering, provide bottom drainage, and be attractive without competing with the plant it holds. Containers may be fabricated of ceramics, plastic, fiberglass, wood, aluminum, copper, brass, and many other materials.

Clay and Ceramic Containers

Unglazed and glazed porous clay pots with drainage holes are sometimes still used by commercial houseplant growers and are frequently left with the plant when it is purchased. Ornate containers are often nothing but an outer shell to cover the plain clay pot. Clay pots absorb and lose moisture through their walls. Frequently the greatest accumulation of roots is next to the walls of the clay pot, because moisture and nutrients accumulate in the clay pores. Although easily broken, clay pots provide excellent aeration for plant roots and are considered by some to be the healthiest type of container for a plant.

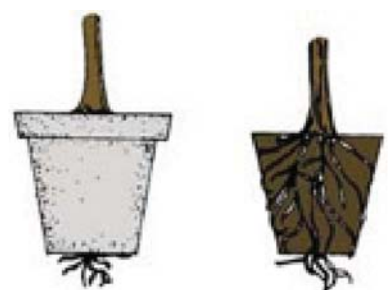
Ceramic pots are usually glazed on the outside, sometimes also on the inside. They are frequently designed without drainage holes. This necessitates careful watering practices. Containers with no drainage are not good flower pots. Small novelty containers have little room for soil and roots and are largely ornamental. They should be avoided. It should be noted that putting pot chips, clay pot shards or gravel in the bottom of a pot does not improve soil drainage; they only provide a small space beneath the soil where some excess water can drain inside the pot.

Plastic and Fiberglass

Plastic and fiberglass containers are usually quite light and easy to handle. They have become the standard in recent years because they are relatively inexpensive and quite attractive in shape and color. Plastic pots are easy to sterilize or clean for reuse, and, because they are not porous like clay pots are, they need less frequent watering and tend to accumulate fewer salts.

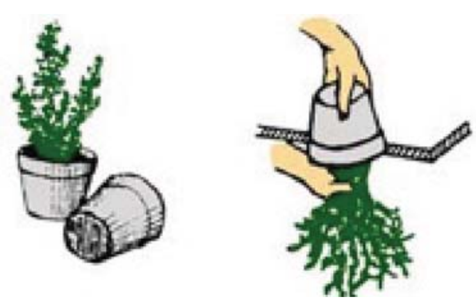
Repotting

Actively growing houseplants require occasional repotting. This occurs very rarely with slower growing plants, more frequently with others. Foliage plants require repotting when their roots have filled the pot and are growing out the bottom of the pot.



When repotting becomes necessary due to these indications by the plant, it should be done without delay. The pot selected for repotting should be no more than 2 inches larger in diameter than the pot the plant is currently growing in; should have at least one drainage hole; may be clay, ceramic or plastic; and must be clean. Wash soluble salts from used clay pots with water and a scrub brush, and wash all pots in a solution of 1 part liquid bleach to 9 parts water.

Potting media used should be coarse enough to allow good drainage yet have sufficient water retention capabilities. Most plants are removed easily from their pot if the lip of the container is knocked upside down against any solid object. Hold your hand over the soil, straddling the plant with your fore and middle fingers while knocking the plant out of its present container.



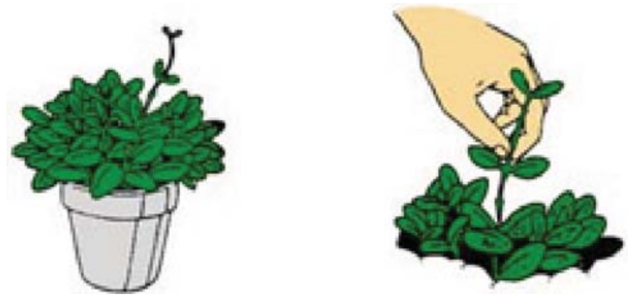
Potting media should be moistened before repotting begins. To repot, place drainage material in the bottom of the pot, if desired, and some new soil. If the plant has become root bound it will be necessary to cut and unwind any roots that encircle the plant, otherwise the roots will never develop normally. If the old soil surface has accumulated salts, the top inch should be removed.

Set the root-ball in the middle of the new soil. Add soil around the sides between the root-ball and pot. Do not add soil above the original level on the root-ball, unless the roots are exposed or it has been necessary to remove some of the surface soil. Do not pack the soil, to firm or settle it, tap the pot against a table top or gently press the soil with your fingers.

After watering and settling, the soil level should be sufficiently below the level of the pot to leave headroom. Headroom is the amount of space between the soil level and the top of the pot that allows for watering a plant. A properly potted plant has enough headroom to allow water to wash through the soil to thoroughly moisten it.

Training and Grooming

This includes a number of minor care activities that distinguish the beginner from the more experienced houseplant grower. Pinching is one of them. Pinching is the removal of 1 inch or less of new stem and leaf growth. When necessary, pinch to just above the node. This leaves the plant attractive and stimulates new growth. It can be a one-time or continuous activity, depending on the need of the plant and the desires of the plant owner. If a plant should be kept compact, but well filled out, frequent pinching will achieve this. Pruning is a similar activity.



1. Leggy plant needs to grow bushier, keep more compact form.
2. Pinch out growing tips of tallest stem, removing it close to leaf joint (node).
3. New growth forms just below pinched-out tip, makes plant bushy.

Pruning includes removal of other than terminal shoot tips. Sometimes an entire branch or section of a plant should be removed for the sake of appearance.

Disbudding is another related care activity. Certain flower buds are removed either to obtain larger blooms from a few choice buds or to eliminate flowering of a very young plant or recently rooted cutting that should not bear the physical drain of flowering early.

Ivies and hoya, as well as philodendron and syngonium, are frequently grown in a formal pattern. This can be easily achieved by training them on trellises.

It is important to keep plants clean and neat. It not only improves the appearance of plants but reduces the incidence of insects and disease problems. Remove all spent flowers, dying leaves, and dead branches. Keep leaves dust-free by washing plants with warm water and mild soap (cover pot to prevent soap from entering the soil). If tips of leaves become brown and dry, trim them off neatly with sharp scissors. Removal of alkali deposits at the soil surface and replacement with clean soil does more for appearance than for the plant itself.

Care of Special Potted Plants

Too little light, too warm an environment, and improper watering are the usual causes of failure in caring for special gift plants. These plants are raised in a greenhouse where there is ample light, the air is moist, and the night temperatures are usually cool. When these plants are brought into a typical home where the light is poor, the air dry, and the temperatures are maintained for human comfort without consideration for the plants, results are frequently disappointing. Do not expect to hold over a gift plant from year to year. Enjoy them while they are attractive and in season and then discard.

Poinsettia


Poinsettia

The poinsettia requires bright light and should be kept away from drafts. A temperature between 65° and 70°F is ideal. Avoid temperatures below 60° and above 75°F. Keep plants well watered but do not over-water. Some of the newer, long-lasting varieties can be kept attractive all winter.

Gardeners frequently ask whether they can carry their poinsettias over to bloom again next year. It is questionable whether the results are worth the effort, since the quality of home-grown plants seldom equals that of commercially grown plants. However, for those who wish to try, the following procedure can be followed.

After the bracts fade or fall, set the plants where they will receive indirect light and temperatures around 55° to 60°F. Water sparingly during this time, just enough to keep the stems from shriveling. Cut the plants back to within about 5 inches from the ground and re-pot in fresh soil. As soon as new growth begins, place in a well lighted window. After danger of frost, place the pot out of doors in a partially shaded spot. Pinch the new growth back to get a plant with several stems. Do not pinch after September 1. About Labor Day, or as soon as the nights are cool, bring the plant indoors. Continue to grow them in a sunny room with a night temperature of about 65°F.

The poinsettia blooms only during short days. To initiate blooms, exclude artificial light, either by covering with a light-proof box each evening or placing in an unlighted room or closet for a minimum of 12 hours of darkness. Plants require full light in the daytime, so be sure to return them to a sunny window. Start the short day treatment in about mid-September to have blooms between December 1 and Christmas.

Azalea

Azaleas require direct sunlight to remain healthy. A nighttime temperature of 60°F will prolong bloom. Keep the soil constantly moist. Do not use softened water. If the leaves should turn yellow, the soil is not acidic enough. Use an acidic fertilizer sold especially for azaleas. When repotting, use a mixture high in acid peat moss.

Azaleas can be planted, pot and all, in a shady spot in the garden during the summer months. Examine them frequently and keep them watered during dry periods. Greenhouse azaleas are not hardy, and need to be brought indoors before freezing weather.

Azaleas need a cool rest treatment before they are forced into bloom. Place the plants in a room with a temperature between 35° to 50°F and filtered light. During this rest period, flower buds will develop. Then place in a well-lighted warm (65°F) room around January 1 and the plant will bloom. Unless you have the proper growing conditions for the azalea, you should not attempt to carry the plants over.

Gardenia

Gardenias grown indoors need special care. They demand an acid soil and should receive the same nutritional care as azaleas. The night temperature should be near 60˚F and the humidity around the plant should be kept high. High temperature and low light intensity will result in flower bud drop.

Amaryllis

The secret of growing amaryllis is to keep the plants actively growing after they finish blooming. Keep the plants in full sun, with a night temperature above 60°F. As soon as danger of frost has passed, set the plants in the garden in a semi-shaded spot. In the fall, before danger of frost, bring them in and store them in a cold, dark place to rest. They will be ready to force again about January 1. Bring them into a warm, light room and water moderately to begin new growth.

Christmas cactus

Christmas cactus

The Christmas cactus has become increasingly popular with the development of several new varieties. At least 3 related species are sold in addition to a number of cultivars. All have similar cultural requirements.

The secret of good bloom seems to be one of temperature and photoperiod control. They will develop buds and bloom if given bright light, short days, and night temperatures between 55°and 65°F. Christmas cacti bloom best when somewhat pot-bound. Repotting is necessary only about once in 3 years. Full sunlight is beneficial in midwinter, but bright sun during summer months can make plants look pale and yellow. These plants grow naturally shaded by a canopy of leaves.

Christmas cacti require less water from October to March than they do when growth is active from April to September. A rest period is very important if plants are to bloom abundantly. Dormancy should be started about the middle of September and continued for 8 weeks. Care should be taken that soil never becomes water-logged during the dark days of winter.

Cyclamen

Cyclamen require full sunlight and a night temperature between 50°and 60°F. They are heavy users of water and must be watered whenever the surface of the soil is dry. Flower buds will fail to develop if night temperature is too high or if light is poor.

Cyclamen can be carried over, but as with the poinsettia, homegrown plants are seldom equal to those grown by a commercial grower. Let the plants die down after they finish flowering. Repot the fleshy corm in June with the top of the corm above the soil line. Allow resting bulbs to dry but not become shriveled.

Propagating Houseplants

Many common houseplants are herbaceous and easily propagated by leaf or stem cuttings or by rooting stem cuttings in water. A few produce plantlets. Refer to the lists below to determine which method works best for a given plant.

The following plants may be propagated by stem cuttings

Botanical Name	Common Name
Abutilon	Chinese lantern, flowering maple, velvetleaf
Acalypha	Chenille plant, Red-hot cattail, Jacob's coat
Aeschynanthus	Lipstick plant
Alloplectus	Goldfish plant
Cissus	Grape ivy
Codiaeum	Croton, Joseph's coat
Coleus	
Crassula	Jade plant
Crossandra	Firecracker plant
Epiphyllum	Leaf cactus, Orchid cactus
Ficus	Figs, Rubber plant
Fittonia	Mosaic plant, Nerve plant
Gardenia	Cape jasmine
Geranium	Cranesbill
Gynura	Purple passion vine, Velvet plant
Hibiscus	Rose mallow
Hoya	Wax plant
Iresine	Blood-leaf
Ixora	Jungle geranium
Jasminum	Jasmine
Justicia	Shrimp plant
Kalanchoe	
Nephthytis	Angel wing
Pachystachys	Golden candle
Passiflora	Passion flower
Pelargonium	Geranium
Pellionia	Trailing watermelon begonia
Peperomia	Radiator plant
Philodendron	

Geranium

Botanical Name	Common Name
Pilea	Aluminum plant, Baby's tears, Creeping Charlie
Plumbago	Leadwort
Pothos	
Rhoicissus	Evergreen grape ivy
Schlumbergera	Christmas cactus
Stephanotis	Madagascar jasmine, Waxflower
Tradescantia	Inch plant, Wandering Jew

The following plants may be propagated by leaf cuttings

African violet

Botanical Name	Common Name
Begonia	
Crassula	Jade plant
Gloxinia	
Saintpaulia	African violet
Sansevieria	Mother-in-law plant, Snake plant
Sedum	Burro's tail, Stonecrop
Streptocarpus	Cape primrose

The following plants produce plantlets

Botanical Name	Common Name
Chlorophytum	Spider plant
Saxifraga spp.	Mother-of-thousands, Strawberry begonia
Tolmiea	Mother-of-thousands, Piggyback plant
Bromeliad	

General Propagation Instructions

- Cleanliness is very important. Make sure all tools, equipment and containers are clean.
- Water plants the day before taking cuttings. This will reduce stress and dehydration.
- Use a mix of 1/2 perlite and 1/2 medium grade peat moss OR 1/2 vermiculite and 1/2 medium grade peat moss as a rooting medium. *When purchasing vermiculite, look for preparations that do not contain asbestos*. Pre-make planting holes in the plant containers.
- Cuttings will succeed without use of a rooting hormone but products such as Rootone will speed up the process. Be careful to treat only the cut surface, and flick off excess from tip.
- Root many cuttings in one shallow container to save space and medium.
- Place containers of cuttings inside plastic bags and tie closed to retain moisture. Use supports to hold plastic up to keep it from touching cuttings.

- Place containers in a warm, brightly lit area. Avoid direct sun since the resulting trapped heat will damage cuttings.
- Check containers regularly for adequate moisture. Punch a few holes in the plastic if soil is too wet.
- Check for rooting by tugging very gently on cuttings. When you feel resistance and see nice root formation, cuttings are ready for transplant. Gently lift and plant into separate small pots.
- Transplant to a larger pot (next size up) after the plant is established and growing well.

Instructions for Specific Types of Cuttings

Stem Cuttings

- Fill containers with rooting mix as described above. Make small holes with your finger, pencil, etc.
- Take cuttings from newer fast-growing stems.
- Cut just below the third or fourth pair of leaves. Strip lower pair(s) of leaves, leaving two sets of leaves.
- Place bare stems in rooting media.

Leaf Cuttings—Whole Leaves

- This method works especially well with plants having fleshy leaves such as begonias, African violets, and gloxinias.
- Cut healthy, mature leaves from parent plant. Take about one inch of leaf stalk (petiole) with the cutting, if possible.
- Insert stalk into rooting media so that the leaf blade touches mix.

Cut or Scored Leaves

- Leaves with prominent veins such as those found on begonias and cape primrose will produce new plants when they are scored or cut into pieces. Leaves or pieces of leaves are placed so that veins are in contact with rooting media.
- When small plants develop, carefully lift, separate, and pot them individually in 3-inch pots.
- Some succulents such as *Sansevieria* can simply be cut into sections, resulting in many new plants.

Rooting Stem Cuttings in Water

This is one of the most common and popular methods of propagating new plants.

- Fill a glass or a jar with water. Place in a bright, warm area.
- With a clean sharp blade, remove healthy cuttings 4 to 6 inches in length. Choose stems that have only a short distance between nodes. Cut just above a node.

- Trim the cutting to just below a node. Remove lower leaves so that you have a length of bare stem at the base.
- Insert the cutting through wire mesh or other support so that stem is suspended in the water.
- Keep water topped so that lower part of cutting is always below water surface.
- Roots should develop quickly. When cuttings have a small network of roots, plant each in a 3-inch container. If you allow the cutting to produce an extensive root system it may not transplant well.
- In general, any plant with a leafy stem will propagate in water. Some that do particularly well are coleus, geranium, ivy, peperomia, and pothos.

Plantlets

Plantlets are "babies" on new plants that grow on the parent plant's leaves, stolons, stems or flowers.

- Detach plantlets from parent. Leave about one inch of stalk or stolon where appropriate.
- Insert stalk or base of plantlet into rootting media so that plantlet rests on surface of the mix.
- Roots should form in a few weeks. Pot plants on their own in 3-inch containers.
- Plantlets of spider plants can be rooted while still attached to main plant and then detached when roots have formed.

Further Reading

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14

Entomology

Topics covered:

- Introduction
- Biology
  - Anatomy
  - Growth & Development
- Insect Identification
  - Identifying Insect Damage
  - Identifying Insects
  - Major Insect Orders
- Insect Diversity & Natural History
  - Host Relationships
  - Life Cycles
  - The Insect Success Story
  - Social Organization
  - Mimicry

Learning Objectives

- Terms related to insect classification, identification, and life cycles
- Appreciation of insects' roles in plant pollination, predation of other organisms, recycling of plant nutrients, and how we and other species benefit from insects
- Understand insects' potential as crop, animal, and structural pests

By

Arthur L. Antonelli, Extension Entomologist, WSU Puyallup

Introduction

Entomology is the study of insects, from the Greek words *entomon* meaning "insect" and *logia* meaning "the study of." Arthropoda translates as "those with jointed feet" from the Greek word *arthron* meaning "a joint" and podos meaning "foot."

Even in a manual about plants, we need to discuss some members of the animal kingdom. As with the plant kingdom, the animal kingdom is split into a number of taxonomic units called phyla. Insects are one of the classes within the phylum Arthropoda.

Arthropods are divided into more clearly defined units called classes. There are about nine classes of arthropods, but only about five or six are important to gardeners, and we will discuss those in this chapter:

Arachnida (spiders, mites, ticks, scorpions, daddy long-legs)

Chilopoda (centipedes)

Crustacea (crabs, shrimp, sowbugs)

Diplopoda (millipedes)

Insecta (ants, beetles, aphids, bees, and others)

Symphyla (garden centipedes)

If we look at each of the classes listed we can see what characteristics separate them into distinctive groups.

FIgure 1. A hobo spider.

The Arachnid class is represented by spiders (Figure 1), mites, ticks, etc. They are anatomically distinctive as a class by having two distinctive body regions: the cephalothorax and an abdomen. Four pairs of legs are attached to the cephalothorax. This class is quite variable in its feeding habits: some are predators (spiders), some are blood feeders (ticks and some mites), and some are plant feeders (some mites).

FIgure 2. A millipede.

The Millipede class (Figure 2) contains arthropods that are rounded or "blocky" in cross-section and elongated with two visible body regions: head and body. Most have 30 or more pairs of legs and all of the body segments possess two pairs of legs with the exception of the first four or five segments. They are rather slow moving and feed exclusively on fungi and decaying plant matter.

Centipede class (Figure 3) members somewhat resemble millipedes but differ in having a single pair of legs on each body segment and appearing flat in cross-section. Also, they are very fast-moving, which aids them in their predacious life-style.

The Crustacean class has only two groups that live their lives entirely on land, and both are of interest to the gardener: pillbugs and sowbugs (Figure 4). They are oval with a hard convex outer shell made up of a number of plates. Pillbugs can roll up in a ball like an armadillo when disturbed; sowbugs cannot. These invertebrates are scavengers that require moisture for their survival and are known for their association with damp habitats. Generally, they feed on decaying plant material like rotting fruit or wood. They are frequently blamed for damage caused by other creatures such as slugs. That damage attracts sowbugs and pillbugs to the fermenting wounds. On rare occasions they will attack healthy plants.

The Symphylan class is a very small group resembling tiny centipedes. They have long antennae, two flattened body regions (a head and body) and 12 pairs of legs on each body segment as adults. They have no eyes (the other classes generally do). The garden symphylan or garden "centipede" is a sporadic pest on the roots of vegetable plants.

Insecta class members (what is really meant when we say "insects") are different from all other arthropod classes and, because they are the most important arthropod group, we will elaborate more on their design.

FIgure 3. A centipede

FIgure 4. A sowbug.

Biology

Arthropods are invertebrates, that is, they do not have a backbone or spinal cord. Arthropods are uniquely separated from all other phyla by collectively demonstrating visible characteristics such as: **bilateral symmetry**, conspicuous segmentation, and a chitinous **exoskeleton**.

Possession of an exoskeleton presents some unique challenges and benefits. The physics of an exoskeleton and internal muscle attachment limits the size such an animal can achieve. On the other hand, the design can bestow an inordinate level of strength on the creature possessing an exoskeleton.

Anthropods are unique from other animal phyla because they have a chitinous exoskeleton as well as bilateral symmetry and conspicuous segmentation.

Anatomy

Insects differ from other arthropods in that they have three distinctive body regions: a head, thorax, and abdomen (Figure 5). At some point in their development (depending on the group) insects will possess three pairs of legs which are attached to the thorax. The **higher insects** will also possess one or two pairs of wings which are attached to the thorax. **Primitive insects** such as springtails, firebrats, and silverfish never evolved wings but do possess the other insectan characteristics.

The thorax of higher insects is heavily muscled to assist flight, walking, and climbing. Most of the digestive, excretory, and reproductive systems are positioned in the abdomen. The circulatory system is open (not contained within blood vessels) and bathes organs and muscles with the aid of a dorsal aortic "heart" of sorts. The insects' "blood" or **haemolymph** has many functions, one of which is hydraulics which becomes important during molting and transformation from one growth stage to another. Insect blood is rarely functional in oxygen transport.

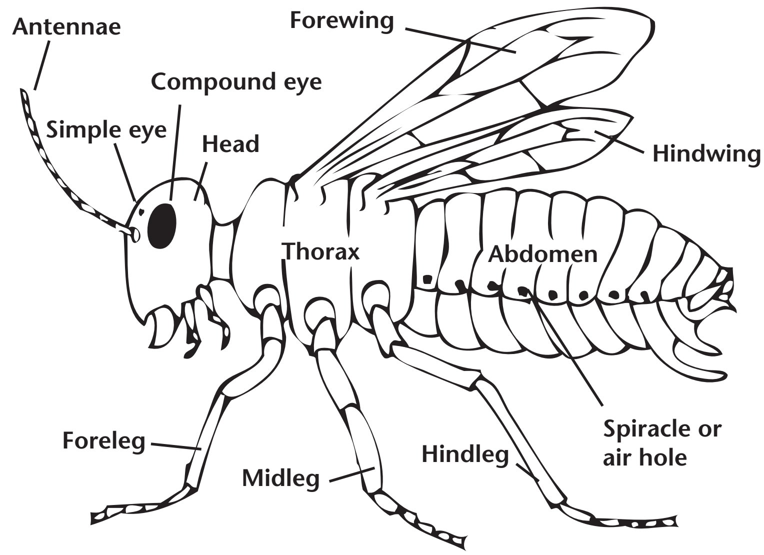

Figure 5. Body parts of an insect.

Movement of oxygen is the job of a unique arthropod system whereby tubes or trachea, starting at the breathing holes called **spiracles**, penetrate the body cavity and bring oxygen directly to the cells of muscles and organs. Knowledge of how the insect respiratory system works has given rise to pest management methods such as the use of horticultural oils to smother pests.

Growth & Development

Most insects change during growth by a process called **metamorphosis**, which means “a change in form.” In higher insects this change in form can be quite radical and dramatic, or simple and modest in scope. Only the most primitive insects have no metamorphosis; they are said to be **ametabolous**. This group includes the springtails and silverfish. The only change they undergo during development from egg to adult is an increase in size.

The more highly developed insects—beetles, flies, fleas, moths, wasps, and ants, for instance—undergo **complex** or **complete metamorphosis**. They develop through the stages of egg, larva, **pupa**, and adult (Figure 6). In pest species, the larval stage is usually most destructive, although the adult also may be damaging. The pupa is a nonfeeding stage; in most cases it also is inactive.

Insects with **simple** or **gradual metamorphosis** change very little during development. They have three stages: the egg, **nymph**, and adult (Figure 7). The nymphs develop wing buds early in their life, but functional wings do not appear until the

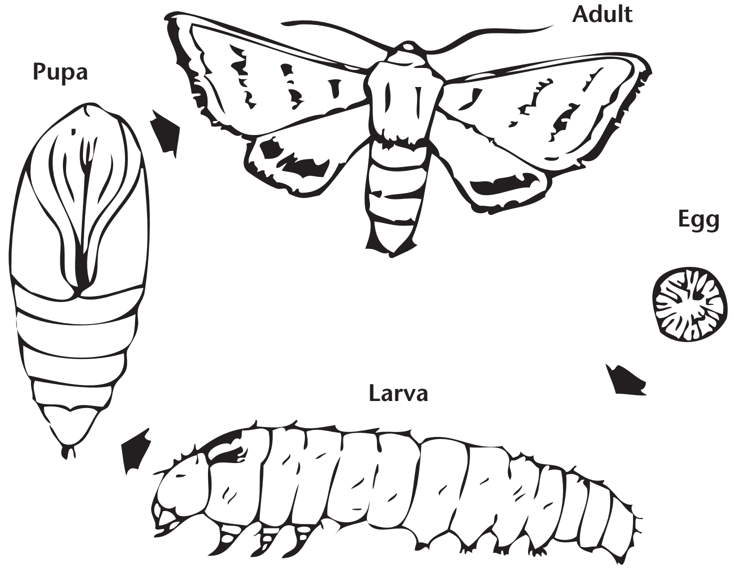

Figure 6. Progression of a moth's body changes from egg to adult, through complex (complete) metamorphosis.

adult stage. Nymphs usually resemble adults closely and have similar feeding habits. Cockroaches, earwigs, termites, lice, true bugs, and aphids are in this group.

A small group of aquatic insects including mayflies and dragonflies are considered to undergo a combination: **simple/ complex metamorphosis**. These insects change radically from the aquatic nymph or **naiad** to the adult stage. Naiads are aquatic, while adults are winged and terrestrial.

When insects molt they literally have to crawl out of their old "skins" or shells and grow between each molt. Each developmental

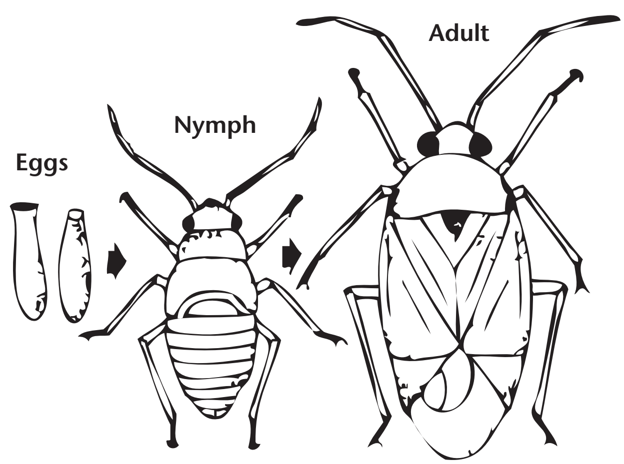

Figure 7. Progression of a bug's body changes as it goes through simple (gradual) metamorphosis.

or growth stage between molts is called an **instar**. Thus you have first instar nymphs or larva, second instar nymphs or larva, and so on.

The hormonal process in molting is complicated and dramatic. Understanding the process has led to the ability to synthesize one of the key hormones involved, namely, juvenile hormone (JH). This is the hormone that effectively inhibits molting between stages. When the immature insects' local environment is overloaded by the artificial JH, molting ceases completely and the insect dies before reaching the reproductive stage. Chemicals such as artificial JH are called insect growth regulators and function as insecticides. They have proven very effective in indoor flea and cockroach control and whitefly control, etc.

Further details of insect anatomy and physiology can be found in some of the listed references at the end of this chapter.

Insect Identification

For gardeners, insect identification operates at two levels: the creature itself and the evidence it leaves or damage that it causes if it's a plant pest. Often, the insect is not found and the only evidence is the damage.

Identifying Insect Damage

Most plant damage by insects is inflicted by cutting, chewing, or sucking action of insects. There are two basic types of mouthparts that cause plant damage: chewing mouthparts and sucking mouthparts (with variations in between).

Pests with chewing mouthparts usually inflict leaf or other tissue gouging. Leaf gouging is often quite generic, so without catching the creature in the act, the accuracy of pest identification would be marginal since the damage may be that of a beetle, cutworm, earwig, sawfly larva, or any of a host of others.

Pests with sucking mouthparts usually leave evidence with predictable symptoms on the plant due to toxins or enzymes in their saliva. These symptoms include chlorosis or stippling, leaf curling and distortions, needle drop, leaf mining, or galling. Once the diagnostician learns these symptoms, the problem diagnosis can often be done without the critters' presence.

In situations where damage is the only evidence, you should preface a tentative diagnosis with words like "possible" caterpillar or "may be" beetle damage. At this point someone should go out at night with a flashlight to catch the critter in the act, collect it, and bring it back for proper identification.

When you have the luxury of having the actual pest to examine, you can use the pest's anatomy and structure to determine its identity. This can be done by comparing the specimen with those in a regional reference collection, if one exists. Reference collections are extremely helpful. Identification can also be done by using a dichotomous or "forked" insect key. Such keys are based on "either–or" choices or couplets, and if the key is well done and you interpret what you're seeing correctly, you will arrive at the right choice in the identification process. One example of an insect identification key, put online by the Amateur Entomologists' Society, can be found at: http://www.amentsoc.org/insects/what-bug-is-this/adult-key.html.

Identifying Insects

Insects are classified as shown in Table 1. While you will rarely need to know a pest's genus and species, remember the importance of scientific names to universal accuracy. While green apple aphid is a common name for *Aphis pomi* in the PNW, it may have a different common name somewhere else. But it is still *A. pomi* regardless of where it's found. Thus the Latin name avoids common name differences.

Table 1. Classification scheme for the green apple aphid, Aphis pomi.

Classification Level	Example
Phylum	Arthropoda
Class	Insecta
Order	Hemiptera
Family	Aphididae
Genus	*Aphis*
Species	*pomi* (the green apple aphid)

Major Insect Orders

There are about 27 orders of insects. Not all of them are important to gardeners and several are rare or don't occur in Washington State, so only half of them—those that gardeners should know—will be discussed here.

Coleoptera. Beetles (Figure 8) and weevils (Figure 9). Coleopterans are variable in size and go through complex metamorphosis. Some of the largest and smallest insects on the planet belong to this order. They have chewing mouthparts. The larvae of beetles have a head capsule and three pairs of legs on the thorax. Weevil larvae lack legs on the thorax. Weevils possess a snout, at the end of which are the mouthparts. Adults usually have noticeable antennae. Adults have two pairs of wings. The outer pair (elytra) is hardened while the inner or hind pair is membranous. A few species are practically wingless and some may have only an

FIgure 8. A predacious ground beetle.

FIgure 9. A black vine weevil.

Figure 10. A springtail.

Figure 11. An earwig.

Figure 12. Cabbage maggot fly.

Figure 13. A stinkbug.

outer pair of wings. They live in a variety of habitats (aquatic, terrestrial, and subterranean) and have very diverse feeding habits and sources that include plants, dung, carrion, and other animals.

Collembola. Springtails (Figure 10). These wingless insects are very small—almost microscopic—creatures that do not undergo metamorphosis. They have chewing mouthparts. Many possess an appendage on their ventral side which acts as a spring to propel them in quick escape. Collembolans are very abundant in moist situations, hence the common reference to "moving piles of soot" in backyards during wet seasons. They feed on decaying organic material, algae, bacteria, animal by-products, dead insects, and there are a few species that feed on plants.

Dermaptera. Earwigs (Figure 11). Adults are moderate-sized insects and most are active at night. They go through simple metamorphosis. They have chewing mouthparts and long antennae. Earwigs have short, hardened outer wings and folded membranous inner wings which, when expanded, somewhat resemble human ears. They have prominent forceps (cerci) at the end of the abdomen and some species have glands on the dorsal part of the abdomen that can emit a foul smelling chemical that serves as protection. They are mainly scavengers, but can be herbivorous or predacious.

Diptera. Flies (Figure 12), mosquitoes, gnats, midges. Most dipterans are small, hairy, soft-bodied insects. Some are quite minute. They undergo complex metamorphosis. Adults have sponging (housefly) or piercing-sucking (mosquito) mouthparts. Larvae may have mouth hooks or chewing mouthparts. Their antennae are variable in length and shape. They have a single pair of membranous forewings. The hindwings are reduced to small, knobbed structures called halteres that act as gyroscopes or balancing organs during flight. A few species are wingless. Some species transmit disease. Larvae of advanced forms, such as houseflies, have no head capsule. Lower forms, such as mosquito larvae, have a head capsule. Their habitats are as diverse as any, ranging from aquatic to terrestrial. Their feeding habits are equally diverse from plant and animal feeders, dung and carrion feeders, to parasites or blood feeders.

Hemiptera. True bugs (Figure 13), aphids (Figure 14), scales, leafhoppers, cicadas, and whiteflies. Hemipterans go through simple metamorphosis and have piercing-sucking mouthparts. True bugs differ from aphids and other Hemipterans by having two pairs of wings which lay flat on their body; the forewings have a basal portion that is thickened and leathery and hindwings that are membranous. Aphids and other Hemipterans have two pairs of membranous wings which are held roof-like over their bodies. True bugs may be plant feeders or predators, while other Hemipterans are exclusively plant feeders—several of which carry pathogens that cause plant damage.

Hymenoptera. Bees (Fig, 15), ants, wasps (Figure 16), and sawflies. Hymenopterans go through complex metamorphosis. In general, they have chewing mouthparts although there are some modifications in some groups such as the bee. Their antennae are usually fairly long, generally having 10 or more segments. Adult hymenopterans have two pairs of membranous wings. They are found in many habitats and on many flowers or vegetation. Many have parasitic or predacious life styles. Larvae have no legs (wasps, bees, ants) or have true legs on the thorax and false legs without hooks on the abdomen (some sawflies). Many hymenopterans construct nests and are highly social.

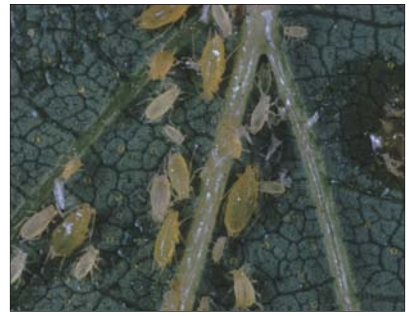

Figure 14. Aphids.

Isoptera. Termites (Figure 17). Termites are small to medium-sized insects that are sometimes confused with ants. Termites have thin, straight antennae, whereas ants have elbowed antennae. Termite reproductives have two pairs of equal-sized wings; while ants in their reproductive stage have two pair of wings of unequal size and length (forewings are longer than the hindwings). Termites go through simple or gradual metamorphosis. Termites live in a variety of habitats: some live in moist subterranean situations, while others live in dry situations above ground. They live in social groups and have a highly developed caste system. Termites have chewing mouthparts and are able to digest cellulose with the assistance of microbes in their digestive tract.

Figure 15. A honey bee.

Lepidoptera. Moths (Figure 18) and butterflies (Figure 19). Moths and butterflies vary from very small to some of the largest insects on earth. They go through complex metamorphosis. The larvae of this order have chewing mouthparts while the adults have a coiled tube for sucking nectar and other liquids. Larvae are unique in that they have pseudolegs or **prolegs** armed with hooks on their abdomen. The antennae of moths are variable, ranging from long and slender threads to something resembling a feather. Butterflies have a single type of antenna which can be described as a filament terminating in a knob. Adults have two pairs of well-developed wings that are covered with small scales. Members of this order produce natural silk. Adults feed on liquids (primarily nectar) while larvae are mostly herbivorous. There is at least one species whose larvae are predacious.

Figure 16. A German yellowjacket (wasp).

Figure 17. Termite workers.

Figure 18. A six-lined sphinx moth.

Figure 19. An alfalfa butterfly.

Figure 20. A grasshopper.

Figure 21. Book lice. (Photo courtesy of K. Grey)

Figure 22. A mountain beaver flea, the world's largest flea.

Figure 23. Drawing of a thrip.

Orthoptera. Grasshoppers, crickets, cockroaches, camel crickets (Figure 20). Adult orthopterans are medium to large sized, often rather hard-bodied insects that go through simple or gradual metamorphosis where nymphs resemble adults except for having underdeveloped wings. This group possesses chewing mouthparts and both nymphs and adults are damaging to plants. Adults usually have two pairs of wings, although in some species they are either absent or rudimentary. The forewings are elongate, narrow and hardened; the hind wings are membranous and fold like a fan (grasshoppers and allies). The hind legs of forms other than cockroaches are enlarged for jumping. **Cerci**, appendages at the end of the abdomen, are usually present. Most orthopterans are plant feeders and can be very destructive.

Psocoptera. Book or bark lice. Book lice (Figure 21) are very small insects that somewhat resemble tiny termites. They have chewing mouthparts and long, slender antennae. They may be winged or wingless. Psocopterans go through simple metamorphosis. They feed mainly on dry organic matter, algae, fungi, or mold. Occasionally they are pests in buildings where they can damage books by feeding on the starchy materials in bindings or they feed in sugar or flour.

Siphonaptera. Fleas (Figure 22). Fleas are small insects with laterally compressed bodies that allow them to move easily through hair and fur. They undergo complex metamorphosis. They have piercing-sucking mouthparts as adults and chewing mouthparts as larvae. Their antennae are quite short and fit into a groove on the head. They do not possess wings. They have powerful legs for jumping. Fleas are **ectoparasites** as adults, feeding on the blood of birds and mammals. Some transmit disease (e.g. plague) or parasitic organisms (e.g., dog tapeworm). The larvae feed on organic debris, particularly adult flea feces. Flea larvae are whitish, slender, and legless, with a well developed head.

Thysanoptera. Thrips (Figure 23). Thrips are very small, slender bodied insects which may be wingless or possess two pairs of wings. The wings are unique in the insect world in that they are long and narrow with few or no veins and fringed with long hairs. The wing appearance is reminiscent of bird feathers. The metamorphosis of thrips is somewhat intermediate between simple and complex. Mouthparts of thrips are of the sucking type. A large number of thrips species are herbivorous and several transmit plant diseases. A few are predacious and a few are fungal feeders.

Thysanura. Silverfish and firebrats (Figure 24). Mature thysanurans are about a half-inch long and covered with fine scales. They have chewing mouthparts, long antennae, and three long anal appendages. Thysanurans do not have wings and do not undergo metamorphosis. They feed on a wide range of material. Some feed on algae, lichens and moss and some feed on higher plants and their by-products. There are several that feed on paper products, paste, fabrics, and books.


Figure 24. A firebrat.

Other Orders. A number of other insect orders are of little concern to the gardener because they do not cause a lot of plant problems. Some of the more common ones that gardeners may see are stoneflies (Plecoptera), caddisflies (Trichoptera), dragonflies and damselflies (Odonata), and mayflies (Ephemeroptera). These orders are all associated with aquatic habitats. Others that gardeners should be aware of include the nerve-winged insects like the green lacewing (Neuroptera), scorpionflies (Mecoptera), sucking lice such as head lice of humans (Anoplura), and chewing lice (Mallophaga).

Insect Diversity & Natural History

The class Insecta is probably the most diverse animal class on the planet. The number of species of insects described so far is just short of a million. **Systematists** (scientists that study evolution and taxonomy) say that if they had access to all microhabitats to collect and catalogue insects from, there would be many millions more insects known to science. The most remarkable thing about these numbers is that most insects are beneficial in some manner with less than 1% of them being even potentially pestiferous.

Less than 1% of known insects are pests.

While animal, plant, and some structural pests are arguably a constant threat, many so-called pests are, in a natural setting, quite beneficial. For example, carpenter ants and dampwood termites can be pests to humans, but in nature they are beneficial as recyclers of rotting wood. Even the lowly housefly, detested by everyone, is extremely important to the health of the earth because housefly maggots are pioneer organisms rendering rotting vegetation, dung, and carrion down to the next recyclable level.

Insects inhabit all habitats and **microhabitats** and perform all known **niches**. In this chapter, we define "microhabitats" as where these animals live, and, while "niche" is a sometimes vague ecological term, we use it here to connote the job an insect performs in its living space or microhabitat.

The open seas and oceans are among the few habitats where insects are not found. One might speculate that it is the salt content that prevents them from being there. But that is not the case since the great salt lakes are home to many insect species. The real limiting factor is who is living there already: the crustaceans (an older evolutionary group) and other animal groups got there first and radiated successfully into all microhabitats and perform all known niches there. You will, however, find many insect species along the seashores, in backwaters, and in estuaries associated with oceans.

The Etymology of Entomology

Etymology: from ancient Greek *eteos*, "true sense" + *logia*, "study of" (Etymology is the study of the history and development of words.)

Entomology: from ancient Greek *entomon*, "insect" + *logia*, "study of"

Insect Orders

Anoplura (head lice) from Latin, *anopl*, "unarmed" + *ura*, "tail"

Blattaria (cockroaches) from Greek, *blattaria*, "shuns light"

Coleoptera (beetles) from Latin, *coleo*, "sheath" + *ptera*, "wings"

Collembola (springtails) from Latin, *coll*, "glue" + *embola*, "bolt"

Dermaptera (earwigs) from Latin, *dermis*, "skin" + *ptera*, "wings"

Diptera (flies, mosquitoes) from Latin, *di*, "two + *ptera*, "wings"

Ephemeroptera (mayflies) from Latin, *ephemero*, "day" or "short-lived" + *ptera*, "wings"

Hemiptera ("true" bugs, aphids) from *hemi*, "half" + *ptera*, "wings"

Hymenoptera (ants, bees, wasps) from Latin, *hymeno*, "membrane" + *ptera*, "wings"

Isoptera (termites) from Latin, *iso*, "equal" + *ptera*, "wings"

Lepidoptera (moths, butterflies) from Latin, *lepido*, "scale" + *ptera*, "wings"

Mantodea (preying/praying mantids) from Greek, *mantodea*, "soothsayer"

Mallophaga (chewing lice) from Latin, *mallo*, "wool" + *phaga*, "eat"

Mecoptera (scorpionflies) from Latin, *meco*, "long" + *ptera*, "wings"

Neuroptera (lacewings) from Latin, *neuro*, "nerve" or "net" + *ptera*, "wings"

Odonata (dragonflies) from Greek, *odonata*, "tooth"

Orthoptera (grasshoppers, crickets) from Latin, *ortho*, "straight" + *ptera*, "wings"

Phasmidia (walking sticks) from Latin, *phasmida*, "phantom"

Plecoptera (stoneflies) from Latin, *pleco*, "folded" + *ptera*, "wings"

Psocoptera (booklice, barklice) from Latin, *psoco*, "small" + *ptera*, "wings"

Siphonaptera (fleas) from Latin, *siphon*, "tube" + *aptera*, "wingless"

Thysanoptera (thrips) from Latin, *thysano*, "fringe" + *ptera*, "wings"

Thysanura (silverfish) from Latin, *thysano*, "fringed" + *ura*, "tail"

Trichoptera (caddisflies) from Latin, *tricho*, "hairy" + *ptera*, "wings

If you looked at the types of microhabitat/niche categories of insects, you would find that they resemble those of many animal groups, in terms of life styles and food patterns. One example of a lifestyle would be **recyclers** such as dampwood termites that live in their food (rotting logs). Another common category would include predators such as dragonflies and many others that make their living by catching and feeding on other animals. **Parasitoids** mimic the predatory life style by laying eggs in, on, or near intended prey so that when eggs hatch, the larva immediately burrow into the host and slowly consume it until the host dies. The only difference between parasitoids and predators is that direct predators immediately kill their prey.

Another niche that somewhat mimics the parasitoid is the true **parasite**, insects like botflies that feed in various locations throughout a host's body without killing it. Some, like cattle grubs, are very important agricultural pests.

Herbivores in all types of habitats dominate the insect world. Aphids, caterpillars, and grasshoppers are just a few examples of this niche and, as one might expect, many are very important economically. Pollinators like bees are a variation of the herbivore niche and are clearly a niche of importance to many organisms on the planet.

Host Relationships

When studying insects, it becomes quite clear that they have a range of dependency on their targeted foods or hosts. In the case of herbivore insects, one will see extremely limited host relationships that include but a single plant species. A local example includes the spiny rose gall wasp which makes its living on wild rose and nothing else. Some herbivores have only a few hosts (that may or may not be related). The cottony camellia scale is one of these and for the most part is only found on camellia, holly, and yew. There are, of course, many generalists among plant feeding arthropods and they may be found on dozens of plant species. A good example of a generalist is the two-spotted spider mite which feed on dozens of different plant species. Predators, parasitoids, and true parasites also exhibit a range of diversity in their feeding habits. Predators are usually generalists feeding on whatever they can find and overpower. An example would be predacious ground beetles that feed on cutworms, craneflies, and such in yards and gardens. But parasitoids and true parasites are far more fussy and specific to certain species or species groups. For example, some parasitoid ichneumonid wasps lay their eggs only on bark beetle larvae, and the parasitic human botfly only produces offspring that feed within hominoid hosts like humans and monkeys in the tropics.

Life Cycles

Insects, like all other animals and plants, have life cycles both as individuals and as populations of species. It is important to know both of these life cycles if you are trying to make decisions about controlling the insects.

Population Cycles. The number of animals in a local population varies from year to year, and even within a single year, for a variety of reasons. Figure 25 illustrates the sort of population size changes that can occur as a result of various environmental or climatic events. The gentle dips and rises (B_1, B_2, B_3) are driven by density-dependent biotic factors such as predators, disease, and food quality or quantity. These are cyclical and interact with the population to keep it near equilibrium with the resources and conditions of the local environment. The rather dramatic crash and upward surge shown in the middle of the graph (A_1) reflects the effect of a density-independent, or abiotic, factor which could be any catastrophic event or even aberrant climate. The crash of a population of insects may reflect, for instance, a late spring frost that kills overwintered insects that have just emerged and begun feeding and were not protected from the sudden cold. An even more dramatic depression of populations would occur in the event of something like a volcanic eruption. Another catastrophic event (C_1) might result in a population fall, followed by a population build-up of dramatic proportion that would look like the rise shown on the far right of the graph. This might be the result of a dynamic die-off of natural enemies (such as from application of a broad-spectrum insecticide) that leads to a population explosion that quickly reaches the **environmental carrying capacity** (total population of a species that can be supported by the local environment, K) at which point members of the population eat themselves out of house and home or experience a plague-like disease so that the population crashes.

Individual Life Cycles. One might ask, what is the usual longevity of insects or how long do they live? This can only be answered by addressing each species or species group. For example, many cutworms have a one-year life cycle. Some species, like houseflies, under optimal conditions may live only a couple of weeks or even just 5 days from egg hatch to adulthood. Then again, some beetles like the golden buprestid have been documented as persisting as larvae in structural wood framing for up to 25 years.

The Insect Success Story

Insects have been on earth since the Devonian Period (about 400 million years), which is a testimonial to their success as a class of animals. There is much that contributes to this notable persistence and success such as insect size, reproductive rate, structure, their physical ability to respond to change quickly, and

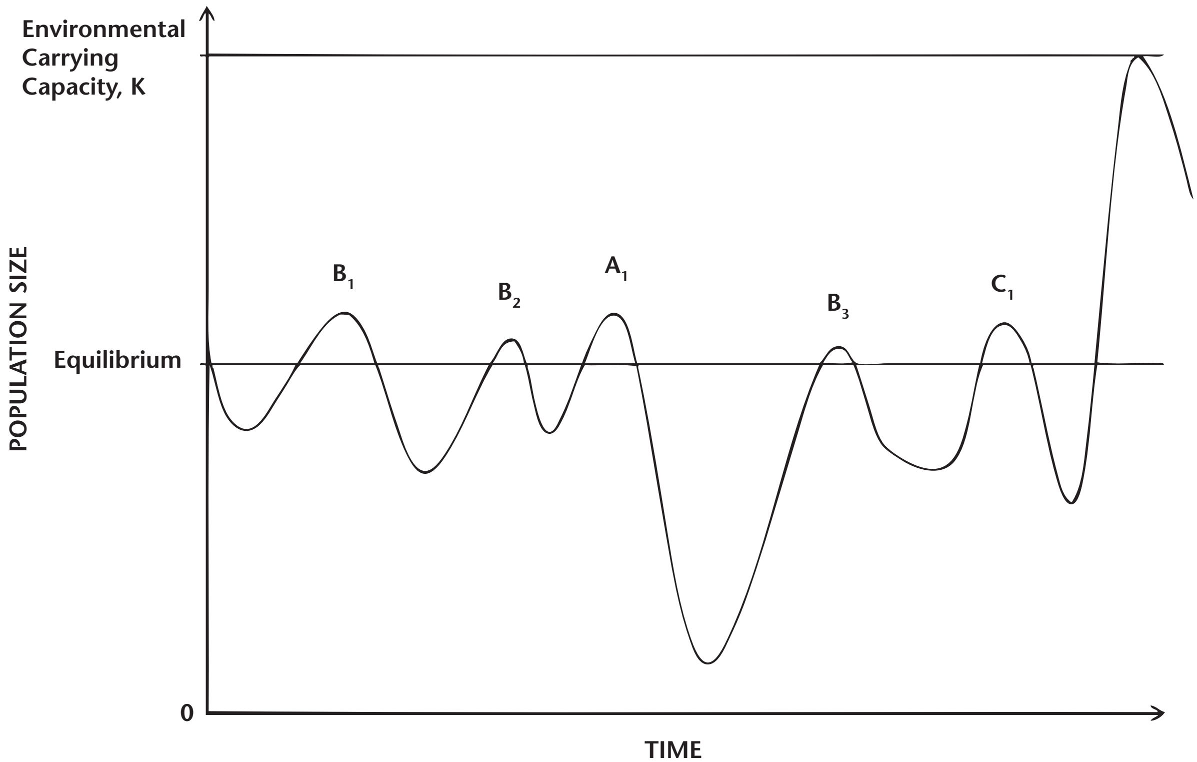

Figure 25. Graph of variations in population density for an animal species, over time. See text for discussion.

their adaptability. Adaptations themselves have a great deal to do with these animals' success stories. There are many of them, but we will address only a few of the more dramatic ones here.

One of the things we witness here in the Pacific Northwest—a temperate region—is a wide variation in temperatures, especially in the winter. Insects are very susceptible to the drying, freezing winds of winter because of their surface area-to-volume ratio—they cannot afford to lose any moisture. Insects would freeze very rapidly if they were not equipped with behavioral and physiological strategies for survival. To avoid cold effects, insects will seek out protective hiding places in soil, tree bark, crevasses, under rocks, and other places. If snow persists then they have the added advantage of a protective thermal blanket. To avoid freezing, many species, prompted by consistent lower daily temperatures and the shortening of day lengths, produce glycerol in their blood. Glycerol is an antifreeze that prevents ice crystals from forming in their blood and cells. (Insects "invented" antifreeze, not humans!) With these physiological and behavioral adaptations, insects of our region have successfully warded off one of their greatest foes: freezing winters.

It is fascinating that humans have actually used insect behaviors and their many adaptations against them in IPM strategies.

For example, several insects (such as aphids) overwinter in the egg stage on primary hosts. If you're dealing with a pest that does this, it could be a candidate for control with horticultural oils. Similarly, mosquito larvae used to be controlled by using light weight oils on the surface of non-productive ponds. Why did this work? Mosquito larvae breathe from a tube that ends in an opening surrounded by hydrophobic hairs that break water tension so gaseous exchange can occur. Oils block this ability, causing suffocation or drowning.

Another example is the use of **pheromones**. Many insects are nocturnal and hide by day. With a life style like this it makes sense to communicate chemically rather than visually, and many insects do so by emitting "external hormones" called pheromones. Pheromones are often used for attracting a mate and it is often the female that produces them. Knowing this, scientists mimic the process or behavior through the use of pheromone traps. Scientists re-create the sex pheromone, impregnating it into a rubber or plastic container and placing it on a sticky trap wherein male insects become stuck trying to find a mate. Pest managers have taken the invention several steps further. They use pheromone traps to determine the presence of a pest and to quantify how numerous they are, and in some cases can use the trapped insects to accurately time insecticide applications. Other types of pheromones include trail pheromones emitted by ants to assist in food finding and nest return, and alarm pheromones in many stinging hymenoptera such as African bees, many yellowjackets, and so forth. An alarm pheromone signals for assistance from nest mates to defend an irritated or threatened nest member. The use of these chemicals makes these insects much more dangerous than a single individual would be.

Social Organization

There are a number of insects from different orders that show some level of social organization (there are also some spiders that demonstrate this). Some of the more advanced of these insects include termites, bees, ants, and stinging wasps. Pest management can sometimes take advantage of this social behavior. Toxic baits, for example, have been manufactured that ant and yellowjacket workers bring back to their nests to feed larvae and the queen. Again, we are using insect behavior and adaptations against them in pest management applications. Conversely, when we are aware of the consequences of disturbing stinging social insects, we might avoid behaviors like throwing rocks at yellowjackets nests or kicking thatching ant mounds to ensure our own safety.

Some social behavior is simply great to observe. There are some leafcutter or weaver ants in Central America that cut leaves apart for piecing together their nests in the trees. Worker ants will use their mandibles to induce their larvae to spin silk from their glands, and then use those silk-spinning larvae as living sewing machines to stitch leaves together. At the same time, other worker ants can be seen holding leaf edges together so that the “sewing ant” can accomplish the task.

Mimicry

The world of insects holds another set of bizarre adaptations that are simply amazing on their own merits and have little to do with management except in some cases where the adaptations are indicators of safety and avoidance. One such adaptation is that of mimicry—at which insects are great masters. There are several types of mimicry. For instance, many insect species resemble rocks, twigs, brambles, dead leaves (Figure 26), living leaves (Figure 27), and so forth. This is known as **cryptic mimicry** and it provides the mimic with some form of camouflage either for safety or to help in hunting, or both.

Figure 26. A dead leaf mimic (katydid).

Two other types of mimicry are worthy of mention, each named for the scientist who defined the phenomenon. One is **Muellarian mimicry**, in which both the mimic and the model insect are dangerous creatures and their similar appearances give a universal message of danger. This is demonstrated by many stinging wasps which have evolved more or less identical color patterns: black and yellow stripes like a yellowjacket, for instance.

Figure 27. A live leaf mimic (mantid).

The other type of mimicry was observed and reported by a scientist by the name of Bates. With **Batesian mimicry** the model is dangerous but the mimic is not. One of the classic examples of Batesian mimicry is the viceroy butterfly which looks like the monarch butterfly. The mimicry developed because their ranges overlap. Monarch caterpillars feed on milkweeds that are poisonous. The plant toxins are incorporated into the caterpillars’ tissues and are passed along to the adult stage butterfly. Any predator that feeds on the adult monarch will become violently ill, and remember it! Thus it will never again eat anything that looks like a monarch butterfly. The look-alike viceroy butterfly (Figure 28) is perfectly edible but is protected from frequent predation by looking like a monarch butterfly.

Figure 28. A viceroy butterfly.

All insect photos are taken by A.L. Antonelli, except for:
Figure 3 by E.D. Akre
Figures 10, 20, 24, and 26 by R.D. Akre
Figure 12 by L. Getzin
Figure 14 by E.C. Klostermeyer
Figure 15 courtesy of USDA NRCS
Figure 17 courtesy of WSU Department of Entomology
Figure 21 by K. Grey

Further Reading

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15

Plant Pathology

Topics covered:

Learning Objectives

- Understand fungal, bacterial, viral, and nematode plant pathogens and how they affect plant growth and development
- Recognize how the plant disease triangle and pathogen life cycles are related to the diagnosis and management of plant problems
- Understand how to use plant health care (PHC) and integrated pest management (IPM) strategies to reduce garden and landscape plant disease problems

By

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Introduction

Plant pathology encompasses the study of plant diseases and their management. For this book, **plant disease** is defined as:

1) any change in the normal structure, function, or development of a plant; or
2) when a plant varies in some way from what is considered healthy.

Many plant pathology references find it useful to distinguish plant disease from plant injury. Diseases result from exposure to an irritant of long duration, such as the presence of a pathogen or the chronic exposure to less-than-ideal growing conditions, while **plant injuries** result from instantaneous contact of a nonliving stressor (Ohio State Factsheet PP401-01). Other definitions limit the use of the term “disease” to just when a plant is infected with a disease-causing or problematic organism, referred to as a **pathogen**, and the result is detrimental to the plant. In this chapter, we will use the broader definition of plant disease because that most closely reflects what is typically observed on the plants in our landscapes and gardens.

You are likely to find plants, or parts of plants, that look unhealthy, are poorly growing, or are diseased in most landscapes and gardens, even if overall the plants have a healthy appearance. The leaves of a rose bush may be infected with the fungal infection black spot (Figure 1). Beans and tomatoes may be growing poorly in gardens due to cold spring temperatures. Fungi called powdery mildews (Figure 2) may be infecting host plants,

Figure 1. Black spot is a fungal infection that affects the leaves of rose bushes.

Figure 2. Fungi called powdery mildew may infect a variety of host plants, covering leaves with white growths of fungal spores and mycelia.

Take this challenge. Stop reading right now and walk around your home and landscape to see if you can find evidence of at least ten diseases (using our broader definition) on your plants.

One of the authors, Jenny Glass, took the challenge and listed the following plant diseases she found in her Western Washington garden, landscape, and houseplants:

1) rose mosaic virus on two roses
2) Monilinia brown rot stem cankers on flowering quince
3) Puccinia rust pustules on overwintering hollyhock leaves
4) Phytophthora root rot on rhododendrons
5) glyphosate damage to turf
6) mechanical injury caused by a lawn mower strike on the trunk of Japanese maple
7) Botrytis damage to emerging tulip petals
8) fungal leaf spot on salal
9) exposure damage and nutrient deficiency to Christmas cactus
10) low light conditions for Benjamin fig resulting in defoliation.

This is not a complete list of problems, for she also observed damage from root weevil chewing on rhododendron leaves and feeding by slugs on daffodils.

Were you able to find at least ten problems? Do not worry if your list currently sounds more like "dead branch on conifer" or "no flowers on rhododendron this spring." As you gain additional horticultural experience, you will be able to put official names to many of these problems.

such as lilacs, apples, pears, peas, or pumpkins, causing leaves to turn white with the growth of fungal spores and mycelium. Other symptoms of plant disease include green leaves turning yellow, branches dying, or fruit shriveling up and falling from the tree. Causes of such problems include abiotic problems such as windstorms, lack of water or nutrients, and too much water or nutrients; and biotic troublemakers such as fungal or bacterial pathogens.

There are many management strategies to prevent plant diseases or reduce their damage pressure on plants. With practice, you will come to recognize when the best solution for a particular plant problem is the complete removal of the plant and replacement with a species less prone to developing problems.

Studying Plant Diseases

The best way to successfully manage any plant disease problems occurring in a garden and landscape is to figure out the underlying causes of the specific problems before trying to implement solutions. Note we use the term "manage" rather than "control" because our techniques aim to reduce disease pressure to a point where the disease is not too damaging to the plant and to an aesthetic level that a gardener can live with, rather than to the point of eliminating all disease on a plant. Trying to eliminate all plant diseases and problems is not a practical goal because we would forever be trying to solve problems, rather than spending our valuable time just enjoying our gardens.

Plant Disease Impacts

Plant diseases can seriously damage the health or appearance of plants we are growing for food or for landscape beauty. The presence of a particular disease on a plant or the plant's propensity towards problems can influence our decision to use a certain species of plant in our gardens and landscapes.

Plant diseases also have historical and current implications for humans as well: plant diseases can seriously damage our food supply, affecting the availability, price, appearance, or taste. Worldwide, pests including disease problems, weeds, insects, and other animals, are estimated to destroy over half the food produced. On a smaller scale, the price or availability of oranges at the local grocery store may depend on whether or not the California crop suffered from frost injury during the growing season. The decision about whether or not to purchase a particular apple can rest on the blemish-free appearance of the fruit skin. The taste of your home-grown pea crops can be ruined by bitterness from an infection of pea enation virus late in the season.

A historic example of an epidemic plant disease affecting food supply is the Irish Potato Famine of the 1840s. The explosion of a disease in the potato-growing regions of Ireland led to widespread crop destruction as potato tubers rotted in the field. Year after year, the loss of the entire potato crop—the main staple of the Irish diet—resulted in the starvation of at least one million people and the emigration of another million. Are we concerned about this disease today? The answer is "yes" because we still encounter the disease, now called late blight, caused by the pathogen *Phytophthora infestans*. Late blight is problematic most seasons on garden-grown tomatoes and potatoes in the Pacific Northwest (Figure 3).

Figure 3. Late blight lesions on a potato leaflet. (Photo courtesy of Howard F. Schwartz, Colorado State University; Bugwood.org.)

The presence of plant diseases on the foods we eat may also impact food safety. Many of the current food concerns focus on animal pathogens contaminating food, such as E. coli, but the presence of certain plant pathogens on food can also be damaging. For example, mycotoxins are poisonous compounds produced by certain fungi. High doses of mycotoxins ingested by animals or people are poisonous. One instance is ergot, a disease of wheat and certain other grains and grasses, where the fungus *Claviceps purpurea* forms sclerotia that replace the grain on infected seed heads; these sclerotia contain alkaloid mycotoxins, which are poisonous. Symptoms of poisoning by ergot may include hallucinations, burning sensations, gangrene, or even death. Ergot-infested grain used in bread flour led to many food-poisoning epidemics during the Middle Ages. But, "the dose makes the poison," and the very chemicals that caused these poisonings are being harnessed today as the active ingredients in certain migraine treatment medications.

Disease Effects on Plants

One of the most important things to remember when determining whether a plant is diseased rather than injured, or when trying to determine the exact cause of a plant disease problem, is to understand that plant diseases impact how a plant, or a plant part, functions. The parts of a plant, including the leaves, stems, roots, and reproductive structures, perform specific functions necessary for healthy plant growth. So you need to understand normal plant functions in order to identify a plant's problem, to determine how damaging that problem might be to a plant, and to decide on the best management strategies.

Plant diseases impact how a plant, or a plant part, functions.

Leaves. Leaves are responsible for photosynthesis, the process that converts carbon dioxide and sunlight energy into sugars and oxygen. Gas exchange, such as water vapor, also occurs at the leaves. When leaf damage occurs, these processes are delayed, disrupted, or stopped completely. Fortunately, most plants make more green tissue than they need for survival. Thus, a few dead leaf spots or some yellow chlorosis to a small part of the leaf would not seriously harm the plant and may require no additional management. However, if large portions of the green tissue are destroyed, then the restriction of important foliar functions may have serious impacts on other plant functions and the overall health of the plant.

Stems. Stems support the canopy of a plant and contain vascular tissues that conduct water, sugars, and nutrients throughout the plant. Damaged stems, such as those with cankers caused by fungal diseases or mechanical injury from wind breaking off a branch, are unable to transport water and nutrients. Such an injury may have a merely local effect on the immediate stem and branch, or the resulting blockage of water and nutrients may result in serious, widespread damage to all portions of the plant.

Roots. Roots anchor a plant in the soil and absorb water and nutrients from the soil. Damage to fine root hairs will reduce a plant's ability to absorb water and nutrients, and may cause the plant to wilt and die. Injury to structural roots may result in death of portions of a plant or the entire plant, and may result in plant instability. Tall trees may become a serious safety hazard following root disease or injury.

Reproductive organs. Flowers, fruit, and seeds are reproductive organs of plants and their function is necessary for a plant's reproductive success. For tree fruits, small fruits, and some of the vegetables, damage to reproductive functions will result in crop injury or loss.

Causes of Plant Disease

Plant diseases generally can be divided into two broad categories: **abiotic** disorders induced by nonliving stresses and **biotic** diseases associated with infection by living pathogens. Many plant problems actually result from a combination of both abiotic factors and biotic organisms.

Abiotic stresses are a common cause of many plant diseases and are considered **non-infectious** because the problem does not spread from damaged tissue to healthy tissue or from damaged plant to healthy plant. Common examples of abiotic diseases include drought stress, wilting associated with transplant problems, or frost injury (Figure 4).

In contrast, biotic diseases are **infectious**; they result from infection of a plant with a living pathogen capable of reproducing

*Figure 4. Winter injury on Canada Yew (*Taxus canadensis*). (Photo courtesy of Howard F. Schwartz, Colorado State University; Bugwood.org.)*

and spreading. Red thread growing on a lawn, fireblight of apples and pears (Figure 5), rose mosaic virus, and phytophthora root rot are examples of biotic diseases. For more information, see Chapter 16: Plant Problem Diagnosis.

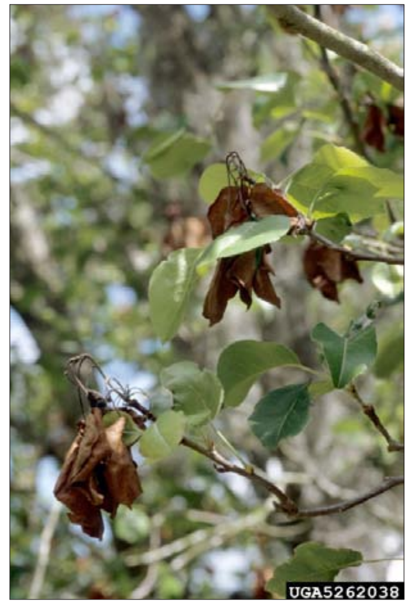

Figure 5. Symptoms of fire blight on pear. (Photo courtesy of Division of Plant Industry Archive, Florida Department of Agriculture and Consumer Services; Bugwood.org.)

Plant Pathogens

The four main types of plant pathogens damaging plants that gardeners may encounter are fungi, bacteria, viruses, and nematodes. Strategies for effective disease management require recognition of the distinctive characteristics of each group.

Fungi. Members of the taxonomic kingdom Fungi include molds, smuts, yeast, mushrooms, and toadstools—many of which are valuable recyclers of organic matter but many of which are also poisonous or pathogenic. Fungi (singular: fungus) are the largest group of known plant pathogens, with over 8000 plant-damaging species having been described. What exactly are fungi? Describing typical fungal characteristics is much easier than pinning down a precise definition of a fungus. Fungi require a food source as they cannot produce their own food; plant-pathogenic fungi use plants as that food source. *Venturia inaequalis*, the apple scab fungus, is one example of a fungal plant pathogen that infects the blossoms, leaves, and fruit of apple (Figure 6).

The growing vegetative body of a fungus is called a **hypha** (plural: hyphae), which appears as a filament; the mass of these hyphae is referred to as the **mycelium**. Most fungi reproduce by spores, which may be produced in a structure called a **fruiting body**. Mushrooms, for instance, are one type of fungal fruiting

Figure 6. Symptoms of apple scab on a red apple. (Photo courtesy of University of Georgia Plant Pathology Archive, University of Georgia; Bugwood.org.)

Fungal Fruiting Bodies

Fungal fruiting bodies (reproductive structures) come in an amazing variety of shapes, sizes, colors, and textures. Mushrooms are just one type of fruiting body, and they also come in many different shapes, sizes and colors.

Bird's nest fungus

Photo courtesy of Joseph O'Brien, USDA Forest Service; Bugwood.org.

Wood rot fungus, *Bondarzewia berkeleyi*

Photo courtesy of Manfred Mielke, USDA Forest Service; Bugwood.org.

Puffball

Photo courtesy of Howard F. Schwartz, Colorado State University; Bugwood.org.

Morels

Photo courtesy of Chris Evans, River to River CWMA, United States; Bugwood.org.

Shiitake

Photo courtesy of Keith Weller, USDA ARS.

Aspergillus fungi growing on a decaying flower

Photo courtesy of Joseph Berger; Bugwood.org.

Orange jelly

Photo courtesy of Joseph O'Brien, USDA Forest Service; Bugwood.org.

Witch's butter

Photo courtesy of Paul A. Mistretta, USDA Forest Service; Bugwood.org.

Violet-toothed Polypore

Photo courtesy of Joseph O'Brien, USDA Forest Service; Bugwood.org.

body. Mushrooms arise from hyphae and produce spores during the reproductive phase.

Fungal pathogens use several different strategies to enter host plants; some fungi are capable of penetrating plant tissue but others require openings, such as stomata, lenticels, nectaries on a flower, or wounds in order to infect the plant. Still other fungi produce enzymes that help break down plant tissue to allow for infection.

In addition, some organisms that resemble fungi, but are more closely related to brown algae, can cause plant diseases. Advances in species characterization have revealed that a variety of these fungus-like organisms (FLOs) that have been traditionally considered fungi (because they superficially resemble fungi) actually have characteristics not found in true fungi. For example, Oomycete water molds like *Phytophthora* and *Pythium* species produce unique spores and have cell walls containing cellulose rather than the chitin found in the cell walls of fungi.

Bacteria. Certain bacteria (singular: bacterium) can also be pathogenic. Bacteria are microscopic, single-celled organisms that reproduce by simple division, also known as **fission**, where the cell replicates by one cell dividing into two, two into four, and so on, in such a way that bacterial populations rapidly expand. The presence of water is required for the spread of most bacterial infections as the bacterial cells are motile (mobile) and can swim in water.

Plant-pathogenic bacteria are not capable of direct penetration of plant tissue and require an entry point into the plant to infect. This entry point can be a wound on the plant, a pruning cut, or mechanical injury from wind, hail, animal damage, or injury from another type of disease. Natural openings on the plant, such as the stomata on the leaf or the lenticels on the stem, may also serve as an opening through which bacteria can infect plants. Once inside the plant, bacterial cells often move in the intercellular spaces and spread throughout the plant.

Viruses. Pathogenic viruses are submicroscopic particles comprised of a core of nucleic acid genetic material, consisting of either ribonucleic acid (RNA) or deoxyribonucleic acid (DNA), which is surrounded by a protein coat called a capsid. Much debate has occurred as to whether viruses are living or nonliving since they are so simple, are unable to produce or generate energy, and cannot reproduce on their own. However, since their parasitic presence induces disease and they control a part of the host cell during their reproduction process, viruses are generally considered pathogens.

Viruses are true parasites because they depend on their host cell for reproduction. Virus particles reproduce in an insidious way by gaining entry into living host cells, which fail to recognize the virus particle as an invader. The host cells then expend energy and use cellular components in the replication of more viral particles.

Viruses spread from host to host in a variety of ways. Some viruses rely on **vectors**, another organism capable of picking up and passing along the virus, to spread from infected plants to healthy ones. Many insects, such as aphids and thrips, are more of a concern because of the viral infections they can vector (spread), than because of the actual feeding damage they do to a plant. Sometimes, a virus infection spreads mechanically through intermingling of the sap from an infected plant with the sap of healthy plant. For example the wind can blow two physically-close-together host plants and cause abrasions as the plants rub together—those abrasions are openings in both plants through which sap intermingles. Pruning cuts are another common way for the mechanical transmission of viruses because virus-infected sap on the blades of pruning tools can be spread to a healthy host plant nearby if the tools are not disinfected after each cut. Other viruses spread when an infected plant reproduces and the subsequent part, be it seed, pollen, or daughter plant, is also infected with the viral particle. Blueberry shock virus is an example of a virus that is spread by pollen.

No practical cures exist for removing virus infections from plants, so when deciding whether to keep or to remove a virus-infected plant in your garden or landscape, it is important to determine how damaging the virus will be to the host plant and the likelihood of its spread in the landscape. Identifying the virus is the first step. See Chapter 16: Plant Problem Diagnosis for help with diagnosis.

Nematodes. Plant-parasitic nematodes are small aquatic worms that feed on plant tissue. These nematodes have a specialized mouth structure called a stylet that allows them to puncture plant cells and ingest cell contents. Saliva of certain nematodes can be toxic to a plant, resulting in the formation of lesions or other injury at the point of feeding. Many nematodes feed on the root systems of plants, though there are a few that climb the plant to feed on the foliage or other upper portions of the plant.

Parasitic Flowering Plants. Plants that are unable to make their own food may parasitize other plants to absorb water and nutrients. These parasitic plants may resemble normal plants and even develop similarly, but lack a root system. Instead they rely on specialized absorption structures called **haustoria** (singular: haustorium) to penetrate a host plant in order to obtain water and nutrients. Mistletoes are a common type of parasitic flowering plant (Figure 7).

Non-parasitic Plants. Lichens, mosses, and English ivy are not parasitic to the plants they are found growing on. These simply live on another plant but do not gain nutrition from it. Lichens and mosses do not kill the plant they grow on, but people sometimes assume they do because they see it on dead branches. Lichens and mosses can be observed on living branches too. English ivy in some regions has been listed as a noxious weed due

Figure 7. Clump of dwarf mistletoe on a pine branch. (Photo courtesy of USDA Forest Service—Rocky Mountain Region Archive, USDA Forest Service; Bugwood.org.)

to its invasive growth. While not parasitic, it is still harmful to the plant it grows on through competition and the sheer weight of its growth.

Conditions for Plant Disease

Pathogenic disease actually results from complex interactions between a susceptible host plant or plant community, a virulent (disease-causing) pathogen population, and an environment conducive for the establishment of the particular disease. This interaction is referred to as the disease triangle, or “overlapping circles of influence” (Figure 8). A plant disease can develop only when all three components are present at the same time and interacting with one another. Removal of any one component of the triangle precludes or eliminates disease. Minimizing the influences of any of the three components reduces the severity of the disease problem. We often alter the dynamics of the disease triangle in our integrated pest management efforts to reduce disease. For example, purchase and use of a dogwood resistant to the fungal disease dogwood anthracnose will reduce the chances of a blighted dogwood in spring. Two other, diverse strategies to manage foliar fungal diseases are careful summer supplemental watering to avoid long spells of leaf surface wetness and the use of preventative fungicides to alter surface chemistry of plant leaves.

Time can also be a factor in the onset of a disease problem. Environments conducive for disease establishment can be quite time-dependent. The host tissue must be susceptible or the pathogen population must have time to develop in order to be

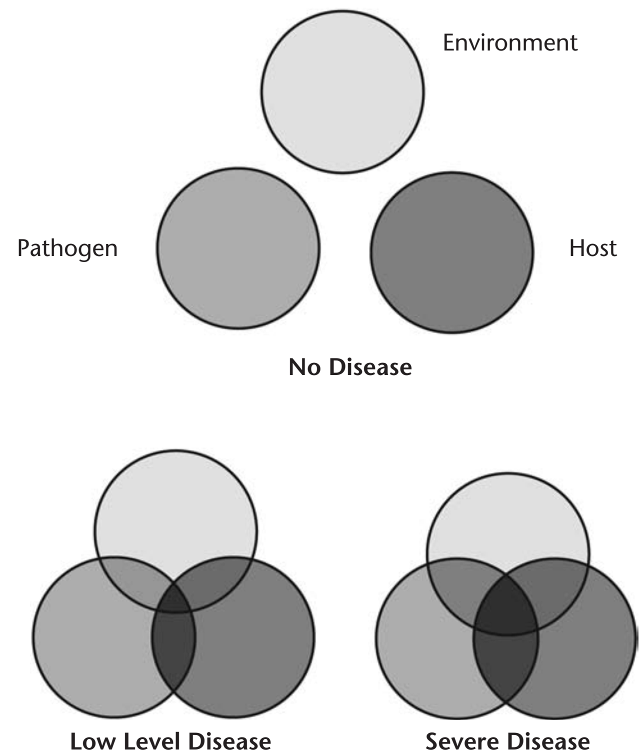

Figure 8. The disease triangle. Only when all three components—host, pathogen, environment—are present and interacting, can a plant disease develop.

significant enough to cause disease. Two examples of the timing component at work in an infection include conifer needlecast fungi that only infect needles newly-emerging from the bud, and the fungal disease brown rot that only gains entry to the cherry and other Prunus hosts through their flowers, meaning that these hosts are only susceptible during bloom.

Pathogen Lifecycles

Another concept important for achieving management of many of the pathogenic plant diseases is knowledge about the individual lifecycle of the pathogen. In general, the lifecycle of a pathogen (Figure 9) has these components: inoculation, penetration, incubation, infection/colonization, reproduction, and spread.

Inoculation occurs when a pathogen makes contact with a host plant. The inoculum of a pathogen can include fungal spores or mycelia, bacterial cells, virus particles, nematodes or their eggs, and seeds of pathogenic flowering plants.

Penetration occurs when the inoculum of the pathogen gains entry to the plant. Incubation is the stage from the time the pathogen penetrates the host until symptoms first appear on the host.

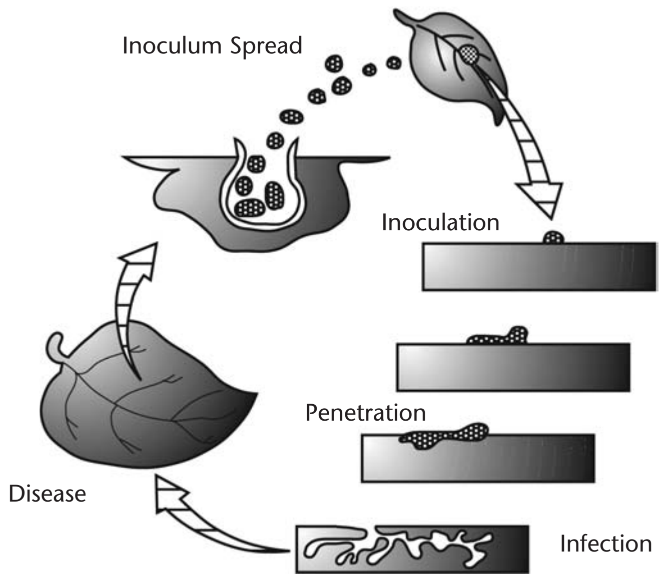

Figure 9. Diseases always develop through three stages: inoculation, penetration, and infection.

Infection and colonization occur as the pathogen becomes well established within a host plant and continues to grow. This is often the time when disease symptoms are noticed on the plant.

Reproduction of disease organisms occurs via cell division for bacteria, spore production for fungi, eggs for nematodes, seeds for plant-parasitic plants, and formation of new particles for viruses. The reproductive phase may occur inside or outside of the host plant, depending on the pathogen.

Spread or dissemination occurs when the pathogen or the inoculum produced via reproduction reaches previously unaffected parts of the plant or other host plants in the area. Sometimes spread occurs right back onto the host plant and the infection repeats several times during the growing season, or there may be a period of time in which the pathogen must survive away from the host plant before conditions for inoculation occur again.

Delving into the plant disease literature and trying to figure out the specifics of the lifecycle of the pathogen that is currently damaging your plants will give you clues as to the most effective way to manage the pathogen. For example, the peach leaf curl pathogen *Taphrina deformans* infects peach buds as they are developing (Figure 10). This knowledge helps to pinpoint the timing of fungicide applications.

Managing Plant Diseases

Disease problems can sometimes be avoided completely by proactively restricting pathogens so they never get established

Figure 10. Infection of peach trees by Taphrina deformans *causes newly forming leaves to develop distorted, yellow to reddish growth. A white "dust" forms later on the outside of the leaf. Repeated infections by the fungus can kill the tree.*

in an area. When a pathogen is already lurking in an area, preventative measures attempt to protect plants from that pathogen. Many of our disease management strategies target the environment surrounding the plant and pathogen interaction.

Proactive Strategies

Managing plant disease problems is easiest when problems are not allowed to get established in the first place. Two proactive strategies, **exclusion** and **eradication**, can be used to keep new problems from getting established in an area. Exclusion of a disease includes numerous steps taken to avoid the problem altogether by keeping a pathogen from entering and becoming established in new places. Exclusion is the basis for many of the plant quarantine laws, our federal or state plant inspection services, and some of our disease-vector control programs.

When a new pathogen first enters an area and is newly reported, the chance exists for eradication of the problem. Eradication efforts are undertaken to kill and prevent the spread of any localized, relatively-small population of an introduced pathogen. These efforts may include the removal of host plants in an area adjacent to where a new pathogen has been found or the use of pesticides around the area where a new disease has been reported. For example, in 2009, the pathogen *Phytophthora ramorum*, the cause of Sudden Oak Death and numerous diseases collectively referred to as "Ramorum leaf and shoot blight" on a large number of hosts, was found in a variety of nursery plants in Washington. Washington State is working to exclude the pathogen from further introductions and to eradicate the pathogen from any infected nurseries to keep this pathogen from becoming established in our landscapes and forest lands.

Preventative Strategies

Preventative disease management means measures taken to prevent infection by an existing or established pathogen. Preventative strategies can be used to manage diseases native to a particular area or when a new, exotic pathogen becomes well-established in an area. Strategies to prevent infection include cultural practices, biological methods, and chemical applications. These preventative strategies are used in Integrated Pest Management (IPM), a multi-tactic approach to managing, among other pests, plant diseases. This multi-tactic approach emphasizes monitoring and assessing plant health and pest status; the use of disease management techniques including cultural, biological, and chemical methods; and the adoption of tolerance for a low or not-seriously damaging level of the problem. In general, many gardeners are already employing IPM strategies in the management of plant diseases in their gardens and landscapes. See Chapter 19: Plant Health Care and IPM for details on managing plant health through IPM.

Cultural Management Methods. Many cultural techniques can either prevent or reduce plant disease problems. For instance, sanitation involves removing damaged plant parts and pathogens from the plant or from the environment of a susceptible plant. Common places for plant pathogen survival include sites on the infected plant, within plant debris, or in the soil. Sanitation is most effective for pathogens that would survive within plant debris or for infected plant parts that can be readily cut out; for example, discrete cankers on branches can be removed. Regardless of other control methods used, sanitation of infected plant material or old plant residue is important at the end of the growing season if the pathogen has an overwintering or survival stage. Note: never compost diseased plant material.

Choosing and growing particular plants under conditions that are healthy for those plants may repress certain pathogens. Techniques that improve the general health and growth of plants, such as appropriate fertilization, proper planting technique, and careful initial site choice for the planting, can also help reduce problems with plant diseases. Improving drainage in a wet area may change the soil environment, making it less conducive to certain pathogens, as with *Pythium* or *Phytophthora* that thrive in saturated soils. Crop rotation and planting date modifications are other cultural strategies that can help reduce plant disease problems. Humidity, often necessary for fungal and bacterial infections, can be reduced by cultural methods: carefully locating the plant in the landscape to achieve optimal air circulation, pruning to open up the plant canopy and increase air movement, and carefully targeting any summer supplemental irrigations to early in the day or around the base of the plant rather than on the foliage.

Biological Management Methods. Sometimes competition with or interference of the pathogen by encouraging another organism may also be employed. The control takes place through competitive exclusion. A notable example is the control of crown gall (*Agrobacterium tumefasciens*) by using non-infective *Agrobacterium radiobacter* in advance of infection. Infection sites are taken up by the non-infective strain, thereby preventing establishment by the infective strain.

Chemical Management Methods. Selective, targeted pesticide use may be part of a gardener's IPM strategy. A correct diagnosis of the disease is critical, and an understanding the biology of the pathogen plus careful reading, understanding of, and following of the pesticide label directions are important when using pesticides, such as fungicides. The pesticide applications must be accurately timed and targeted in order to best manage the pathogen and may need to be reapplied, should the plant continue to develop unprotected new growth under environments conducive for disease infection.

Chemical management of plant diseases in the home landscape is typically reserved for the fungal infections of plants. Fungicides typically work to prevent growth and infection of fungal pathogens and thus are used to protect the plant from the pathogen, not to actively kill the pathogen. Many fungicides work by altering the surface chemistry of plant tissue and preventing fungal growth and infection. Few fungicides available to home gardeners have any extensive curative or “kick-back” ability against fungal diseases. For fungicides to be applied at the most efficacious time, we cannot use the “wait and see” monitoring stage used for insects and mites. Instead, the decision to employ fungicides involves contemplating the history of a particular disease on a plant, the likelihood that recent and forecasted weather will promote the particular disease, the severity of the problem to plant health and aesthetics, as well as one's personal gardening philosophies about the use of pesticides in disease management or a preference for the use of only certain types of chemistries.

The lifecycle of the pathogen is another important consideration when using fungicides. The timing of fungicide applications typically must coincide with the inoculation or penetration stage of the lifecycle because most fungicides work by suppressing fungal growth, not by actively killing the pathogen.

And finally, when pathogens can spread easily from infected plants to healthy plants via sap on pruning tools, tool disinfection becomes a worthwhile effort.

Summary

Many gardeners are amazed by the number and complexity of problems facing their landscape and garden plants. While some problems are extremely detrimental to a plant, crop, or landscape, the vast majority of plant diseases cause only minor damage to plants and are often more damaging to the aesthetics of the plant than to its overall health. Remember also that many of our best landscaping and gardening practices are also good integrated disease management strategies, so most of your time can be spent enjoying your garden and landscape, rather than combating plant diseases.

Further Reading

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Plant Problem Diagnosis

Topics covered:

- Introduction
- Preparing to Diagnose
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    - Resources for Plant Problem Diagnosis
    - Diagnostic Tools
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- Evaluation of Plant Problems
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    - Abiotic Diseases and Their Symptoms
    - Biotic Diseases and Their Symptoms
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Learning Objectives

- Be able to develop a working plan for diagnosis of plant problems
- Recognize typical plant problem symptoms
- Be able to distinguish fungal, bacterial, viral, nematode, and abiotic diseases
- Be able to use integrated pest management (IPM) strategies to reduce garden and landscape plant disease problems

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Introduction

Do the following questions and comments sound familiar?

> *"Why are my raspberry plants dying?"*
>
> *"Can you tell me why the inner needles on my spruce tree look so brown?"*
>
> *"This cherry has been beautiful for years but this spring it suddenly died right after the leaves emerged."*
>
> *"Why has my Japanese maple never given me beautiful fall color?"*
>
> *"What is eating holes in the leaves of my rose bushes?"*
>
> *"I planted two rows of beans in my garden this spring and only three plants came up."*

You likely have a list of your own questions or you want to learn more about how to promote healthy plant growth in your garden and landscape, as well as how to avoid having your plants become damaged and diseased. One key to managing and preventing plant problems is diagnosis of plant problems. Diagnosing plant problems can be both a challenge and a joy; the overall experience will mostly depend upon how you go about learning about and working on plant problem diagnosis.

Preparing to Diagnose

An accurate determination of the origin of the problem is essential for choosing the optimal plant problem management strategy. Knowing how to manage the problem and what strategies are likely to be the most effective will help you make decisions and will save you time and money. For example, if you were trying to manage leaf curl, fungicide applications may be appropriate to suppress the problem of a *Taphrina deformans* fungus-induced peach leaf curl (Figure 1) but would not be appropriate if the leaf curl was the result of a plum tree infested with leafcurl plum aphids. Similarly, removal of crop debris would not be an effective deterrent of winter injury. So it is important to take the time to thoroughly investigate the development and underlying causes of any problem before taking steps to alleviate the issue.

Vocabulary

Plant pathology uses a variety of terms to cover the array of plant problems that occur. For example, leaf damage may be called a spot, blotch, **blight**, or wilt, while damage to a stem is often referred to as a canker or blight. Sometimes special nomenclature is also used. The term "anthracnose," for example, is used for diseases caused by a certain group of fungi but the symptoms can

Figure 1. Taphrina deformans *causes peach leaf curl: deformation of new leaves on a peach tree.*

be variable depending on a host involved: dogwood anthracnose causes a blight of the bracts, leaves, and small twigs; maple anthracnose and oak anthracnose refer to foliar blights plus stem and twig cankers; while apple anthracnose refers to a disease of the branches (Figure 2) and a "bull's eye rot" of fruit, not a foliar infection at all.

Figure 2. Apple anthracnose presents as cankers on twigs and branches of apple trees. These cankers are caused by a fungal infection.

Most plant symptoms can be broken into three main damage categories:

a) **necrosis**, the death of tissue (Figure 3)

b) color change, such the yellowing of tissue known as **chlorosis** (Figure 4)

c) tissue malformation, such as stunting, distortion, galls (Figure 5), leaf roll, witches' broom, etc.

A pathogen is a living entity that causes disease or harms the plant. Pathogens that attack plants can be fungi, bacteria, viruses, or nematodes. The vast majority of fungi, bacteria, and nematodes are free-living or beneficial, and these do not adversely affect the health of plants—pathogenic species, capable of causing plant damage, only comprise a small subset of these overall groups.

Pathogenic organisms gain food from their host plant in the form of living or dead plant tissue. Pathogens that are parasites obtain nutrition directly from the cells of a living host. Powdery mildew fungi, fairly common in our landscapes, are parasites: they infect living epidermal cells and gain nutrition from them. Other parasitic pathogens include rust fungi, virus diseases, and plant-pathogenic nematodes. Some pathogens live as **saprophytes**, gaining nutrition from dead organic matter. Many of the

Figure 3. Poplar leaves showing marginal leaf necrosis.

Figure 4. River birch leaves showing iron deficiency-induced chlorosis.

Figure 5. Rose canes with a crown gall caused by bacterial infection of Agrobacterium tumefaciens.

saprophytic pathogens produce chemicals that break down plant tissue to create a food source for the pathogen. Most of the stem cankers, canopy blights, leaf spots, and root rots are examples of diseases caused by saprophytic pathogens.

A **host plant** is a plant on which a particular disease can develop. For example, rose is one of the many hosts of the bacterial disease crown gall, as are apple, blackberry, cottonwood, euonymus, honeysuckle, poplar, pyracantha, turnip, and myriad other species (Figure 6). The **host range** includes all plants and/or cultivars or varieties of a plant where a particular disease can develop. When a particular disease cannot infect a plant, we call that plant a **nonhost**. Fir trees are nonhosts of the crown gall pathogen. This knowledge is helpful for eliminating suspects during a diagnosis, and is also key to plant disease avoidance–one of the most effective plant disease management strategies.

Other plant-related terms include **resistance** and **susceptibility**. If a plant has features that prevent or impede development of a particular disease, we refer to that plant as a resistant plant. Susceptible plants are those that can become readily infected by a particular pathogen. Sometimes resistance and susceptibility is more a continuum in situations where plants have been weakened by abiotic stresses. For example, a shade-loving plant planted in full sun may be more damaged by a particular disease problem than it would be if it were grown under optimal conditions. When a particular pathogen cannot infect a plant at all, that plant is said to be immune to that problem.

Figure 6. Dahlia tubers with crown gall. Plants infected with Agrobacterium tumefaciens *develop large tumors on their roots and at the bases of their stems. (Photo courtesy of R.S. Byther.)*

Problems appearing on plants are referred to as **symptoms** (the damage occurring on the plant) or **signs** (evidence of the organism responsible for doing the damage). Many types of symptoms exist, including necrosis, chlorosis, spots (Figure 7), wilting, distortion, galls, cankers, and stippling-feeding damage. What particular symptoms look like can depend on many factors including the plant species affected, the stage of development, the severity of the problem, and the underlying health of the affected plant.

Figure 7. Water-soaked leaf spots on iris blades are symptoms of Mycospaerella *leaf spot disease.*

Signs, by contrast, are the visible physical presence or evidence on the plant of the actual living organism responsible for causing the symptoms of plant damage. Signs on damaged plants, visible to gardeners, can include fungal mycelium, pustules of spores, or the presence of an insect or mite pest. Signs also can be some part of the organism or something produced by the pest or pathogen (Figure 8). For insects and mites, signs might include eggs, webbing, **frass** (fecal material) or shed exoskeletons (also referred to as cast skins). Fungi are the pathogens most likely observable as signs, such as with a mass of spores from a fungal rust pustule or the mycelial growth of powdery mildew covering a leaf surface. With the use of a simple hand lens or magnifying glass, diagnosticians can often identify additional fungal signs, such as the olive-colored coating of spores that overlays an apple scab infection on fruit or leaves. The other pathogen groups—bacteria, viruses, and nematodes—are typically too small or too obscure to present any real likelihood of seeing signs without extensive additional effort or by the use of a microscope.

Signs are typically diagnostic for the cause of the problem while symptoms may or may not be as illuminating. Symptoms typically

Figure 8. Chewed leaves are one symptom of a pest problem, but eggs, frass, or shed exoskeletons are some of the signs of pests.

alert us that the plant is experiencing a problem. For example, a wilted plant lets you know that the plant is in trouble because not enough water is reaching the leaves and branches but doesn't say why the water is insufficient. Does the wilt reflect that too little water has been provided to the plant? Does the wilt suggest that while enough water is available, the plant cannot use it? What might have happened to the plant tissues such as roots or stems to prevent water absorption? Table 1 presents a matrix of possible problems and their causes that may contribute to plant wilting. These reasons are not mutually exclusive—more than one can occur to the same plant at the same time, and some can contribute to further problems that compound the symptoms. For instance, landscape rhododendrons will often wilt and die when growing in saturated soils, conditions under which the Phytophthora root rot pathogens can thrive. The pathogen *Phytophthora* destroys the fine feeder roots that absorb water resulting in a "drought stress" appearance to the plant even though water is not a limited resource in the soil.

Table 1. Matrix of possible reasons for plant wilting. As with many plant problems, there are many possible causes—all of which may be the result of yet other problems and conditions.

Overarching cause	Resulting from	Brought on by	Due to
Insufficient water to the plant canopy	Drought	Insuficient rain	
		Broken or inadequate water system	
		Plant in wrong environment	Gardener error; plant label error
	Stem or twig damage	Girdling	Too small or strangling mechanical support for the plant (twine, wire, or label left on the plant) Too tight an insect barrier Gnawing animals
		Kinked or broken stem or twig	Ice or snow load Animal activity
	Root damage	Temperature extremes	Freezing; sun scald
		Burns from high salt concentrations	High native soil salinity Saline irrigation water Excessive fertilization Urine from large animals
		Improper transplanting	Inattention; dull tools
		Mechanical activity	Trenching for construction Compaction from traffic Gnawing animals
		Chemical applications	Misuse
	Poor root growth	Low oxygen in the soil	Saturated soil Compacted soil
	Root death	Pathogenic infection	Fungi Bacteria Nematodes

Resources for Plant Problem Diagnosis

Your personal gardening experiences and those of your gardening colleagues are some of the best sources of gardening information, both about the individual plants grown in the Northwest, as well as the problems that develop on these plants. You can gain additional expertise by building a good horticultural and diagnostic reference library. Reference materials will help you get an idea of what conditions promote healthy growth of plants and what conditions result in the development of problems. Most gardeners have their favorite horticultural references. Many excellent plant diagnostic resources exist including the guides called "Landscape Plant Problems" and the Pacific Northwest Plant Disease Management and Insect Management Handbooks. University Extension bulletins are research-based publications and offer invaluable problem-specific reference information.

Internet websites can provide further information to help you gather additional information about a particular problem or to find ideas for the various likely types of damage that occur on a particular plant. But remember, distinguishing the gems from the junk on the Internet can be difficult. For more effective use of Internet search engines, use the Latin names of plants and diseases rather than their common names. For example try a search using the correctly-spelled *Phytophthora ramorum* rather than "Sudden Oak Death" and do not even think of searching for the dahlia leaf disease "white smut" by anything but its Latin name *Entyloma*. You may also find it handy to add some qualifier words, such as "Extension," "Master Gardener," "Research," or "University" to your search because these words often help to eliminate links to websites of dubious worth. And always remember to consider how credible and up-to-date the information found on a particular website is likely to be. For example, many plant disease and insect management bulletins provide excellent details about an issue and provide valuable research-based management strategies, but may not have been updated to include recent advances in biological control options or pesticide chemistry.

Here are just a couple of the university websites that gardeners might find helpful:

1. http://pep.wsu.edu/hortsense/
   WSU Hortsense was prepared by the WSU Urban IPM team especially for use by WSU Master Gardener volunteers and home gardeners in Washington State. This website provides numerous factsheets on common landscape problems with information covering both cultural management options and, if applicable, registered chemical management options. This site is updated yearly.
2. http://plant-disease.ippc.orst.edu/
   Plant Disease Control Online is an online version of the Pacific Northwest Plant Disease Management Handbook. This site is updated yearly.

Diagnostic Tools

Diagnostic Tools

- Sharp knife
- Pruners
- Shovel
- Clean containers for samples
- Magnifying glass or hand lens (5x to 10x)

The right tools will improve your diagnostic experience and ability. A sharp knife can be used to make cuts into woody plants in order to determine where the plant tissue is alive and where is it dead. Pruners are handy for gathering samples or for cutting a large sample down to a useable size. Shovels may be necessary when trying to excavate around the root system to check for problems. Clean bags, vials, or other containers will help to keep a sample intact. Magnification is a must, since most of the readily observable signs of plant damage, including insects, mites, and fungal fruiting bodies, are quite small. Learn to use a magnifying glass or hand lens (Figure 9). It should provide at least 5 times the magnification of the unaided eye. You will want to practice using the magnifying tools by examining a printed page first. Once you are proficient at bringing the small dot of an "i" into focus, you will feel more confident when using your hand lens to search for a spider mite scampering across a leaf, or to look for tiny black fungal fruiting bodies growing at the center of a necrotic leaf spot.

Figure 9. The right tools help with diagnostic work. Pictured here are cutters, sample containers, a magnifying glass and a 10× hand lens.

Your attitude towards diagnosis is another important tool that should not be overlooked. Cultivate an excitement about diagnosing plant problems. With all the interest in challenge games, such as Sudoku and crossword puzzles, people should be clamoring for the problem-solving opportunities that occur in a typical try at plant problem diagnosis. Figure out where your individual skills lie and see how they fit as part of a plant problem investigative team. Cultivate the skill of engaging people in diagnostic questioning to obtain background information about the plant and its problem. Do you have a sharp analytical mind and excellent problem-solving skills? If so, be the person to volunteer an opinion as to whether or not the problem has a living origin or if the client's use of a chemical weed killer in the landscape had anything to do with the problem's development. Do you have a vast range of Pacific Northwest gardening experiences? If so, sing out on the joys or sorrows of growing the particular plant in our region, thus helping to explore the possible causes of the problem and to eliminate unlikely possibilities. Are you a good mediator? If so, help your fellow gardeners work together to combine knowledge with the hope of determining the cause of the problem. You will also want to practice saying "I don't know" a few times because plant problem diagnosis can be a humbling experience when, after lots of hard work on your part, the concluding diagnostic answer is, “Here is what we learned the problem is *not*, but at this time we don’t know what the problem *is*.”

Steps for Diagnosing

Diagnosis requires information—both in the form of samples to examine and in the form of facts. Here is how to collect each.

Sampling

You will need to carefully examine a damaged plant to determine the cause of the problem. If observation of the actual plant is not possible—for example, while assisting people on the telephone—ask for a sufficient and representative sample of the problem to be submitted for examination.

First, if the problem is showing more than one type of damage—leaf chlorosis plus stunting, for example—then the sample you need should include tissue showing the entire range of symptoms. Second, the sample should contain tissue from the transition area between the healthy and damaged tissue because pathogenic disease organisms and insect pests will often be found at the margin of the damage moving into healthy tissue. Third, the sample should also include root material and/or observations about the condition of the soil, the roots, and the main stem or trunk at the soil line because many aboveground problems, such as branch death and leaf wilt, actually result from root problems, not from problems originating at the tissues actually showing the damage. Fourth, additional investigation of a healthy plant, or of nondamaged tissue from the plant, may also provide a useful comparison necessary to diagnose the cause of the problem, especially when you are unfamiliar with a particular plant species. Poor quality samples including dry, dead plant corpses, oozing slimy tissue, or disgusting smelly rotten samples are rarely useful for diagnosis—they are simply too far gone.

Sleuthing

Since the plant cannot talk to you and tell you what is wrong, you need to gather information from observation of the damaged plant and testimony of the person concerned about the problem. One of the best ways to gain information about a plant and the problem is to ask questions of the person concerned about the plant. Try not to make too many assumptions when starting a plant problem diagnosis, particularly if you are working to help with the diagnosis of another person’s plant. Information to learn includes a thorough background history of the plant, its growth and care, as well as details on the development and spread of the problem. Ask about the condition of other plants and the distributions of symptoms on a plant, within a landscape, and development of the problem with time because these characteristics often give clues as to whether the problem is caused by a living organism or by an abiotic stress. Open-ended, discussion-stimulating questions and sympathetic comments often produce the most helpful information from a client. Following are numerous questions that may help illuminate a plant problem situation and help pinpoint the causes of the problem.

Tell me about the history of this plant in the landscape. This type of question helps to gain a general picture of the damaged plant—its age and its size, the age and size of the landscape, how it was planted, where the plant was growing and the conditions it experiences, and what landscape practices might be influencing its growth. You may need to ask additional or follow-up questions to get all the necessary information.

Describe the development of the problem in the landscape. Determining when a problem develops, what plants are affected, what plants are not showing the problem, and if the damage appears to be spreading over the landscape or getting worse with time are all factors that will be clues as to whether the problem is likely to have an abiotic or biotic origin and may help you pinpoint that origin. In general, problems caused by living organisms (biotic origin), generally show a random distribution on a plant or within a landscape, often develop slowly over time, and may get progressively worse—particularly if the environment is conducive for growth of the pathogen or pest population. In contrast, problems caused by abiotic factors often show very uniform patterns of damage, for example, all the old leaves on a plant are yellow, suggesting nitrogen deficiency. Abiotic damage caused by a single event, for example hail injury, typically shows a distinct start and stop time to the plant problem. But remember, people sometimes think a problem was sudden, when they just hadn't noticed it before.

Describe your weed management practices. This phrasing typically provides much more detailed and honest answers than do more accusatory questions such as “Do you use herbicides to kill weeds?” or “Did this plant come in contact with weed killers?” Gaining information about the use of herbicides provides important clues about whether or not plant damage might be associated with their use. Note that many herbicides function as plant hormone mimics so symptoms of distorted plant growth, including twisted petioles, bud proliferation, and leaf curl, may be associated with accidental contact of a growth-regulating herbicide. However, herbicides and other pesticides can be used in a landscape without inducing damage on non-target plants, so don't assume that any use of herbicides in a landscape must be the cause of the reported damage.

What do you think the problem might be? By asking the client about their particular plant concerns, you often learn about management attempts that worked or did not work, as well as issues that later might be determined as the origin of the problem or might be ruled out as contributing to the development of the problem.

Can you think of anything else to tell me about this plant, its problem, or the situation? This type of question often reveals the quirky details associated with the unusual types of plant damage, such as the abrupt transplanting of a large, thirty-year-old, prized dogwood in the middle of summer with only a week's notice and the help of one neighbor and his lawnmower tractor. Another time, a client might tell about how he took a two-month-long vacation midwinter which led to the diagnosis of chilling injury because the damaged silver queen Aglaonema houseplant had remained behind in the unheated home.

Evaluation of Plant Problems

Unfortunately, plant problem diagnosis cannot be done by answering yes and no questions down a dichotomous key, as is often possible for identification of insects and plants. Nor is there a single list of questions that must be answered with the answers pointing to one and only one possible answer. Some problems can be quite easily diagnosed, based on symptoms, or signs, or by the particular situation under which they occur, but the vast majority of plant damage observed can arise from a multitude of causes. Anyone working to diagnose plant problems should develop a systematic approach to diagnosis that provides a framework for approaching plant problems. This way, whether the plant is an orchid, a lilac, a Douglas fir, or someone's cherished bonsai plants, you can get started on a diagnosis.

The typical diagnostic method recommended for determining the cause of unknown plant problems has four main steps:

Step 1: Identify the plant and the environmental requirements that the plant needs to thrive. Pay close attention to the plant's cultural requirements (hardiness factor, drought and/or poor soil-drainage tolerance, shade-loving versus sun-loving) because adverse physical stresses are often the origin of plant problems or predispose the plant to attack by insects and pathogens. During this step, begin an evaluation of the plant damage but also describe any healthy attributes of the plant.

Step 2: Work to develop a hypothesis about the origin of damage on the plant. Breaking up the big question "What went wrong with this plant?" into smaller stepwise questions will help to move you through the diagnostic process. Questions to consider include:

Is the observed "damage" truly a plant problem? For example, larches and bald cypresses are two types of deciduous conifers, so loss of the needles from these trees in fall would be a normal event. Even some of the evergreen conifers are known for spectacular needle discoloration and drop of older needles in fall.

Where exactly on the plant is the problem originating? This question can often be difficult to determine as the tissue being damaged may or may not be the original site of the problem development. For example, necrotic leaf spots may develop because a pathogen or pest is attacking the leaves but certain patterns, such as necrosis around the margin of the leaf edge or dead patches developing between every major vein on a leaf, typically reflect a water or nutrient stress event often associated with damage occurring at the stem or root tissue, not on the foliage itself.

Does the pattern of damage suggest that the problem has an abiotic or biotic origin? In general, damage from abiotic causes typically occurs in a regular or uniform pattern on an affected plant, may develop quickly, occurs on numerous types of plants in the same geographic location, may have a distinct start and stop time to the damage, and does not spread or get worse over time. In contrast, damage from living organisms generally develops slowly, is expressed in a random pattern of damage on the affected tissue or plant, and generally spreads or gets worse with time.

What do the observed symptoms and signs suggest about the specific cause of the problem?

Step 3: Determine what evidence should be present on a plant to validate or invalidate a hypothesis about the origin of damage. For example, the presence of spider mites, the reported use of a pesticide, or fungal mycelium developing after the sample has been incubated in a moist chamber could all be examples of "evidence." Evidence may not always be immediately apparent at the time of the investigation. The poplar petiole leaf gall aphids may have migrated to one of their other hosts. Decay fungi and bacteria may have flourished after the sample was collected for diagnosis, overshadowing other evidence and making it difficult to determine if a pathogen was originally present.

Step 4: Do the work to check for the evidence and evaluate the hypothesis about the cause of damage. The key to an accurate diagnosis is assessing the validity of the hypothesis you have been developing, so closely check the plant for evidence of the cause of the problem and review the background about the plant and its problems, looking for further clues to identify the issue. Sometimes all the evidence will point to the fact that your hypothesis is right on the mark. Other times you may not be able to find concrete evidence, you might be looking for the evidence at the wrong time of year or without the appropriate tools or expertise, but if nothing you find suggests that the hypothesis is wrong, you should accept that your diagnostic answer is valid. In these cases, inform the client of the diagnostic process used, the diagnosis arrived at, and any relevant management options.

If the evidence you accumulate is contradictory to the hypothesis you have developed—for example, if the problem does not develop at that particular time of year or in that weather, or if the plant investigated is not a host of that particular problem—then the hypothesis should be reevaluated. This last step is often another great place to consult another diagnostician with more expertise on a particular plant or a particular problem.

This method is not foolproof and will not always produce an accurate diagnosis but it is certainly better than thumbing randomly through books or just winging it with a guess.

Reviewing Causes

Remember, plant diseases can be caused by abiotic stresses or by infection or infestation with living organisms. Abiotic factors are some of the most common sources of plant damage in our landscapes. Well over half of the common landscape plant problems are estimated to result from damage by nonliving stresses, rather than a primary pathogen or pest problem. Too, plant problems often result from complex combinations of both nonliving factors and living organisms. Often, stressed plants exude pheromones or other chemicals to which insects are attracted, and pathogens may more readily infect damaged plant tissue.

Distinguishing between Abiotic and Biotic Damage

The patterns of damage on the plant, in the landscape, or over time, may reveal whether or not the problem is likely to have an abiotic cause or is the result of biotic causes. Gardeners need to be keen observers in order to detect these patterns. For example, when investigating the cause of a leaf spot problem, first note the characteristics of the problem on an individual leaf:

What are the shapes and colors of the leaf spots? (Round, bull's-eye, light, dark, yellow, red, etc.)

How many spots are present on each leaf? (Lots or just a few.)

Where are the spots found on the leaf? (Top surface, bottom, margins, between veins, etc.)

Then consider the location of the problem on the plant and within the landscape:

> Where are the affected leaves found, on a particular branch of the plant? (Outer edges, in by the stem, etc.)
>
> Where on the plant are the affected branches? (Top, lower branches, outer branch tips, etc.)
>
> How many and which plants are affected?
>
> Where, relative to other unaffected plants in the landscape, are the damaged plants located?

In general, you want to determine if a damage pattern has a uniform, or regular, distribution on the plant or within the landscape. The more uniform or regular a problem appears, the more likely it is that the problem developed due to an abiotic cause, such as adverse environment or mechanical injury. This type of damage may happen quite rapidly and may occur on a diverse group of plants growing near each other. By contrast, random or irregular distributions of damage on the plant or in the landscape are often typical of plant problems with biotic causes which often develop just in one area or under certain conditions, but not others. Also, biotic problems often develop slowly and typically spread over the affected plant or within the planting in the landscape and may get worse with time. Damage from biotic causes may develop over a large geographic area.

The more uniform and wide-spread a problem is in a landscape, the more likely the problem is due to an abiotic cause.

Not all problems will have a clear-cut pattern or timing characteristics that help us determine the most likely origin of damage. In addition, many problems are exceptions to the rules. Gardeners who valiantly garden with deer can relate—your apple trees were fine before someone forgot to shut the gate to the deer proofing fence, and by the time anyone noticed the gate open, both the deer and the tender leaves are gone! These patterns can go undetected and are not available to "outsiders" when trying to diagnose a problem. Queries to a client about the distribution of the problem on the plant, in the landscape, and over time are often answered with the frustrating response "I don't know," both because the patterns are subtle and because the property owner didn't know to look.

Check for any associations or connections that may help to pinpoint the factors or organisms involved in the damage. Does the problem develop on only one type of plant or is it damaging to numerous members of that particular plant family? Is the damage occurring in only one area of the landscape? Is there any common attribute among all the plants showing a particular type of damage? Are the damaged plants sensitive to a particular stress, such as heat, cold, or drought, and was it possible they experienced that stress? Are the affected plants from the same source, planted using a similar method, or growing in a particular area of the landscape? Is there some characteristic of the landscape that might be connected to the damage, for example, proximity to lawn or recent construction activity?

Abiotic Diseases and Their Symptoms

Physical Environment. Physical environment conditions that are less than optimal for healthy plant growth commonly lead to plant problems. Abiotic environmental stresses can include exposure to adverse temperatures, excessive or insufficient light, and limited or excess water. Extreme conditions, such as days that are blazing hot or bitterly cold, and rapid fluctuation between two distinct conditions often induce the most damage in affected plants. For example, sunscald, a type of winter injury, occurs on the trunks and branches of susceptible trees when the exposed side of the plant is warmed by the winter sun during the day, causing the plant tissue to break dormancy; the tissue is subsequently killed when the temperatures drop below freezing again during the night. While nothing can be done to alter the weather, gardeners can work to reduce plant problems caused by environmental stresses by using plants hardy to the region, by carefully matching the plant used in the landscape to the particular attributes of the landscape site, and by providing adequate but not excessive supplemental water when required.

Mechanical Injury. Mechanical injury is not just injury from machines, as the name might infer, but rather, damage that is a breaking, tearing, crushing, or cutting of plant parts by any method or agent. Mechanical injury to plants includes damaged bark and cambium, root loss, torn leaves, or branch removal. For instance, the incorrect use of a weed trimmer or lawnmower resulting in the girdling or choking off of the plant's cambium is a common cause of the death of woody landscape plants. Other mechanical injuries include damage to plants from construction practices, such as severe soil compaction, and damage from severe weather events such as hail and strong winds. Even the way a plant is growing—in particular, circling roots that choke one another off—may lead to mechanical damage.

Pesticide Injury. Pesticides are chemicals that are used in and around the landscape to manage problematic pests,such as insects, weeds, fungi, and rodents. Pesticides can sometimes cause damage to desirable plants. The symptoms of pesticide damage depend on many factors including the type of product used, the rate of application, the environmental conditions under which the application was made, and whether the product contacted the plant through drift, vaporization, or by root absorption.

Herbicides are the group of pesticides most likely to cause plant damage if they contact desired plants and vegetation. Many of the herbicides used to kill weeds in landscapes function as plant growth regulators. For example, the active ingredient 2,4-D mimics auxin hormones produced naturally by plants and disrupts plant growth. When this type of herbicide contacts the wrong plant, plant-growth-regulating effects can occur. A common source of such exposure in home landscapes occurs when turf products containing both fertilizer and herbicide are applied to the lawn over the root system of a large broadleaf shrub. The shrub's roots often absorb a damaging, but not lethal, dose of the herbicide so the plant grows distorted foliage. When assessing the potential for growth regulator herbicide injury to plants, look for specific symptoms such as the twisting of needles and leaf petioles, the proliferation of buds, and curl at the margins of leaves.

Nutrient Stress. Plants require at least sixteen nutrients for healthy growth. If the plant is unable to absorb sufficient nutrients for its needs, nutrient deficiency symptoms may develop. Symptoms can range from chlorosis, to stunting, to leaf roll, to purpling of the tissue. Specific symptomology depends upon the element that is lacking.

While sometimes nutrient deficiency results because the soil lacks or is very low in a particular element, in many cases the element is present in the soil but remains unavailable to the plant because of soil pH or root system problems. For example, the roots of rhododendrons and blueberries can absorb iron if the soil pH is low (acidic), but in Eastern Washington and in urban soils of Western Washington, the pH of the soil may be neutral to alkaline, rendering iron unavailable to the plant. Keep in mind that root rot of the tiny feeder roots and other damage to the root system, such as injury from chewing insects, can also cause the plant to exhibit nutrient deficiency symptoms.

Where the symptoms are located on an affected plant may give you a clue about the nutrient that may be lacking, because nutrients are either **phloem-mobile** or **phloem-immobile** depending on whether or not they can be moved from one part of the plant to another, via the phloem. Many nutrients, such as iron and manganese, are phloem-immobile, meaning that they cannot be taken from where they have been in the plant tissue and moved upward into new, developing growth. If one of these nutrients becomes limited in the soil, nutrient deficiency symptoms will show on new growth. In contrast, if the soil nutrient deficiency is of a phloem-mobile nutrient such as nitrogen, phosphorus, potassium, magnesium, or sulfur, the element can be withdrawn from older, previously formed leaves and moved, via the phloem, to the growing points of the plant (Figure 10). In this case, the nutrient deficiency symptoms—often expressed as chlorosis—will be observed in older leaves that lost the nutrient, while the developing tissue will appear healthy.

In some alkaline soils in Eastern Washington, over-application of some nutrients when there are already adequate levels in the soil can result in toxic effects on the plant often exhibited as **foliar necrosis**. Another common cause of toxicity in plants is foliar exposure to pollutants such as ozone and sulfur dioxide.

Some plants are quite sensitive to a particular element, whether it is a required nutrient or not. Note that leaves of the houseplant dracaena often develop necrotic spots when irrigated with municipal water containing fluoride.

Biotic Diseases and Their Symptoms

Fungal Diseases. The vast number of fungal pathogens, the variety of diseases they cause, and the many environments in which they thrive make them a common issue in the garden and landscape. Depending upon the exact pathogen, infection of a plant by fungi can take place in the foliage, the flowers, the stems, the leaves, or some combination of areas.

With experience, many gardeners come to recognize quickly many of our common fungal diseases that produce distinctive symptoms. For example, apple scab infection results in the scabby appearance of the fruit surface and brown spots to the leaves. Brown rot, caused by the fungus *Monilinia*, causes scattered dead branches with brown leaves and flower clusters clinging to them throughout the canopy of a cherry tree. A Japanese maple whose branches are dying in a branch-by-branch manner, typically just on one side of the tree, suggests that the plant has become infected by the soilborne fungus disease Verticillium wilt. To confirm the diagnosis of Verticillium wilt, you must look for symptoms within the plant's water-conducting tissue by making thin cuts under the bark to check for olive-green streaking or discoloration in the xylem tissue of the wood.

Figure 10. Nutrient deficiency symptoms (left to right) on a Norway spruce and corn. (Photos courtesy of Petr Kapitola, State Phytosanitary Administration, Czechia; and R.L. Croissant; all through Bugwood.org.)

Other fungal infections are recognized more by the signs they produce than by any characteristic damage they induce. Powdery mildews, a common problem in Washington, are readily noticed as white powdery coatings growing over infected leaves. By contrast, rust diseases are easily diagnosed because of their abundant production of colorful yellow, orange, or reddish powdery spores formed in tiny pustules.

Fungal infections, generally, often show foliar lesions that are round with diffuse borders (Figure 11) and within the damaged spot you might even observe concentric rings of damage. These patterns develop because of the way some fungi infect and grow on the tissue and how they move into the uninfected tissue. Fungal leaf damage to plants can also show up as irregular leaf spots with even large portions of the plant blighting or dying back. Do not fall into the trap of eliminating fungal infections as the cause of a problem simply because the spots are not round. Check the damaged leaf carefully for evidence of the pathogen because many signs, including mycelium growth or the production of fungal fruiting bodies bearing spores, can be observed within lesions.

Fungal infections of stems may develop and present in many ways. Some problems develop as cankers—dead areas of the stem—while other fungal infections induce blights where large portions of the stem, buds, and leaves die. Still other stem-infecting fungi infect and grow through the plant's vascular tissue, often inhibiting water movement in the plant, leading to wilting and death of the infected plant.

Figure 11. Symptoms of Coniothyrium *fungus infection on a yucca leaf. (Photo courtesy of Howard F. Schwartz, Colorado State University; Bugwood.org.)*

Figure 12. Armillaria root rot rhizomorphs can be found just under the bark of infected trees. (Photo courtesy of Fabio Stergulc, Università di Udine; Bugwood.org.)

With root rots the earliest symptoms may be as vague as poorly performing or dying plants that require further diagnostic efforts to determine the origin of the damage. In order to investigate root problems, we need to inconveniently dig around the root system so root problems often get overlooked. In general, root damage from fungal pathogens may result in the rotting of the entire root system, the killing of fine feeder roots, or discoloration and death of the structural roots. Several root diseases common in Washington State have characteristic symptoms, such as the cinnamon-brown discoloration of tissue caused by Phytophthora root rot that can thrive in poorly drained soils, or the root-pruning of young vegetable seedlings caused by infection from a *Rhizoctonia* species. Another fungus associated with root rots in many landscapes is the pathogen *Armillaria* sp. which is often found in newly cleared soils and is transmitted between plants by root contact or by spread of shoestring-like **rhizomorphs**—dark strands or clumps of fungal mycelia growing on or just beneath the bark (Figure 12). Symptoms of root rot typically include production of smaller-than-normal leaves, leaf yellowing, leaf drop, dieback of branches, and eventual death of the tree. White thread-like masses of the fungal mycelium, referred to as **mycelial fans** or **mats** (Figure 13), may be found beneath the bark near the crown of infected trees. Honey-colored mushrooms (Figure 14) often grow near the base of infected trees in the fall. Diagnostic experience and a microscope may be necessary to recognize these fungal structures.

Bacterial Diseases. Bacterial diseases are another common problem in Washington landscapes and gardens. Leaf spots and blights of blossoms, foliage, and stems, and the soft rotting of fleshy plant parts are commonly observed damage that may be caused by bacterial infection.

Figure 13. Mats or fans of fungal mycelium grow beneath the bark of infected trees. (Photo courtesy of Joseph O'Brien, USDA Forest Service; Bugwood.org.)

Figure 14. Honey-colored mushrooms (fruiting bodies) can be found growing near the base of some Armillaria root rot-infected trees. (Photo courtesy of Andrej Kunca, National Forest Centre—Slovakia; Bugwood.org.)

Many bacterial infections develop as leaf spots. Leaf spots include lesions that initially have a water-soaked appearance, then develop into angular-shaped necrotic lesions that are often delineated by major leaf veins (Figure 15). Sometimes the lesions may have a transparent quality when the leaves are held up to the light, or may have a yellow halo surrounding the necrotic damage. These attributes of color and shape of bacterial lesions reflect the enzymatic activity of the bacterial pathogen, as well as the way the bacteria move from cell to cell in the intercellular spaces of the leaf tissue.

Blights—where large portions of the plant become necrotic and die—are also a common type of symptomology associated with diseases caused by bacteria. Numerous woody landscape plants and fruit-producing plants, including maple, lilac, cherry, and raspberry, are susceptible to the bacterial blight pathogen *Pseudomonas syringae*. Typical symptoms include leaf spots, dead buds, branch or trunk cankers, and branch dieback. This *Pseudomonas* pathogen can be very damaging to its host plants as it produces a protein upon which ice crystals can form. These crystals create winter wounds on the plant through which further infection occurs. *Pseudomonas* also produces syringomycin, a powerful plant toxin that kills tissue and aids in infection. Infections through natural openings and wounds occur during wet periods, especially during cool, wet weather.

Blights are a common symptom associated with bacterial diseases.

In Eastern Washington, fire blight caused by *Erwinia amylovora* is another bacterial blight infection gardeners may encounter as it damages members of the Rose family such as pear, apple,

*Figure 15. Bacterial infection symptoms include leaf spots or lesions that span the tissue between leaf veins. Shown here is a lesion from bacterial blight (*Pseudomonas syringae *pv.* aptata*) on a beet leaf. (Photo courtesy of Howard F. Schwartz, Colorado State University; Bugwood.org.)*

Figure 16. This branch of a crabapple shows distinctive symptoms of fire blight. (Photo courtesy of William Jacobi, Colorado State University; Bugwood.org.)

crabapple, and pyracantha. The pathogen typically attacks host plants via wounds or blossoms. Initially, twigs and flowers appear water-soaked and infected tissues quickly turn brown to black and die, leaving the infected plant appearing scorched (Figure 16). Cankers can develop on twigs and branches (Figure 17), sometimes girdling the limbs and causing dieback or even killing the plant.

Figure 17. Another symptom of fire blight is the development of cankers on twigs and branches. (Photo courtesy of William Jacobi, Colorado State University; Bugwood.org.)

Several bacteria, most notably *Agrobacterium tumefaciens*, the cause of crown gall, may induce a plant to grow abnormally, forming galls. Crown gall is found on many landscape plants, fruit trees, and caneberries, most commonly on rose, cherry, apple, euonymus, raspberry, and blackberry (Figure 18). Young galls are fleshy, white, enlarged masses on roots or stems and rarely cause serious plant damage. Older galls are hardened and turn dark brown and woody or corky in appearance and, depending on the location, may seriously weaken or even kill the host plant.

Diagnosticians must typically rely on the symptoms for diagnosis of bacterial diseases, rather than find any confirming signs of the presence of bacteria. The plant pathology literature often suggests looking for the signs of **bacterial ooze** and bacterial streaming to confirm the diagnosis of bacterial diseases. Few of the bacterial diseases, however, produce bacterial ooze, a sticky liquid containing the plant-pathogenic bacteria, in association with the lesions or cankers. In many cases, **gummosis** of cherry and other *Prunus* species may be mistaken for ooze associated with bacterial blight, but these globs of sticky plant sap develop in association with numerous issues on cherry, not just due to bacterial blight. Checking for sign of bacterial streaming requires cutting the damaged tissue and using a microscope to examine the sample

Figure 18. Crown gall shows up as enlarged masses of tissue at the base of many landscape plants, fruit trees, and caneberries. (Photo courtesy of the Division of Plant Industry Archive, Florida Department of Agriculture and Consumer Services; Bugwood.org.)

for the presence of bacterial cells flowing from the cut edge of the lesion. This type of investigation is rarely available to gardeners and only works well when the sample examined is in the early stages of disease because when the damage is more advanced, the necrotic tissue may be colonized by numerous saprophytic, but nonpathogenic, bacteria.

Diagnosticians typically must rely on symptoms for diagnosis of bacterial and viral infection, rather than signs of the actual pathogen.

Viral Infections. Symptoms of viral infection in plants range from the stunning to the subtle. Since the presence of virus particles in plant cells often impedes the plant's ability to function normally, leaves of an infected plant may develop striking symptoms including chlorotic rings or circles of red or black, **mosaic** (various shades of green in the leaf tissue, Figure 19), vein banding (tissue surrounding veins turns yellow), and mottling (large patches of yellow on infected leaves). Only a few viruses, such as Impatiens Necrotic Spot Virus, Blueberry Shock Virus, or Blueberry Scorch Virus, create necrosis on their host as a primary symptom. Infected plant tissue may also be distorted in shape. Other times, the viral presence within a plant simply stresses the plant, resulting in a weak, unhealthy, or stunted plant. That damage could be attributed to other, often more likely, causes such as nutrient or water stress. Virus infections in plants can also be symptomless with the viral infection going unnoticed.

Viruses particles come in a few basic shapes, variations of round or rod shaped, but are too small (typically 20 to 2000 nanometers in size) to be seen with the unaided eye or even a typical light microscope without specialized staining techniques. Electron microscopy, in which an electron beam rather than light is used, is necessary to achieve resolution of small objects like virus particles.

Figure 19. The mosaic pattern of coloring on plant leaves may be symptomatic of a virus infection. Shown here are the common mosaic virus on a bean plant (left) and apple mosaic virus on hop leaves (right). (Photos courtesy of Howard F. Schwartz, Colorado State University, and David Gent, USDA Agricultural Research Service, respectively; Bugwood.org.)

Thus, we will not be looking for the actual virus particles in damaged plants. We may, however, check for signs of the insect vector associated with a particular viral disease. For example, thrips can vector several devastating virus diseases including Impatiens Necrotic Spot Virus or Tomato Spotted Wilt Virus, so the presence of thrips on damaged impatiens, petunia, or tomato plants expressing large necrotic lesions on leaves, sends the signal to consider that the damage is associated with one of these viral infections.

Nematode Damage. Nematode damage to plants typically shows up as a poorly growing plant, or you may notice circular dying patches of plants in a field crop situation. These symptoms result from feeding damage by nematodes on the roots resulting in the plants' inability to absorb sufficient water or nutrients for healthy growth. Observation of nematode injury is not that common since so rarely are roots pulled out of the ground for examination. We may find evidence of nematode injury, typically small bumps covering the surface of tubers or roots when crops such as potatoes or carrots are harvested or dahlia tubers are dug up for storage. If a nematode-infested root system or tuber is dug up and examined, galls or lesions induced by the nematode's feeding may be present on the roots. Some galls on the roots also signal the site where a female cyst nematode is reproducing and protecting eggs within her enlarged body. Take care not to confuse beneficial root associations, such as the nitrogen-fixing bacteria nodules or root infection by mycorrhizal fungi, with damage from nematode feeding.

One group of nematodes for which you can readily observe symptoms is foliar nematodes that injure leaves when they feed.

Wedge-shaped, necrotic spots on the foliage of many common host plants, including African violets, ferns, and elderberry, are a typical symptom of foliar nematode infection. Microscopic investigation of the damaged tissue is necessary to observe the actual nematodes feeding within the leaves.

Insect and Mite Damage. The feeding habits of insect or mite pests and their lifecycles are important things to consider when diagnosing insect and mite damage on plants. Plant damage from pests' feeding will have different attributes depending on whether the pest species involved has either chewing mouthparts or piercing-sucking mouthparts. Matching the damage observed on the plant with the type of mouthpart that would create the injury is the first step in identifying which insect or mite pest is responsible for the injury.

Damage caused by pests with chewing mouthparts results in missing plant tissue.

Damage caused by pests with chewing mouthparts results in missing plant tissue such as leaf notches, holes, and tunnels or mines (Figure 20). Small notches on the margins of leaves are symptomatic of feeding injury by an adult root weevil. Other plant chewers include cutworms, leafminers, leaf cutting bees, and slugs. A slime trail may cover the surface of a chewed leaf, suggesting

Figure 20. Striped cucumber beetles (above left) have chewing mouth parts and eat more than just cucumber leaves. Adult lilac root weevils chew and damage leaves on numerous plants, including this privet (above right). Bronze birch borers (left) also have chewing mouthparts; shown here is an adult next to a hole bored into a birch trunk. (Photos courtesy of Whitney Cranshaw, Colorado State University, and Joseph O'Brien, USDA Forest Service; Bugwood.org.)

Figure 21. Spider mites use their sucking mouthparts to feed on leaves, resulting in chlorotic stippling of those leaves, as shown here. Also visible are mites and eggs at the base of this leaf. (Photo courtesy of Whitney Cranshaw, Colorado State University; Bugwood.org.)

snails or slugs as the pest to combat. Frass, or insect fecal material, is another common sign of chewing pests. Many chewing insects feed at night, so go out at night and use a flashlight to carefully examine the problem plants to see if you can capture the pest in action.

Many other insect pests such as aphids, lacebugs, and scale insects, as well as spider mites use piercing-sucking mouthparts to feed on leaves. They leave chlorotic stippling injury as a result (Figure 21). This stippling injury looks like tiny pinpricks of yellow or brown on a leaf or conifer needle. Often the pest is no longer actively feeding on the plant when the damaged is noticed, so check for signs it may have left behind, especially shed exoskeletons, frass, or eggs.

Sometimes, the damage induced by insects or mites comes from toxins present in their saliva that induce abnormal plant growth or damage. Leaves may be curled or galls may have formed. The presence of a tiny eriophyid mite, the maple bladder gall mite, leads to the production of galls on infested maple leaves. Other common pests associated with toxic plant effects include the fuchsia gall mite, the poplar petiole leaf gall aphid, the balsam woolly adelgid, and the Cooley spruce gall adelgid.

Details of the suspected pest's lifecycle will come in handy when trying to find evidence to support the hypothesis you have developed about the cause of damage. For example, apple maggot damage is often observed in apple fruit long after the maggot has dropped from the fruit.

Vertebrate Animal Damage. Larger animals, including birds, rabbits, dogs, and deer may damage plants. Feeding on plants or scratching of claws along the bark, trunk, or roots of plants results in mechanical injury to the plants. You may notice deep holes in fruit, such as cherries or apples, which indicate that birds have been feeding on the fruit. Salt from an animal's urine may burn plant foliage or roots if deposited in high concentrations or quantities. Dog urine injury often shows up in lawns as dead spots surrounded by a halo of well-fertilized grass or on low shrubs as yellow or brown areas. For more details on identifying and managing animal pest problems, see Chapter 18—Vertebrate Pest Management.

Physiological or Genetic Damage. Some damage can be induced by the plant itself for no readily apparent reason. We refer to this type of damage as "physiological" or "genetic" in origin. Some sort of abiotic stress is believed to induce many of these problems but, as of yet, no definitive causes have been determined. Some examples include tissue proliferation at the soil line of the trunk of certain varieties of rhododendron, and **fasciation** (Figure 22), the flattened, ribbon-like growth found on a variety of woody landscape plants including willow, daphne, cherry, and maple. Burrknot, a condition where apple branch tissue starts producing roots, is also thought to be a physiological condition. Another example is certain horsechestnut trees that show severe leaf scorch during the summer while other trees nearby look healthy.

Figure 22. This Hinoki falsecypress exhibits the flattened growth known as fasciation on a twig. Subsequent growth is nearly normal. (Photo courtesy of Anton Baudoin, Virginia Polytechnic Institute and State University; Bugwood.org.)

Summary

After learning more about plant diseases and their diagnosis and management, you may notice a lot of plant damage you had not observed previously because now your eyes have been opened to the world of plant diseases and insect pests. Do not worry if your diagnostic batting average isn't as high as you'd like it to be at the beginning, or even in thirty years. The question "What caused the damage on this plant?" is a very big one to answer and one that can be complicated by the vast array of plants, diseases, pests, environments, and landscape practices. Do not be discouraged; plant problem diagnosis is something you can become successful at and enjoy doing. Remember, you will have many opportunities to improve your diagnostic skills.

Further Reading

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17

Weeds and Weed Management

Topics covered:

- Introduction
  - Definition
  - Weed Problems
  - Weed Sources
- Weed Attributes
  - Weed Competition
  - Weed Persistence
  - Weed Invasiveness
- Weed Identification
  - Weed Life Cycles
- Managing Weeds
  - Prevention
  - Mechanical Control
  - Cultural Control
  - Biological Control
  - Chemical Control
  - Integrated Weed Management
- Specific Herbicides

Learning Objectives

- Know the attributes that result in a plant being considered a weed
- Understand the biology of weed growth, development, and spread
- Know accepted methods of weed management for home yards and gardens

By

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"Both thorns and thistles the ground shall bring forth for you." Genesis 3:18.

"Many things grow in the garden that were never sowed there." Thomas Fuller, *Gnomologia*, 1732.

Introduction

Few would argue that weeds (such as the "thorns and thistles" above) have been a plague for humanity for a long time! In fact, ever since the advent of agriculture some 10,000 years ago, weeds have fought with, and often defeated, our treasured crop and landscape plants. This chapter will discuss where weeds come from, why they are so successful at what they do, and what gardeners can do about them.

Definition

Weeds are often defined as those plants that are growing where we don't want them to grow. Yet, this "plant out of place" definition doesn't tell the whole story. While it is true that a volunteer squash plant growing in your pea patch may very well be a "weed" because you would prefer it not grow there, it is also true that this situation doesn't take into account the fact that squash plants are not particularly "weedy"—that is, squash plants are not especially competitive, they do not tend to spread to new sites, nor do they tend to infest the same soil year after frustrating year. So a better definition of a weed would cite the biological attributes of the plant—those that make the plant weedy—in addition to the manner in which it is disagreeable to the gardener. A textbook weed would therefore be "a plant that is competitive, persistent, invasive, and interferes with human activities and is therefore undesirable."

Weed Problems

Weeds cause multiple problems for gardeners, farmers, and land managers. Weeds compete with plants we are trying to grow as crops or landscape plants and harbor plant-harming diseases and insects. Weeds also may attract and hide rodents that feed on our desirable plants. Weeds can reduce the aesthetic value of landscapes and the monetary value of real estate, and negatively affect native plant and animal communities in forests, rangelands, and streams. On roadsides, weeds obstruct sight lines and can shorten the life span of asphalt shoulders. In waterways, weeds can interfere with water drainage patterns, increase sedimentation, and increase the likelihood of streambank failure in times of high stream flow. Weeds can create a fire hazard in suburban forested locations, along rail and road ways, and in electrical substations. Finally, many weeds often present direct allergy or toxicity hazards for humans and livestock through skin contact, inhalation, or ingestion.

This is not to say that weeds are wholly without positive attributes. As Ralph Waldo Emerson observed, a weed is "a plant whose virtues have not yet been discovered." St. Johnswort, for example, was once simply a bad weed of rangelands throughout the West, but is now prized as an herbal antidepressant. Sometimes a weed's virtues are readily apparent. Many weed species are a delight to the eye, nose, or taste buds, and sometimes are planted purposefully for those uses. One need look no further than Scotch broom or purple loosestrife to find a beautiful ornamental that soon becomes too much of a good thing. A similar Jekyll-and-Hyde theme applies to plants such as white clover, which can be a good addition to pasture vegetation but also frequently infests lawns and attracts stinging insects to where barefoot children like to play.

St. Johnswort

Scotch broom

Weed Sources

Most problem weeds in North America are native to foreign regions where many of our common agricultural crops had their beginnings: in Europe and Asia. This shouldn't be a surprise. After all, as crops such as wheat, barley, oat, pea, beet, cabbage, and many others were brought by early settlers to North America, seed contaminants such as wild oat, common lambsquarters, and shepherd's-purse almost certainly were carried along and introduced at the same time, albeit not on purpose. These weeds found the plowed fields where the new crops were planted very much to their liking and promptly made themselves at home.

Japanese knotweed

For the most part, weedy species are problems outside their homeland. This is not to say that these plants weren't weedy in their native lands (they were and they still are), but there is a tendency for many species to be more aggressive in their new homes than where they came from. This is usually because plants in their homeland are generally surrounded by natural enemies—diseases or insects that attack the plant and keep the population in check. Another factor may be that since certain plants evolved under more severe conditions in their homeland than in their new location, the new environment is more conducive to their growth and spread. Consider the case of Japanese knotweed, which competes well with bamboo in its native environment and therefore is able to easily out-compete the native vegetation of western Washington. Sometimes these new plant species fill a previously empty niche in their introduced environment, such as was found and exploited by downy brome (cheatgrass) throughout the Intermountain West. Or perhaps it was a combination of these reasons, giving plants like yellow starthistle, kochia, or purple loosestrife the opportunity to establish themselves and dominate their new surroundings.

Weed Attributes

Although we may not always think in these terms when talking about plants, it is survival of the fittest in our lawns and gardens, and "the fittest" plants are often weeds. You'll remember that we defined weeds as plants that are competitive, persistent, invasive, and interfere with what we want to do with the land. Let's examine these attributes separately and see why weeds are so good at what they do.

Weed Competition

Whenever two plants grow close enough to each other to interact, competition occurs. Plants compete with each other for four things: light, water, nutrients, and space. Often it is the first plant on the scene that enjoys a competitive advantage in gaining the lion's share of these four resources. Because most garden soil is chock-full of weed seeds, usually the first plant emerging from disturbed soil is a weed. This pioneer plant occupies physical space (1), rapidly produces a root system to gather water (2) and nutrients (3) from the soil before another plant can do the same, and grows a leaf canopy to harvest light energy (4) while shading out other, smaller plants. The bigger a weed gets, the better it is at competing against other vegetation, and the more of these four resources it gets.

Keep in mind also that the longer two plants grow together, the more intense the competition becomes. Because weeds frequently emerge before vegetable plants do, early-season competition from weeds can slow crop growth appreciably. In fact, early-season competition may permanently reduce the yield capacity of those vegetables even if those weeds are removed later. Research has shown that if weeds are controlled early in a cropping system, crop plants grow larger early in the season and become increasingly better able to compete with late-germinating weeds and yield loss can be avoided.

Weed density can also play a role in competition. Two common lambsquarters plants are more competitive with carrot than is one common lambsquarters plant. In another example, one published report showed that as few as three white mustard plants per square foot can reduce green pea yield by 47%, and that situation is similar for other weed/crop interactions. Given that the number of weeds in garden soil commonly exceeds 100 seedlings per square foot, it becomes clear that weed densities are almost always high enough to severely restrict crop productivity. Such reductions can be exacerbated if more than one species of weed is competing with our crop at the same time, since different weeds may compete with crops in different ways. It may be that one redroot pigweed plant and one field pennycress plant growing with one broccoli plant may be worse for the crop than two pigweeds or two pennycresses with the same broccoli plant.

Another way weeds outcompete other plants is through **allelopathy**. This is the production or accumulation of certain compounds in the leaves, stems, or roots of certain plants that, upon release into the soil, inhibit the growth of surrounding vegetation. Most of these allelopathic chemicals affect all the plants growing at a particular site. Salt cedar plants, for example, exude excess salts on the surface of their leaves and this, over time, makes the underlying soil less suitable for new plant establishment, giving the established perennial an advantage against everything else that might challenge it. Other chemicals don't inhibit the growth of the plant species producing them but do slow the growth of most other plants, resulting in monotypic stands of single species. Spotted knapweed is one example of an allelopathic weed.

Spotted knapweed

Weed Persistence

Once a weed has established itself or gone to seed in a garden, it seems we have that weed (or its progeny) to deal with every year afterwards. What makes weeds so persistent? First, they are difficult to kill. They tend to break off in our hands if we try to pull them, growing back from small pieces of root or crowns left in the soil. They also produce lots of seeds, averaging tens of thousands per plant compared to only several hundred seeds produced by most crop plants.

Hairy nightshade

Unlike crop plants, weed seeds typically do not all germinate at the same time. Weed seeds tend to germinate only when conditions are right for establishment for that given species. So weeds that like warm temperatures, such as barnyardgrass or hairy nightshade, produce seeds that normally won't germinate until the days are long and soils are warm (late spring and summer). Compare this to seeds produced by shepherd's-purse, which tend to germinate in cooler soils that are usually prevalent when day lengths of less than 12 hours (fall and early spring). Most weed seeds also won't germinate unless they are exposed to some light, regardless of soil temperature. Such a germination response is important to prevent weed seeds from germinating when they are buried too deeply to allow their seedlings to emerge. It also allows weeds to respond quickly to disturbance of soil or vegetation which creates an empty space where the weed can thrive.

Most weed seeds also display a high level of dormancy, so that some weed seeds remain safely alive, but not germinating, even when conditions are right for germination. These dormant seeds allow the species to persist even if a late frost kills all the early-germinating seedlings. This also helps weed seedlings avoid your attempts to kill off the population by careful removal of the first flush of seedlings in the springtime. Dormant or buried weed seeds may survive for many years before they are brought to the surface by soil disturbance. Still, weed seeds are not immune to the ravages of time. Most weed seeds germinate or rot away within the first three or four years after they are produced, provided that conditions are adequate for germination. It is the last 0.5 to 1% of the total seed production that lies buried for 40 years or more, waiting for its chance to sneak in a crop of weeds and more seeds when your guard is down. Of course, if only 0.5% of the perhaps 20,000 seeds that a single weed can produce in a single year survives for 25 years, we're still talking about 100 seeds—not an inconsequential number of weed seedlings to deal with!

Seeds aren't the only way weeds can beat you. As many plants do, weeds also reproduce vegetatively through creeping roots, rhizomes, stolons, bulbs, or tubers. These vegetative reproductive structures contain a lot of stored sugars and starch that provide a young plant with much more energy than is available from most seeds. New shoots arising from a tuber or rhizome fragment, then, are able to emerge from a greater soil depth than a shoot from a seed ever could. Such shoots also usually grow faster and capture space (and the light, water, and nutrients within that space) much more quickly than will a typical weed or crop seedling.

Weed Invasiveness

Weeds simply don't stay where they first grow. By hook or by crook, they constantly spread to new ground. They do this primarily by means of seeds, many of which are well-suited for movement after they are mature. Some seeds (or the fruits that bear them) are covered with hooks, spines, or awns which attach to fur or feathers or clothing. Examples include burdock, catchweed bedstraw, and foxtail barley. Some seeds bear hairs or wings which allow them to blow with the wind; examples include dandelion, Canada thistle, and showy milkweed. Some are corky or hollow and extremely buoyant in water; one example is curly dock. Some are borne in tasty or colorful fruits that are consumed by animals and spread in their fecal material; examples include Himalayan blackberry, bittersweet nightshade, and English ivy. Such adaptations mean there will be no shortage of weed seeds in most yards and gardens waiting for their chance to sprout and establish in these new areas.

Weeds also spread vegetatively, not only by means of the reproductive structures mentioned above, but also by movement of the plants themselves. Mowers, vehicles, and cultivation equipment constantly dislodge and move plants from one place to another, often resulting in weed introductions into new areas. Animal bedding, bird seed, or hay bales may contain weed seed that either gets deposited on the ground or ingested or otherwise spread by the animal. People purposely introduce potential weed species for their beautiful foliage or sweet-smelling flowers, but are unaware of their weedy nature. Sometimes these introductions are accidental, through purchase of containerized plants growing in infested potting soil, weed rhizomes entwined in bare root ornamentals, or weed **propagules** in contaminated mulch, beauty bark, compost, or topsoil.

Weed Identification

The best way to control any weed species is to hit it at its weakest point. Therefore, you must know something about the weed in question: its biology, its habits, its strategies for success. In a real sense, the first step toward effective weed management is to identify which weeds you have. Once you know you are looking at common chickweed, for example, you know you are fighting a particular kind of weed with a certain life cycle and certain likes and dislikes. Often, weed identification can easily be accomplished by matching your unknown plant with photos published in reference books or websites.

The process of weed identification is easier if you know a little about the plant in the first place. Taxonomically, weeds (as with all other plants) are classified by what they look like: are they a monocot, dicot, or miscellaneous (moss, ferns, horsetails, etc.)? What plant family are they in, and what are the main family characteristics? Since common names can vary widely by their geographic distribution, knowing a weed's scientific name is necessary.

Why is knowing family characteristics important? Consider that there are approximately 250,000 plant species in the world. Of these, only about 3% (8000 species) of all plants are weedy in agriculture, while about 250 or 0.1% of the total are major problems in world agriculture. By knowing a few characteristics of an unidentified plant, we can often link a plant to its family—often removing 90% or more of known plants from the list of possible plants in one fell swoop. For example, plants that bear flowers with four petals and six stamens often belong to the mustard family (Brassicaceae), while plants with square stems and opposite leaves often are in the mint family (Lamiaceae). Since it is much easier to compare an unknown weed with plants from a given family, as opposed to all the weeds in a particular book, plant identification can be accomplished more quickly and accurately.

Mustard

Weed Life Cycles

Weeds, like garden plants, can also be classified by their life cycle: annuals, biennials, and perennials. Weed control strategies are often similar for weeds with the same life cycle, so knowing and applying this information can pay you off with some very practical benefits.

Annuals. Annual weeds progress from seed to seed in less than 12 months; indeed, some annual weeds may germinate and reproduce viable seed in as short as 45 days! The successful reproductive strategy employed by annuals is to produce lots of seed in as short amount of time as possible, then die and get out of the way for the coming generation. There are two major types of annuals: winter and summer.

Purslane

Winter annuals are typified by those species whose seed are programmed to germinate during times of cooling soil temperatures, increased soil moisture, and shorter day lengths—common conditions in the fall of the year. Resultant seedlings survive the winter and begin growth again as temperatures warm in late winter through early spring. Seedlings then flower and produce their seeds before soils begin to dry out in mid- to late-spring, often dying out very early in the year (sometimes as early as April or May in Washington). Winter annuals take advantage of relatively mild winters (with snowfall keeping them warm in many areas) and time their peak growth and reproduction to occur when the majority of our natural precipitation occurs—winter and early spring. Some common winter annuals include downy brome, field pennycress, and common groundsel in eastern Washington and common chickweed, annual bluegrass, little bittercress, shepherd's-purse, and pineappleweed throughout the state.

Annual bluegrass

Summer annuals are those plants whose seeds germinate when soils are moist, day lengths and soil temperatures are increasing, usually in the spring but sometimes not until early summer. Summer annuals take advantage of excellent conditions for growth early in the season and rapidly sink their roots deeply in the soil to maximize plant size and, in turn, total seed production. After setting seed in late summer to fall, most summer annuals die. Common summer annual weeds in Washington include barnyardgrass, crabgrass, the pigweeds, common lambsquarters, purslane, and hairy nightshade.

Little bittercress

Keep in mind that the distinction between winter and summer annual weeds is not hard and fast. Some species that are strictly summer annuals in Washington may be winter annuals in warmer climates. For example, wild mustard is generally a summer annual in the Columbia Basin, but in Tennessee, it is just as likely to be a winter annual.

Biennials. Biennial weeds take 12 to 24 months to progress from seed to seed. Seeds will germinate whenever favorable conditions occur during the first year, often in spring but sometimes after the onset of fall rains. Biennial weeds are strictly vegetative their first season, regardless of when seed germination occurred, usually forming tight rosettes of leaves. Cool and moist soil conditions coupled with short day lengths through the winter **vernalize** the biennials, predisposing them to flower during their second year. Vernalized rosettes make good use of the appreciable amount of energy (in the form of starches and sugars) they stored in their roots during their first year, and these second-year plants grow quickly. Following bolting, flowering, and seed production, biennials normally die. Biennials differ from winter annuals in that vernalization is required for biennials to flower, while winter annuals can flower without being vernalized, but reproduction in winter annuals is actually delayed by cold winter temperatures. Some common biennial weeds in Washington include wild carrot, bull thistle, poison hemlock, meadow salsify, and tansy ragwort.

Poison hemlock

Perennials. Perennial weeds live longer than two years and remain alive even after they produce seed. Some perennial weeds do not produce seed their first year (as mentioned above, some don't produce seed at all!), but most will produce seed each year of their life. As with other plants, perennial weeds are usually subdivided into two categories: woody and herbaceous.

Tansy ragwort

Woody perennials are species with above-ground structures that survive winter. Because these shoots are exposed to colder air than are roots, branches of woody perennials are made up of tough (woody) tissue and produce buds to protect tender meristematic tissue from being injured by winter temperatures. In the spring, buds break and new vegetative and reproductive growth emerges. Examples of woody perennials in Washington include Scotch broom, wild rose, and blackberry (note that blackberries produce biennial canes from a perennial root system).

Canada thistle

Like woody perennials, herbaceous perennials are weed species that grow from sometimes massive root systems. The roots of herbaceous perennials, however, produce flowering/fruiting shoots each year but, because they are cannot survive cold temperatures, they die back to the ground each winter. Some herbaceous perennial weeds in Washington are field bindweed, Canada thistle, dandelion, horsetail, quackgrass, and Japanese knotweed.

Perennial weeds can also be classified as to whether they are simple or creeping. Simple perennials spread primarily by seed, although they can produce multiple crowns on the same root. Simple perennials include dandelion, broadleaf plantain, curly dock, and spotted knapweed. Creeping perennials, on the other hand, spread vegetatively as well as by seed. Common creeping perennials are Canada thistle, horsetail, field bindweed, quackgrass, and creeping buttercup.

Broadleaf plantain

Managing Weeds

Since we will always have weeds to contend with, the wise gardener develops a strategy by which such plants can be managed and their adverse effects minimized. Whenever possible, these strategies should be considered before beginning a landscaping or other garden project, but it is a rare site indeed where weed control efforts won't be beneficial even if applied after weeds are already established. The following pages will categorize and describe several different management strategies which will aid in your struggle with weeds.

Prevention

The old saw about "an ounce of prevention being worth a pound of cure" is abundantly true with regard to weed management. And any good weed control program must begin with a positive identification of the plant(s) in question. Never be content letting a weed go unrecognized—if you don't know what it is, find out. Remember that a weed population is far, far easier to kill before it has had a chance to establish itself on a site. Even the worst weed infestations in Washington, from yellow starthistle on the rangelands to Scotch broom along the forest highways to field pennycress on the farms, probably began with the introduction of just a few individual plants. If control measures had been implemented at the time the species was first detected, it might have been eradicated and the infestation avoided altogether. Given our state's location at the edge of the continent, we no doubt receive introductions of many potential weed species on an annual basis. It pays to be vigilant! Who knows? You may prevent the next spotted knapweed invasion.

We are often our own worst enemies in regard to spread of weeds. While there is ample evidence that weedy plants get around very well on their own devices, people are very good at aiding them in their spread. A weed's travel is enhanced through movement of equipment and vehicles (think about that soil aerator you just rented or those weeds you ran over during your drive in the woods the other day); through contaminated seedlots, plant materials, mulch, or animal feed/bedding (think about that cut-rate lawn seed you bought or that bargain beauty bark you spread on your rhodies that turned out to be bristling with new horsetail shoots a month later); or simply because we don't know the whole story (think about that "cute" little ground cover in your friend's garden that you transplanted into your yard not realizing that it was trouble until it had overgrown your entire perennial landscape).

Preventing the spread of weeds is the concept behind noxious weed laws. **Noxious weeds** are non-native species declared by the state to be plants that cause harm to the state's agricultural, range, or forest lands, or roadsides or waters. The responsibility of controlling noxious weeds rests with the owner of the land on which the noxious weed is found. In Washington, the law has three tiers, or classes, of weeds: A, B, and C. Class A designations are for weeds with very small distributions. The goal is to eradicate these species before they become too widespread. Class B weed species may be locally abundant, but are not found throughout the state. Some counties, then, may choose not to require control of the species since nearly everyone already has it (Class B non-designate), but other counties may designate that species for control because they have no, or very small, local infestations (Class B designate). Another Class B designate might be a weed that may cause severe local harm if left to grow unchecked. Wild carrot, for example, is a Class B weed in Washington primarily because, if growing close to carrots being grown as a vegetable seed crop, it may cross-pollinate with the carrot crop, rendering the resultant seed useless as a vegetable seed. To avoid such losses, it is listed a Class B designate in counties producing carrots or carrot seed but Class B non-designate elsewhere. Finally, Class C weeds are those that may or may not be widespread in the state, but are a priority for certain counties county to control.

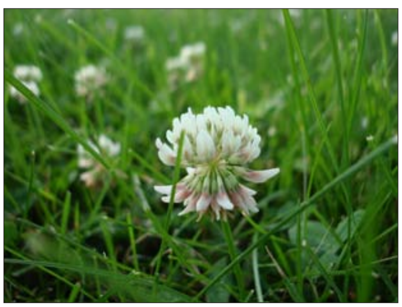
One other designation of importance is the plant quarantine list. Quarantined species are particular noxious weeds that are usually ornamental; that is, they may bear bright foliage or produce attractive flowers that would entice many people to plant them in their landscape. Once planted, they almost invariably escape to become new noxious weed infestations. In Washington, it is illegal to move, buy, sell, or offer to sell a species on the quarantine list. More information on the Washington State Quarantine List is at http://www.nwcb.wa.gov/weed_laws/quarantine_overview.htm. The noxious weed list for Washington State is at http://www.nwcb.wa.gov/weed_list/weed_list.htm.

Mechanical Control

Mechanical weed control is physically doing something to an individual weed in order to kill it (this method is also, logically, referred to as “physical weed control”). Cultivation is the most common method of mechanical weed control, typically hand-pulling, hoeing, or rototilling. These methods uproot the weeds, causing them to dry out and, hopefully, die. Cultivation, therefore, is more effective on dry days than on rainy days; plants left on moist soil surfaces are more likely to re-root than plants left on a dry soil surface. In the same way, warm, sunny days are better for hand-weeding than cool, overcast days. Further, it is advisable to weed early in the day so uprooted weeds are exposed to maximal water stress during the heat of the day rather than weeding in the evening, which provides freshly-uprooted plants time to recover during nighttime hours when cooler, darker, and more humid conditions prevail. Too, the smaller the individual weed, the more susceptible it is to mechanical weed control. It is the seedling in the cotyledon stage of growth that is most vulnerable to cultivation, because older plants have substantial stored energy and water in leaves, stems, and roots which allow that plant to re-root or re-grow from a root or crown fragment. Keep in mind, too, that while soil disturbance may kill the emerged weed, it also brings new weed seeds to the soil surface where they can then germinate and leave you as weedy as where you were before. So be careful not to hoe too deeply!

Controlling established perennial species using mechanical weed control methods is tough, especially controlling those perennials with vegetative reproductive structures. Because such perennials generally have considerable stored energy in their roots, they are able to recover from considerable injury, even total defoliation. Perennial roots must expend substantial energy to accomplish that re-growth, however, and unless they are able to replace that energy through photosynthesis, carbohydrate reserves in those roots can be depleted to the point of root death. Since shoots continue to use the stored energy from their roots up until the time when the first leaves have fully expanded, mechanical control efforts should be timed to coincide with that stage of re-growth, maximizing the stress on those perennial roots. Certain perennials, such as Canada thistle and field horsetail, are actually quite sensitive to defoliation, provided that all shoots are removed whenever they become photosynthetically self-sufficient. This requires persistence on the part of the gardener—occasionally hand pulling a few shoots over the course of a summer won't do the trick.

Rototilling cuts weed roots and foliage into small pieces and buries them. This usually results in excellent control of most small annual and biennial weeds. Unfortunately, perennial weeds with vegetative reproductive structures greatly benefit from rototilling, since cutting their rhizomes or roots into small pieces creates a massive number of new shoots for you to contend with a week or two later. Bulbs and tubers can also be scattered from the mother plant to new sites through the tillage operation. Unless employed frequently, then, rototilling established perennial weeds is not advisable.



White clover

Mowing is another method of mechanical weed control. It is most often used in turf, but can also be used along roadsides, bare areas, or under trees. While most weeds re-grow after mowing, seed production can be drastically reduced by timely removal of top growth. Annuals in particular tend to be susceptible to mowing through the summer, since they can't produce seed if flower stalks are continually mowed and the plant will usually die during the winter. Exceptions are those weeds with a prostrate growth habit (such as prostrate knotweed or puncturevine), since most of their foliage is found below the blade of a lawn mower. It is especially doubtful that low-growing perennials (such as white clover, creeping buttercup, dandelion, or many of the speedwell species) sustain much damage from mowing.

Dandelion

Another mechanical method of weed control is the use of mulches. Mulches function by depriving light from either the young weed or non-germinated seed, and usually consist of gravel, pumice, bark, or wood chips. Mulches have the added benefit of slowing water loss from soil, which helps keep the soil cool and moist during hot summer months. These products are best spread thinly, prior to weed seed germination, usually around the bases of woody landscape plants. If applied too thickly, mulches reduce gas exchange with the soil which can injure shallowly-rooted perennials such as rhododendron. In cool maritime climates particularly, mulches also may result in soils that are excessively cool and wet, increasing the incidence and severity of root or crown diseases in desirable vegetation.

Mulches in vegetable gardens also improve weed control and, if used with drip irrigation, increase water use efficiency. Typically, black plastic is used to prevent light transmission to weeds that would otherwise grow beneath the plastic. To use the mulch, first work the soil into a good seed bed and then lay out drip tape where you will be placing the vegetable plants. Then lay out the sheeting and anchor along the sides and on the ends. Cut slits or holes through the mulch and plant the vegetable seedlings.

Quackgrass

If placed before weed seeds germinate, control of annual weeds with black plastic is nearly excellent. Control of established perennials varies, depending on mulch thickness and the ability of weeds to “punch” through the mulch. Plants with sharp-tipped rhizomes, such as quackgrass or yellow nutsedge, will be more successful at getting through the plastic than creeping perennials not so well-equipped, such as Canada thistle, field horsetail, and field bindweed.

In warmer regions of Washington, clear plastic may be used for soil solarization, which heats the soil. This may be helpful to reduce populations of soil pathogens, insects, and even the vegetative reproductive structures and seeds of certain weed species. In cooler regions, however, clear plastic simply provides weeds with a nice warm place in which to grow and so is not recommended.

Cultural Control

Cultural methods of weed control manage the level of competition between desired plants and weeds. The idea is to make conditions as favorable as possible for shrubs, turf, or vegetables while making things as difficult as possible for the weeds. The result will be that desirable plants are made more competitive and their growth and development will therefore be favored over the weeds. Gardeners can achieve this in a number of ways. First, be sure your desirable vegetation is as healthy as it can be—whether we’re talking about landscape plants, turf, or vegetables. Choose plants that are well-adapted to their environment, fertilize and irrigate them properly, mow lawns to keep their growth vigorous, and prevent outbreaks of diseases or insects which decrease overall plant health and competitive ability.

A second means of employing cultural weed control is to use transplants when possible. Remember that weeds compete with desirable plants for physical space, and space capture usually goes to the first plant that shows up to occupy it. Often that first plant is a weed, and often that weed emerges several days sooner than does our carefully planted crop seed. Weed seedlings often also grow faster than crop seedlings, which results in dominance of the soil by weeds. When gardeners use transplants, space capture usually goes to the crop plant, and since transplants usually grow faster than younger weed seedlings, the competitive ability of the crop is improved at the expense of the weed.


Chickweed, close-up

Another trick gardeners can use to improve weed control culturally is to practice crop rotations. Weeds often will do best when growing with crop plants that share similar life cycles and growing conditions. For example, when hardy vegetables such as lettuce, spinach, or peas are seeded in late winter or early spring, early germinating weed species (usually winter annuals such as common chickweed, shepherd's-purse, and field pennycress) tend to dominate the weed spectrum because these species prefer cool soils. In fact, seeds of later germinating weed species (such as barnyardgrass or purslane) may not even get an opportunity to germinate, since the crop plants and winter annuals have already captured the space and are providing shade to the soil surface and making conditions unfavorable for further seed germination. Conversely, when non-hardy vegetables such as squash, sweet corn, or beans are seeded in late-spring to early-summer, late germinating weed species (such as redroot pigweed or green foxtail) tend to dominate because the weeds that germinated prior to crop seeding are killed by the cultivation of seedbed preparation, leaving the site open for colonization when the soil is warm. Weeds also tend to "hide" in the foliage of similar-appearing plants. Hairy nightshade is notorious for growing amongst closely-related and visually similar tomatoes and potatoes, making the nightshade hard to see and remove until after it has already flowered and set seed. For these reasons, it's a good idea to rotate your vegetables with an eye toward their life cycle to avoid continuously selecting for particular weed species.

Winter cover crops can also be used to aid in weed control. Planting winter hardy, densely-growing crops in the fall allows them to capture space in your garden and reduce the amount of weed growth compared with bare soil. This is particularly true in central and eastern Washington, where winters are cold enough to slow the growth of, or even kill, weeds that germinated at the same time as the cover crop. In western Washington, weed control resulting from cover cropping will usually not be as great as in other parts of the state, although nutrient capture and improved organic matter production remain as two important benefits to cover cropping. However, mustard cover crops have been shown to significantly reduce weed growth by springtime, due primarily to production of large leaves and thorough ground coverage by that crop. Disadvantages of cover cropping include delayed crop seeding in the spring (cover crops must be incorporated into the soil and have time for initial breakdown of foliage), hindered crop seed germination from allelopathic or biofumigant qualities of the cover crop, and increased pest insects or slugs which may benefit from the cover provided.

Ground covers can often be used to good effect—both aesthetically and as a tool against weeds. Good ground covers do exactly that: they cover the ground and don't allow light to reach the soil surface, thereby limiting the germination of most weedy species. Ground covers also compete well with weed seedlings, making them less likely to establish and reproduce themselves. The biggest concern about ground covers may be that they could become weedy in their own right. Be sure to thoroughly investigate unproven ground covers to see if they are weedy elsewhere in the United States or in similar climates throughout the world before using or recommending them for planting.

Biological Control

Biological weed control, or biocontrol, uses an organism to act on or control a weed species. The classic use of biological control organisms is against non-native weeds of range and forest lands—usually after that weed has infested thousands of acres and other methods of weed control won't be cost-effective. Recall that most weed species are not native to where they are weedy, due, in part, to lack of damaging insects or diseases in their new habitat that might slow their spread. Entomologists and plant pathologists, then, travel to a weed's country of origin to identify insects and disease pathogens that are detrimental to the health of that weed species and prevent it from dominating its native land. These organisms are then tested in greenhouses to determine whether they will exclusively feed on or infect our out-of-control weed, and whether they damage any closely-related crops or native plant species. Suitable organisms are then released with the hope they will at least slow the spread of some particularly nasty noxious weed species. Biological control organisms can be particularly helpful in the management of noxious weeds where other types of weed control may not be feasible, such as in sensitive wetlands or sites inaccessible to sprayers or cultivation equipment.

Grazing animals can also be used for weed control. Goats preferentially graze broadleaf plants and often are less affected by plant toxins that may injure horses or cattle, so they have been used to selectively remove range weeds such as leafy spurge or tansy ragwort. "Weeder geese" have also been used to forage for grassy weeds in perennial plantings or broadleaf row crops. In cases such as these, careful management is necessary to ensure that the animals don't cause damage to the desirable vegetation.

In general, biological weed control has less to offer backyard gardeners than other methods of weed control. First, biocontrol does not normally result in complete weed control. Because they are living entities, biocontrol organisms require a low level of the weed be maintained to provide food for their progeny; such a population of these weed species would not be acceptable in most urban or suburban sites. Second, most backyard weed species don't have biocontrol agents available for their control, and, most gardeners don't have the weeds for which biocontrol agents have been developed. Finally, having goats, geese, or the like grazing in their backyard is not something that a typical homeowner can legally do even if they wanted to, and the likelihood that such grazing animals would cause damage to horticultural species is high. Still, gardeners with larger tracts of land may find biological control helpful.

Chemical Control

Chemical weed control involves the use of herbicides to disrupt certain plant functions, thereby killing the treated plant. While many herbicides are registered for commercial use in various agricultural, horticultural, and non-crop situations, homeowners have access to only a fraction of these products. As with any chemical, gardeners using herbicides should use care in the mixing and application process to prevent accidental exposure to themselves or others, and to avoid injury to desirable vegetation.

Herbicide types

Herbicides are usually one of two types: contact products or translocating products. **Contact herbicides** are applied directly to weed foliage and result in leaf/shoot kill or damage. Once absorbed, contact herbicides do not move around inside the plant, for example, from the leaves to the roots. Consequently, control of established perennial weeds with contact herbicides requires many applications, since these weeds have a large mass of roots from which new shoots replace those killed by the herbicide. If all shoots are removed as they appear, the perennial root will eventually run out of energy and die, similar to what would result from constantly cutting off shoots with a hoe. Because of that large root mass, control of larger annuals or biennials is especially difficult when using contact herbicides. These products should be applied to adequately cover as much of the shoot as possible, but not so much that it runs off the plant leaf (although contact herbicides generally have very limited soil activity, if any). Examples of home and garden contact herbicides include diquat, glufosinate, or oxyfluorfen, potassium salts of fatty acids, and acetic acid (vinegar).

Translocating herbicides are absorbed into the plant and then move, for example, from roots to leaves, from leaves to roots, or from leaves to other sites of meristematic activity. Such products, then, are either designed to be applied to soil (usually before weeds emerge from the ground or **preemergence**), or to the foliage of emerged weeds (**postemergence**). Some common home and garden soil-applied products include diclobenil, trifluralin, and oryzalin; foliar-applied products include 2,4-D, MCPA or MCPP, dicamba, triclopyr, and glyphosate.

Another category to consider for herbicides is whether the product is selective or non-selective. **Selective herbicides** provide control of certain weeds but don't damage other vegetation. An example of a selective herbicide is 2,4-D, which selectively kills broadleaf weeds in turf while not injuring the grass. Most herbicides labeled for use by homeowners are selective products. Alternatively, **non-selective herbicides** damage plants of all kinds. Some are contact products such as diquat; others are translocating like glyphosate (Roundup). These products must be applied with great care to avoid unintentionally spraying foliage of desirable vegetation.

Foliar-applied herbicides, typically, are liquid formulations. They are available either as pre-mixed (ready-to-use or RTU) sprays, or concentrates that must be mixed with water before application. Read and follow the product label directions to determine how much concentrate you should add to a given amount of water, and how and when to apply the specific mixture.

Soil-applied products are available to homeowners typically as granular products. Most are very volatile and placement on clay or finely ground materials helps to stabilize the active ingredient and keeps it from evaporating immediately after application, as can happen with liquid sprays. Granules are made to be applied *dry* to the soil, then incorporated using tillage equipment, or by irrigation or rainfall.

Weed-and-feed products are fertilizers that have been mixed with broadleaf herbicides such as 2,4-D or dicamba. Weed-and-feeds are formulated to be applied just like any commercial fertilizer blend—preferably using a drop-type spreader rather than a cyclone-type spreader which may fling the product into places you don't want it to go. Some weed-and-feed products are designed to be spread using a hose-end applicator. Be very careful not to over-apply weed-and-feeds! Calibrate your spreader based on the herbicide content of the mix, not its nitrogen content. (Refer to Chapter 5: Plant Mineral Nutrition, for instructions on how to calibrate a spreader.) Also, be cautious applying these products near desirable broadleaf vegetation, as desirable plants may be injured by the herbicide in the mix.

Grocery store vinegar is not labeled for use as an herbicide and may not be recommended as such.

Organic-style herbicides. Two organic-style herbicides may have caught your attention over the years. The first is acetic acid, which can also called vinegar in some situations. Let's take a minute to talk about when it's called vinegar and when it's called acetic acid to avoid any later confusion. The chemical name is acetic acid, but EPA and FDA call it vinegar when the concentration is below 8%. This is what you buy in the grocery store for cooking purposes. When the concentration is above 8% it's called acetic acid and this higher concentration is what is used as an herbicide. The distinction is important for several reasons. Grocery store vinegars are not registered pesticides so you can't recommend their use as such. Acetic acid products are sold in several strengths. Research shows that 5% acetic acid concentrations are not strong enough to be very effective as a foliar herbicide but when used as a drench will perform a little better. Control is best when the acetic acid product is applied to weeds from cotyledon stage to 2 or 3 leaves. For treatment areas having a large number of weeds, the cost of drenches may be excessive when compared to other registered herbicides.

The second organic herbicide commonly available to homeowners is corn gluten meal (CGM). CGM is the protein fraction of grain corn that remains after the carbohydrates are extracted. It is usually ground fine (similar to corn meal) and applied as a granular product, chiefly to turf and in vegetable gardens. In the laboratory, CGM reduces elongation of the roots from germinating seeds of many species, resulting in weed seedlings that are less able to withstand periods of drought. CGM therefore has no ability to control established weeds, only germinating seeds. Unfortunately, CGM has not been shown to be particularly effective at killing weed seedlings in the field, even when applied at high rates. In studies conducted in western Washington, CGM has not provided enough weed control, even of annual species, to be properly considered a herbicide. In turf, it is suspected that any weed control associated with use of this product is probably related more to improved fertility and resulting turf competitiveness (CGM is 10 to 12% nitrogen) than to any direct herbicidal effect by the product: release of nitrogen by CGM causes grass plants to grow more luxuriantly and to compete better with annual weeds. Consequently, corn gluten meal is not currently recommended by Washington State University for weed control.

Corn gluten meal is not currently recommended by Washington State University for weed control.

Mixing and applying herbicides

Always read and follow label directions for any chemicals.

When mixing liquid herbicide concentrates, follow these steps:

(1) Add approximately half the water to the spray tank,

(2) add the measured amount of concentrate to the spray tank,

(3) add the rest of the water to the spray tank,

(4) put the lid on the spray tank, and shake vigorously to fully mix the product,

(5) pressurize the tank, and

(6) apply the herbicide.

Liquid, foliar-applied products usually require about six hours of contact time to fully move into plant tissues. Avoid spraying during wet weather—spraying wet foliage results in runoff of the herbicide, while rainfall shortly after application washes the herbicide from the plant. Most herbicides also are bound up by soil and organic matter, so weeds that are dusty or crusted with dried mud will not be fully controlled. Consequently, foliar-applied liquid sprays work best when applied to clean, dry weeds that are actively growing.

The potential for drift of herbicide sprays should always be kept in mind. There are two kinds of drift: physical drift and vapor drift. **Physical drift** occurs when the mist from a liquid herbicide application doesn't land where you wanted to apply the product. This is most likely to occur if you are spraying when winds are over about seven miles per hour, or in very calm (inversion) conditions when small droplets may linger in the air for several minutes or even hours. Inversions frequently occur during early morning hours, and often about sunset. Under inversion conditions, occasional breaths of wind may move these suspended droplets quite a distance from where you sprayed the product. If these droplets move to a susceptible species, that plant can be injured. **Vapor drift** occurs when environmental conditions cause the applied herbicide to volatilize or evaporate from either the vegetation or soil surface. Vapor drift is maximized when a volatile herbicide is sprayed during humid conditions, followed by bright sun and warm temperatures. Spraying when soil is saturated with water also tends to cause more vapor drift than spraying when the soil surface is dry.

There are several things you can do to minimize drift. First, don't apply herbicides when winds are greater than seven miles per hour, or when the air is very still. A light breeze is usually better than no wind at all, since the spray droplets more quickly disperse and evaporate in a breeze than during dead calm conditions. Second, do not use too fine a mist because the smallest droplets are more prone to floating off-target. Instead, use a coarser spray at lower pressure to reduce the formation of these small droplets. Finally, don't spray wet soils, or when the day is supposed to get hot.

Calibrate your spreader based on the herbicide content of the mix, not its nitrogen content.

For soil-applied products, it is important to obtain an even distribution when applying granules so the herbicide isn't over-applied in some spots (potentially causing injury to nearby ornamentals) and under-applied in others (resulting in lack of weed control). Be especially careful during windy conditions, as granules are usually quite light and may blow to where you don't want them! Do NOT mix granular products with water and attempt to spray them!

Most soil-applied products need to be applied before seed germination occurs, because most kill weeds by inhibiting the germination process and by preventing normal seedling growth. When optimally applied, an herbicide will kill susceptible weeds before they even have a chance to emerge from the soil. If the site has weeds that have already emerged, these will first have to be removed via shallow tillage, hand weeding, or a postemergence herbicide.

To maximize a preemergence herbicide's effectiveness, place the herbicide near the germinating seed. Since most weed seeds germinate in the top inch or two of soil, this is where the herbicide should be placed. If the herbicide is placed too shallowly, seeds germinating below the herbicide zone will have normal roots and the plants may not absorb enough herbicide through their shoots to kill them. Conversely, if the herbicide is placed too deeply, the herbicide may become diluted to the point where a plant does not absorb a lethal dose.

In addition to getting the herbicide next to the weed seed, most granular products require incorporation into the soil to prevent the loss of volatile components. Incorporation is usually easiest using irrigation or rainfall. Most granular products work best if incorporated to a depth of two to three inches, which requires about one inch of rainfall or irrigation. If rainfall is spotty, successful incorporation can occur over several days—as long as conditions remain cool and moist. If only light rain is received and temperatures begin to warm, it's a good idea to finish the incorporation using a sprinkler. If applying the granules to the bare ground around newly-planted ornamentals, a rototiller or garden rake may be used. First apply the proper rate of granular product (according to label directions), then till to a depth of about six inches. This will mix most of the granules to a depth of about three inches. If rainfall is not expected within a few days after incorporation and soils are not particularly moist, it may be necessary to irrigate to fully activate the herbicide before many weed seedlings begin to emerge from the soil.

With the exception of dichlobenil or Casoron (which does a good job of controlling many herbaceous perennial weeds), the best most granular products will do is suppress established perennials, not kill them. If you have lots of perennial weeds, you might wish to consider other products.

In order to be successful, herbicide applications should coincide with the time when the weed is the weakest or most susceptible to the herbicide's action. All seedlings are easiest to control shortly after germination because very young plants have scant energy reserves available for growth and development. It is not until a plant gets older and begins to produce leaves that it becomes able to make all its own food via photosynthesis. As the seedling continues to grow, it is increasingly able to survive any type of control methods used against it. Consequently, control of seedling weeds using herbicides is best accomplished with soil-applied products used before weeds emerge from the soil, or with foliar-applied products used soon after emergence.

Control of second-year biennials and established perennial weeds generally requires treatment with a foliar-active herbicide that translocates from shoots to roots. After application to leaves, this type of herbicide moves within the plant to kill growing points both above and under ground, reducing the weed's ability to re-sprout. However, a single herbicide treatment will not generally result in complete perennial weed control. Repeat applications are nearly always necessary to rid a site of established weeds.

Regardless of what type of herbicide you choose, be very careful to apply the proper amount of herbicide to the site! Poor weed control will result from an under-application, and injury to desirable vegetation may result from an over-application. Too, if certain types of herbicides are over-applied, the herbicide can "carryover" in the soil much longer than normal, with the potential for injuring seeds or transplants long after the application. Applying too much product can also increase the risk of off-site movement of the herbicide, either through storm or irrigation runoff or in water percolating through the ground. Finally, because over-application of herbicide does not control weeds any better than the labeled rate (after all, dead is dead), it ends up wasting your money.

Over-application of herbicide does not control weeds any better than the labeled rate.

Personal Safety

You can minimize exposure of people to herbicides in several ways. Wear protective clothing (long sleeves and long pants) and eye protection when mixing and applying herbicides. Granular products are normally watered-in, so direct exposure to these herbicides after application is minimal. Exposure to liquid herbicide sprays can be minimized by keeping pets and people away from treated areas until sprays have dried. On a warm sunny day this usually takes about an hour. Remember that herbicides, as well as any other pesticides, should be stored out of the reach of children and pets and should be kept in their original containers.

Integrated weed management

Integrated weed management involves combining two or more methods of weed control in an effort to more effectively manage the weeds in our lawns, landscapes, or gardens. These combined strategies should be employed in such a way as to target the weed when it is most susceptible to being controlled by each particular strategy. A three-part integrated weed management plan for a larger vegetable garden infested with winter annual weeds might be formulated as follows:

(1) Till the garden in the spring (mechanical weed control).

(2) Wait three weeks for weed seeds brought to the surface to germinate, then spray the area with an approved weed killer (chemical weed control).

(3) Transplant vegetable seedlings three days after spraying (cultural weed control).

This plan is one of a myriad of "stale seedbed" programs that could be designed. Note that in the plan above you could kill the emerged weeds using shallow tillage or flame instead of herbicide if you prefer, or follow the initial weed germination period with repeated tillage and a second waiting period to more thoroughly exhaust the supply of weed seeds. The point is to tailor the weed control program to the site by implementing strategies that control the weed species present without causing damage to other vegetation. Keep in mind that overall management objectives, soil type, temperatures, and precipitation patterns may all influence the selection and suitability of a particular strategy.

Common groundsel

Creeping buttercup

It is very important to keep weed management goals realistic! Most of us tend to overestimate the effectiveness of any weed control program, while at the same time underestimating the amount of labor generally required to make that program effective. Nowhere is this more true than with herbicides. It will help to realize that herbicides are simply a tool that can help to provide weed control, and to avoid thinking that they are a "silver bullet." Full weed control almost always requires a site be treated more than once and usually in combination with a large dose of elbow grease. Expect, too, that sometimes certain weed species are just darn hard to kill with the products available (consider speedwell or creeping buttercup in turf). We also tend to think that mechanical control alone will solve all our weed problems, and we fail to correctly estimate how many hours that really takes to control species such as Canada thistle or field horsetail or common groundsel—one or two times of weeding in the spring will not do the trick.

Finally, it is also important not to give up the cause before the battle is truly over. Remember that weed problems do not crop up overnight—neither will they be solved immediately. But they can be solved. Armed with a sensible plan, proper tools, and a large helping of persistence coupled with a good attitude, anyone can effectively manage weeds in nearly every situation.

Specific Herbicides

Here is some more information about particular herbicides that may be found in homeowner formulations (chemical names are given to help cross-reference the herbicide with the label on the product, regardless of the trade name or product manufacturer). More information, including toxicology information sheets, can be found on the Extension Toxicology Network at http://pmep.cce.cornell.edu/profiles/extoxnet/index.html or at http://www.epa.gov/iris/index.html.

1. Preemergence, soil-applied materials (kills both grasses and broadleaf plants).

Dichlobenil (2,6-dichlorobenzonitrile), granular. Available for control of many weed species including annual broadleaf plants, grasses, and rhizomatous perennials such as Canada thistle, horsetail, and quackgrass. Do not use this product in areas where you want to transplant annuals or seed other plants, whether annual or perennial. Apply diclobenil only to established woody perennial ornamentals when they are dormant (winter to early spring). The chemical is volatile, and poorer weed control will result if applied during warm temperatures. For optimal weed control, apply immediately prior to rainfall, or cover target plants with a thick bark mulch after application and then irrigate. If the site has weeds that have already emerged, remove these first using shallow tillage, hand weeding, or another type of herbicide.

Oryzalin (4-(dipropylamino)-3,5-dinitrobenzenesulfonamide), hose-end sprayer. Available for control of many annual grasses and broadleaf weeds, including common chickweed, common lambsquarters, redroot pigweed, shepherd's-purse, and annual bluegrass. Oryzalin is generally safe for all established perennial ornamentals, so similarly, it will not kill established perennial weeds. Do not use this product in areas where you want to transplant annuals or seed other plants, whether annual or perennial. Apply oryzalin to dormant perennial beds in late fall or early spring. The chemical is volatile, and poorer weed control will result if applied during warm temperatures. The chemical should be incorporated by rainfall or irrigation immediately after a surface application, or may be incorporated in the top 2 to 3 inches in the soil using a rototiller. If the site has weeds that have already emerged, remove these first using shallow tillage, hand weeding, or another type of herbicide.

Oxyfluorfen (2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl) benzene), liquid pre-mixed with glyphosate (see glyphosate). Available for control of many annual broadleaf weeds such as annual sowthistle, common lambsquarters, shepherd's-purse, and common groundsel. Do not use this product in areas where you want to transplant annuals or seed other plants, whether annual or perennial. Used by itself, oxyfluorfen has some postemergence activity, but it is best applied preemergence to weeds. When it comes pre-mixed with glyphosate, however, this herbicide blend should be applied after the weeds are up and growing. Oxyfluorfen will then provide some residual weed control to the spray (glyphosate has no residual). Remember also, because it is pre-mixed with glyphosate, the herbicide blend is non-selective.

Trifluralin (2,6-dinitro-*N*,*N*-dipropyl-4-(trifluoromethyl) benzenamine), granular. Available for control of many annual grass and broadleaf species such as annual bluegrass, barnyardgrass, common chickweed, henbit, common lambsquarters, and redroot pigweed. Do not use this product in areas where you want to transplant annuals or seed other plants, whether annual or perennial. Apply trifluralin granules to established perennials at any time of year, but before weed seeds germinate. Trifluralin will not control existing weeds; these must be either removed manually or mechanically, or by using a different herbicide. Incorporate with irrigation, rainfall, or light tillage (if possible).

2. Postemergence, selective materials.

A. Kills broadleaves only.

2,4-D ((2,4-dichlorophenoxy)acetic acid), liquid or granular; usually pre-mixed with dicamba, mecoprop, or MCPA (see those herbicides). Available for control of many annual and perennial broadleaf weeds such as annual sowthistle, common lambsquarters, shepherd's-purse, redroot pigweed, common groundsel, and various thistles, knapweeds, hawkweeds, and docks/smartweeds/knotweeds. Do not use this product in areas where you want to transplant annuals or seed other plants, whether annual or perennial. Apply to lawns, bare ground, or weeds growing in pastures. Be careful when applying near trees or other broadleaf ornamentals, as 2,4-D may injure them. Treat re-growth as necessary.

Dicamba (3,6-dichloro-2-methoxybenzoic acid), liquid or granular; usually pre-mixed with 2,4-D, mecoprop, or MCPA (see those herbicides). Available for control of many annual and perennial broadleaf weeds such as annual sowthistle, common lambsquarters, shepherd's-purse, redroot pigweed, tansy ragwort, and various thistles, knapweeds, hawkweeds, and docks/smartweeds/knotweeds. Do not use this product in areas where you want to transplant annuals or seed other plants, whether annual or perennial. Apply to lawns, bare ground, or weeds growing in pastures. Be careful when apply-

Henbit

ing near trees or other broadleaf ornamentals, as dicamba may injure them. Treat re-growth as necessary.

Dichlorprop ((±)-2-(2,4-dichlorophenoxy) propanoic acid), liquid or granular; usually pre-mixed with 2,4-D or mecoprop (see those herbicides). Available for control of many annual and perennial broadleaf weeds such as annual sowthistle, common lambsquarters, shepherd's-purse, redroot pigweed, common groundsel, and various thistles, knapweeds, hawkweeds, and docks/smartweeds/knotweeds. Do not use this product in areas where you want to transplant annuals or seed other plants, whether annual or perennial. Apply to lawns, bare ground, or weeds growing in pastures. Be careful when applying near trees or other broadleaf ornamentals, as dichlorprop may injure them. Treat re-growth as necessary.

MCPA ((4-chloro-2-methylphenoxy)acetic acid), liquid or granular; usually pre-mixed with 2,4-D, dicamba, or mecoprop (see those herbicides). Available for control of many annual and perennial broadleaf weeds such as annual sowthistle, common lambsquarters, shepherd's-purse, redroot pigweed, common groundsel, and various thistles, knapweeds, hawkweeds, and docks/smartweeds/knotweeds. Do not use this product in areas where you want to transplant annuals or seed other plants, whether annual or perennial. Apply to lawns, bare ground, or weeds growing in pastures. Be careful when applying near trees or other broadleaf ornamentals, as MCPA may injure them. Treat re-growth as necessary.

Mecoprop ((±)-2-(4-chloro-2-methylphenoxy)propanoic acid), liquid or granular; usually pre-mixed with 2,4-D, dicamba, or MCPA (see those herbicides). Available for control of many annual and perennial broadleaf weeds such as annual sowthistle, common lambsquarters, shepherd's-purse, redroot pigweed, common groundsel, and various thistles, knapweeds, hawkweeds, and docks/smartweeds/knotweeds. Do not use this product in areas where you want to transplant annuals or seed other plants, whether annual or perennial. Apply to lawns, bare ground, or weeds growing in pastures. Be careful when applying near trees or other broadleaf ornamentals, as mecoprop may injure them. Treat re-growth as necessary.

Oxyfluorfen (2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl) benzene), liquid; pre-mixed with glyphosate (see glyphosate). Available for control of many annual broadleaf weeds such as annual sowthistle, common lambsquarters, shepherd's-purse, and common groundsel. Do not use this product in areas where you want to transplant annuals or seed other plants, whether annual or perennial. Used by itself, oxyfluorfen has some postemergence activity, but it is best applied preemergence to weeds. When it comes pre-mixed with glyphosate, however, this herbicide blend should be applied after weeds are up and growing. Oxyfluorfen will then provide some residual weed control to the spray (glyphosate has no residual). Remember also, because it is pre-mixed with glyphosate, the herbicide blend is non-selective.

Triclopyr ([(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid), liquid; alone or mixed with 2,4-D (see 2,4-D). Available for control of many annual and perennial broadleaf weeds such as annual sowthistle, common lambsquarters, shepherd's-purse, redroot pigweed, tansy ragwort, blackberry, and various thistles, knapweeds, hawkweeds, and docks/smartweeds/knotweeds. Do not use this product in areas where you want to transplant annuals or seed other plants, whether annual or perennial. Apply postemergence to weeds growing in pastures or around trees, usually in early summer or late fall. If using the pre-mixed triclopyr + 2,4-D product, be careful when applying near conifers, as 2,4-D may injure those trees. When spraying perennial weeds, allow weeds to reach a height of at least 6 to 10 inches before application. Treat re-growth as necessary.

B. Kills grasses only.

Fluazifop ((±)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy] propanoic acid), liquid; alone or pre-mixed with diquat (see diquat). Available for control of many annual grass weeds. Do not use to control weedy grasses in lawns because injury to turfgrasses may occur. Control of most perennial grass species will require multiple applications. Do not use fluazifop in areas to be seeded to turf or other grasses. Apply postemergence to actively growing grasses in and around broadleaf ornamentals. If using the pre-mix formulation of fluazifop + diquat, remember that the herbicide blend is non-selective and broadleaf vegetation can be severely injured.

Sethoxydim (2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one), liquid. Available for control of many annual grass weeds. Do not use to control weedy grasses in lawns because injury to turfgrasses may occur. Control of most perennial grass species will require multiple applications. Do not use sethoxydim in areas to be seeded to turf or other grasses. Apply postemergence to actively growing grasses in and around broadleaf ornamentals.

3. Non-selective materials.

A. Contact, no residual.

Diquat (6,7-dihydrodipyrido[1,2-a:2′,1′-*c*]pyrazinediium ion), liquid; alone or mixed with fluazifop (see fluazifop). Available for use only where complete vegetation suppression is desired. The product controls most annual species in one application; perennial species will normally require re-treatment. Do not use the pre-mix of diquat + fluazifop in areas to be seeded to turf or other grasses. Apply postemergence and be sure to adequately cover foliage.

Glufosinate (2-amino-4-(hydroxymethylphosphinyl)butanoic acid), liquid. Available for use only where complete vegetation suppression is desired. The product controls most annual species in one application; perennial species will normally require re-treatment. Apply postemergence and be sure to adequately cover foliage.

Potassium salts of saturated fatty acids, liquid. Available for use only where complete vegetation suppression is desired. The product controls most annual species in one application; perennial species will normally require re-treatment. Apply postemergence and be sure to adequately cover foliage.

B. Contact, residual. (None available for home and garden use.)

C. Translocated, no residual.

Glyphosate (*N*-(phosphonomethyl)glycine), liquid; alone or pre-mixed with oxyfluorfen, acifluorfen, imazapyr (see those herbicides). Available for control of most annual, biennial, and perennial grass and broadleaf weed species. Apply postemergence to actively-growing weeds.

D. Translocated, residual.

Imazapyr ((±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-pyridinecarboxylic acid), liquid or granular. Available for use only where complete vegetation suppression is desired. Controls most plant growth for 6 to 12 months. Do not apply near desirable plants (or where their roots may extend), or where runoff can occur. Do not use this product in areas where you want to transplant annuals or seed other plants, whether annual or perennial. Apply pre- or postemergence, in midwinter in dry climates or early spring in wet climates. Re-treat when re-growth occurs.

Prometon (6-methoxy-*N*,*N*=-bis(1-methylethyl)-1,3,5-triazine-2,4-diamine), liquid or granular; alone or mixed with imazapyr (see imazapyr). Available for use only where complete vegetation suppression is desired. Controls most plant growth for 6 to 12 months. Do not apply near desirable plants (or where their roots may extend), or where runoff can occur. Do not use this product in areas where you want to transplant annuals or seed other plants, whether annual or perennial. Apply pre- or postemergence, in midwinter in dry climates or early spring in wet climates. Re-treat when re-growth occurs.

4. Moss killing materials.

A. In turf.

Ferrous sulfate (monohydrate or anhydrous). Available for control of moss in turf. Products containing iron generally should not be used on structures or on concrete, as black staining will usually result. Apply any time moss is actively growing.

B. On structures or concrete.

Zinc (metallic), liquid and **zinc sulfate** (monohydrate), liquid or granular. Available for control of moss on structures or on concrete. These products should not be used on lawns, as damage to turf grasses may occur. Apply any time moss is actively growing.

Further Reading

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Vertebrate Pest Management

Topics covered:

- Introduction
- Population Dynamics
- Management and Control of:
  - Moles
  - Pocket Gophers
  - Voles
  - Ground Squirrels
  - Tree Squirrels
  - Rabbits and Hares
  - Commensal Rodents
  - Raccoons
  - Opossums
  - Mountain Beavers
  - Beavers
  - Deer and Elk
  - Bats
  - Birds
  - Dogs and Cats

Learning Objectives

- Know features, biology, and habits of common vertebrate pests of gardens and landscapes
- Identify pests and their damage
- Know management options for vertebrate pests

By

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Introduction

Vertebrates (animals possessing backbones) can occasionally become yard and garden pests. Compared with diseases (Chapter 15) or invertebrate problems (Chapter 14) they are relatively rare.

A "pest," of course, is in the eye of the beholder but in this chapter we will define it as an organism that causes, is perceived to cause, or is likely to cause economic or aesthetic damage to people or their property. Pests may simply be managed, that is, their habitat or target plants manipulated in order to discourage the pest, or pests may be controlled—removed by trapping or eliminated by lethal means.

If an animal is perceived as being a problem, the first question to ask is, is control really necessary? Here are several things to consider before attempting control.

- Type of animal. Identification of the animal is important for effective management in most cases. Since most vertebrates are nocturnal or simply difficult to observe, identification often must be made by studying just the signs left by the animal: evidence of nesting, chewing, or feeding; paw prints; droppings; or even territorial marking.
- Benefits of control versus the cost of damage. What are the economic or aesthetic thresholds at which the extent of potential damage warrants control? How much damage might occur without any control?
- Legal status or aesthetic or recreational value of the species. If the pest species is listed as endangered or protected, your options may be limited. Your regional office of the Washington Department of Fish and Wildlife (WDFW) is your best resource for this information. See: http://wdfw.wa.gov/wlm/living/rules.htm.
- Any consequences of a control program for non-target species or the environment.

If you conclude some sort of management is needed, there usually are at least a couple of options, depending on the animal. Consider whether there are alternative ways to manage a problem species before beginning any direct control action such as setting out traps or poison baits. Sometimes just changing the animal's behavior pattern is all that is needed. Other times, you may need to actually repel or even eliminate the animal. In some cases, hiring a trained professional who has experience and access to other pest management tools might be a useful option. Whatever you decide, you must be sure that your actions are legal and will not endanger people, non-target species, or the environment. Remember that repellents are considered pesticides in Washington State. If you choose traps or pesticides, check with your state and local authorities on regulations that determine the proper use of these tools.

Pest Control in Washington State

1. Because legal status of wildlife as well as trapping restrictions and other information changes, contact your local Washington Department of Fish and Wildlife for current status and information: http://wdfw.wa.gov/about/regions/.
2. Due to the passage of Washington initiative 713 in November 2000, catching any animal with "body-gripping" devices is no longer legal, with the exception of "common rat and mouse traps." Some other gripping-type traps may be used but only with a special permit from Washington Department of Fish and Wildlife (WDFW). Although some older, pre-Initiative 713 WSU publications may refer to traps that grip an animal in some way, Washington State University explicitly recommends against the illegal use of body-gripping devices for animal management. Because future legal or legislative action might result in changes to this law, citizens should always check with WDFW first, before purchasing or using traps.
3. Per their contract, WSU Master Gardener volunteers may ONLY recommend pesticides (including repellents) that are listed in WSU-approved home and garden references: http://mastergardener.wsu.edu/documents/WSUExtensionMasterGardenerVolunteerApprovedReferencesforPestManagementRecommendations.pdf.

   Pesticide registrations continually change, so be sure to check before recommending any of the chemicals mentioned in this chapter.

Population Dynamics

Most large vertebrate pests must be managed indirectly—without resorting to chemicals or traps—that is, by manipulating their habitat. To manipulate the habitat effectively, you need to know exactly what pest species you are dealing with, and know a little bit about **population dynamics** as well as how any changes to the environment will affect the species in question.

In a nutshell, any living area will support only a limited number of members of any particular species—that number is the **carrying capacity** of an area for a given species. Animals in excess of that number either leave (migrate) or die. Carrying capacity is determined largely by three limiting factors: food, water, and shelter. Controlling these factors—especially food and shelter—is the key to manipulating the population density of many species.

Moles

The most common vertebrate pests in yards and gardens are probably moles (Figure 1). These animals are not rodents, as is sometimes thought, but belong to a different order, and are insectivores. Washington State has three of the seven North American species: the tiny shrew-mole (*Neurotrichus gibbsii*), the coast mole or, Pacific mole, (*Scapanus orarius*), and the Townsend's mole (*Scapanus townsendii*) which is one of the largest moles in the world at 8 to 9 inches long.

Figure 1. Moles have large front feet, especially good for digging.

The two larger species, the coast and Townsend's moles, are very similar in appearance and can be serious tunneling/mound-making pests in lawns, gardens, and fields (Figure 2). Moles are seldom observed but their presence is obvious by the many large, volcano-like molehills that they produce while tunneling.

Figure 2. When a nice lawn turns overnight into a molefield, those molehills seem like mountains.

Moles are active year-round and feed almost exclusively on invertebrates (earthworms, grubs and soil-dwelling arthropods). Rarely, they may sample bulbs, root crops, and sprouting seeds. People usually blame moles for plant damage that is actually caused by voles (*Microtus* spp.), which also tunnel and will also use moles' tunnel systems.

Control

Whatever method you choose for controlling moles, it is most important that you apply your treatments only to active tunnels. You can easily locate these "underground highways" by stomping down molehills in the afternoon. By the next morning, hills that are being used will be pushed back up. During certain times of the year, you may see no activity at all, even though moles are present. At these times, you can monitor mole activity by opening small holes in the tunnels with a probe (a broom-handle, long screwdriver, etc.) and checking the next day to see if a mole has plugged them up.

Once you locate an active tunnel, use your probe to locate a deep run about 6 to 18 inches away from the mound. When you strike the tunnel, the probe will suddenly drop a couple of inches. Apply your treatment of choice, being sure to follow label directions if using a pesticide, and repeat in all active runs. Monitor the tunnels again in a few days with your probe and you will soon find out whether your "treatment of choice" is effective or not.

Trapping. Historically, the only effective way to control problem moles was lethal trapping. In Washington, only non-body-gripping-type traps or common rattraps and mousetraps ("snap-traps") are legal for use as of 2000. (See RCW 77.15.194) None of these, however, have proven effective for mole control. You can try making "pitfall traps," as described below for voles but these seldom work on western moles.

Other Controls. Some other control methods are sometimes recommended for mole management. Most have not been proven to be effective.

- Castor-oil-based repellents (Scoot® Mole) show some effect when tested on eastern moles (*Scalopus aquaticus*). Effectiveness has not been proven on western species. The one registered blood-based mole- and gopher-repellent has not been tested on our western species.
- Mole plants have not been proven effective.

WSU does not recommend home remedies for moles or any other pests. Home remedies are not scientifically tested, often cost more for ingredients than registered pesticides, and may damage the environment.

Moles or Gophers?

Both of these animals build mounds but most control methods are very different so accurate identification of the pest is important.

Moles usually prefer moist lowland areas west of the Cascades, while gophers are found mostly east of the Cascades. But one species, the Mazama pocket gopher, lives in the south Puget Sound area, together with moles.

The shape and texture of the mound will usually indicate which animal made it. Mole mounds are pushed up through the tunnel and so, are generally "cloddy" looking and conical in shape. Gophers work like tiny bulldozers, pushing soil out of their tunnels in flatter, fan-shaped mounds, usually leaving an obvious plug in one end when they are finished.

Pocket Gophers

Pocket gophers (*Thomomys* spp.) are burrowing rodents that feed almost exclusively on plant material below, and occasionally above, ground. They will also gnaw on plastic irrigation pipes, buried cables, and similar items.

There are two species of pocket gophers in Washington. The northern pocket gopher (*Thomomys talpoides*) is the most widespread species in the eastern part of the Northwest (Figure 3). The Mazama pocket gopher (a.k.a. western pocket gopher, *T. mazama*) is the only pocket gopher west of the Cascades, found on the Olympic peninsula and in the south Puget Sound area. Both of these species grow to about 8 inches long. Their fur usually is gray or brown and their typical rodents' incisors are easily visible. Pocket gophers are so called because of their external, fur-lined cheek pouches. These "pockets" are used for carrying food to storage tunnels.

Figure 3. Gophers, Thomomys talpoides*, have typical rodents' incisors—the better for eating our landscapes. (Photo courtesy of Dave Powell, USDA Forest Service; Bugwood.org.)*

Management and Control

In some cases, you may be able to tolerate these native rodents in your landscape. They are quite solitary so you will not develop large populations. Like moles, their tunneling is beneficial to the soil in many cases. Pocket gophers can churn up 2000 lbs of soil each year and pull vegetation into their tunnels where, along with gopher feces and urine, it improves the tilth and fertility of the soil.

Cultural Techniques. If you don't mind the gopher mounds in your yard but don't like the damage to your garden, you can plant in raised beds with ½ inch hardware cloth bottoms. Alternatively, you can build an underground fence to protect small plots as described in the section on voles. Individual flower bulbs can be planted in half-inch mesh wire baskets to prevent damage.

Pocket gophers also feed above ground, so wire guards may need to be placed there, too.

In some cases, pocket gophers gnaw on buried cables and plastic water lines. Installing these items in trenches surrounded with at least 6 inches of one-inch gravel will discourage chewing.

Lethal Controls. Before using lethal controls in Western Washington, call your local WDFW office or check their website. Some sub-species of northern and Mazama pocket gophers are candidates for protection under the federal Endangered Species Act.

Pocket gophers can be controlled any time of the year but the most successful time is in the spring and fall when mound-building is under way. Both traps and toxic baits are effective. Live traps are seldom effective.

Baiting with rodenticides is another option. Gopher baits containing zinc phosphide, or the anticoagulant diphacinone are registered for some uses in Washington as of 2010. For application, place toxic gopher baits in main tunnels exactly according to label directions. Locate the tunnels with a probe and place the bait down the probe hole. An alternative method is to excavate the tunnel with a trowel and place the bait directly in the run. Bait each burrow system in two or three places for best results. Check the area periodically for 2 weeks after treatment and dispose of any carcasses you find to eliminate any possibility of secondary poisoning of nontarget animals.

Flooding the tunnels quickly with 5-gallon buckets of water (much faster than using a hose) will sometimes drive a gopher above ground where it can be dispatched.

Registered repellents containing dried blood or castor oil are not consistently effective.

Voles

There are over 18 species of voles (*Microtus* spp.), or "meadow mice," in the Northwest. They all feed on plant material, and most species are tunnelers. West of the Cascades, the most commonly seen voles are the Townsend's vole (*Microtus townsendii*, up to 9 1/2 inches) and the creeping, or Oregon, vole (*M. oregoni*, 6 1/2 inches). East of the Cascades, the montane vole (*M. montanus*, 7 7/8 inches) is most prevalent in gardens and orchards.

Lethal Control of Wildlife in Washington State

The Washington Department of Fish and Wildlife has specific regulations regarding human–wildlife interaction with rules to address property damage and other problems caused by wildlife. These rules stipulate when lethal control may be used, what manner of lethal control may be used, and on which wildlife species. These rules may change.

Before any lethal removal of wildlife, property owners must use preventative measures and then document those measures used in attempts to discourage wildlife damage. WDFW rules also stipulate how to dispose of wildlife killed for causing personal private property damage.

Note that is unlawful to kill any protected or endangered species unless special authorization is received, along with special state and federal permits.

Before trapping or killing wildlife that is damaging private property, consult the WDFW website for local contact information and current regulations and requirements: http://wdfw.wa.gov/wlm/living/rules.htm and http://apps.leg.wa.gov/rcw/default.aspx?cite=77.36.030.

Signs of Vole Problems

- Gnawed roots. (Look for the tiny, paired grooves left by the vole's two front incisor teeth.)
- Fruit trees that are easily wiggled in the soil due to missing (eaten) support roots. If you pull up a vole-ravaged tree, the entire root-ball may be gone.
- Leggy and sparsely leafed fruit trees with a reddish tinge to the foliage.
- Girdling of tree trunks just above the soil line.
- Extensive, well-used tunnels through soil, grass, or thatch.
- Open holes, about ¾ to1½ inches in diameter.
- Vegetables and tender flowers cut off above ground showing tiny incisor marks on the chewed parts.

Vole damage may be confused with damage caused by rabbits, hares, or mountain beavers, but rabbits and hares usually damage trunks and twigs higher up than voles can reach and leave larger tooth marks at 45° angles. Mountain beavers also leave larger tooth-marks and often clip branches several feet off the ground, leaving 2-inch stubs.

These small, short-eared, short-tailed rodents, mostly feed on grasses but can cause damage in orchards by gnawing on tree roots and around the bottoms of tree trunks during the winter, often girdling trees and killing them. They will also tunnel through gardens, feeding on many kinds of roots, tubers, and bulbs. Many gardeners blame this sort of damage on moles. Voles will certainly use moles' tunnels, as well as their own, when making these raids, and will also feed above ground.

Voles are active at any time of the day and night and in all seasons. Most species spend most of their time underground or in dense vegetation so they are seldom seen. Some species may have as many as 5 litters per year, with up to 11 kits per litter. Because voles are prolific, they serve as a primary food source for many predators.

Management and Control

Cultural Techniques. Managing the surrounding vegetation (reducing the carrying capacity) is very important for keeping vole populations low.

- In orchards, keep the grass very short or completely away from the trees for at least 36 inches on all sides of the trunks. Mow between rows to keep the grass short.
- Manage thatch in lawns, which can provide habitat for voles.
- Be very careful using mulches around trees and shrubs! Deep, loose mulch can provide protective cover. Reducing the depth of the mulch near a tree trunk to 1–2 inches and keeping it 2–3 inches away from the trunk, especially during the fall and winter, will help discourage activity.
- Remove fallen fruits, nuts, seed pods, etc. so voles cannot feed on them.
- In gardens, keep grass in the surrounding area short, and control thatch.
- Don't leave root vegetables in the ground over winter.
- Clean up fallen seed from bird feeders. Fallen seed is a sure draw for many rodent species, including voles.

To protect shrubs and young trees, place galvanized hardware cloth cylinders (1⁄4-inch mesh) around the base of tree trunks. A double layer of aluminum foil rolled into a cylinder and set in the same way also works well and is a cheap substitute if you have many seedlings to protect. Tree guards placed only at the ground surface do not prevent vole damage since voles feed mostly underground.

An underground "vole fence" can be installed to protect entire gardens. To make a vole fence, galvanized ¼-inch hardware cloth is buried in a trench at least 8 inches deep and wide, with

Figure 4. While outdoor cats can be a danger to songbirds and other desirable wildlife and a garden pest in their own right, a good "mouser" can be a valuable ally in the battle against voles and other small rodents. This cat has not been seen stalking birds, but has been known to deliver 6 voles or mice (shown above) in the course of a single day to her home, often leaving them (or parts of them) next to her bowl of cat kibble.

the bottom 6 inches of the wire bent outward, away from the garden, at a 90-degree angle. Six to 12 inches of fence should extend above ground. Vole fences can stand alone or be added to the bottom of existing fences. If made at least 24 inches deep, these barriers will also help protect the area from pocket gophers, ground squirrels, and moles. You can prolong the life of the fence by treating it with rust-preventative paint before installation.

Biological Controls. Many predators love to feed on voles. Hawks, owls, coyotes, foxes, snakes, weasels, skunks, and others can help keep vole populations moderate (Figure 4).

Trapping. Small vole populations can be controlled with common rattraps or mousetraps. Other body-gripping traps are not legal to use in Washington. Up to 100 traps per acre may be necessary for large populations. For protecting particular plants or small gardens, you may only need a few traps. You can save time and effort by trapping only where there is feeding activity.

Since vole populations fluctuate wildly, it's a good idea to locate and confirm areas of active vole feeding. Place apple or carrot pieces (see which your voles prefer, first) in various likely places, such as damaged areas, tunnels, and runways. To be most effective, you should have 4–8 monitoring stations per acre. Cover the slices with shingles or 12×12-inch pieces of cardboard. Stake down the covers to keep them from blowing away. Keep the bait as dry as possible to encourage feeding. If there is no feeding on these materials within 24 to 48 hours, there probably are no voles within the immediate few square yards. If 20–25% or more of the slices are chewed, there is a high probability of damage to your plants. Monitoring should be done in late summer and early fall because most serious damage occurs over the winter.

In areas where voles are feeding, they can be controlled with ordinary mousetraps baited with peanut butter or apple. Mousetraps with expanded triggers can be used unbaited and this may reduce non-target catches of beneficial shrews.

Place traps by digging into the underground tunnels and placing the traps crosswise in the tunnels, or position traps crosswise in surface runways. Cover them to avoid harming birds or other non-target wildlife. Check snap-traps daily and reset as needed.

You can also make "pitfall" traps by burying coffee cans below a vole runway, so that the open top of the can is level with the bottom of vole runways and covering the runways with boards. Voles (and other small vertebrates) will fall in the cans and be unable to escape. The relatively expensive Tin Cat® multiple-catch mouse live-trap is also effective for some vole species. Check live traps often and deal with your catch in a humane manner. Trapping is very time-consuming but useful for small areas and wherever you cannot use poisoned baits.

After you think you have captured most of your pests, put out some more apple or carrot pieces. If there is no feeding within a couple of days, your trapping program was successful.

Chemical Controls. Several "mole & gopher" baits registered for home use will kill voles when applied to underground tunnels exactly according to label directions, but they are not specifically registered for use on voles. This use is within Federal Insecticide, Fungicide and Rodenticide Act guidelines if the site is listed on the label of the product.

Always read and follow label instructions for any pesticide!

Ground Squirrels

Five species of ground squirrels (*Spermophilus* spp.) occur in Washington, mostly east of the Cascade crest. Ground squirrels (Figure 5) range in size from the small Washington ground squirrel (*Spermophilus washingtoni*, about 9 inches) to the California ground squirrel or "gray digger," (*Spermophilus beechyi*, 18 inches). These rodents are herbivorous and will feed on a wide variety of crops and landscape plants. They also are accomplished tunnel diggers, leaving many open holes, 2–4 inches in diameter, throughout their home ranges. Unlike most other rodent pests, ground

Figure 5. Ground squirrels, Spermophilus *spp., are herbivorous burrowers that are active during the day. (Photo courtesy of Terry Spivey, USDA Forest Service; Bugwood.org.)*

squirrels are diurnal so you can often see them scampering around their burrows. Some species have been implicated in the transmission of plague and other diseases. On the other hand, these native rodents are a valuable part of the food chain and, like pocket gophers, improve the tilth of the land with their constant burrowing.

Ground squirrels generally go dormant during the hottest part of summer and hibernate over winter. Population densities of more than 100 per acre have been recorded.

Management and Control

Some species of ground squirrels are legally protected, so check with WDFW before using lethal methods.

Cultural Controls. Metal rodent guards placed around tree trunks usually protect fruit and nut trees from species that climb. Fencing often is not effective in excluding these rodents from an area but solid 3-foot-high fences that the animals cannot see through have sometimes been effective in limiting colony expansion. The bottom of the fence should be buried 12 inches underground. Scare devices are not effective for these animals but constant harassment (filling in and/or digging up tunnels, using repellents, etc.) will sometimes drive them away.

Plants that are being damaged can be protected with commercially available repellents or wire cages. Remember that repellents are not very effective if feeding pressure is high and there are lots of animals competing for food.

Trapping. Trapping can be effective with small infestations. Cage-type live-traps may be used, but animals cannot legally be released off the property so they must be destroyed. If you must euthanize a trapped animal, use humane methods. Check with the WDFW for suggestions.

For small ground squirrels, common rat traps are legal and may be effective. One trap for every 10 to 15 squirrels present should quickly control the population. Be sure to keep traps inaccessible to children, nontarget wildlife, and pets. Note: some species of ground squirrels are legally protected, so check with the WDFW before using lethal methods.

Other Controls. Encouraging natural predators will help keep populations of these rodents under control. If that is not sufficient, professionals should be considered.

Tree Squirrels

Washington is home to several species of tree squirrels. On the west side of the Cascades, the native Douglas squirrel (*Tamiasciurus douglasii*) is common in conifer forests. Its Eastern Washington counterpart, the red squirrel (*Tamiasciurus hudsonicus*) is the most common native on the east side of the state (Figure 6). Both are about 14 inches in length and have a dark red coat. The Douglas squirrel has an orange belly and, ironically, the red squirrel's underparts are white. In many urban and suburban areas, the

Figure 6. The red squirrel, Tamiasciurus hudsonicus*, is a native pest in eastern Washington. (Photo courtesy of Michael Mengak, University of Georgia; Bugwood.org.)*

Figure 7. The eastern gray squirrel is an introduced pest in Washington, and has made itself right at home. (Photo courtesy of Karan A. Rawlins, University of Georgia; Bugwood.org.)

large, introduced eastern gray squirrel (*Sciurus carolinensis*, about 20 inches total length), with its rust–and-gray fur (there are black populations of this species) and white belly, seems to have taken over (Figure 7).

The introduced eastern fox squirrel (*Sciurus niger*) usually has a reddish coat and belly, though, like the eastern gray, it can be very dark. At 22 inches long, it is one of the largest North American squirrels. This species is rather rare in Washington. The rare western gray squirrel (*Sciurus griseus*), a shy native, is even larger (up to 24 inches total length) and has a gray coat and dusky feet. It is found mainly in areas where the garry oak, or Oregon white oak (*Quercus garryana*), grows. Finally, the nocturnal northern flying squirrel (*Glaucomys sabrinus*, up to 14 inches) is fairly common but, being our only nocturnal squirrel, is seldom seen. Flying squirrels are the smallest of the Pacific Northwest tree squirrels. These little gray gliders may be found wherever there are green belts or coniferous forests.

Squirrels become pests when they infest structures or damage crops and landscape plants. They are determined raiders of bird feeders. Some species occasionally damage trees by clipping twigs and stripping bark. In areas where nesting places are scarce, squirrels may gnaw into buildings.

Management and Control

How squirrels are managed depends largely upon the squirrel species and type of damage. Non-lethal methods must be used on all native squirrels unless they are damaging crops, in which case a permit is required from the WDFW. A combination of exclusion, repellents, and cage-trapping is usually adequate. Non-native squirrels are not protected so marauders may be killed any time of year, though the non-lethal methods are more acceptable. Check with your local office of the WDFW for local regulations. Trapping and relocation to other properties is neither legal nor good for the environment.

Suggested management methods include standard rodent control steps:

- Elimination of food sources will help keep the carrying capacity low. Clean up unharvested fruits, nuts, ornamental berries, etc. and use “squirrel-proof” stations for feeding birds.
- Protect susceptible plants with wire cages or squirrel repellent.
- Cover flower bulb beds during the winter with chicken wire to prevent digging. Stake the wire down securely, and cover it with a light mulch.
- Protect fruit and nut crops by placing 24-inch-wide sheet metal collars as rodent guards on tree trunks, 6 feet off the ground. This method will only work if there are no other tall trees, fences, or buildings nearby. Squirrels will leap many feet to raid fruit and nut trees.

Rabbits and Hares

In Washington, there are seven species of rabbits and hares. A few of them can become garden pests. Whitetail and blacktail hares, or “jackrabbits,” (*Lepus townsendii* and *L. californicus*) are found east of the Cascades (Figure 8). Our most widespread hare is the “snowshoe rabbit” (*L. americanus*), which lives throughout most of Washington except for the dry, desert areas.

Our true rabbits include the rare pygmy rabbit (*Sylvilagus idahoensis*) and the mountain cottontail (*S. nuttallii*); both are Eastern Washington species. The eastern cottontail (*S. floridanus*) was introduced as a game animal many years ago and is still spreading. Domestic rabbits (*Oryctolagus cunniculus*) have become feral in the San Juan Islands and in some urban areas.

Rabbits and hares may have as many as six or more litters per year, with several kits in each litter. Damaging populations can grow quickly.

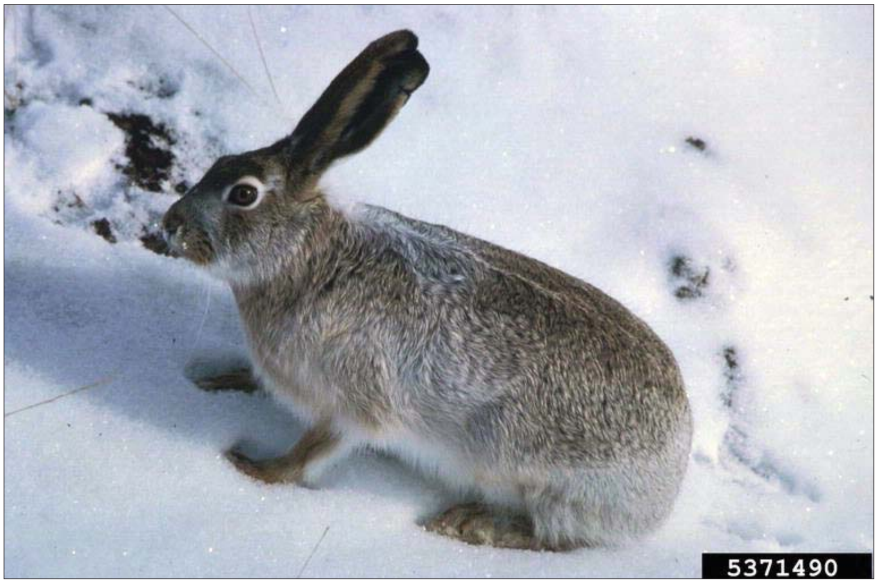

Figure 8. Whitetail hares, Lepus townsendii*, are found east of the Cascades. (Photo courtesy of Dean Biggins, US Fish and Wildlife Service; Bugwood.org.)*

These long-eared pests will eat a wide variety of plants. They often feed on woody bark and stems of trees and shrubs during the winter, causing considerable damage to orchards, gardens, and crops. In spring and summer, they devour crops and herbaceous landscape plants.

When feeding upon bark and twigs, rabbits and hares leave easily identifiable tooth scars. Twigs are neatly clipped at a 45° angle and the bark on lower stems and branches may be eaten, leaving parallel tooth scars on the wood. There will usually be droppings visible in feeding areas. Rabbit and hare droppings are spherical and about 3/8 inch in diameter.

Management and Control

Barriers. Fencing, once again, is the most effective way to reduce damage. A simple chicken-wire fence only a couple feet high usually is all that is needed to protect garden plants from cottontails. Any small-mesh fencing will work, but young animals may be able to squeeze through anything larger than an inch or so. The bottom edge of the fence must be very tight against the ground or even buried a few inches. If hares or feral domestic rabbits are causing problems, the fence should be taller: 30 to 36 inches high is adequate. You may need to bend the bottom 6 inches outward at a 90-degree angle and bury it 6 inches deep in the ground to prevent digging underneath.

Tree wraps or cylinders of ¼-inch mesh hardware cloth, about 18 to 20 inches high, can be placed around individual plants to prevent de-barking. The carrying capacity of an area can be reduced by removing juniper or briar patches, brush piles, and other hiding places. This will eventually reduce the population and, therefore, the amount of damage in the area.

Repellents. Repellents can be somewhat effective for protecting crops and landscape plants from rabbits and hares if the feeding pressure and population are not too great. There are several repellents available but many are for use only on landscape plants so be sure to read and follow the label!

Scare devices, such as Mylar balloons and tape or hanging aluminum foil strips or pie-pans can afford temporary protection. Motion detector sprinklers (for example, Scare-Crow®) can also be effective.

Lethal Controls. Since native rabbits and hares are game animals or otherwise protected by law (the pygmy rabbit is listed as an endangered species), contact the WDFW for regulations and information about controlling your pest species. Feral domestic rabbits may be cage-trapped (but not re-located) or shot at any time.

Commensal Rodents

Rodents that live in close proximity to humans are known as **commensal rodents**. These include animals such as mice and rats—the most common and widespread of the vertebrate pests we deal with, although they are more problematic in homes and other structures than in yards and gardens. Rats and mice are relatively minor garden pests, especially compared with birds, raccoons, and deer.

Rural buildings are often infested by native deer mice (*Peromyscus maniculatus*) rather than house mice, but control methods are the same for both species. Deer mice are distinguished by their white underparts on the body and tail (Figure 9), whereas the house mouse is gray.

Mice and rats are largely nocturnal, so a person may not be aware of an infestation until the population is quite large. Learning what signs to look for will help prevent the buildup of a serious rodent problem. For instance, mice and rats tend to move over regular routes and usually produce defined runways. These runways show up particularly well in dusty areas, especially if flour or other "tracking powder" is sprinkled around likely spots as "tracking patches." Outdoors, rats leave runways under groundcovers and make 2- to 3-inch holes in and around buildings and foundations. Another sign is the grease stain that rats leave when rubbing against walls during their travels. Finally, the droppings, which are moist and soft when fresh, are a definite sign of infestation. Mouse droppings are about ¼ inch long and look much like grains

Figure 9. Deer mice have white undersides. (Photo courtesy of David Cappaert, Michigan State University; Bugwood.org.)

of burnt rice. Rat droppings can vary in appearance, depending on the animals' age and diet. They can be up to ¾ inch long and ¼ inch in diameter.

Management and Control

There are four important steps to effective rat and mouse management:

- Reduce available food and water
- Reduce habitat
- Rodent-proof structures
- Remove the rodents

Reduce Available Food. Minimizing exposed food materials is essential for any successful rodent control program.

- Secure garbage and food wastes in tightly covered metal cans.
- Never leave pet food exposed outdoors after dark.
- Dispose of dog droppings in the garbage or bury them. Rats can survive on a straight diet of feces.
- Clean up fallen fruits, nuts, and old ornamental seedpods.
- Use rodent-proof bird feeders to feed birds, and clean up any spilled or scattered seed.

Reduce Habitat. Reduce the available hiding places for rodents in order to reduce the local carrying capacity and help discourage rodent infestations. Rodents are attracted to woodpiles, dense vegetation, compost piles, and sheds. Reduce dense vegetation and other hiding places around structures as much as possible. Remove branches close to the ground on landscape trees and shrubs. Also, avoid planting dense groundcovers near buildings that might offer shelter to rats.

Rodent-proof Structures. To rodent-proof structures, close or screen any opening they can get their teeth into. Young mice can squeeze through openings as small as 3⁄8 inch so be sure to seal all gaps around pipes, wires, etc., or stuff them with copper wool or stainless steel wool. If rodents attempt to gnaw under doors, cover the edges with heavy sheet metal or wire mesh. Screen any vents or other openings with 19-gauge or heavier ¼-inch-mesh hardware cloth. Offset curtain walls may be installed under foundations or around outbuildings in severe infestations to prevent rats and other burrowing animals from gaining entrance.

Remove Existing Rodents. Along with controlling the food resources and habitat, the rodents themselves must be eliminated. Trapping is the preferred method for controlling commensal rodents but is more difficult, labor-intensive, and unpleasant than using rodenticides. There is no poisoning hazard when using traps and they can be re-used many times. Also, there is little chance of dead animal odors becoming a problem, because the animal won't crawl away to die within a wall or building space.

There are usually no instructions provided when you purchase traps. Here are the general rules you should follow in order to be a successful trapper:

For rats, set one or two rattraps at least every 15 to 20 feet wherever there are tracks, droppings, or trails. For mice, place mousetraps every 5 to 10 feet. (Note: Mice can be caught in rattraps but rats may escape from mousetraps and become trap-shy.)

Place traps, with the triggers facing the wall, along baseboards and near possible entry holes or other cover. Alternatively, you can place two traps end to end against the wall so that the triggers face away from each other. When possible, wire traps to a secure anchor to prevent the possibility of trapped rodents dragging them off. If traps are used outside, they must be protected in a box to prevent harm to pets, children and wildlife.

Try different baits to see what is most attractive to the local rodents. Nutmeats, peanut butter, gumdrops, or raw bacon are just a few of the possibilities. Attach baits securely to the trap so they cannot be licked off or stolen. Note that rats are generally cautious by nature and may avoid unfamiliar baits or traps for many days, while mice are curious and relatively easy to trap.

Glue-board traps can be quite effective when set in confined runways. The law has not yet determined whether use of these body-gripping traps is legal under I-713. Large glue-boards can be used for either rats or mice, but rats sometimes can escape or create a mess with these traps, so fasten them down. Be aware that glue-boards do not work well in cold, wet, or dusty areas, and captured rodents may be alive and struggling when found.

Traps should be checked daily to remove rodents and to reset any sprung traps. Wear rubber gloves when emptying traps to avoid being bitten by parasites, and put the dead rodents into sealable plastic bags for disposal.

Multiple-catch traps, such as the “Tin Cat®” and “Ketch-All®” are very effective for catching mice alive but are relatively expensive and the captured rodents must be dealt with in a humane manner.

Electronic repelling devices are sold by many companies but there is little or no research to back their claims. These units emit various sonic frequencies which are claimed to disrupt rodents’ activities and eventually drive them away. The few devices that have been tested under laboratory conditions have failed to live up to these claims.

Rodenticides (poisons) are very effective for killing rats and mice and there is an overwhelming variety available. Homeowners may prefer to have a professional pest service monitor the situation and provide bait, traps, and removal.

Once control is achieved, it’s a good idea to continue with a preventive baiting program if there is a high probability of reinfestation. Permanent, tamper-proof bait stations (special boxes for presenting rodenticides only to pests) placed around buildings, following label directions on the product, will take care of incoming rodents before they become a problem. Follow the directions on the label for placement of bait stations.

For best results, baits and traps must be placed where rodents will find them easily without having to come out into the open. The bait must also be protected from dampness, wildlife, pets, stock, and children. For prolonged baiting and outdoor situations, you can make or purchase tamper-proof bait boxes that are easy to replenish with a continuous supply of fresh bait. Be sure bait stations are clearly marked “POISON.”

A rodent control program may be unsuccessful if:

- There is a lot of other food available in the area.
- There are too few bait stations or traps.
- Not enough rodenticide is used for the entire population.
- If you stop baiting or trapping too soon.

Raccoons

Raccoons (*Procyon lotor*) can be serious pest in yards, gardens, and structures. These native carnivores live throughout the United States (Figure 10). Raccoons are opportunistic animals, adapting to all sorts of environments. They can weigh as much as 50 pounds and, if they lose their fear of humans, can be aggressive. Deliberate feeding by well-meaning neighbors can cause populations to grow out of control.

*Figure 10. Primarily nocturnal, raccoons (*Procyon lotor*) can be seen any time of day, especially when your favorite garden crop has just ripened. (Photo courtesy of Terry Spivey, USDA Forest Service; Bugwood.org.)*

Raccoons are primarily nocturnal and are omnivorous. These masked raiders easily climb fruit trees and knock over corn stalks. They will readily tip over garbage cans, and will roll up newly laid turf or dig holes in it to get at the juicy invertebrates underneath. In structures, they will invade unprotected crawl spaces and rip into attics, often destroying the insulation and leaving large quantities of odorous feces. The droppings often contain the eggs of the "raccoon roundworm," which can be deadly to children if ingested. In eastern North America, raccoons are the primary vectors of rabies.

Management and Control

As with most native vertebrates, exclusion usually is the most effective and preferred way to minimize damage.

Barriers. A simple two-strand electric fence is usually sufficient to protect crops, landscapes, ponds, and gardens. The bottom wire should be about 6 inches from the ground with the top wire about 6 inches higher. Wooden, chain-link or chicken-wire fences, with a strand of electrified wire stretched along the top and another near the outside bottom are also effective.

To protect fruit trees, simple rodent guards, as suggested for squirrels, should be mounted on the trunks well before harvest time.

Deterrents. As a temporary measure to protect ripening crops, a radio playing in the garden may repel pests until the crop can be harvested. Place the radio in a garbage can or bucket lying on its side to protect it from rain.

Motion activated sprinklers and/or lights can be effective deterrents but raccoons may become accustomed to these devices within a short time.

A large dog patrolling a fenced yard is an excellent deterrent against most medium to large vertebrate pests.

Trapping. Raccoons may be cage-trapped and destroyed if they are damaging crops or domestic animals. Raccoons cannot be released away from the property where they were trapped without a special permit. Call your local WDFW office for more information.

Raccoons can be large, aggressive animals and trapping is probably best left to professional Nuisance Wildlife Control Operators. WDFW offices keep a list of licensed NWCOs. Removal of animals is usually a short-term solution unless additional measures are taken.

Opossums

The opossum is the only marsupial native to North America. Female opossums, as with most marsupials, have an external pouch in which they carry their young. The Virginia opossum (*Didelphis virginianus*) is native to the eastern U.S. and was introduced to the Northwest in the 1930s. It has become a common animal in many areas. Opossums have a rat-like appearance with their pointed snouts and naked tails. (Figure 11). Their fur is mostly gray, and they can grow up to 40 inches long and weigh up to about 14 pounds.

Opossums are quite solitary animals and feed on a wide variety of animal and vegetable material. They can be beneficial since they eat insects and other invertebrates including slugs and snails. On the other hand, they often raid hen houses, gardens, fruit trees, bird feeders, garbage cans, and bird nests. They will readily nest under unprotected houses and sheds, causing damage similar to that of raccoons.

Figure 11. Opossums, Didelphis virginianus*, are native to eastern North America, but they are an introduced species in the Northwest.*

Management and Control

Management of opossums is generally the same as for raccoons. If you want to use a cage trap, be aware that, as with most live-trapped wildlife, any captures must be euthanized or released on the same property on which it was trapped.

Mountain Beavers

The mountain beaver (*Aplodontia rufa*), is not really a beaver of any kind but is more closely related to squirrels. Mountain beavers are a very restricted species, being found only in the coastal areas and foothills of western North America.

Known by several common names including boomer, whistler, chehalis, and sewellel, this tailless rodent resembles a giant moth-eaten hamster with scruffy dark-brown fur and large, digging claws. Mountain beavers usually live in or near wooded areas or damp ravines with abundant vegetation such as ferns, blackberry, and salal. This vegetarian rodent feeds on these and many other plants and trees.

These rather solitary rodents dig many shallow tunnels 4 to 8 inches in diameter and up to 3 feet deep throughout their territories. They feed on nearby vegetation and will sometimes cut and stack the material near their burrow entrances. They often destroy much more vegetation than they actually eat. In home landscapes, mountain beavers seem particularly attracted to rhododendrons, though they will readily feed on a wide variety of herbaceous and woody plants. They usually damage woody plants by clipping off stems and branches, leaving 2-inch stubs. Mountain beavers will often climb several feet into a shrub or tree to “prune” or they may just cut down an entire shrub or small tree. They also sometimes strip the bark from the bases of larger trees.

Management and Control

Where only a few plants are being damaged, just enclosing the individual plants with 18-inch or taller wire mesh or sheet metal/aluminum flashing fence will often discourage feeding. Two-strand electric fences, with the bottom wire about 3 inches above the ground, should also work. To control more widespread damage, you can fence an entire yard with a rabbit-proof fencing (such as chain link or chicken wire). Be sure the bottom of the fence is tight against the ground or even buried a foot or two. If boomers try to dig under the fence, place a 2-foot apron of fencing flat on the ground on the outside, pointing away from the yard, and securely attached to the bottom of the fence. Stake it down and/or cover lightly with soil. Tilting the fence outward or installing it so the fence is loose and floppy can help prevent the occasional climber.

Most repellents have not proven consistently effective for reducing mountain beaver damage but some researchers have had fair results with products containing 36 percent putrescent egg solids.

Trapping. Mountain beavers can usually be cage-trapped but then must be euthanized or released elsewhere on the same property. Moving wildlife is not legal in Washington without a special permit from WDFW. Mountain beavers make a lot of holes but use only a few regularly so it is important to set traps only at active burrows. Use a rabbit-size cage trap, set directly in the main entrance of a mountain beaver tunnel system. Cover the trap with a tarp or burlap bag so the cage looks like a continuation of the tunnel. The cover helps direct the animal into the trap and protects it. Baiting the trap with pieces of apple, sweet potato, or some of the plant that the animal is attacking may make it more attractive.

Be aware that mountain beavers can die of hypothermia (“freeze to death”) if temperatures dip below 50°F. To avoid inhumanely orphaning young, do your trapping after May.

Check with your local office of the WDFW for recommendations if you need to euthanize animals. Killing animals is distasteful to most people so you may wish to hire a wildlife control professional to handle these problems if you cannot live with, or otherwise deal with, the pests. Local offices of state fish and wildlife departments usually have a list of licensed nuisance-animal trappers who can be hired to help. But be aware that good mountain beaver habitat is likely to attract new residents as fast as you remove the old residents.

Beavers

True beavers (*Castor canadensis*) are the largest of our North American rodents. They can grow to over three feet in length and can weigh over 60 lbs. This well-known, semi-aquatic rodent is common in lakes, creeks, and rivers throughout the Northwest (Figure 12).

Figure 12. True beavers, Castor canadensis*, are well known aquatic rodents and dam engineers.*

Beavers are accomplished engineers and are famous for their well-built dams and beaver lodges. Dams and lodges are not always present where beavers are living but the damage inflicted on trees and shrubs by the beaver's huge incisor teeth is a positive sign that these animals are around. Beaver dams are beneficial to wildlife but they can flood a considerable area and cannot always be tolerated. Where dams are causing problems, the water level can sometimes be altered by flow devices to keep flooding within reasonable limits. Installation of flow-control devices (or removal of dams, which is generally a waste of time) requires a Hydraulic Project Permit from WDFW. The WDFW can also provide information on design and installation of flow devices.

Management and Control

If beavers are damaging trees and/or landscape shrubs, there are several ways plants can be protected.

Barriers. Trunks of large trees and shrubs can be loosely wrapped with layers of chicken wire, hardware cloth, or galvanized wire fencing, at least three feet high. Be sure you monitor the trees as they grow, or leave room for the plant to expand. Protect more slender trees with large-diameter plastic pipe: split 3-foot lengths of plastic pipe and fit them around the trunks. Use light-colored pipe because dark colored plastic may cause overheating and damage young trees.

Large plantings can be protected with a variety of fencing. Four-foot field fencing, installed so that the bottom is tight against the ground, works well as does a 2-strand electric fence with the strands stretched at 8 and 12 inches off the ground.

Repellents. Repellents can be helpful in reducing beaver damage, especially if the animals are new to the area. Repellents are seldom 100% effective. Commercially available repellents containing egg solids or blood meal have shown some success but must be reapplied often.

Protective paint for applying to tree trunks can be made by mixing 2/3 cups masonry (sharp) sand in a quart of latex paint.

Removal or Lethal Control. If beavers must be removed, it is best to contact your local WDFW office to locate a professional wildlife control operator. Note: State wildlife offices do not provide animal removal services. In some cases, you may be allowed to shoot the offending animals, but removal is seldom a permanent solution as good habitats are usually repopulated by migrating beavers within a couple years.

Deer and Elk

Several species of deer and elk occur in Washington. They are usually highly valued as game animals and watchable wildlife, but in garden or orchard situations they can cause a great deal of damage to a wide variety of plants.

Members of the deer family feed on many kinds of woody and herbaceous plants. Most serious damage occurs when they browse woody landscape plants, fruit trees, and crops. Members of the deer family lack upper incisors so their browsing damage leaves ragged tips. Rabbits and rodents, on the other hand, leave clean cuts with their sharp incisor teeth.

In general, blacktail deer (*Odocoileus hemionus columbianus*) live on the west side of the Cascades, while mule deer (*O. hemionus hemionus*) are found on the east side (Figure 14) but there is some hybridization in the Cascades. Whitetail deer (*O. virginianus idahoensis*) also live in several eastern parts of Washington and are spreading. An endangered subspecies, the Columbian whitetail (*O. v. leucurus*), lives along the lower Columbia River. Whitetails are easily identified by their brown and white bushy tails, which are used as alarm signals. Mule deer have smaller tails with black markings. All these species will occasionally hybridize.

Figure 13. Mule deer, Odocoileus hemionus*, have big ears, and small tails with black markings. (Photo courtesy of Terry Spivey, USDA Forest Service; Bugwood.org.*

Two subspecies of elk (Figure 14) also occur in Washington. The Rocky Mountain elk (*Cervus elaphus nelsoni*) is found in many eastside areas. The Roosevelt elk (*C. elaphus roosevelti*) lives west of the Cascade crest. Moose (*Alces alces*) are found in a few places in Eastern Washington, too, but are very rarely a problem.

Management and Control

Feeding and population pressure will dictate how aggressive your management methods must be. The more animals there are in an area, the more food they require, and the more appetizing your garden or landscape will look to them.

Barriers. Deer and elk damage is most effectively controlled by fencing off vulnerable plants. Where feeding pressure is light, simple electric fences baited with peanut butter may be adequate. (The peanut butter bait entices animals to lick the wire, thus getting a shock which teaches them to stay away.) In areas where damage is common, expensive 8-foot, woven-wire or high-tension electric fencing may be needed. It is very important that fences be flagged or otherwise visible, at least for the first several months, so that animals see them and don't accidentally stampede through them.

If browsing damage is occurring on just a few scattered plants, individual fences made with welded wire mesh can be placed around each one. Plastic mesh tubes or netting is effective for protecting young seedlings. The lush, tender leaders of young

Figure 14. Elk are recognizable by their coloring and stature. (Photo courtesy of Terry L. Spivey, USDA Forest Service; Bugwood.org.)

conifers can be protected by fastening simple conical caps over the growing tips until the leaders grow out of browsing range.

Repellents. If fences are not practical, repellent products may help reduce damage. Deer repellents made from animal material, such as eggs and blood, usually are most effective but other repellents also work quite well if feeding pressure is not high. Repellents must be reapplied periodically, especially after heavy rain. Be sure to read and follow all label directions. Repellents work best if they are applied before serious damage takes place. If animals habitually feed in the area already or if populations are high, repellents are less effective.

Deer repellents made from animal material, such as eggs and blood, usually are most effective but other repellents also work quite well if feeding pressure is not high.

Frightening devices can also be effective. Motion sensor sprinklers or lights can protect small areas and, like most scare-devices, work best if they are moved often. Combining strategies, such as using repellents in combination with frightening devices is more effective than relying on a single method.

Cultural Controls. Replacing susceptible plants with less tasty varieties is another option. There are some varieties of landscape plants said to be resistant to deer and elk damage to varying degrees. Note that even some of these “deer-proof” plants may be browsed if feeding pressure is high.

Lethal Control. If damage is serious and your land is in an area where hunting is allowed, you might consider opening your land to responsible hunters. Reducing the local population will reduce feeding damage.

Bats

Bats are not rodents, as is often thought. They are the world's only true flying mammals and are beneficial to farmers and gardeners because they eat problem insects such as mosquitos and other flying insects, and can help with pollination and seed dispersal. However, as a result of loss of natural habitat, bats sometimes cause problems if they inhabit attics and wall voids. While roosting bats don't usually cause any structural damage, homeowners often dislike the mess and the noises they can make. Large colonies deposit quantities of guano (feces) and some may carry ectoparasites thus representing a health hazard. Furthermore, the occasional rabid bat can transmit rabies if it happens to bite another mammal before dying of the disease itself. For this reason people should never handle a live bat with bare hands, especially if it is fluttering on the ground or otherwise acting abnormally. Children, especially, should be warned. If you are bitten or scratched, or if you find a bat in a room with a child or sleeping adult, capture the animal with the head intact and contact your local health authorities. Also be sure your dogs and cats are vaccinated against rabies on a regular basis.

There are at least 15 species of bats in the Northwest, but the little brown bat (*Myotis lucifugus*) is the one that usually causes problems in buildings. These animals are usually highly colonial and colonies may include several hundred individuals. The young bats are born in June or July, one per female and can live at least 30 years.

The way to prevent a bat problem in a building is to close all possible entry points. The smaller bat species can enter cracks as narrow as 3⁄8 inch wide, so older structures may be impossible to bat-proof.

Bat Proofing

Before proceeding with a bat proofing program, you must first evict any bats present. To begin, spend some time on warm evenings to see where the bats are coming out. There may be several entry points. Next, hang 1⁄4-inch mesh or smaller bird netting or screen loosely over the entrances. Fasten it to the wall on the top and sides (duct tape works well for this) and leave the bottom loose a foot or so below the opening. Bats will be able to fly out (or rather, fall out and fly away) but will not be able to get back in. In places where netting will not work, one-way bat-tubes can be made from plastic pipe, a few inches in diameter, taped over openings so they hang vertically downward. To prevent young, flightless bats from dying inside the house, do your bat-proofing before May or after August. Consider putting up bat houses nearby to give the animals a place to go. This may help prevent them from looking for other ways back into the building.

It may take up to 3 or 4 days for all the bats to leave the building. After they are out, close any large openings in the building with wood, sheet metal, or small-mesh screen (1⁄4-inch or smaller). Caulk small cracks and gaps in walls and roofs. Other possible fillers include copper or stainless steel wool, galvanized window screen, or expanding foam insulation. Be sure the foam has time to dry before bats become active so they won't get stuck in it. After evicting the resident bats, remove the guano to the garden and mask any lingering indoor odors with aerosol deodorants or odor-killing disinfectants.

Birds

Numerous bird species can cause problems in yards and gardens. Some cause aesthetic or economic damage by their roosting, nesting, or feeding habits. Some of the most common problem birds include crows, robins, woodpeckers/sapsuckers, starlings, non-native pigeons (European rock doves), house ("English") sparrows, and geese. Many species of birds are protected by state or federal law, so managing them can present special problems. For instance, robins are federally protected. Any permit to lethally control these species would need to be issued from the U.S. Fish and Wildlife Service and would likely only be issued in very extreme cases. Information about protected birds can be found at http://www.fws.gov/migratorybirds/RegulationsPolicies/mbta/mbtintro.html and lists of protected bird species are at http://www.fws.gov/migratorybirds/RegulationsPolicies/mbta/compare.pdf.

Management and Control

Some bird species leave large quantities of guano (feces) in areas where they roost or nest. Bird droppings are not just unsightly but can damage painted surfaces, machinery, and animal feed, and can present possible disease hazards to humans, pets, and livestock.

Barriers. Birds that cause problems with their roosting habits can be discouraged by obstructing the roost-site. A variety of barriers are often effective. Ledges can be protected with solid, angled barriers of wood or sheet metal, or with wire or plastic "porcupine wires." Tightly stretched wire or heavy monofilament arranged a couple inches above the roost site can also prevent birds from using ledges and roofs as roosts.

Wire or plastic barriers, bird netting, screens, and other devices can help prevent unwanted nests in buildings. Once nesting has begun for the season, it is illegal to disturb the nests of native species so prevention is the best route. For any birds, though, remove all old nests and then screen or seal any vulnerable openings well before nesting season. Plastic bird netting is not strong enough to keep out starlings in particular, so use something sturdier for these pests.

Once nesting has begun for the season, it is illegal to disturb the nests of native species.

Deterrents. Crows can be a serious nuisance if there is a communal roost near houses. Hundreds of crows may use such roosts daily and create an unbearable racket when they gather. Accumulations of droppings and possible associated diseases can also be a problem. A combination of scare devices, netting, and continued harassment may encourage them to relocate but persistence is essential. Thinning up to half of the limbs of the roost trees can also discourage roosting. Lethal control (shooting) may be used if large numbers of crows create a nuisance or are destroying crops, but even that may not solve the problem. Check with WDFW before attempting any lethal control.

Scare devices, such as Mylar strips, balloons, motion-detector devices or hanging aluminum pie-pans are often used to limit damage. One method to repel woodpeckers in particular, is to hang bird netting from the eaves so it dangles a few inches from the side of the structure.

Preventing Tree and Crop Damage

A few species of woodpeckers, the sapsuckers, attack several species of trees to harvest the sap. They peck small holes into the trunks in neat, horizontal rows (Figure 15) and the sap is periodically licked up. Gardeners usually only see the tell-tale horizontal rows of “sap wells” in the bark and often think the trees are being attacked by beetles. These sap wells seldom cause permanent injury but the scars are unsightly (or fascinating, depending on your point of view). If scarring is severe, trees can be protected by loosely wrapping the affected areas with ¼-inch galvanized hardware cloth or burlap, or by using a combination of scare-devices.

A few bird species can damage a variety of tree fruit and berry crops, most commonly including cherries, strawberries, blueberries, apples, sweet corn, grapes, and hazelnuts.

To reduce damage:

- Plastic bird netting is a very useful tool for protecting low-growing berry bushes and dwarf fruit trees. The netting must be closed around the trunk or reach the ground to prevent birds from attacking from below.
- Netting or cages can be used to protect strawberries, sweet corn and other crops. Corn plants must sometimes be

Figure 15. Some species of woodpeckers are sapsuckers. They attack certain species of trees and peck small holes in neat, horizontal rows in order to lick up the sap that will leak out. (Photo courtesy of James Solomon, USDA Forest Service; Bugwood.org.)

covered from the moment they are seeded until they are at least 8 inches tall, and then again when the ears start to ripen.

- A variety of scare devices, including old-fashioned scarecrows, hanging reflective strips, flags, balloons, and such can reduce damage. To be most effective, these devices must be moved often to prevent desensitization.
- Sonic devices that broadcast alarm calls are effective for the particular species making the call. These units are mostly for commercial use, as they are expensive and very loud. Other sonic devices have not been proven effective.
- Trapping may be used for control of non-native birds (English sparrows, starlings, and domestic pigeons). Trapping is labor-intensive and usually not effective. To control small numbers of pigeons or English sparrows, trapping may reduce local populations to an acceptable

level. Specific kinds of cage traps must be used and captured pest species must be euthanized. Native birds must be released.

Many birds, including some game birds such as pheasant, quail, and grouse cause damage in vegetable gardens when they stop by for a dust bath. While these visitors may help manage invertebrate pests in the garden by eating them, dust bathers can be a problem. Birds roll around in dry, bare soil as part of their grooming and to rid themselves of mites and parasites. Bathing birds wallow in the dirt—creating dust bowls, uprooting small plants, and throwing enough dirt to cover surrounding vegetation. After the bath, birds often linger to peck, snack on, and ruin nearby fruit and vegetables such as tomatoes. Discourage the dust bathing by covering as much of the bare garden soil as possible—a thick layer of mulch such as dry grass clippings or straw works well. Before adding the mulch layer, review Chapters 17 (Weeds and Weed Management) and 22 (Composting) for information on avoiding weed seed or herbicide contamination from clippings or straw.

Dogs and Cats (Domestic Pests)

Free-roaming pets can sometimes cause physical and/or aesthetic damage to landscape and crop plantings. Not only is it unsightly to have the neighbor's dog defecate on one's lawn, pathogens and parasites can be spread in that way. Likewise, free-roaming cats defecating in the vegetable or landscape garden can be health hazards.

Management

As with many animal problems, "good fences make good neighbors." A well-fenced yard or garden will prevent most domestic pet conflicts. A tall, chain-link or solid board fence will keep out most dogs but cats may climb or hurdle such a barrier. A single strand of "hot" electric fence wire along the top (if allowed in your municipality) should put a stop to that.

If a fence is not practical, a motion-detector type sprinkler (Scare-Crow®) can be effective for protecting limited areas, or the offending animals may be harassed by spraying them with a garden hose or "giant-soaker" squirt-gun when they trespass.

Deter cats that use your garden as a toilet, by putting down a layer of chicken wire, pegging it down securely, and covering it with a thin layer of mulch.

Finally, various commercially available home-use dog and cat repellents, labeled for the site in question, can offer some protection.

Further Reading

WSU Extension Publications available at: http://cru84.cahe.wsu.edu/

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Plant Health Care & IPM

Topics covered:

- Introduction
- Plant Health Care (PHC)
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    - Pest Diagnosis
    - Monitoring
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- Strategies for Pest Management
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- Summary

Learning Objectives

- Know principles of cultural, biological, mechanical, and chemical pest management methods for yards and gardens
- Understand the use and processes of monitoring and threshold assessment in making decisions about pest management

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Introduction

Half of the sick plants submitted for diagnosis at Master Gardener plant clinics are not suffering from insect pests or disease organisms. Instead, their problems result from cultural and environmental factors such as over-watering, drought stress, or winter damage. These problems do not have a simple, one-shot cure and require a big-picture assessment of the landscape or garden in order to promote overall health.

Plant Health Care (PHC)

In an attempt to develop a holistic system that focuses on healthy landscapes, several terms have been suggested: integrated plant management, integrated landscape management, sustainable landscaping and gardening. One term that has received widespread acceptance in the tree care industry is **plant health care** (PHC).

Plant health care is as much a change in attitudes as a change in techniques. Not only does it emphasize plant health over pest management, it takes an ecosystems approach that emphasizes working with nature instead of fighting nature; it sees proper culture as the foundation of a healthy landscape and healthy gardens as well.

The first step in implementing a plant health care system is to identify and list all plants in your yard. How can you take care of your plants if you don't know what they are? Once you have a plant list, do some research to learn more about your plants: their cultural needs, likely pest problems, and common environmental problems. During this research, you will uncover some **key plants**—those that are problem prone and likely to require the most attention.

After identifying the plants in your garden, you can determine the **key problems**, both biotic and abiotic. Key problems are the ones most likely to impact plant health and require your attention. For example, in Western Washington, rhododendrons are often diagnosed as suffering from root weevils or poorly drained soil. In Eastern Washington, rhododendrons most often suffer from root weevils and iron-deficiency-induced chlorosis from alkaline soil. Learn more about these key problems if you grow rhododendrons. A garden example might be strawberries and slug damage. For pests, learn to identify various stages of their life cycles, recognize symptoms of damage, and learn which management options are both effective and environmentally sound.

The next step is to study your yard's ecosystem. Your garden truly is an ecosystem with complex interrelationships among flora, fauna, soil, weather, and other factors. Be aware of climatic factors such as minimum temperatures, the amount of sun that various parts of your garden receive, prevailing wind patterns, and seasonal patterns of precipitation. Understand soils and drainage patterns. This information is essential, because healthy gardens result from carefully matching plants to the environmental conditions in your yard or garden.

Landscapes and gardens are dynamic. A key to any plant health care program is frequent monitoring: at least every two weeks during the growing season and perhaps once a month during the winter. When monitoring, pay particular attention to symptoms of plant stress (yellow or wilted leaves, dead branches, etc.) and be on the lookout for developing pest problems. Concentrate your monitoring on key plants and key problems.

With knowledge of your plants, their potential problems, and your yard's ecosystem, you have the tools to optimize plant health. A healthy landscape or garden starts with smart planning: select pest resistant plant species, match plants to the existing climatic and soil conditions ("right plant, right place"), and include a diversity of plant species to limit infestations of monocultures and to support a diversity of beneficial organisms.

Employ good cultural practices: improve soil conditions by using mulches, practice correct planting methods (as outlined in Chapter 11—Trees & Woody Landscape Plants), and pay careful attention to watering, fertilizing, and pruning (too much of these last three may be just as bad as too little; see Chapter 11 and Chapter 21—Pruning Woody Landscape Plants). Sound cultural practices are the basis of a plant health care program. They benefit any landscape or garden whether new or well established.

When we promote total plant health ("preventive medicine"), we avoid many problems. Cultural and environmental problems are minimized, and healthy plants are better able to withstand insect, disease, and weather-related damage.

Components of Plant Health Care

- Know your plants
- Determine key problems: biotic and abiotic
- Study the landscape or garden's ecosystem
- Optimize overall plant and garden health
- Employ integrated pest management techniques

Integrated Pest Management (IPM)

When monitoring indicates that pests require attention, plant health care employs an **integrated pest management** (IPM) approach to managing pests. Integrated Pest Management is an environmentally friendly and common sense approach to

With knowledge of your plants, their potential problems, and your yard's ecosystem, you have the tools to optimize plant health.

Right Plant—Right Place

The notion of planting the right plant in the right place is drilled into Master Gardener volunteers over and over again. What exactly does it mean?

Getting plants, including trees, in the right place means considering all of a plant's traits and requirements—cold hardiness; light, soil, and water requirements; and mature size—before purchasing and planting something.

managing insects, diseases, weeds and other pests of landscapes and gardens by using all the various tools available to gardeners, starting with their skills of observation.

Gardeners should always be watching to see who and what is growing, creeping, and crawling in their yards and gardens. Besides the entertainment value, this provides gardeners with the earliest alert about possible problems. IPM depends on that frequent monitoring of plants and pests so that control strategies are used only when and where needed.

With IPM, a variety of control methods—cultural, mechanical, biological, and chemical—may be employed. Furthermore, IPM takes a holistic approach to pest control encompassing all herbivore pests (including vertebrates, insects, mites, and slugs), weeds, diseases, and the monitoring thereof, rather than singling out only one pest-plant problem.

IPM can reduce pesticide usage in the landscape by 50 to 90 percent without sacrificing the appearance of plants (Holmes and Davidson, 1984). Pesticide usage in the garden also may be greatly reduced using IPM strategies.

IPM Decision-making

IPM is a decision-making process that begins with accurate identification of the plant pest and determination of the pest status (Figure 1). Next in the IPM process are monitoring of the pest population size and threshold assessment. Then, safe and environmentally friendly management methods are used to achieve sound pest suppression.

Pest Diagnosis

Accurate diagnosis is the first step in IPM. A wrong identification can result in choosing the wrong management options, leading to ineffective actions and possibly misapplication of a pesticide.

For effective IPM, a gardener or property owner must be able to identify the pest and understand pest life cycles and behaviors. Whatever control method is chosen must coincide with a pest's most vulnerable stages. With insects, this often is the immature feeding stage.

It is also important to know where the pest occurs on the host plant. For instance, applying a barrier-type fungicide to a plant's leaves will do nothing to protect the roots from a soil-borne pathogenic fungi. Neither can you "pick off" fungi from the soil like you can hand-pick some foliar-based insects. Because

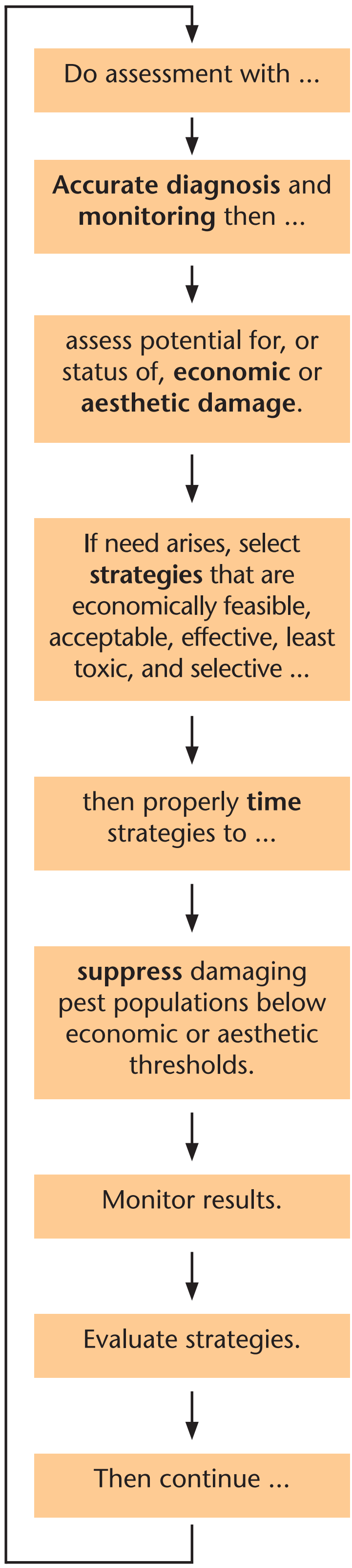

Figure 1. The IPM decision-making process.

root rot organisms thoroughly infest soil, removal of the entire infected plant would probably be necessary. A different plant, resistant to the disease-causing organism, could then be planted in the contaminated soil. There are many examples like these, so knowledge of life cycles and behaviors will most certainly make the gardener a more effective pest manager.

Monitoring

Once you have determined that a pest is doing some damage, it must be monitored from that point on. It may be that the pest is low in numbers when first noticed and may not reach levels where control is necessary. You won't know this unless you regularly monitor the population. A gardener has access to a number of different monitoring tools that range from frequent visual monitoring (simply looking) to complex chemical traps (attracting and catching samples). We'll discuss a few examples.

Visual Monitoring. In visual monitoring we count the pests that we see to determine whether the population is increasing. Sometimes insect pests are elusive and can only be observed at night with a flashlight. Weevils of many kinds fall into this group. Keep a diary so you can document real increases. Monitoring includes noting numbers of aphids or mites per leaf or grubs or larvae per square foot of turf. Sometimes the pest numbers increase slowly during the sampling period (as with mites). At other times, the population increases quickly (as with crane fly larvae in turf). Usually with pests that have several generations per season, like aphids and spider mites, sampling will continue until the decision to control the pest is made. Conversely, pests with one generation per season often require only a single sampling to determine what action to take.

Trap Monitoring. Some insect pests are difficult to monitor without some sort of trap. One common type of monitoring trap is the colored sticky trap. The color yellow is a powerful attractant for many insect pests, including whiteflies, fungus gnats, certain beetles, and yellowjackets. Blue sticky traps are particularly attractive to certain thrips. Colored sticky traps are easy for gardeners to construct. Other traps rely on the sense of smell. Traps baited with olfactory lures are commercially available for wasps and other pests. Home gardeners are now able to purchase pheromone traps (Figure 2) for various pests, usually some kind of moth. These sticky traps, impregnated with synthetic female sex lures, attract males. Pitfall traps are often used for root weevils, etc.

Determining Thresholds

If a pest is life-threatening to a plant—such as certain diseases or virus vectors—mere presence may dictate management action.

Figure 2. Pheromone traps are available to home gardeners for various pests, usually some kind of moth. This sticky trap uses an olfactory lure to attract Indian meal moths. (Photo courtesy of Michael Bush, PhD, WSU Yakima County Extension)

However, mere presence does not always require action. For example, most arborists agree that deciduous trees and many other plants can take up to 25 percent defoliation before plant health is impaired, unless the plants are also otherwise stressed.

Pest damage can have two types of thresholds: economic and aesthetic. The **economic threshold** is defined as the point at which the cost of crop losses resulting from the pest problem equals the cost of control. Usually this principle is used in agricultural situations, but it also applies if you have to decide whether to manage a pest or replace plants in a landscape.

In landscapes we also talk about **aesthetic thresholds** which are determined by how much of the pest problem or plant damage the property owner can tolerate. An aesthetic threshold is hard to quantify and is often quite low because our society is quite intolerant of pest problems and plant damage. However, when people understand that, for example, deciduous trees can tolerate up to 25% foliar loss from chewing pests and still be healthy, they tend to become more tolerant.

Timing of Control Methods

Proper timing is an essential component of IPM whether it is for a mechanical method, the release of biological control agents, or a chemical application. In terms of population management, there is almost always a window of opportunity or period of maximum

Progressive Quiz

For the landscape situation given below, what would you suggest the homeowner do? What further questions would you ask about the situation? With each additional piece of information, reconsider your advice—would you change your strategy and advice, or not?

Situation: On a half-acre suburban lot with many mature evergreen, deciduous, and fruit trees, two trees grow side-by-side with intertwined branches: a Douglas fir and a spruce. A Cooley spruce adelgid infestation fluctuates from year to year but is constantly present (Figure A). The trees are otherwise apparently healthy. *What treatment or action would you suggest—should anything be done to one or both of these trees?*

Both trees are mature (at least 40 years old) and over 40 feet tall. They are in line with 5 other trees of similar age and size, including another spruce, all planted about 10 feet apart. There are ground covers plus wild rose and Oregon grape under the trees. *Does this change your advice? If so, how?*

The trees grow along the property edge, bordering the street. The trees are less than 10 feet from, and parallel to, power lines. The utility company shears one side of the line of trees every 4 to 5 years, to keep branches away from the power lines (Figure B). *Does this change your advice? If so, how?*

The Douglas fir and spruce are otherwise healthy, and the insect infestation has not spread to the other spruce. The rest of the trees in the line are also healthy, although one of the pines is very crooked and leans out over the street. *Does this change your advice? If so, how?*

Would you suggest a different planting there, instead of these trees, as a screen from the street?

Figure A. Typical twig damage on spruce from Cooley spruce adelgid. This pest requires both Douglas fir and spruce trees in relative close proximity to complete its life cycle. Planting them so close that their branches intertwine virtually guarantees an infestation.

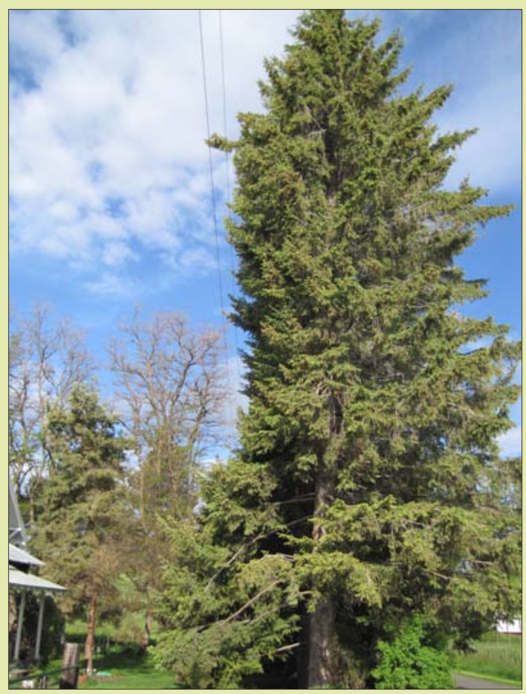

Figure B. End view of a line of evergreen trees regularly sheared by a utility company to keep the tree branches away from power lines.

vulnerability when an application will give you the “biggest bang for the buck.” One guideline, of course, is monitoring to determine when pest feeding begins, or when the pest emerges, or when the eggs are laid. These events often indicate when it’s time to implement control.

Sometimes monitoring tools aren’t available, so another guideline may be used. A pest’s life stages are often related to the plant’s **phenology** or life cycle stage (bud break, bloom, new growth, etc.). For example, with some insect pests there is a temporal correlation between leaf emergence and egg hatch. Each year, leaf emergence may begin on a different calendar date and that date may vary by as much as a month from one year to the next because it is related to a weather and other environmental factors. The timing of insect egg hatch will vary just as the plant growth does, for some of the same environmental reasons, or because of the plant’s development, or because of the interplay between all of those conditions.

Plant diseases can also be related to a plant’s phenology. Certain fungal diseases only infect the blossoms or the new growth of the plant, so this would be the most critical period to manage these problems. When fungicides are used as part of an IPM approach, the application is usually timed to prevent the fungus from penetrating the plant surface.

Weeds, too, are more easily controlled during some stages of their growth. In general, it is usually true that weeds can be controlled most easily when they are small.

Timing is especially important when using biological controls for pest management. There is a species-specific appropriate time for release of live biological control agents. If you wait too long to release a particular biological agent, it may be too late to effectively manage the problem. The pest population may have increased to a point where it outpaces the biological control agent’s ability to control it before damage occurs.

Strategies for Pest Management

The methods for suppressing or preventing pest damage to plants include mechanical, cultural, biological, and chemical controls. There are numerous techniques within each of these categories.

Mechanical Control

This approach probably goes back to when man first saw a wild horse using its tail as a fly swatter. Mechanical control techniques involve some method of removal and physical destruction of the pest. The fly swatter was probably the earliest mechanical tool after simply stepping on or squishing insects. Some forms of mechanical control can be quite effective in many cases and often inexpensive. Mechanical control is most effective if implemented early in the season when pest populations are low.

Insect removal. A fairly strong stream of water can wash away aphids or pear slugs. This works well if the tree or shrub can be sprayed on both its upper and lower leaf surfaces. These insects cannot usually reinvade the host tree and often die stranded on the ground. Hand-removal of large caterpillars or hornworms from garden plants such as tomatoes works well for many gardeners. Pruning out the nests of webbing caterpillars and disposing of or destroying them is still another form of removal and physical destruction.

Insect Traps. Insect traps are considered to be a mechanical approach (Figure 3) and they're often used along with monitoring tools as mentioned earlier. If placed early enough, colored sticky traps like those used for detecting whiteflies can often adequately suppress a pest population. This is also true of pitfall traps and other traps used for monitoring. Sticky tree wraps are quite effective when used for certain migrating caterpillars.

Figure 3. Insect traps are considered a mechanical approach to pest management. This apple maggot trap is covered with insect stickum or glue and hung in an apple tree where it mimics a ripe apple, trapping any insects that land on it—pests and beneficials alike. (Photo courtesy of Michael Bush, PhD, WSU Yakima County Extension)

Electric "zapper traps" are not a recommended IPM tool for outdoors. They involve an ultraviolet light that attracts insects and an electrocution grid that kills them. When used outdoors

Figure 4. Lightweight row covers keep insects away from plants, which is a good thing unless bees are needed for pollination. Row covers can foil some vertebrate pests too, but moles, voles, and other burrowers can get under the covers and wreak havoc. Heavier material can be used for frost protection as well.

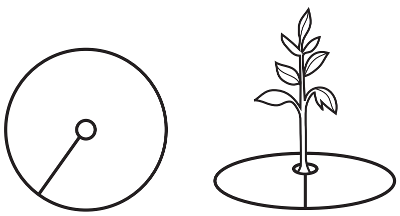

Figure 5. Female root maggot flies infest crops by laying eggs at the base of plants. Heavy paper discs keep them from depositing their eggs near protected plants.

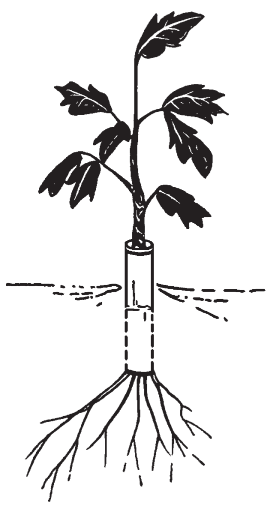

Figure 6. A 2-inch section of drinking straw, slit up the side and placed around the stem of a transplant, prevents cutworms from gnawing on the tender stem. As the stem grows broader, the split allows the straw to expand and not strangle the plant.

they attract many pest insects from long distances but they also attract and kill a huge number of beneficial insects.

Floating Row Covers. This very popular cultural method involves the use of light-weight spun material to prevent egg laying on or near several types of vegetables. This method was pioneered during some WSU organic gardening research many years ago (Figure 4). Some of the success stories include prevention of cabbage maggot establishment on cabbage, broccoli, turnips, and radishes, as well as preventing carrot rust fly on carrots and spinach leafminer on beets and spinach. Basically, this approach can be used on virtually any garden crop that doesn't require pollination by bees.

Insect Barriers. Variations of the floating row cover method may be pest- and plant-specific, such as using paper disks to keep root maggots from infesting the crowns of brassicas, radishes, and turnips (Figure 5). Similarly, drinking straws as collars on transplants can be effective barriers to cutworms (Figure 6).

Cultural Control

Cultural control techniques were probably the most common management strategies before pesticides were widely used. With cultural management, the plant or the environment, or both, are changed to make them less conducive for pest problems. Cultural management can include a variety of approaches.

Right Plant—Right Place. This philosophy encourages gardeners to choose plants that are well-suited to the region where they will be planted. Most plants have an ideal site or set of conditions in which they will flourish; if they are planted in a site without their preferred conditions, they become stressed and more prone to pest attacks. If a particular plant is known to have a serious pest problem in your area, don't plant it. For example, spruce does well in Eastern Washington and is relatively pest-free with one exception: coolley spruce gall adelgid, but in Western Washington, it is prone to attack by three serious pests: spruce spider mite, spruce aphid, and coolley spruce gall adelgid. Similarly, there are several other plant species that gardeners insist on planting, and they should reconsider. Always select plants that are suitable for the site.

If a particular plant is known to have a serious pest problem in your area, don't plant it.

Even if a plant is selected that is well-adapted to the region, it must also be suitable for the planting site. For example, if landscape plant species are planted in an appropriate site with proper drainage, adequate shade or sun exposure, etc., then we can predict a successful plant with the ability to tolerate some pest presence. However, all too often, gardeners inappropriately place new trees and shrubs in very wet soils where the plants are jeopardized by root rot and other problems. Conversely, if a tree or shrub that prefers a damp site gets placed in gravelly, well-drained soil, it may gradually decline, often being "attacked" by bark beetles along the way. Paying attention to the plant's preferred conditions and providing proper health care will go a long way in plant survival and the ability to avoid, or at least tolerate, certain pest species.

Plant Resistance. The use of resistant plant varieties to avoid several insects and many plant diseases is yet another cultural technique. There are quite a few landscape and garden plants that have shown resistance to some of our common insect and disease problems. Flowering crabapple is a desirable landscape tree, but is susceptible to powdery mildew and scab. Crabapple varieties that are resistant to these diseases were identified through research conducted at the WSU Mt. Vernon Northwestern Washington Research and Extension Center. Information on resistant varieties for Washington gardens and landscapes can be obtained from university resources and experienced nursery specialists.

Proper Planting Techniques and Dates. Many plants won't survive if they are improperly planted. During plant selection, check the plants for developing root problems, particularly in pot-bound plants. Plants with circling and girdling roots should be avoided, because those roots will continue to grow, encircling and strangling the root mass in a manner that will lead to drought stress. Planting dates can also affect pests and diseases, and plant susceptibility to them. For example, waiting until a later date so soil temperatures can rise or using floating row covers to raise soil temperatures can prevent some diseases of roots and seedlings.

Crop Rotation. Crop rotation is an age-old practice that still has value as a cultural method of pest management. Planting garden crops in the same spot year after year encourages the buildup of many diseases and arthropod pests. If you rotate the kind of plants in a particular place in your garden each year, you can suppress pest build-up or even stop it. This is particularly true with annual ornamentals or edible crops that are planted every year. See Chapter 6—Vegetables, for more information.

Pruning. Pruning can be considered a cultural method for disease management. When pruning is used to thin tree and shrub canopies, it increases air circulation and leaves dry more quickly. The environment in the canopy is then less conducive to the development of fungal diseases such as scab.

Roguing. Simple removal and destruction of problem plants that have chronic pest problems is known as **roguing** and is a viable cultural approach.

Induced Competition. This can be accomplished by establishing dense groundcovers that can outcompete weeds. Maintaining a weed-free vegetable garden will go a long way toward limiting unwanted pests.

Mulching. Another cultural strategy that shouldn't be overlooked is mulching to help suppress weeds. Mulch can be made of organic materials such as wood chips, wet newspaper covered with seasoned sawdust, or other wood products. There are also inorganic mulches available such as plastics and gravel or rock. Mulches can be an effective method of weed management. See Chapter 11—Trees & Woody Landscape Plants for a more detailed discussion of mulches and how to apply them.

Country Music. This is not considered a viable form of cultural control. While the loud playing of country music made the heads of Martian invaders explode in the movie Mars Attacks, it has not been scientifically proven to be an effective method of pest control and therefore cannot be recommended.

Biological Control

Biological control is primarily the use of living organisms to suppress other pest organisms. It can be done, for instance, by releasing herbivores such as goats to control noxious weeds or by releasing predator arthropods or parasitoids to control pest insects such as mites. There has been a history of success with the deliberate implementation of biological controls in the past century or so. One of the landmark cases is the introduction of the vedalia beetle to control cottony cushion scale on California citrus trees in the 1880s. But the history of biocontrol success goes back even further: in ancient times, the Egyptians employed cats for rodent control. In recent decades, biological control has become quite sophisticated and is frequently used in the IPM process as a primary means of pest control.

There are three main types of biological control: conservation, augmentation, and classical biocontrol.

Conservation Biocontrol. This method strives to protect non-target (non-pest) organisms that act as biological agents in places where they are already performing natural control. Improving habitat by incorporating blooming plants into landscapes and gardens to attract and support beneficial insects helps conserve agents. When using insecticides, a selective product should be chosen—one least likely to affect the natural population of predators and parasites, in order to protect existing agents.

Augmentation Biocontrol. This method enhances existing (usually native) beneficial insects by increasing their numbers or rejuvenating a dwindling population of a beneficial organism. Insects may be purchased for release to rejuvenate a local population and habitat can be improved to encourage their survival. Some prime examples of augmentation biocontrol include the addition of native green lacewings to suppress aphids and their relatives, and the use of wasp parasites to control many pests. Also, several insect-eating nematodes are effective in managing root weevil larvae.

Classical Biocontrol. This method is used when an invasive pest or foreign species becomes established in our country. Government agencies locate and import the natural enemies of this new pest from its land of origin. When required quarantine periods have passed and necessary screening is completed, the foreign beneficial is released into the infested area. A good example of classical biocontrol in the Pacific Northwest is the introduction of cinnabar moth. The cinnabar moth's larvae feed on tansy ragwort, a noxious weed.

Note that some beneficial insects are not good candidates for release on small tracts of land. Lady beetles are one example. Because of genetic programming, lady beetles must disperse after hibernation before they can settle down, mate, and lay eggs. Since they are normally collected during hibernation and sold before dispersal flight occurs, purchasers are usually chagrined by the disappearance of the flocks they just released – often occurring by the following day. To keep purchased lady beetles around, release small amounts of the beetles at a time in an enclosed space such as a greenhouse, cold frame, or under a row cover. This limits the area to which they can disperse while allowing them to follow their natural instincts.

Competitive Exclusion. For disease management, **competitive exclusion** uses certain beneficial bacteria or fungi to suppress pest organisms through competition for attachment sites on plants.

For example, crown gall (*Agrobacterium tumefaciens*) is an infectious disease that can be prevented by using a non-infective strain (*Agrobacterium radiobacter*) before the infectious strain invades. Infection sites are locked up or filled by the non-infective bacterial strain, thereby preventing the establishment of the infective strain.

Mating Disruption. This biologically based management method uses species-specific pheromones impregnated into twist ties or capsules. A number of these lures are placed in tree canopies to emit the equivalent of a cloud of sex lure scent that obscures the scent live females are emitting. This effect is called **male confusion** and it prevents males from successfully finding females, thereby preventing procreation of the next generation of pests.

Bee Warning

Many insecticides are highly toxic to honey bees, bumble bees, and other wild bees. Sevin is particularly hazardous to bees. It should not be used where bees are obviously foraging on blooming weeds or flowers.

Simple steps like removing (mowing) blooming clover should always be taken before applying materials hazardous to bees. Avoid using dusts if possible. Sprays are preferred for bee safety.

Chemical Control

Chemical control—the use of pesticides—can be a viable option in an IPM program or approach. When gardeners consider using a pesticide, they should first ask several questions.

- Am I really at a point where my plant will be in jeopardy?
- Is there a selective and environmentally friendly choice among the pesticides available?
- Is the pesticide safe for bees?
- Among those pesticides that are effective, which is the least hazardous chemical option?

When pesticides are used to manage diseases instead of insects, the approaches are somewhat different but the IPM goals are the same: a well-timed, least hazardous but still-effective application. Pest managers monitor pest populations and plant responses. If the numbers necessary for management action aren't reached, then spraying is avoided.

Complications

Several negative outcomes can result if pesticides are applied protectively and without monitoring. This approach may result in **pest resurgence** or **secondary pest explosion**. It could also result in the selection (development) of a resistant strain of the pest and development of other unnecessary environmental impacts. Pest resurgence and secondary pest explosions commonly occur when IPM is not used consistently.

Pest resurgence. This occurs when a broad-spectrum garden insecticide is used and, as usually happens, it fails to achieve 100% control. Not only does the broad-spectrum insecticide affect the target pest, but the application is harmful to the beneficial arthropods that otherwise might have suppressed the pest population and kept it below the damage threshold. The pesticide may kill the beneficial directly, or the beneficial may starve or leave because its food source (the primary pest) is no longer available. It may take a season or more for the beneficial insect population to recover and build back up to effective levels. If the target pest is a multiple-generation pest such as whiteflies, mites, or aphids, that pest population will continue to increase, often quickly rebounding to beyond where it was at the time of the original pesticide application (Figure 7). The gardener may have to continue applying pesticides for the rest of the growing season to keep the pest from destroying the crop. This illustrates the common saying: when you kill a beneficial insect, you inherit its work!

Remember, when you kill a beneficial insect, you inherit its work!

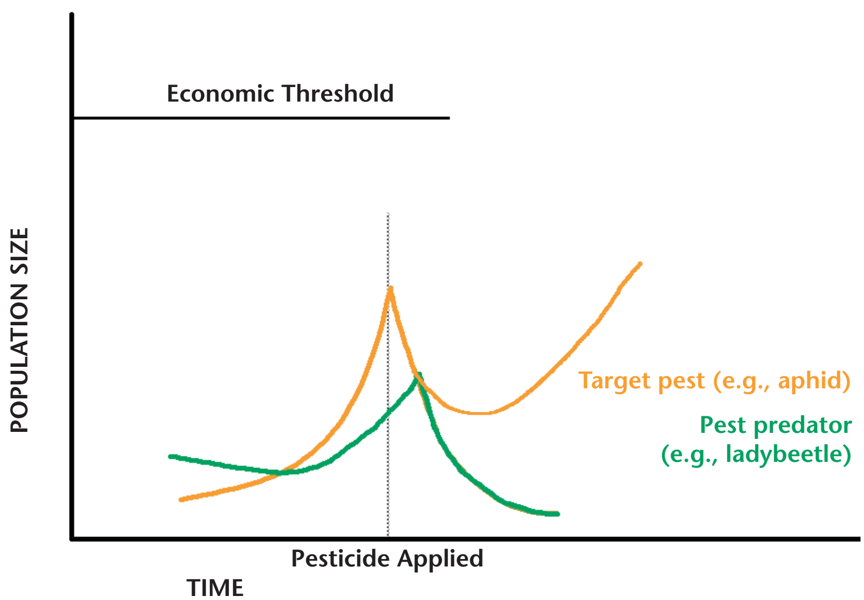

Figure 7. Pest resurgence occurs for a population after it has been targeted by a broad-spectrum pesticide that also kills the predators that had been keeping the target pest in check.

Secondary pest explosion. A secondary pest explosion or outbreak somewhat resembles a pest resurgence. It occurs when a gardener applies a broad-spectrum insecticide to a primary pest before its numbers threaten the crop (below the economic threshold). While the product may be effective on the target pest, it can also be quite effective in killing any beneficial predator insects that might be keeping other, unnoticed pest species in check as well. This can allow another (a secondary) pest to prosper because the beneficial insect that had been keeping it under control has been removed. Figure 8 illustrates an example of this. The graph documents a leafroller (primary pest) population and a separate, unrelated predator population and what happened as a result of improper insecticide application. The insecticide killed the predator as well as the target pest. Then, without the predator present, the spider mites (a previously undetected secondary pest) increased beyond tolerable numbers ("Economic threshold of secondary pest") and additional pesticide applications had to be made to control it. If a selective material had been used just to control the leafrollers, the spider mite predator would have been spared and continued to manage the spider mite population.

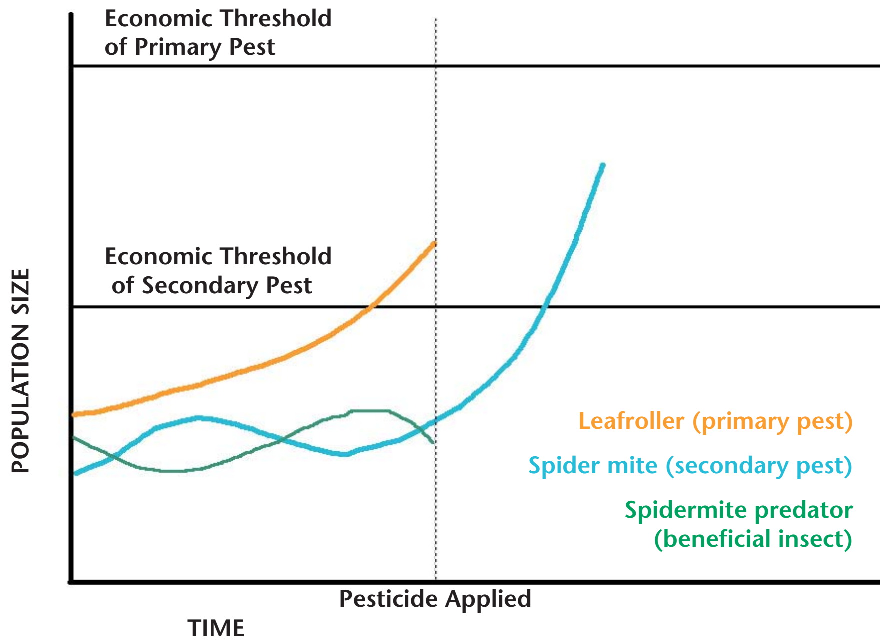

Figure 8. Population graph documenting a secondary pest outbreak. See text for discussion.

Pest Resistance. Since the inception of synthetic pesticides, improper use has led to hundreds of resistant pests, including weeds, insects, mites, and diseases. These strains have been selected by using the same pesticides over and over or by using the same class of pesticides repeatedly. We are now aware that resistance management must be practiced to prevent further development of resistant strains. Gardeners can practice resistance management by following a few simple rules.

- Be tolerant of a pest's presence when possible. Remember, it takes a certain number of pests to do intolerable damage.
- Use all of the available, effective IPM options when you need to manage a pest problem.
- Choose to apply pesticides only when necessary.
- Do not rely on the same class of pesticide, year after year.

If you choose to make pesticide applications, choose your products carefully and find one that will have the least impact on the environment and non-target organisms. Only buy ready-to-use premixed products, so that mixing of any solution and calibration of a sprayer are not necessary. Read all product label directions and follow them carefully. Practice “spot spraying” instead of treating all similar plants or the whole property. You may have only one rhododendron with the pest problem. Why spray the others if they’re not threatened by the target pest?

Summary

The PHC approach must include garden and landscape planning and consideration of plants’ needs. A proactive approach will go a long way in avoiding pest problems. If a pest problem arises, the gardener must get an accurate diagnosis of the problem and determine which IPM options are effective.

The IPM decision-making process is not always the same. Whatever strategies are used, it is important for the gardener to evaluate the strategies after using them and determine how well they worked. Keeping good records is essential for useful evaluation of results. Gardeners must also take advantage of educational opportunities to further their knowledge of new IPM developments.

And remember, the outcome of a successful IPM approach is to suppress pest populations, not necessarily to eradicate them. It is usually not practical to eradicate a pest. Eradication is usually only attempted when a new invasive species arrives. Once pests are established, our management goals are to successfully suppress the pests below damaging levels while minimizing impacts on the environment.

Further Reading

WSU Extension Publications available at: http://cru84.cahe.wsu.edu/

Approved References for Pest Management Recommendations for WSU Extension Master Gardener Volunteers. http://mastergardener.wsu.edu/documents/WSUExtensionMasterGardenerVolunteerApprovedReferencesforPestManagementRecommendations.pdf.

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Understanding Pesticides

Topics covered:

- Introduction
    - Defining "Pesticide"
- Pesticides and the Law
    - Understanding a Pesticide Label
        - Directions for Use
        - Product Brand Name
        - Active Ingredient Statement
        - Signal Words and Symbols
        - Statement of Practical Treatment
        - Precautionary Statements
        - Environmental Hazards
- Pesticide Toxicity
- Pesticide Selection
- Safe, Effective Applications
- Safe Pesticide Handling
    - Safe Transport
    - Safe Storage
    - Safe Disposal
    - Pesticide Spills
- First Aid
- Checklist for Pesticide Purchase and Use

Learning Objectives

- Know the terms related to pesticide products, labels, and effects
- Understand the pesticide labeling process, information, and laws
- Know proper application methods, timing, rates, and handling of pesticides
- Understand that "organic" does not always mean "less toxic"—some organic pest control products can be as lethal or more lethal to beneficial organisms than synthetic ones

By

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Introduction

Pesticides are but one tool in your integrated pest management (IPM, Chapter 19) toolbox. Pesticides are commonly selected when insects, weeds, or plant disease conditions warrant corrective measures that cultural, biological, and mechanical practices did not remedy. Sometimes pesticides may be used as a preventive treatment to manage key insects or diseases on host plants, or for weed management when establishing new lawns or landscape plantings. This chapter addresses basic pesticide facts and how the pesticide label provides the key information for safe and effective use.

The goal of pesticide use within an integrated pest management program is to manage pest populations so they stay at low, tolerable levels (thresholds). Pest tolerance levels vary, depending on the site and people's own desires for their landscapes or gardens. The proper selection, handling, and use of a pesticide provides for both effective pest control and environmental protection. If you select the wrong product or do not follow all directions related to use and timing, you may not achieve effective control and could potentially make your pest problems worse.

When you decide to use a pesticide in your IPM program, it is imperative that you understand what the pesticide is and how to read a pesticide label. This will ensure that you make the proper pesticide choice and that you achieve the most effective pest management in your garden or landscape. Additionally, anyone possessing, handling, or applying a pesticide is responsible and can be held liable for any damage, loss, or unintended consequences to humans or the environment that the pesticide may cause. Handling and applying pesticides requires knowledge, care, and good judgment.

Always read the pesticide label.

The single most important point in this chapter is to **ALWAYS READ THE PESTICIDE LABEL**. Read the pesticide label before you buy the pesticide, before you mix the pesticide, before you apply the pesticide, and finally before you store or dispose of the pesticide and the pesticide container.

Defining "Pesticide"

Pesticides (*pest*-nuisance, *icide*-kill or strike) control, destroy or repel pests. When using the term pest, we include weeds, insects, rodents, birds, fungi, germs, or other organisms that are annoying, unsightly, harmful to health, or cause crop, consumable product or household loss or damage. Thus, a pesticide is any product (man-made or natural) that a manufacturer claims controls, destroys, or even repels a target pest.

It is incorrect to use the terms "pesticide" and "insecticide" as synonyms, since insecticides are only one type of pesticide. Table 1 lists just a few of the many types of pesticides and their respective target pests. For more information on recognizing and treating specific types of pests, see Chapters 14, 15, 17, 18, and 19. Chapter 15 also explains how to distinguish between biotic and abiotic damage.

Table 1: Types of pests controlled by various pesticides.

Type of Pesticide	Type of Pest Controlled
antimicrobial/disinfectant	germs
bactericide	bacteria
fungicide	fungi
herbicide	weeds
insecticide	insects
miticide	mites
molluscicide	slugs and snails
nematicide	nematode
rodenticide	rodents

One common misconception is that organic/natural pesticides are "safer" than man-made or synthetic pesticides. Today, a number of man-made pesticides pose lower risks than do natural/organic pesticides. Another common misconception is that home remedies are legal, cheap, and safer than commercially produced products. They are not legal and, depending on the ingredients, may be more dangerous than products which have passed regulatory approval. And practically speaking, there is nothing inexpensive about having untested, potentially toxic materials with no safety or use instructions lying around the home.

Keep in mind that regardless of the origin of a pesticide, whether extracted from nature (for instance, *Bacillus thuringiensis* bacteria, "Bt") or man-made (such as malathion), all pesticide active ingredients undergo the same federally required screening for potential adverse effects on humans, domestic animals, wildlife, and the environment. The hazards that become evident during the pesticide screening process are clearly indicated on product labels. Evaluate any product considered for your IPM program by reading the information found on the product label and make sure that product has been fully reviewed and approved by the U.S. Environmental Protection Agency (EPA).

In Washington State, a pesticide can only be used on a target host plant or landscape site that is specifically noted on the product label. Any use of the product on a target host plant or site that is not on the label is illegal.

In Washington State, a pesticide can only be used on a target host plant or landscape site that is specifically noted on the product label.

Pesticides and the Law

Protection of people and the environment from harmful effects of pesticides is based primarily on three factors.

The ORTHO Group
P.O. Box 1749
Columbus, OH 43216
Form AC000806010
EPA Reg. No. 239-2679

Figure 1. An EPA registration number on a product label indicates a product has been screened and approved by the EPA.

By law, people who use pesticides must read, understand, and follow label directions.

Any violation of pesticide label directions is a violation of both state and federal law.

1. Pesticides must meet federal review standards as administered by the EPA before they can be sold or applied. Once pesticides meet the standards and have appropriate label information, they are officially registered by the EPA for use and are given an EPA registration number. Pesticides also must be registered by the Washington State Department of Agriculture for distribution and use in Washington. The best way to ensure a product has been reviewed for its potential adverse effects on human health and the environment is to look for the US EPA registration number on the product container label.
2. The EPA requires each registered product be extensively tested for potential adverse health effects for humans and domestic animals, and for environmental impacts such as water quality and effects on beneficial insects, fish, and wildlife. Pesticide labels are developed (and EPA-approved) to inform people who handle them about safe and proper use of the product, to warn about potential risks, and to recommend methods to avoid risks.
3. Directions for use and safety precautions are all stated on the label and **THE LABEL IS THE LAW**. Any violation of the label directions is a violation of both state and federal law. The label is quite specific about where a pesticide can be legally used, how much can legally be applied and how often.

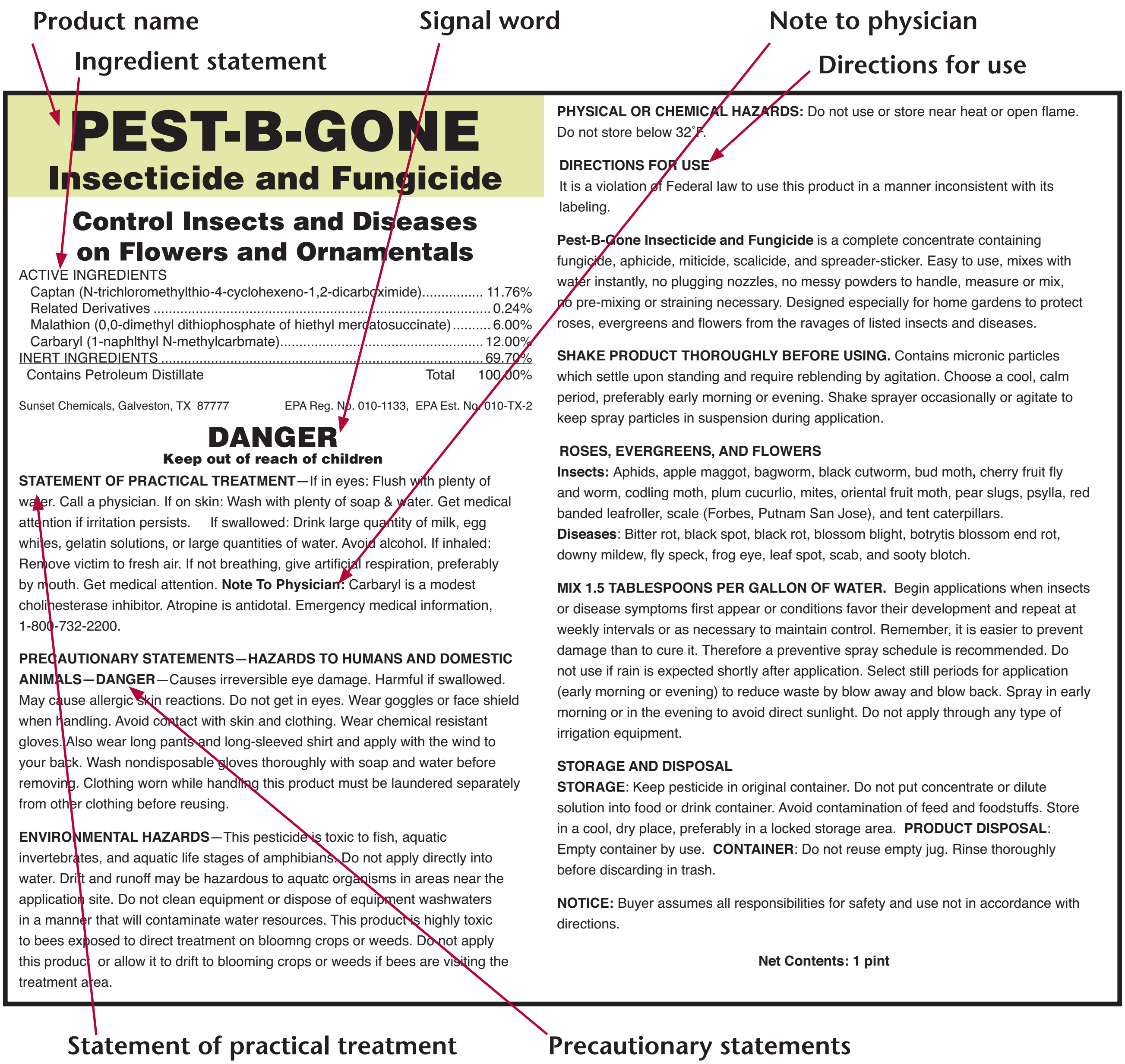
Understanding a Pesticide Label

By law, certain kinds of information must appear on a pesticide label (Figure 2). People who use pesticides have a legal responsibility to read, understand and follow the label directions. Besides a legal responsibility to read the label, it just makes sense to read the label to learn as much as you can about a product you are about to use. The label includes the printed material affixed to the pesticide container and any accompanying booklets.

Directions for Use. This section of the label begins with the statement, "It is a violation of Federal law to use this product in a manner inconsistent with its labeling." Read the rest of this portion of the label first to see where the product can be legally applied and what pests it controls. It also gives explicit instructions on how to mix and apply the pesticide. Other, equally important information that should be included in your IPM decision-making and that you need to understand prior to selecting a pesticide product include the product's name, active ingredients, and human health and safety precautions.

Product Brand name. Every pesticide has a **product brand name**, sometimes referred to as a **trade name**. Examples of some product brand names include Off! Deep Woods® insect repellent, Black Flag Roach Motel®, Lysol® brand disinfectant,

Figure 2. Sample pesticide label with some of the specifically required label elements noted.



PEST-B-GONE
Insecticide and Fungicide

Control Insects and Diseases on Flowers and Ornamentals

ACTIVE INGREDIENTS
Captan (N-trichloromethylthio-4-cyclohexeno-1,2-dicarboximide)................ 11.76%
Related Derivatives 0.24%
Malathion (0,0-dimethyl dithiophosphate of hiethyl mercatosuccinate) 6.00%
Carbaryl (1-naphlthyl N-methylcarbmate)........ 12.00%
INERT INGREDIENTS 69.70%
Contains Petroleum Distillate Total 100.00%

Sunset Chemicals, Galveston, TX 87777 EPA Reg. No. 010-1133, EPA Est. No. 010-TX-2

DANGER
Keep out of reach of children

STATEMENT OF PRACTICAL TREATMENT—If in eyes: Flush with plenty of water. Call a physician. If on skin: Wash with plenty of soap & water. Get medical attention if irritation persists. If swallowed: Drink large quantity of milk, egg whites, gelatin solutions, or large quantities of water. Avoid alcohol. If inhaled: Remove victim to fresh air. If not breathing, give artificial respiration, preferably by mouth. Get medical attention. **Note To Physician:** Carbaryl is a modest cholinesterase inhibitor. Atropine is antidotal. Emergency medical information, 1-800-732-2200.

PRECAUTIONARY STATEMENTS—HAZARDS TO HUMANS AND DOMESTIC ANIMALS—DANGER—Causes irreversible eye damage. Harmful if swallowed. May cause allergic skin reactions. Do not get in eyes. Wear goggles or face shield when handling. Avoid contact with skin and clothing. Wear chemical resistant gloves. Also wear long pants and long-sleeved shirt and apply with the wind to your back. Wash nondisposable gloves thoroughly with soap and water before removing. Clothing worn while handling this product must be laundered separately from other clothing before reusing.

ENVIRONMENTAL HAZARDS—This pesticide is toxic to fish, aquatic invertebrates, and aquatic life stages of amphibians. Do not apply directly into water. Drift and runoff may be hazardous to aquatc organisms in areas near the application site. Do not clean equipment or dispose of equipment washwaters in a manner that will contaminate water resources. This product is highly toxic to bees exposed to direct treatment on bloomng crops or weeds. Do not apply this product or allow it to drift to blooming crops or weeds if bees are visiting the treatment area.

PHYSICAL OR CHEMICAL HAZARDS: Do not use or store near heat or open flame. Do not store below 32˚F.

DIRECTIONS FOR USE
It is a violation of Federal law to use this product in a manner inconsistent with its labeling.

Pest-B-Gone Insecticide and Fungicide is a complete concentrate containing fungicide, aphicide, miticide, scalicide, and spreader-sticker. Easy to use, mixes with water instantly, no plugging nozzles, no messy powders to handle, measure or mix, no pre-mixing or straining necessary. Designed especially for home gardens to protect roses, evergreens and flowers from the ravages of listed insects and diseases.

SHAKE PRODUCT THOROUGHLY BEFORE USING. Contains micronic particles which settle upon standing and require reblending by agitation. Choose a cool, calm period, preferably early morning or evening. Shake sprayer occasionally or agitate to keep spray particles in suspension during application.

ROSES, EVERGREENS, AND FLOWERS
Insects: Aphids, apple maggot, bagworm, black cutworm, bud moth, cherry fruit fly and worm, codling moth, plum cucurlio, mites, oriental fruit moth, pear slugs, psylla, red banded leafroller, scale (Forbes, Putnam San Jose), and tent caterpillars.
Diseases: Bitter rot, black spot, black rot, blossom blight, botrytis blossom end rot, downy mildew, fly speck, frog eye, leaf spot, scab, and sooty blotch.

MIX 1.5 TABLESPOONS PER GALLON OF WATER. Begin applications when insects or disease symptoms first appear or conditions favor their development and repeat at weekly intervals or as necessary to maintain control. Remember, it is easier to prevent damage than to cure it. Therefore a preventive spray schedule is recommended. Do not use if rain is expected shortly after application. Select still periods for application (early morning or evening) to reduce waste by blow away and blow back. Spray in early morning or in the evening to avoid direct sunlight. Do not apply through any type of irrigation equipment.

STORAGE AND DISPOSAL
STORAGE: Keep pesticide in original container. Do not put concentrate or dilute solution into food or drink container. Avoid contamination of feed and foodstuffs. Store in a cool, dry place, preferably in a locked storage area. **PRODUCT DISPOSAL**: Empty container by use. **CONTAINER**: Do not reuse empty jug. Rinse thoroughly before discarding in trash.

NOTICE: Buyer assumes all responsibilities for safety and use not in accordance with directions.

Net Contents: 1 pint

Roundup® herbicide, and Hi-lex® bleach. Some plant protection guides indicate a specific brand name; however, others refer to the pesticide by its active ingredient which means that you need to do more label reading and investigate the active ingredient section to find out if the product has the correct active ingredient for your target pest.

Active Ingredient Statement. Every pesticide label must specifically list any and all active ingredients and their amounts in the product. Some products may contain more than one active ingredient. An active ingredient is the actual chemical that controls the pest. The active ingredient may have a common (or generic) name, such as glyphosate or malathion. Other ingredients are added to a product formulation to aid mixing, safety and product effectiveness; these additives are lumped into the inert ingredients percentage and not listed individually, as in this example:

Active Ingredient	
malathion	32%
carbaryl	10%
inert ingredients	58%
Total	100%

Often garden magazines recommend certain pesticides by providing the reader with the common name of an active ingredient (for example, captan, a fungicide; malathion and carbaryl, insecticides; and glyphosate, an herbicide) instead of recommending a specific brand name product. In that case, a person has to read the labels to find out which products 1) contain the active ingredient noted in the article, and 2) are registered for use on the target host plant or landscape site where they plan to use it. Many different pesticides contain the same active ingredient. By purchasing pesticides according to the common or chemical name you are sure to get the active ingredient you want, no matter what the trade name or formulation.

Signal Words and Symbols. Pesticides may be toxic to humans by being corrosive or irritating to skin and eyes, or by causing illness. A signal word on the label (Figure 2) indicates the product toxicity to humans from a single exposure. This signal word is the best initial indicator of the hazard a product poses to humans. It is important that you know and differentiate these four signal words. The toxicity of a product (signal word) and your own actions of personal protection from exposure determine the hazard that a pesticide poses to you.

- **DANGER-POISON** along with a skull-and-crossbones symbol are found on products that are highly toxic and potentially deadly even at low doses. The words "Danger-Poison" always are printed in red ink. There are very few products in the home and garden market that carry these signal words, and most of those are rodenticides. There are other household products, such as the older formulations of antifreeze, that carry "Danger-Poison" and are deadly at low doses.
- **DANGER** (single word only) products are corrosive and can cause irreversible eye damage or severe skin injury. It is important to distinguish "Danger" from "Danger-Poison" because their adverse effects are very different—an exposure to a very small amount of one can cause blindness (Danger), while a small exposure to the other can kill you (Danger-Poison). Again, there are few home and garden pesticides with "Danger" signal words; however, many other household chemicals carry the

signal word "Danger" for eye injury and corrosiveness (for example, gasoline).

- **WARNING** products are moderately toxic or may cause moderate eye or skin irritation when these sensitive tissues are exposed. You can tell whether the concern is due to causing irritation or eye damage or causing illness by reading the precautionary statement section elsewhere on the label.
- **CAUTION** products are slightly toxic or may cause slight eye or skin irritation when body parts are exposed to a significant amount of the product.

Note: Bleach, liquid soap, furniture polish, gasoline, and antifreeze are examples of household chemicals that have hazards similar to pesticides; some are quite dangerous and require special handling, while others are much less harmful. Signal words and precautionary statements on labels of all household chemicals indicate product hazards and how to handle them safely.

Statement of Practical Treatment and the Note to Physician section of the label provide information on the first aid treatment for someone accidentally exposed to that particular pesticide. These label sections may contain poison antidote information and often provide an emergency phone contact for further information.

Other important numbers are for Poison Control in case of any exposure, and the National Pesticide Information Center, which is a clearing house for pesticide information.

National Poison Control
1-800-222-1212

National Pesticide Information Center
1-800-858-7378
http://npic.orst.edu

Washington State Poison Control
1-800-222-1222

Note that first aid treatments can be started immediately by the injured person or a bystander, or the injured person may require treatment by emergency medical personnel or a physician with poison treatment information. See the section on first aid, below, for specific actions to take.

Precautionary Statements. These statements identify potential hazards and recommend ways to minimize or avoid risks. There may be several sections of these statements.

Types of precautionary statements include:

- **Hazards to Humans and Domestic Animals.** With this, the signal word is listed, followed by statements indicating which route(s) of entry (mouth, skin, lungs, eyes) is the most likely to result in harmful exposure. This directly

Signal words and precautionary statements on labels of all household chemicals indicate product hazards and how to handle them safely.

National Poison Control
1-800-222-1212

National Pesticide Information Center
1-800-858-7378
http://npic.orst.edu

Washington State Poison Control
1-800-222-1222

tells the pesticide handlers which parts of the body must be protected. The label also indicates whether the major concern is irritation, corrosiveness, or illness. The label specifies actions that can prevent overexposure to the pesticide, such as wearing required protective clothing and equipment during the application.

- **Environmental Hazards.** This section of the label warns of pesticide risks to wildlife, birds, fish, bees, or to the environment, including water quality. It provides practical ways to avoid harm to organisms and the environment. Bee precautions are common on labels of insecticides that can kill your pollinators. Other precautionary statements to protect the environment can be found in the Directions for Use section of the label (drift, run-off, plant damage, temperature extremes, etc.)
- **Physical or Chemical Hazards.** This section of the label warns of any special fire, explosive, or chemical hazards the product may pose.

Pesticide Toxicity

As indicated by the signal words, pesticides can cause physical injury to skin or eyes and can cause illness. Accidents most commonly occur with children who gain access to products that are improperly stored. Because children are small, the dose required to have adverse symptoms is much lower than the dose required to harm an adult. Even adults can have adverse reactions if they do not heed the precautionary statements on the label and do not protect themselves from exposure or do not clean up properly afterwards.

The major routes by which people are exposed to pesticides are skin, eyes, inhalation, swallowing. The skin is the most commonly exposed area. However, the skin provides a fairly good barrier in most instances. Consider wearing long-sleeved shirt, long pants, and gloves to cover most of your skin.

Some products pose significant risks to the eyes due to their corrosive nature, so handle products in such a manner that you do not splash material or allow fine droplets to reach your eyes.

Breathing fumes and small droplets can pose problems in a few instances. Read the label to see if this route of exposure poses a risk.

Lastly, swallowing is not generally a problem for those who are using the pesticides but poses significant risk for those who do not realize that the item is not a food. Proper storage is the key to ensuring people, especially children, do not get access to pesticides.

Chronic effects (long-term exposures to low doses) are studied by the EPA when reviewing product registration and labeling. If a product has significant potential to cause chronic effects, the label lists this concern in the precautionary statements section.

Human symptoms of exposure vary a lot among pesticides, especially if an individual has an allergy. Herbicide injury is typically a skin reddening or rash, but some nausea can occur. Insecticide poisoning can cause mild fatigue, headache, nausea, dizziness, cramps, and diarrhea, or can cause moderate symptoms like weakness, muscle twitching, constricted pupils, and chest discomfort. Severe insecticide poisoning symptoms are coma and convulsions. Fumigants and solvents can make a person appear drunk with poor coordination, slurred speech, confusion, and sleepiness.

Illness or skin/eye injury resulting from a pesticide exposure occurs within 4 to 12 hours. If symptoms show up more than 12 hours after a pesticide exposure, some other illness or contaminant is more likely responsible. If you have used a pesticide and have symptoms develop within 12 hours, contact your medical provider.

There are a few additional safety-related terms you need to know. These terms are used on labels and describe further protection for people.

- **Restricted entry interval** is a specified time period immediately following the pesticide application when no one should enter a treated area. If the label states a restricted entry interval for 4 hours, keep people out of the area for those first four hours. If nothing is stated, it is safe for people and pets to reenter when the sprays have dried and the dusts have settled.
- **Pre-harvest interval** is a time period after an application that allows pesticide residues to degrade prior to harvest to ensure that the residue levels at harvest-time are safe. (It is still a good idea to wash your fruits and vegetables prior to consumption.) For example, if you applied a product to apples that had a pre-harvest interval of 7 days, you need to wait a full seven days after the application prior to picking the fruit.

Pesticide Selection

Legally, you must only use a product on the target host plant or landscape site listed on the label—no exceptions. In addition to making sure you have a product that can be legally used on a site, you need to evaluate the product to ensure:

1) the product controls the target pest;
2) you can apply the product according to label-stated timing;

3) you understand the product's hazard to humans and the environment;
4) you have the appropriate application equipment;
5) you know how to mix when necessary and calibrate the application equipment; and
6) you know how much you need in one season.

Until you are truly prepared to address each of these issues, you are not ready to purchase a product.

To ensure you find a product that legally can be applied to the site and that controls the target pest, there are numerous resources available: the Hortsense Web site, lawn and garden books and magazines, and WSU Extension bulletins.

Hortsense plant problem fact sheets are the best Northwest resource; they not only discuss pesticides, but provide cultural and mechanical pest control methods first (http://pep.wsu.edu/hortsense/). The pesticides listed in Hortsense have been screened by WSU Extension and research staff to ensure that 1) they are registered in Washington and 2) are appropriate for control of the specified pests on the noted host. Hortsense provides recommendations by active ingredient and lists a sample of brand name products that contain that active ingredient. (Chapter 17 also provides a list and basic information on some common herbicides.)

Table 2. Useful conversions.

Volume		
3 teaspoons	=	1 tablespoon
2 tablespoons	=	1 fluid ounce
4 tablespoons	=	¼ cup
8 fluid ounces	=	1 cup
2 cups	=	1 pint
2 pints	=	1 quart
4 quarts	=	1 gallon
Area		
9 square feet	=	1 square yard
43,560 sq. feet	=	1 acre
Mass		
16 ounces	=	1 pound

When selecting pesticides you have a choice of container sizes to purchase (big versus small container). Buy only the amount you need for one growing season. Too often people purchase larger volumes thinking they are economizing, when in reality they do not use all of the product and end up disposing of it through a household hazardous waste program. Be conscientious of the environment, and buy only what is needed.

It is a good choice to purchase ready-to-use products rather than concentrated products that require mixing with water. Ready-to-use products require no mixing and in most instances require no calibration of application equipment. You can easily achieve effective pest control with ready-to-use products.

When you purchase products that require mixing you must have the proper application equipment and be confident that you can determine how to accurately measure the appropriate dose, which may require conversion of measuring units (Table 2). Make sure you apply the correct dose that controls the pest and do not go over the allowed application rate specified on the label.

Pesticide products come as liquids, dry material that is mixed with water, and those applied in dry form. Those applied in dry form require different application equipment than those applied as liquid sprays.

Some products require a fair amount of time and effort to calibrate your application equipment to ensure that you apply the proper rate to the target host or site. For these products the user must calibrate the application equipment to determine how much spray is delivered per area, say 100 square feet, and then mix in the appropriate amount of product for each unit area the equipment is going to cover. For some people, these calculations are bothersome or difficult. Nevertheless, gardeners must work through these calculations to avoid under applying (poor efficacy) or over applying their pesticides (environmental contamination, plant damage, and legal liability).

Safe, Effective Applications

Every pesticide label has explicit directions so the user knows where to apply the product, how much to apply, and the proper timing and placement of the pesticide. This information is generally found in the Directions for Use section of the pesticide label. Additionally, some pesticides are known to cause harm under certain circumstances, so the label states prohibited acts and precautions to make certain that no unreasonable adverse effects occur such as drift, run-off, and plant damage.

Common environmental problems occur with soil- or lawn-applied pesticides or fertilizers when subsequent rain or irrigation washes the chemicals off the target site and into waterways and fish-bearing waters. It is important to monitor for rain/irrigation and time your application so that you prevent water contamination (see Chapter 5 for more information on the proper application of nutrients). Some insecticide products pose a low hazard to bees—again something you should consider during your IPM decision-making.

Before applying a pesticide, make sure that the pest problem has been accurately diagnosed, and try all reasonable cultural control methods first. If those fail, or are not applicable to your situation, choose pesticide products with active ingredients that are appropriate for managing the specific pest. In some cases the best approach may turn out to be a combination of cultural and chemical methods.

The label may outline a range of application rates for a single pest dependent on infestation levels (low, medium, high) and the pest growth stage (young, mature). If you have low infestation levels or very young pests, the low dose typically is sufficient. For high population levels or mature pests, use the high dose.

Alternatively, the label may list a single application dose for each site or target host. If so, adhere to that single rate. Applying pesticides at rates greater than those listed on the label (for example using 3 ounces of product on your apple trees to kill aphids when the label says use 1 ounce) is not only illegal, it can also damage desirable vegetation and kill beneficial organisms.

The label may outline application rates that differ due to the species of pest. For example, a higher dose may be listed for a perennial weed like Canada thistle than for an annual weed like lambsquarters.

Timing the application is critical to ensure effective control. Timing is usually directly related to the life stage of the pest. With insects, you may need to target the larval stage of one pest, while targeting the adult of another species. Weed control is also dependent on proper timing of pesticide applications; some herbicides are applied prior to weed seed germination (pre-emergence) while others are applied to the soil or foliage after the weeds are growing (post-emergence). Chapter 17 provides a more in-depth discussion of weeds and weed management.

Fungicides must be applied before the onset of disease symptoms. Hortsense notes special timing for pesticides, but it is always important to read the specific label for each product and only apply pesticides when they are effective at controlling the target pest.

Another key application principle for achieving pest control success is the proper placement of a pesticide. Some insecticides and herbicides must be incorporated into the soil to become active and available to the plants. Incorporation can be achieved by light cultivation, irrigation, or rainfall.

If you only have a small patch of weeds in one area of the yard, treat only that area. Do not spray the entire yard. The same goes for an infestation of insects in a tree. Treat only the affected area. This protects natural enemies, keeps extra pesticide out of the environment, and saves money.

There are a few more terms you need to know because they are used on labels and describe how a pesticide functions. Understanding these terms will help ensure you use a pesticide in a way that will effectively treat the target pest.

- **systemic.** a chemical applied to a host plant that moves through the plant's vascular system, such as an insecticide absorbed by the roots or foliage of a tree that kills aphids when they ingest the insecticide by feeding on the leaves.
- **translocated.** a chemical applied to a pest plant and moved through its vascular system, such as herbicides that enter the roots or foliage and are moved to the growing points and roots to control the (susceptible) pest plant species from the inside.
- **selective.** a chemical that kills only certain species of plants, insects, or fungi, but does not harm other species; for example, the insecticide *Bacillus thuringiensis* (Bt) that controls caterpillar species, but not bees and parasitic wasps; or 2,4-D, which selectively controls broadleaf plants while not injuring grass species.
- **nonselective.** a chemical that kills all species; for example, the herbicide Roundup®, which kills any green tissue of any plant.

Safe Pesticide Handling

As the pesticide handler, you are the decision-maker regarding risk. You select the product based on its toxicity (as indicated by the label signal words and precautionary statements) and your exposure. If you select a more toxic product, take the extra precautions to protect yourself from exposure (wear a long-sleeved shirt, long pants, closed shoes, gloves, and a hat). The label may specify what personal protective clothing or equipment you should wear. Avoid wearing soft contact lenses when dealing with pesticides. They may trap material between your eye and the lens.

You also are in control of your personal hygiene and it is important to wash your hands (and any other body parts that come in contact with the pesticide) after handling a pesticide, because your contaminated gloves or hands transfer residues into your home and onto your children or pets. Do not eat, drink, or smoke while using pesticides. Clean your equipment carefully so that you and the environment do not become contaminated; apply your equipment rinse-waters back on to your application site.

Be prepared for emergencies by knowing where the pesticide label is, and be familiar with its first aid statements. Also post your medical provider's phone number and the National Poison Control Center phone numbers near your phones.

Read the precautions listed in the label's Environmental Hazard section and Directions for Use section regarding protections for fish, animals, and beneficial insects. Adhere to the guidelines regarding wind direction and speed to ensure no off-target drift of spray droplets occurs. Irrigate carefully after any application, and don't apply pesticides when rain is expected to ensure you do not wash pesticides into our waterways.

When making any application, keep children and pets away. Do not allow them to enter a treated area until the sprays have dried, the dusts have settled, or the restricted entry interval has passed. Consider what items might end up with pesticide residues after a landscape application—you may want to wash children's toys, picnic tables, or other lawn ornaments and furniture. Check your neighbors' yards and, if appropriate, advise them of your intention to spray so they can keep their kids and pets inside while you make the application.

Keep your eyes open and be aware of your surroundings the entire time you make the application. Things can happen unexpectedly that require you to stop and wait for a better time.

Mix only what you need for that single application. Some products do not store well once mixed.

Safe Transport

When you purchase your pesticides from a store, separate them into a different bag from the groceries. Protect bottles by wrapping them to reduce the chance of breakage if they fall over or crash together. Secure containers upright to make sure they cannot fall or be knocked over. It is best to transport them in the trunk of the car, away from people and groceries.

Safe Storage

Never put pesticides in soft-drink bottles or other containers.

Store pesticides in such a manner as to eliminate access by children and pets. Place them four feet off the ground, preferably in a locked and labeled cabinet. This area should be dry and well-ventilated. Children are the most common victims of pesticide poisoning. They can ingest chemicals or get them in their eyes and on their skin.

NEVER PUT PESTICIDES IN SOFT-DRINK BOTTLES OR OTHER CONTAINERS. Never store pesticides with food or medical supplies. Store pesticides in their original containers and apply transparent tape over the label to keep it legible. Check pesticide containers periodically for leaks, corrosion, breaks, tears, or rust. If a container is broken, take it to your local household hazardous waste collection site.

Safe Disposal

Avoid disposal problems! Purchase only what you need. Never flush unused pesticides down the toilet, sink, or storm drain. Improper disposal can harm aquatic plants and wildlife. Empty containers as thoroughly as possible in your last application and then discard the containers into your household waste, or as directed on the label. Do not reuse empty pesticide containers.

Never attempt to burn pesticide containers in the fireplace, woodstove, or burn barrel. Do not put containers in trash compactors. Always follow label directions for disposal.

Pesticide Spills

Know what is spilled in order to recognize the hazard. At a minimum, wear gloves when cleaning up spills. If a spill occurs, clean it up promptly. Do not leave the spill unattended. If help is necessary, send someone else to get assistance.

DO NOT WASH A GROUND SPILL AWAY—runoff can damage non-target plants or pollute surface and groundwater. Sprinkle spills with sawdust or kitty litter. Sweep the mixture into a plastic garbage bag and dispose of it as directed in the label's Safe Disposal section.

If you spill pesticide on yourself, wash it off immediately with soap and water, or as the label instructs.

First Aid

In the case of an accidental pesticide exposure, do basic first aid and **GET MEDICAL HELP IMMEDIATELY!** Check the product label for first aid information.

In general:

- If a pesticide spills on clothes or skin, remove contaminated clothing and wash the affected body area with soap and water. Bag the contaminated clothing and discard the clothing at a household hazardous waste facility or turn-in event.
- When a pesticide gets into the eyes, flush the eye slowly and gently with water for 10 to 15 minutes.
- When someone inhales pesticide vapor, move the individual to fresh air.
- If someone is not breathing, give artificial respiration—unless they have swallowed the pesticide.
- Read the pesticide label to find out if you should induce vomiting.

Always:

1) Stop the victim's exposure to the toxicant by removing contaminated clothing, and/or rinsing exposed skin and eyes.
2) If the toxicant was swallowed by the victim, check the pesticide label and follow the instructions regarding whether or not to induce vomiting.
3) Move the victim outside into fresh air if victim was exposed to contaminated air in a poorly ventilated room.

Unless you are trained in first aid, do not administer anything (food, liquid, or medicine) to an exposed person unless expressly instructed to by the product label or medical personnel. Contact medical personnel to follow up the initial first aid treatment.

Checklist for Pesticide Purchase and Use

Before you buy a pesticide, read the pesticide label to determine:

- where the pesticide can and cannot be applied
- if the pesticide controls the target pest or pests
- what hazard it poses to you
- if the pesticide can be applied safely and legally under the application conditions
- necessary application and safety equipment
- amount of pesticide needed for the application (buy only the amount needed)
- relevant restrictions for use of the pesticide

Compare different pesticide labels. Several different products often can control the same pest on the same site. Comparing the labels, their precautionary statements, and product prices helps you select the product that controls the pest and is less toxic to humans or the environment.

Before you mix the pesticide, read the label to determine the following:

- protective equipment you should wear
- amount of the pesticide to use
- mixing procedure

Before you apply the pesticide, read the label to learn:

- safety measures you should follow
- procedures that minimize potential harm to people, animals, plants and the environment
- how to apply the pesticide
- when and where to apply the pesticide

- the restricted entry interval
- the pre-harvest interval

Before you store or dispose of the pesticide or pesticide container, read the label to determine:

- where and how to store the pesticide
- how to decontaminate and dispose of the pesticide container
- where and how to dispose of surplus pesticide

For More Information

National Poison Control Center: 800-222-1222

National Pesticide Information Center: 1-800-858-7378. http://npic.orst.edu.

Further Reading

WSU Extension Publications available at: http://cru84.cahe.wsu.edu/

National Pesticide Information Center. 1-800-858-7378. http://npic.orst.edu/.

Foss, C. and A. Antonelli. 2009. Hortsense: Home gardener fact sheets for managing plant problems with IPM or Integrated Pest Management. http://pep.wsu.edu/hortsense/.

National Pesticide Telecommunications Network. 800-858-7378. http://ace.orst.edu/info/nptn.

Pesticides: Learning about labels. WSU Extension publication FSIPM001.

Pesticides: Safe handling. WSU Extension publication FSIPM002.

The Homeowner's Guide to Integrated Pest Management (DVD). WSU publication DVD0110.

Washington State University Urban IPM & Pesticide Safety Education. http://pep.wsu.edu.

21

Pruning Woody Landscape Plants

Topics covered:

- Introduction
- Reasons to Prune
  - Aesthetics
  - Health
  - Performance
  - Safety
- When to Prune
  - Dormancy
  - Flowering Patterns
- Equipment for Pruning
- Pruning Effects
  - Types of Pruning Cuts
  - Wound Closure
- Pruning Deciduous Trees
  - What to Prune from Trees
  - When to Prune Trees
- Pruning Deciduous Shrubs
  - Blooming Shrubs
  - Foliage Plants
- Pruning Broadleaf Evergreens
  - Hedge Plants
  - Rhododendron and Azalea
- Pruning Conifers

Learning Objectives

- Know the reasons for pruning trees and shrubs
- Understand the processes that affect bud growth and development, and flowering and fruiting of trees and shrubs—and how those processes influence pruning decisions
- Understand the types of pruning cuts and the effects each has on subsequent tree and shrub growth

By

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Introduction

Pruning plants is the deliberate cutting off and removal of plant parts. It is not a simple process, given the wide variety of plant species that may be found in a landscape. The issue becomes more complex when one considers trees versus shrubs, deciduous versus evergreen, and broadleaf versus conifers, plus the fact that pruning processes and procedures, not to mention personal preferences, vary. There are many different styles of pruning to create different effects.

Pruning is both an art and a science. It is an art when a plant is sculptured to a certain form or enhances an area in the landscape. The science is the knowledge of how, where, and when to perform the cuts to create the form. Pruning of shrubs is complicated by the enormous number of species of deciduous and evergreen plants, different uses for these plants, and hearsay recommendations (not based on science) of how these plants should be treated.

This chapter covers the pruning of woody landscape plants such as typically found in home landscapes, other living areas such as condominium/apartment complexes, and parks. Pruning of fruit trees, small fruit plants, and herbaceous perennials is discussed in Chapters 7, 8, and 10, respectively.

Reasons to Prune

There are many reasons to prune a tree or shrub: aesthetics, plant health, plant performance, and safety being the main sorts of reasons. Many reasons are valid, but make a plan and carefully choose where to make pruning cuts. Do not just wander the yard or garden with loppers in hand—you will end up lopping limbs that did not need removing.

Aesthetics

Maintaining or limiting the size of a plant is probably the most common reason for pruning. If plants get too large, they may contact structures, become entangled in overhead utility lines, or overwhelm the landscape they are in. A healthier, lower maintenance approach is to choose plants or cultivars that can grow to maturity and fit in the location. If a tree needs to be drastically pruned (reduced in size) every 5 to 7 years, it is probably too large for the location and a smaller species should be planted there instead. Repeated chopping back of a large tree to keep it confined in a too-small landscape stresses the plant and makes it more susceptible to pests and diseases.

Health

Pruning should be part of a gardener's comprehensive plant health care program. Pruning helps maintain plant health and vigor. It may help prevent the spread of disease, insects and, in some cases, internal rot of the main branches and the trunk. Correct pruning can increase the light penetration and air circulation into the interior portions of a plant. Removing any rubbing, interfering, or wrongly placed branches, and limbs that form narrow "V" crotches can avoid serious plant problems later. The earlier this preventive maintenance can be done in a plant's life, the better.

Performance

Training young plants is another reason to prune. Improving the basic structure and form of a plant while it is young is easier than trying to correct problems later with a chainsaw. This is especially important in fruit tree pruning. Any pruning for unusual types of plant forms, such as topiary, bonsai, or espalier, should be started when the tree is young.

Maintaining the shape of a plant is another performance-related reason for pruning. This is especially important for hedges, screens, topiary, bonsai, etc. where the natural shape or form of the plant isn't exactly what is needed or desired for its function in the landscape.

To improve flowering and fruiting performance, both the pruning procedures and timing of the pruning are important. Proper pruning can maintain the right balance between vegetative growth (leaves and shoots) and flowers (fruit). Alternate year flowering and fruiting may also be minimized by judicious pruning. Pruning can also stimulate the production of larger flowers or fruit.

When pruning, remove dead, diseased, or damaged branches first.

Pruning the canopy was thought to compensate for lost roots. Traditionally, this was done for a plant that had just been transplanted. Research has shown that this procedure is of little value. Newly transplanted trees need the energy stored in buds, leaves, and bark to support establishment.

Safety

Dead or otherwise dangerous branches should be removed for safety reasons. Other limbs to be removed are those that interfere with a line of sight, such as near a street or intersection, or those that interfere with utility lines. For fire prevention and safety, reduce the likelihood of a ground fire moving into the crown of a mature tree by removing branches growing within 10 feet of the ground or understory vegetation. Also, remove branches within 15 feet of roofs and chimneys.

When to Prune

In general, pruning in the Northwest may be undertaken at any time of the year, with some limitations. Special growth pattern effects (such as bonsai, topiary, hedges, and flowering) may dictate a specific or optimum time period for pruning. Pruning in very cold weather may cause damage to the tissue immediately surrounding a pruning cut. Pruning should be avoided when temperatures drop below 15°F. Light pruning to remove dead, weak, damaged, or heavily shaded branches can be done any time. One improperly timed pruning won't kill a plant, but repeated ill-timed pruning can stress the plant, shortening its life span by making it weaker and more susceptible to pests and disease.

Maximum growth or more rapid plant development will occur if a plant is pruned while dormant—in the time between when the plant has completely stopped growing in the autumn and before it starts growing in the spring.

Minimum growth (or maximum dwarfing effect) is brought about if the pruning is done while the plant is in leaf. This would be after the first flush of growth in the spring until just before growth stops in the fall. With the removal of leafed-out branches, obviously, some leaves (the food manufacturing factories of the plant) are also removed.

"Bleeding" after pruning occurs on some species if they are pruned in the late winter or early spring. Note that the flow is sap, not blood, and would have gone to the plant part that was cut off. It generally does not hurt the plant. If excessive, the sap, being nutrient- and sugar-rich, may allow some fungi (mostly non-pathological) to grow along the flow line down the stem of the plant. If the sap flow is found to be excessive or objectionable, the easiest solution is to prune at a different time.

Dormancy

Growth of plants will start in the spring of the year when environmental conditions are proper for the species. Plants will continue to grow until they receive a signal to stop growing and get ready for winter. Declining day lengths in later summer and early fall will initiate a plant's acclimation to cold and its **dormancy** process. Plants become physiologically dormant in the winter, during which they receive a certain amount of chill; the plant will start to grow again in the spring when environmental conditions are correct for the plant to break dormancy and start to grow. Then the process starts all over again.

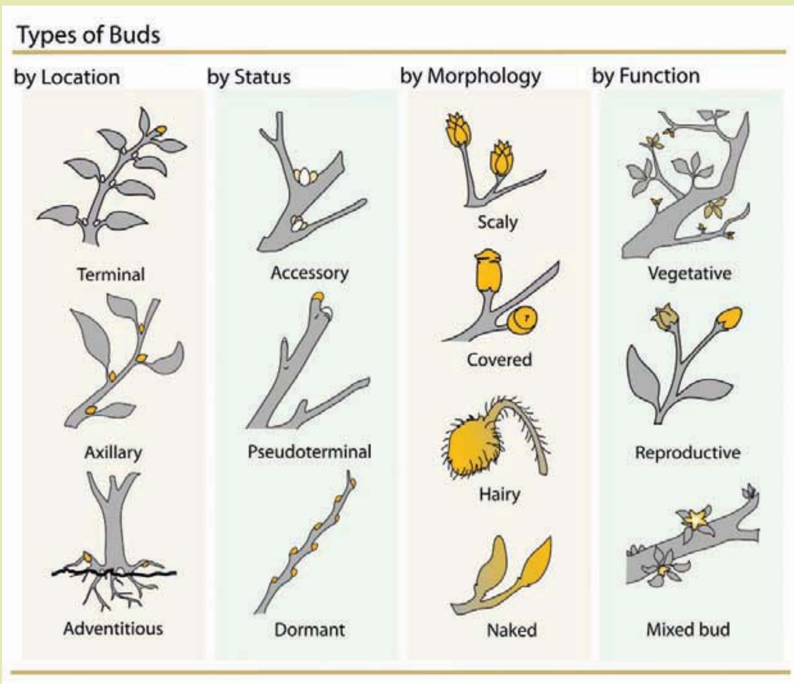
Problems sometimes arise when plants are pruned just before or as they start to go dormant. Pruning at this time causes vigorous regrowth which may not harden off in time for winter, resulting in winter die-back of the new growth and wasting of the plant's energy.

Flowering Patterns

It is important to know when a particular plant initiates its flower buds and where those buds occur on the plant, if it is to be pruned properly—especially if the pruning is done to enhance flowering. There are a number of different blooming patterns of woody plants. A few will be considered here, but there are variations with each.

Review: Plant bud terminology

Buds are undeveloped plant shoots that contain vegetative tissue (leaves, stems) or reproductive tissue (flowers) or both. They can be classified by location, status, morphology, and function.



Woody plants may bloom in the spring from buds which they initiated the previous fall. They may bloom on the terminal end of the branch from simple buds (star magnolia, *Magnolia stellata*; Burkwood viburnum, *Viburnum* ×*burkwoodii*). They may also bloom from the end of the stem from a mixed bud (horsechestnut, *Aesculus hippocastanum*; Norway maple, *Acer platanoides*). Some woody plants bloom on the end of short, specialized branches, called **spurs**, that have very short, compressed internodes (apples, *Malus* spp.; chokeberries, *Aronia* spp.; serviceberries, *Amelanchier* sp.).

Woody plants can also bloom from the lateral portions of the stem which was produced the previous year. These may be from a simple bud (forsythia, *Forsythia* spp.; Thunberg's spirea, *Spiraea thunbergii*; bridalwreath spirea, *S. prunifolia*) or a mixed bud (large-leaf hydrangea, *Hydrangea ×macrophylla*; red currant, *Ribes sanguineum*; Vanhoutte's spirea, *Spiraea ×vanhouttei*; most mockoranges, *Philadelphus* spp.; and weigelias, *Weigelia* spp.).

Many later-blooming shrubs and trees set up their flower buds as they are growing. These include PeeGee hydrangea (*Hydrangea paniculata grandiflora*), Bumalda spirea (*Spiraea ×bumalda*), and blue mist (*Caryopteris clandonensis*). Note that both spirea and hydrangea include some species that initiate their flower buds in the fall and other species which set up flower buds as they are growing.

There is no such thing as a "fruit bud." Fruit results from flower buds, since all plants must flower before they set fruit.

Note that a plant has to flower before it can set fruit. Flower buds on many species of temperate zone plants are formed in the late summer or early fall prior to the spring in which they bloom. These plants usually bloom in early to late spring. Pruning later in the fall or in the dormant season can cut off flower buds. Pruning when plants begin their flower bud initiation may force them into vigorous growth which can sap the plant's energy so it may not have the ability to initiate flower buds.

Other plants set up their flower buds after they break dormancy in the spring of the year. These plants generally bloom later in the summer and into early fall. They may be pruned during the dormant season and into the early spring without losing bloom potential. Many of these plants may be cut to the ground in the fall or up to the early spring and still flower at the normal time.

If in doubt about when to prune a plant to enhance flowering, prune it right after it blooms.

Equipment for Pruning

Pruning is quicker, easier, and safer with the correct tools in good working condition. Choose tools that are big enough and strong enough for the job and are easy to sharpen and use. Use the tools without twisting or straining the blades. Position the branch to be cut as deep in the jaws as possible. If you have to strain to make a cut with a sharp blade, use a larger tool. With sharp scissors or a pruning knife, trim any tears or rough edges that result from a poor cut. Store your tools and equipment out of the weather. Sharpen and oil your tools regularly to keep them in good working order.

When pruning diseased plants, disinfect your tools after every cut to prevent spreading the disease to healthy branches or plants. Use a registered household disinfectant such as Lysol© brand disinfectant. At the end of the day, be sure to oil any tool that was disinfected, because disinfectant products can cause rust on metal parts.

Pruning tools range in size from small hand shears to pole pruners and chainsaws. Choose the right size tool for each cut. Trying to cut too large a branch with a too-small tool will result in a poor cut and may ruin the tool.

Hand shears are made to be held and operated by one hand. They typically can cut branches up to ½ inch in diameter. There are two types of hand shears: bypass shears (scissor action) or anvil shears (Figure 1). Bypass shears are usually more expensive, but make cleaner cuts than anvil shears which often mash a branch rather than cut cleanly.

Figure 1. Hand shears come in two basic styles: bypass shears (left, center) and anvil-pruners (right). Bypass shears are preferred because they typically make cleaner cuts than anvil pruners do and don't crush twigs or branches.

Lopping shears are scissor-action cutters with long handles, used in a two-handed operation (Figure 2). They can cut branches up to 2 inches in diameter, depending on species and hardness of the wood being cut.

Pole pruners have a cutting action similar to loppers, with the blades mounted on a long pole to reach high into trees (Figure 3). Pole pruners may include an attached saw blade with the lopper tool. Using a pole pruner can be dangerous because of the long reach that may allow the tool to contact utility lines and because material falling from each cut can hit operators or get in their eyes. Always use caution and wear head and eye protection when using a pole pruner or any powered equipment.

Hedge clippers are used for shearing, rather than cutting one branch at a time. Hedge clippers may be manual or powered, and generally require two hands to operate (Figure 4).

Figure 2. Lopping shears, or loppers, have long handles to reach into a large shrub or up into a tree. (Equipment photos courtesy of Therese Harris.)

Figure 3. Pole pruners cut like loppers and may also have a saw blade for cutting larger limbs. Be sure to wear safety equipment when using a pole pruner, and be extra careful when working around power lines. Do not stand directly under the branch being cut with a pole pruner.

Figure 4. Hedge clippers may be power-driven or manual.

Pruning saws include folding saws or bow saws (Figure 5) and are useful for cutting larger diameter branches and small limbs. Their teeth are coarse and wide-set, usually cutting on the pull stroke and dropping out the sawdust better to prevent binding of the saw in a green wood cut. Pruning saws cut faster and straighter through a limb than a carpenter's saw would.

Figure 5. Pruning saws come in a variety of shapes and sizes and are useful for cutting branches or limbs between 2 and 4 inches in diameter.

Chain saws come in a variety of sizes and may be electric or gas-powered (Figure 6). They are more appropriate for tree removal or cutting firewood, but can be used to cut live plant material. Always use extreme caution and wear protective clothing and eye- and hearing-protection when using a chainsaw. Because of

Figure 6. Chain saws come in a variety of sizes and styles. Use extreme caution and wear protective clothing as well as eye- and hearing-protection when using these power tools.

safety concerns, chainsaws are not for juggling and should only be used when the operator is standing on the ground. Powered saws should only be used high up in trees by certified arborists.

A pruning knife is handy for trimming any rough edges around a pruning cut so it can heal more quickly and cleanly. A pruning knife is also good for trimming out small conks, or doing graft work.

Besides pruning equipment, basic safety equipment is necessary. Heavy duty gloves can help prevent splinters or blisters. Safety glasses will keep sawdust and debris out of your eyes. Hearing protection is important whenever you use powered equipment. A hard hat is a good idea, too, whenever working on overhead branches.

Pruning Effects

Pruning is visually selecting a branch and removing it—removal of one branch at a time. By contrast, **shearing** is overall removal of branch tips, comparable to shearing the wool off a sheep. Shearing is what is done with hedge clippers to shape a hedge. **Pinching back** is a labor-intensive process of hand-picking off the terminal buds of plants to keep plants smaller and bushier, or to keep plants like basil from bolting.

Types of Pruning Cuts

There are basically two different pruning cuts which can be made on woody plant material. They are a **heading cut** and a **thinning cut**. A heading cut is made to shorten a branch, allowing buds below the cut to grow. The effect on the plant is generally to create a denser, more compact plant. A thinning cut removes an entire branch, opening or thinning the canopy of the tree or shrub.

Heading cut. Heading cuts are necessary for the proper pruning of some fruit trees, such as apples, to create tree forms with a central leader or an open-center tree. Heading cuts are also made to stimulate more bud initiation to increase the number of flowers on plants that bloom on the terminal tips of their branches. On shrubs, heading cuts are used to remove stems to maximize the flowering or fruiting potential. Certain nursery shade tree production procedures require heading cuts to ensure a plant has the proper form and its plant parts are proportional. When any type of heading cut is made on a plant the effect is localized to where the cut is made: the shoots behind the cut will be invigorated.

Heading cuts can be made in one of two ways. The first is a cut made above a bud on one-year-old wood. This allows remaining buds below the cut to grow. The other type of heading cut is when a relatively large branch is indiscriminately removed without regard to any other branches, buds, or other plant parts. This is also called stub cutting, topping, and hat racking. Most bad pruning jobs on trees and subsequent rot and hazardous tree development problems are due to the overuse of heading (stub) cuts on larger limbs.

There are multiple ill effects of stub cutting. When large limbs are stub cut (headed) their sapwood is exposed. Internal rot will most probably start, since the exposed sapwood is the most rot-susceptible part of the xylem. This rot will eventually result in a hollow tree, and a hollow tree is a danger and hazard. Vigorous new growth will emerge from below the cut from latent and possibly adventitious buds. These branches will be more weakly attached than branches that form in the normal manner. In subsequent years they will be much more susceptible to breakage during severe weather, and their lush growth is more disease prone. There will be less light penetration and lower air circulation in the canopy which can lead to other problems. And, finally, stub-cuts give a tree an ugly, misshapen and unnatural shape. Therefore, stub cuts to tree limbs are to be avoided.

Thinning cut. With thinning cuts, branches are removed back to a point of origin or a point of attachment. That is, an entire branch will be cut off back to another branch or back to the main trunk. If the top portion of the main trunk is to be removed, it should be removed back to a limb that is at least one-third the size of the main trunk so that the subsequent growth can be directed to that limb. If the main trunk is cut off above a limb which is less than one-third the size of the main trunk, the pruning cut will behave just like a stub cut.

The effects of thinning cuts include:

1. Growth is directed to the remaining branches and trunk.
2. The natural shape of the plant is retained with the plant maintained at less than full mature size.
3. The natural form of the plant (especially trees) is preserved while vigorous sprouting at the site of the cut is minimized.
4. The amount of rank, vigorous and undesirable (sucker) growth is minimized.
5. More light is allowed into the center of the plant, especially trees.
6. Wind resistance is decreased.
7. Risk of disease problems is reduced.

When making a thinning cut to remove a large limb, if you just cut from the top of the limb down, the weight of the limb as it falls away from the cut can strip the bark from the tree trunk under the large limb (Figure 7), permanently scarring the trunk and leaving a large wound open to infection. So, to remove a large limb, first cut part way through from the underside of the limb (Figure 8), then make a second cut from the top a little farther out, cutting all the way through until the branch falls away. Finally, cut the lightweight stub back to the branch collar. Do not remove the branch collar.

Figure7. Cutting straight down through a large limb causes the limb to break before the cut is completed. The weight of the falling limb peels the bark away from the remaining stub and even the trunk, leaving a very large and ugly wound. (Photo courtesy of Joseph O'Brien, USDA Forest Service; Bugwood.org.)

Wound Closure

Woody plants are unable to heal wounds the way animals do. Plants grow callus tissue over the wound, but the damaged tissues are not repaired. Woody plants can chemically wall off the wounded area through a process called **compartmentalization**. Different plants vary in their ability to compartmentalize a wound. Some are good compartmentalizers and others are much more susceptible to rot.

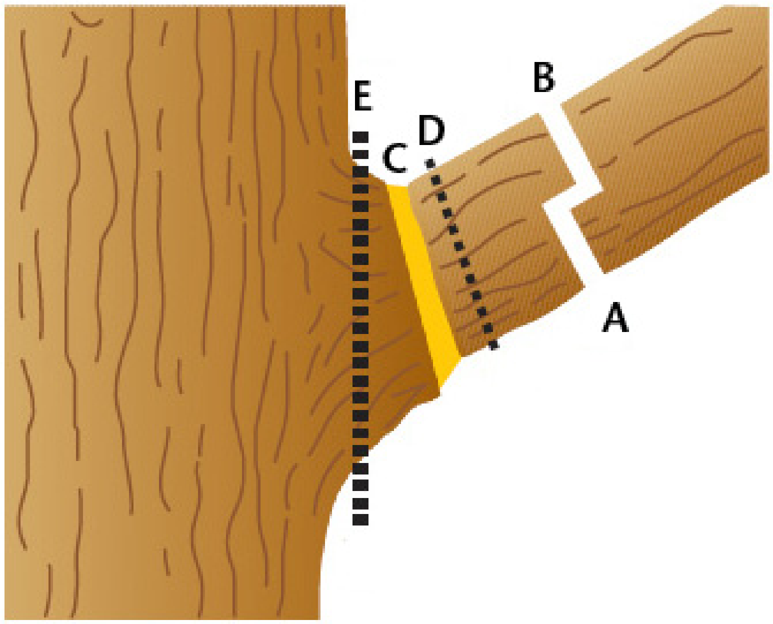


Figure 8. To avoid bark stripping when removing a large limb, make the first cut at A, below the limb about 12 inches out from the trunk. Make the second cut at B, further out on the limb from A. When the limb sags and breaks, it will break to A, leaving a stub. Make the final cut at C, just outside the branch collar to remove the stub. A cut at D would leave too much of a stub, which might rot before the branch collar can grow over it, and a cut at E is a flush cut that would damage the branch collar and inhibit wound healing.

Even the best pruning cuts are wounds on a plant. Make pruning wounds as small as possible (do the least amount of damage) to allow the plant to close the wound quicker. The longer a wound stays open, the more chance it has to develop internal decay. A clean edge around a pruning cut also allows the plant to callus over the cut more quickly and cleanly (Figure 9).

There are a number of wound seal preparations on the market (usually asphalt-based materials) which, when applied to pruning and other woody plant wounds, are reported to seal the wound, reduce rot and diseases, inhibit insect attacks, and allow the plant wound to close over more quickly. Research has shown that not only do these tarry preparations not seal anything, the incidence of rot can be greater behind the compounds, various types of insects (especially boring insects) love to overwinter behind the material, and many times the tree wound compound will actually retard the plant's regrowth process. They do not have to be used and perhaps should not be used.

Figure 9. Two completely callused over (sealed) pruning wounds on an oak tree. Small, clean pruning cuts allow the plant to close the wound sooner, preventing infection and rot and leaving a smaller scar. (Photo courtesy of Therese Harris.)

Pruning Deciduous Trees

Trees, by definition, are single- to multi-trunked woody plants with an aerial crown, which means that usually all the growth occurs in the top portion of the plant (at the tips of its branches), with very limited growth activity at the base of the plant or near the soil line. Pruning is one of the most important maintenance tasks to be done for trees. Proper pruning can help maintain the health, vigor, and attractiveness of trees. Correctly placed, healthy, well pruned trees dramatically increase property values.

What to Prune from Trees

There are three goals in any typical pruning job:

1. Remove any dead, diseased, or damaged wood.
2. Eliminate any rubbing, crossing, or otherwise interfering branches.
3. Prune the tree (or any plant) to the shape desired, which, in most cases, is to accentuate the natural form the plant has.

Diseased wood should be pruned out by cutting back to sound, healthy tissue. This is done by making a heading cut on one–year-old wood or making a thinning cut on two-year or older wood. Do not cut the diseased tissue; make a cut further back in healthy tissue to be sure you've eliminated the diseased part. With this type of pruning, pruning tools should be disinfected between every cut. Use a registered household disinfectant such as Lysol©. Oil pruning tools at the end of the day to prevent rust caused by the disinfectant solutions.

Figure 10. Branches growing together with a very narrow angle between them can pinch the bark between the branches. This bark acts like a wedge between the branches, weakening their connection until they split and one or both branches falls. (Photo courtesy of Joseph O'Brien, USDA Forest Service; Bugwood.org.)

Cut off any branches that are rubbing, will eventually rub, or are growing in the wrong direction.

Narrow "V" branch crotches occur when two leaders compete to become the main leader. These branches grow very close together and parallel to each other. As they increase in diameter, a layer of bark, known as a **bark inclusion**, is squeezed between the two stems (Figure 10). Bark has no structure or holding power, and acts as a wedge between the stems. One or both limbs may break off in heavy weather, such as high winds, ice, or wet snow.

Rather than pruning large co-dominant leaders, they may be braced and cabled. In this procedure threaded rods, with nuts and washers, are braced between the co-dominant leaders and a cable is attached to the two limbs two-thirds of the way up the limbs from the bark inclusion. This process should only be under taken by a certified arborist.

After a severe pruning or plant damage, water sprouts, suckers, or other forms of vigorous growth may occur. These usually arise at a broken limb or a stub cut. Species such as flowering plums, crabapples, and hawthorns produce these types of shoots when many thinning cuts have been made on large branches. Most of these shoots fall into the interfering/wrongly placed category and should be pruned when young or rubbed off when they first emerge. Monitor the plant during the year and remove these shoots as they arise.

Tree Topping. Tree topping is a very poor practice and is not recommended. Topping removes a major portion of the tree's top by cutting large branches back to stubs (Figure 11). Topping a tree will reduce property value, shorten the life span of the tree, and will most probably make the tree a safety hazard. Topping a tree disfigures it and stimulates vigorous, rank growth that is more susceptible to ice, snow, and other storm damage. Production of that lush growth can deplete food reserves in the roots, weakening them and increasing pathological problems. The large stubs produced by topping result in numerous other problems. The large surface area of the stubs may not callus over, leaving the stem open to rot. This causes hollow trees which become hazard trees. Stubs may also die back because of sun scald.

Tree topping is a very poor practice and is not recommended.

If a tree is too high or otherwise too large for the landscape, or requires severe size reduction regularly, it should be removed and replaced with another species which has a smaller mature size. Topping a large tree is not the answer!

Drop crotching. The only good way to reduce the overall size of a tree is to make thinning cuts in a procedure called "drop crotching." This is done by cutting the main trunk off to a lateral branch which is at least one-third the size of the main trunk, or by cutting a lateral branch back to another branch which is at least one-third the size of the branch to be removed (Figure 12). This can reduce the overall plant height while retaining the natural shape of the tree and allowing the wounds to grow over.

Pollarding. This formal pruning technique involves removing all of the previous year's growth, pruning back to the same stubs every year. This results in swollen, knobby branch ends that regrow dense batches of new twigs from the same growing points every year. This is commonly done on fruitless mulberry trees (*Morus* spp.) and willows (*Salix* spp.). This does not preserve the normal form of the tree but produces trees of a consistent size each year—especially important where a row of identical trees is desired.

Figure 11. Tree topping is a very poor pruning practice, involving the cutting of many large branches back to stubs. (Photo courtesy of Joseph O'Brien, USDA Forest Service; Bugwood.org.)

When to Prune Trees

Trees may be pruned at any time of the year, but pruning in different seasons can cause different responses. Late winter and early spring after a general warming trend are good times to prune because callus tissue will form most rapidly at this time. This is the period of quickest redevelopment and readjustment for the remaining limbs. Too, disease and insect activity is usually much lower at this time. Trees that bleed, such as birches (*Betula* spp.), walnuts (*Juglans* spp.), some maples (*Acer* spp.), and snowbell (*Styrax* spp.) may be pruned in late summer and early fall, although bleeding is not generally harmful to the plant.

Pruning away foliage after a flush of growth in the spring tends to retard or dwarf the plant. If slowing down the growth of a plant is desired, this is the time to prune. To encourage more rapid plant development, prune while trees are dormant: after growth stops in the fall but before it starts again in the spring.

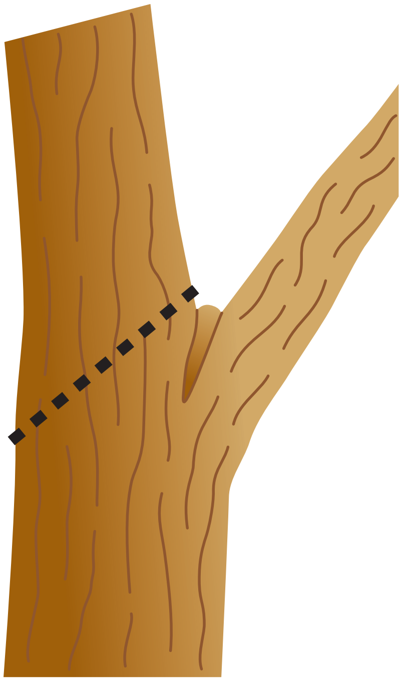


Figure 12. The only good way to reduce the overall size of a tree is to make thinning cuts to remove the main trunk back to a lateral branch that is as least a third of the size of the main branch that is being removed.

Pruning in late summer and into early fall is problematic because it may cause vigorous regrowth that may not harden off before winter. At the same time, there is usually more insect and disease pressure, and callus formation over pruning wounds is much slower. Pruning during very cold periods may cause some dieback around the pruning cut.

Pruning Deciduous Shrubs

There is a systematic approach to pruning generic landscape shrubs correctly by following a few simple rules. As always with rules, there are exceptions—there is always that deviant species or that deviant use of a plant which dictates a deviant style of pruning. Especially for those unusual instances, consult Brickell's 1979 book, Pruning, and Brickell and Joyce's 2003 book, Pruning and training plants: A complete guide.

Most deciduous shrubs are in a landscape for their aesthetic or wildlife habitat value. Many of these shrubs have a naturally informal habit. The primary objective of pruning, in these cases, is to enhance flowering (and subsequent fruiting if applicable) and to retain the natural loose, flowing habit of the plant. Plants grown for their foliage or stems rather than blooms, are pruned to emphasize those non-bloom characteristics.

If in doubt about when to prune a shrub (or most any other plant) for better flowering, prune right after flowering. This gives the plant the ability to adjust and set up the flower buds for the following year.

Blooming Shrubs

Blooming patterns of most flowering shrubs fall into three major categories: lateral bloomers, terminal bloomers, and late (or continuous) bloomers. Most shrubs will initiate flower buds in the fall before going dormant. These buds are either on the lateral portions of a stem or at the terminal tip of a stem. The third category of flowering pattern includes the late bloomers which start out in the spring with no flower buds but develop flower buds as the plant grows into the summer. These plants usually start flowering much later than most of the more typical shrubs. The lateral bloomers, terminal bloomers, and late bloomers are each pruned differently if the goal is to enhance flowering.

Lateral Bloomers. Plants that bloom from the lateral portions of stems may be identified by the presence of the largest winter buds on the sides of the branches rather than at the ends or tips of branches. They may also be recognized later in the year by having flowers and fruit borne along the stem rather than on the terminal end of the stem. These plants will bloom from either a simple bud (containing a single flower) or a compound, or mixed, bud (containing multiple flowers on the end of a short stem). Examples of simple bud bloomers are forsythia and Thunberg's spirea, Examples of mixed bud bloomers are snowmound spirea and Japanese kerria.

Since these plants develop their flower buds along the sides of stems that were initiated and grew the previous year, these types of shoots should not be pruned before they bloom, in order to maximize the flowering potential of the shrub. As a stem which originates from the base of a plant gets older and older, the new (flowering) stems on the upper portions of that old stem will get progressively shorter each year. This leads to shorter branches which actually do the flowering. Therefore the flowering decreases as the stem gets older.

The best blooming of these types of shrubs is achieved when a few of the oldest (largest) stems are pruned off right at the base. This removes some of the dense, twiggy, poorly flowering wood. It also allows new, vigorous, better flowering growth to arise from the base of the plant.

It is best to prune this type of shrub right after flowering. Pruning later in the summer may induce vigorous growth which may not set flower buds for the following spring. Pruning even later, in the fall and early winter, will remove some stems with flower buds and thus reduce flowering for the following spring. Shearing the plants rather than selective cane or stem removal increases the "twiggyness" of the plant and generally decreases flowering.

Terminal Bloomers. Shrubs that bloom on the terminal tips of their branches, such as roses, can be identified by the occurrence of their largest buds on the ends of their branches. These shrubs can be made to flower more prolifically if the number of terminal tips is increased. This is done by heading back young shoots and removing some of the older branches to cause increased branching and thus more terminal tips. Shearing will also increase the number of terminal tips. These plants are best pruned or sheared soon after flowering.

Continuous Bloomers. Late summer blooming shrubs, such as blue mist and summer sweet (*Clethera alnifolia* L.), that set up their flower buds in the current growing season may be pruned any time during dormancy from fall until growth starts in the spring. Spring pruning (rather than winter pruning) is suggested for the colder regions of Washington. Since flower buds are initiated on currently growing stems, increasing the number of new shoots can also increase flowering. This is accomplished by heading branches back to increase shoot production. These plants may also be cut to the ground in the spring and still bloom the same year.

Roses. Roses are terminal bloomers that set buds during the current growing season. Early in the spring, prune away all but 3 to 6 canes on hybrid tea roses to encourage fewer but larger blooms. Vigorous rose bushes will benefit from thinning to provide good air circulation and help prevent fungal disease. Remove any dead, diseased, or damaged woody canes. Remove spindly canes, too, as well as crossing branches that rub, and blind shoots (stems with no terminal flower buds, just leaves). When pruning the canes, cut them back to clear white wood. Make an angled cut about a quarter inch above an outward pointing bud so the developing twig will not grow towards the middle of the bush. If the bush tends to sprawl, just cut above a bud that points in the direction you want the resulting twig to grow.

Throughout the summer, deadhead regularly so the plant will produce more flowers rather than set seed. When deadheading, cut twigs with spent blooms at a 45-degree angle just above an outward-facing leaf with 5 leaflets (Figure 13). Also prune out any twigs that have grown into the center of the plant, in order to promote good air circulation. Remove weak or twiggy growth and any dead or dying stems. Remove any sucker growth coming from below a graft. Prune as necessary to shape the bush.

Stop deadheading by September 1, and let the rose bush set hips (go to seed) in preparation for winter. After several hard freezes, when the plants are dormant, prune bushes (except for old garden roses, climbers, and tree roses) back to about 2 feet tall to keep the

Figure 13. Remove spent roses by deadheading: cut the twig just above the next 5-leaflet leaf to encourage more blooms. (Photo courtesy of Therese Harris.)

canes from whipping about in winter winds. Severe or prolonged rocking of the plant damages the root system and can kill the plant.

Foliage Plants

Shrubs with brightly colored stems (for example, red twig and yellow twig dogwoods, *Cornus* spp.), brightly colored/unique foliage (golden privet, *Ligustrum ×vicaryi*) or good fall foliage color (winged euonymus, *Euonymus alatus*) may be pruned differently to emphasize the unusual or distinctive characteristic rather than any flowering. Shrubs with brightly colored stems may be cut to the ground in early spring so that new vigorous stems may be enjoyed the following winter. Plants with showy or unique foliage may be pruned hard in the spring to induce vigorous growth to induce more of the showy foliage.

Pruning Broadleaf Evergreens

Evergreen plants (both conifers and broadleaf) keep their leaves for more than one growing season. This varies from losing leaves mid way through the second season (madrone, *Arbutus menziesii*; English holly, *Ilex aquifolium*) to plants which may hold on to their leaves for four or more years (some rhododendron species and also some coniferous plants). Broadleaf evergreens include trees such as madrone or southern magnolia (*Magnolia grandiflora*). Broadleaf shrubs bloom on the lateral portions of the stem (drooping leucothoe, *Leucothoe fontanesiana*; Oregon grape, *Mahonia* spp.) or bloom on the tip (Burkwood viburnum). They should be pruned according to the guidelines for these particular plants.

There are a few special groups of broadleaf evergreens which should be discussed separately.

Hedge Plants

Plants grown as hedges and plants that are pruned to a certain shape are usually sheared to keep them in bounds or to maintain their shape. Examples include cultivars of boxwood (*Buxus sempervirens*) and Japanese holly (*Ilex crenata*). Shearing may be done at different times during the year to achieve or maintain the desired effect. For a tighter, more compact plant, plants may be sheared in the spring just before and as growth starts, and then once or twice again before fall. Plants that are kept to a very formal appearance, or plants that have to maintain a very close size tolerance, may be sheared as often as every 4 to 6 weeks. Trees that were sheared but not maintained will revert to their original growth pattern on their newest, topmost branches. This leads to some interesting results as shown at the end of the Pruning Conifers section.

Do not shear these plants too late in the summer or early fall, as pruning may force a burst of soft growth that may not harden off in time for winter weather. Then, shearing after all growth has stopped in the fall, but before real cold weather, can have another unfortunate effect. The cut ends of the branches and any partially cut leaves from the shearing process may die back. This will give the entire plant a rather unpleasant brownish cast for the whole winter until new growth starts again in the spring.

Rhododendron and Azalea

Many people are afraid to tackle pruning rhododendron, but by knowing a few simple facts, they may be one of the easier groups of plants to prune. Rhododendron and azalea belong to the genus *Rhododendron*. There are many, many species in this genus. There are also many, many different cultivars and hybrids, and both deciduous and evergreen varieties. For pruning purposes, the entire genus may be roughly divided four groups:

- large-leaf evergreen rhododendron (**elepidotes**, or, non-scaly leaved plants),
- small-leaf evergreen rhododendron (**lepidotes**, or, ones with scaly leaves),
- evergreen azalea, and
- deciduous azalea.

Small-leaf rhododendron and evergreen azalea can treated as one group for pruning purposes.

Rhododendron are pruned for the same reasons as other plants: for size containment, for health (prune out diseased tissue, etc.), to increase flowering, to create a more compact plant, or to create a certain form (bonsai, etc.).

Almost all rhododendron and azalea bloom from the terminal ends of their branches. These flower buds are typically initiated in the summer or early fall prior to the growing season in which they bloom. Generally, the more terminal tips there are on the plant, the greater the potential for flowers.

Large-leaf evergreen rhododendron. These types have large bulbous flower buds and narrow, slender vegetative buds. The leaves are usually clustered toward the terminal end of the one-year branch in a fan like arrangement. Typically the lower portions of that stem are devoid of leaves and therefore devoid of buds. Remove large single terminal vegetative buds to cause more branching. More terminal tips will mean the potential for more flower buds. This will also produce a denser, more compact plant. For size reduction, stems can always be pruned back to a bud, or to a place where there was a fan of leaves. Leaf scars and buds associated with those leaf scars can usually be seen going back 5 or 6 (or more) years on the stem. If single (slender) vegetative buds are removed (pinched by thumb and forefinger) from the terminal tip, the subtending buds will be forced to grow, causing more branching and greater potential for more flowering. Removal of faded flowers (deadheading) may stimulate greater bud growth with potential for greater flowering the following year. This may be of questionable benefit on older plants, but it will increase the aesthetic appeal of the plant.

Small-leaf rhododendron and evergreen azalea. These plants have leaves up and down the stem, so there are buds up and down the stem. This means that stems may be cut anywhere and there will be buds there. Many of these plants do not need pruning, but for size containment they may be sheared right after flowering. For a denser plant they may also be sheared after the first flush of growth in the spring. They may also be pruned (thinned) after flowering for a looser habit.

Deciduous rhododendron and azalea. Deciduous rhododendron and azaleas are basically deciduous shrubs that bloom on their terminal tips. They have varying degrees of basal bud activity. Some of the older canes may be removed to stimulate new shoot formation. The resultant new vigorous shoots may be headed while growing to cause branching and increase the potential for more flower bud formation. Thinning cuts may be made to reduce the size of plants. Deadheading younger plants and perhaps older plants may be beneficial for increased branching and flowering.

When pruning, dead, diseased and damaged branches should be considered and removed first. Many rhododendron and azaleas may be pruned to the ground and, under most conditions, will resprout.

Pruning Conifers

Conifers, like many of the plants considered above, have many different species and cultivars. This group includes some very large species which do not belong in a home landscape. What is unfortunate is that some of these are native Washington plants. However, being native to Washington does not mean that they are the “right plant” for an urban or small yard site. Placement of the right plant in the right place will avoid many pruning problems.

For good pruning practices, growth patterns and location of buds for new growth have to be determined. On upright tree types, pruning the central leader will produce multiple leaders, which could be dangerous or hazardous in time. Thinning cuts on almost all species can be made.

Coniferous plants can also be placed into groups which have similar growth patterns and therefore can require similar pruning procedures. A few of these will be considered here.

Spruces (*Picea* spp.), firs (*Abies* spp.), Douglas fir (*Pseudotsuga menziesii*) all have a central leader bud, which has just a few or no primary branch buds directly beneath it. Additionally, there usually are secondary branch buds on the stem beneath these. In the growth pattern, the central leader will grow straight up, the primary branch buds will form lateral branches beneath these and the secondary branch buds will form smaller branches beneath the primary lateral branches. This imparts a pyramidal growth pattern to these plants. The lateral branches have the same bud/growth patterns, except the branches are flat or planar rather than pyramidal or conical.

For size reduction, a thinning cut can always be made. This means pruning back to another branch. The size or plant density may also be maintained by annual shearing. This is usually accomplished by shearing, pinching, or pruning shoots as they are growing. Pruning the central leader may cause multiple leaders to form which could become a hazardous situation in years to come if they are all allowed to grow.

Topping these plants for size reduction does little good. They can form new leaders in a number of different ways. These multiple leaders almost always create a hazardous situation in a few years. If one of these plants needs to be topped for size containment, it is best to remove the tree completely and plant a smaller species in its place. Many popular species have slower growing or dwarf varieties which need little or no pruning.

Another group, the hemlocks (*Tsuga* spp.) and yews (*Taxus* spp.) have buds all along the stem and good bud potential into older wood and spurs on older wood. These species lend themselves to shearing, and they are very often used for hedges, with yews also used in topiary work. There are hemlock and yew hedges on the U.S. east coast and in Europe that are decades, and sometimes centuries, old.

For size containment, the plants are sheared just before spring growth starts or while the plants are growing. For very formal applications they may be sheared several times during the growing season.

Topping hemlocks will result in new leaders being formed, which can become dangerous in the years following if all the leaders are allowed to grow.

Pines (*Pinus* spp.) have a central leader bud with a whorl of buds directly beneath it on the main leader and also beneath the lateral branches. Note: there are no other buds down any of the stems! If a heading cut is made on any mature wood, that stem will die back to the next branch or whorl of branches.

For size reduction, make a thinning cut: prune branches back to another branch or whorl of branches.

Figure 14. Newly developing shoots on a pine branch are called "candles" both because of their form and their brighter color which makes branch tips look lit up. (Photo courtesy of Joseph O'Brien, USDA Forest Service; Bugwood.org.)

If **candles**, the developing new shoots (Figure 14), are sheared, pruned, or pinched before the needle bundles are fully opened (usually mid-June or earlier depending on the location and the species) and before the terminal bud is formed, then new buds will form in the needle fascicles (needle bundles) under the pruning cuts. This is how pines to be used as Christmas trees are formed into very dense, compact plants. If pruned early, more buds will be formed. Most pines may be maintained at almost any size for many years.

Junipers (*Juniperus* spp.), falsecypress (*Chameacyparis* spp.), arborvitae (*Thuja* spp.) and a few other less common genera all have basically the same leaf and branching pattern. Note: our so-called western red cedar (*Thuja plicata*) is actually an arborvitae. In most parts of the world it is known as the giant arborvitae.

These plants all have scale-like and/or short needle-like (awl) leaves (Figure 15). Where there are green (live) leaves there are buds. Where there are no green leaves there usually are no buds.

Constant shearing will increase the density of a plant. The denser the outside of the plant, the more shaded the interior portions will be. This limits air circulation to the interior portions of the plant and usually leaves just a thin shell of green leaves on the outside and a dead zone on the inside of the plant. If the dead zone is cut into and exposed, the plant usually does not have the ability to generate new shoots to cover the dead area (Figure 15). Shearing more often but removing less material each time helps avoid exposing the dead spot.

*Figure 15. Eastern arborvitae (*Thuja occidentalis *L.) has scale-like leaves. (Photo courtesy of Connecticut Agricultural Experiment Station Archive, Connecticut Agricultural Experiment Station; Bugwood.org.)*

Shear plants early as growth starts in the spring, for a looser, less compact plant. Shearing later in the season will give a tighter more compact plant. Shearing 2–3 times during the growing season will give a very tight, compact, formal looking plant. Shear early enough, before growth stops at the end of the growing season, to allow some regrowth to cover the shear marks. If plants are sheared, allow a little growth each year as in “poodle” cuts and topiary work.

Plants that have been sheared for many years and then left untended revert to their natural growth pattern, often with odd or unfortunate results (Figure 16). Plants may always be pruned (via thinning cuts) for a more open and natural-looking plant. Thinning cuts are the preferred option.

Figure 16. This spruce was sheared regularly for its first 10 years, but not maintained after that. The later, untouched growth exhibits the tree’s natural growth pattern, resulting in a tree that looks like it is being engulfed from below by a completely different, more compact tree. (Photo courtesy of Therese Harris.)

Summary

Pruning is both an art and a science. It takes patience, practice, observation, and learning. Reading a book or this chapter, or listening to a lecture will increase your knowledge of pruning procedures. But beyond that, there has to be the understanding of the effects of a pruning cut. This can only be done by monitoring that pruning cut afterward and observing what happens to the plant.

It is unfortunate that pruning is often relegated to a certain time slot such as, “It is the last week in September, so everything has to be pruned this week!” It is imperative to understand what is to be achieved and when the best time is to achieve it. When working in the garden, a good horticulturist will always have pruning shears handy, but will use them judiciously.

Further Reading

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22

Composting

Topics covered:

- Introduction
- Managing the Decay Process
    - Raw Materials
    - Other Factors Affecting the Composting Process
    - Health and Safety Concerns
- How to Make Compost
    - Slow Composting
    - Fast Composting
    - Troubleshooting
- Using Compost
    - Amending Soil
    - Mulching
- Vermicomposting
    - Supplies for Vermicomposting
    - Worm Bin Management
    - Harvesting the Vermicompost
- Summary

Learning Objectives

- Realize the importance of composting for improving garden soils as well as for reducing the amount of waste in landfills or other waste treatment facilities
- Understand the biological principles of the composting process
- Understand effective methods and suitable materials for successful composting

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Introduction

Plant-based compost has been deliberately made and used by gardeners for ages to improve garden soil. Today, the practice of composting is also an important way to reduce the amount of material that is burned or dumped in landfills. Yard waste and kitchen vegetable scraps can make up as much as 20 percent of household garbage. The practice of composting puts that “waste” to use and keeps it out of the **garbage stream**.

Composting is part of the natural biological cycle of growth and decay. Plants grow by capturing energy from the sun, carbon dioxide from the air, and nutrients and water from the soil. When plants (and the animals that eat them) die, their remains become raw materials for the composting (decay) process.

Microorganisms, fungi, insects, worms, mites, and other creatures convert the carbon compounds from dead plants into energy for their own growth, releasing carbon dioxide into the air. Similarly, these organisms recycle nutrients from decaying plants into their own bodies and eventually back into the soil. Other plants and microorganisms use the carbon and nutrients released by the composting process, and the cycle begins again.

Compost, the material that remains from the decay process of composting, is similar to other soil organic matter. Compost contributes nutrients and holds water and nutrients in the soil, making the soil richer, more porous, and easier to dig (Figure 1).

Figure 1. Finished compost is rich in organic matter and should be dark and crumbly.

People can speed up the decay process in a compost pile by fostering the internal microbial activity. This is known as fast, or hot, composting. For fast composting, a pile must have a balance of raw source material, water, and air to favor the growth of thermophilic (heat-loving) microorganisms. When conditions encourage those high-temperature microorganisms, compost piles heat rapidly to 120° to 150°F. These high temperatures kill most weed seeds and pathogens, but do not kill the beneficial fungi that will help plant roots absorb nutrients. Once the hot phase of composting is complete, lower-temperature microorganisms plus worms, insects, and other invertebrates work to complete the decay process.

If ideal conditions cannot be maintained for hot composting, microorganisms still break down wastes through slow, or cold, composting. Decay will just be slower and less effective at killing weed seeds and pathogens. If plant waste material is simply piled and left alone long enough, it will decay and form compost through this process (Figure 2). This is what happens naturally on the forest floor, for instance, to form humus.

Managing the Decay Process

People can affect the speed of the composting process and the quality of finished compost by managing the basic ingredients of the compost—that is, the raw materials—as well as the other factors such as particle size, mixing of materials, size of the compost pile, moisture content, and oxygen content.

Figure 2. This casual compost pile shows the layers of yard waste material that, even left untended, are composting. The bottom-most material is about 3 years old; the top layer is less than 2 weeks old.

Raw Materials

For fast composting, the initial mix must have the proper combination of organic materials that provide a rich food (energy) source for bacteria, along with the right amount of moisture and air. Table 1 lists some raw materials commonly used in making compost. They are designated as energy materials (high nitrogen), bulking agents (low nitrogen), and balanced materials, based on their chemical makeup and contribution to the compost process.

Energy materials provide the nitrogen and high-energy carbon compounds needed for fast microbial growth. Sometimes these are called "green material" because they are such things as grass clippings. If piled alone, without bulking agents, these materials usually are too wet and dense to allow much air into the compost pile. When you dig into or open a pile of just this material, it will have a foul, "rotten egg" smell.

Bulking agents are dry, porous materials that help aerate the compost pile. They are low in moisture and nutrients and so decay very slowly on their own. These are sometimes called "brown materials" because they include things like dry hay, twigs, and other woody material.

Balanced materials have both energy and bulking agent properties. These materials readily compost even without being blended with other ingredients. Examples of balanced materials include horse manure mixed with bedding, spoiled alfalfa hay, and deciduous leaves. These materials help ensure the success of hot compost piles.

Pine cones, pine needles, and parts of the western redcedar are resistant to decay and break down slowly in a compost pile.

Mixing bulking agents with energy sources provides the right balance of nutrients, moisture, and air for rapid composting. A mixture of one part energy material with two parts bulking agent (by volume) usually gives a reasonable mix for rapid composting.

Some plants contain compounds that slow microbial decay. For instance, pine cones, pine needles, and western redcedar (*Thuja plicata*) plant parts, because of their resistance to decay, break down slowly in compost piles.

Other Factors Affecting the Compost Process

Particle Size. Small particles have more surface area for microbial activity and are easier to mix. Grinding, cutting, smashing, or chopping raw materials reduces particle size. Hot composting requires a relatively uniform particle size of 1⁄8 to 1⁄2 inch in diameter.

Woody branches that have not been ground up make it difficult to turn a pile. They also decompose very slowly. Grind or chip woody branches or pile them separately to compost.

Table 1. Raw materials for successful composting.

Energy materials
(High moisture, low porosity, high nitrogen)
Grass clippings
Fresh dairy, chicken, or rabbit manure
Fruit and vegetable waste
Garden trimmings
Coffee grounds
Bulking agents
(Low moisture, high porosity, low nitrogen)
Wood chips
Sawdust
Grass hay
Wheat straw
Corn stalks
Balanced raw materials
(Low to medium moisture, medium porosity, medium nitrogen)
Ground-up tree and shrub trimmings
Horse manure mixed with bedding
Deciduous leaves
Legume hay

Decay Resistance. Some materials present problems because they are decay-resistant (Figure 3). Avoid large pieces of woody materials because they break down slowly and make the pile hard to turn. Keep seed heads of weeds out of your compost pile. Also avoid weedy rhizomes (runners) that may not be killed in a backyard pile.

Mixing. Layering materials is simple, but not the best way to build a pile. When you first build a compost pile, mix the materials thoroughly. If more materials accumulate over time, add new materials to the center of the pile. This practice also helps fluff the pile, improving the flow of oxygen into the center of the pile where anaerobic conditions are likely to occur.

Pile Size. A compost pile must be big enough to insulate itself and hold heat. A hot pile decays much faster than a cold pile. Small piles usually are colder because they have small cores that hold less heat. Small piles also dry out faster. A pile of about 1 cubic yard (3 feet tall, deep, and wide) is big enough for year-round composting, even in cold-winter areas.

Moisture. All materials in the pile must be moist but not soaking wet. Check moisture when you turn the pile. The mixed material should feel moist (like a damp sponge), but you should not be able to squeeze water out of it with your hands. During hot, dry times of the year, you may need to add water. In rainy winter locations, a pile may not heat up unless you cover it to keep out rain.

Aeration. The microorganisms responsible for fast decomposition need oxygen. Therefore, a compost pile needs to be porous enough to convect, that is, to pull in outside air to replenish oxygen as

Figure 3. Some materials, such as plastic, never decay and should not be put in a compost pile deliberately. Even with hot composting, when the compost is finished, some of the raw materials may still be recognizable (avocado pits, peach pits, egg shells, pine cones, sticks, etc.). Simply pull those out of the finished compost and add them to the next batch of compost to go through the cycle again.

it is used. You can create a porous compost pile by including bulking agents in the mix of materials. As the pile decomposes, it will settle, collapsing in on itself and reducing aeration. Turn the pile or add more bulking agents to restore porosity and improve aeration (Figure 4).

Microorganisms. Raw materials put in a compost pile usually contain all the microorganisms needed to make compost already. You do not need to add soil or compost starters with special microorganisms. The best source of microorganisms (if needed) is finished compost, so a scoop or two can be used as an inoculant in a new pile, but usually is not necessary.

Nutrients. Just like other living creatures, microorganisms need nutrients (such as nitrogen, phosphorus, and sulfur) to grow and reproduce. These nutrients are present in the raw materials of the compost mix. Additional fertilizer from any source (organic or inorganic) usually is not needed.

Nitrogen fertilizer may be beneficial for mixes consisting primarily of bulking agents. The best way to add fertilizer, then, is to dissolve it in water and wet the pile with a dilute solution.

Note that compost additives such as blood meal and bone meal are simply organic fertilizers; they do not contribute anything magic or even necessary to a compost pile.

Figure 4. Stirring or turning a compost pile fluffs up the materials and adds oxygen back into the mix.

Health and Safety Concerns

Problem materials for composting include things that contain pathogens or are decay-resistant. Keep diseased plants and seed heads of weeds out of your compost pile.

Do not put dairy or meat scraps in a compost pile. The pile's temperature may not get high enough or be maintained long enough to kill pathogens in those products, and the longer those materials linger in the compost pile, the more likely they are to attract pests. Similarly, do not add the results of home canning gone bad or the contents of commercial cans that have swollen or show signs of botulism.

Some rose thorns and other stickers present a hazard because they take longer to compost than the rest of those plants' materials, so avoid putting them in your pile to minimize the pain and danger of a handful of them when you handle the finished compost later.

Compost Fires. A compost pile will ignite only if it has a very hot zone next to a dry zone. Fires do not start in moist or small (cool) piles. Therefore keep the pile turned and water it when it starts to get dry.

Manure in Compost. Fresh animal manures sometimes contain human pathogens such as *Salmonella* sp. or *E. coli* O157:H7, or parasites, such as *Cryptosporidium parvum*. These pathogens are not taken up into plants, but they can be present in soil that adheres to the surfaces of roots or low-growing leaves and fruits. Careful washing or peeling will remove most of the pathogens responsible for disease, but some risk remains. Alternatively, thorough cooking will effectively kill pathogens carried on garden crops. If no fresh manure is used in the garden, the risk is minimized.

The greatest risk from manure-borne pathogens is with root crops such as carrots, leaf crops such as lettuce, and fruit crops such as strawberries. The edible part of these crops may become contaminated with soil, the crops are difficult to wash, and they are often eaten raw.

Pathogens in fresh manure typically die off in the environment over time, especially when the manure dries out or is exposed to freezing and thawing. The rate of pathogen die off depends on the types of pathogen and manure and on environmental conditions such as temperature, moisture, and sunlight. Thorough, high temperature composting kills pathogens, but it is difficult to maintain these conditions in a backyard compost pile. You can limit exposure to pathogens by excluding fresh manure from backyard compost that will be used on fresh garden crops.

Always keep dog and cat manure out of your compost pile and garden. Parasites found in these manures may survive for long periods in compost or in the soil and remain infectious for people.

For more information on animal manure and food safety, refer to *Food Safety Begins on the Farm*, produced by the Cornell University Good Agricultural Practices Program.

Herbicides in Compost. Although it is a rare occurrence, herbicides lingering in compost have harmed plants grown in soils amended with that compost. Herbicides break down in the environment over time, with the rate of breakdown depending on the type of herbicide and environmental conditions. The higher temperatures and biological activity in a compost pile accelerate the breakdown of most herbicides. Binding with organic matter in the compost also inactivates herbicides. Breakdown and binding reduce the risk of herbicide damage.

Lawn clippings may be a source of herbicides in some home compost piles. The best way to eliminate this source of herbicides is to leave treated grass clippings on the lawn, rather than compost them. Leaving clippings also benefits the lawn. If you suspect herbicides in your own compost pile, let the pile sit for a year or more, allowing more time for breakdown and binding. Other options are to reduce herbicide use in areas where you compost the residues, or choose herbicides that break down quickly in the environment.

Some agricultural herbicides (for commercial-use only) may persist through the composting process, and have resulted in the contamination of some composts. Those herbicides are not registered for home use, but are occasionally present in manure from animals who consumed forages treated with those herbicides. Residues of those herbicides pose no threat to humans or animals, but can harm susceptible plants.

How to Make Compost

You do not need a bin or other container to make compost. Simple piles work well. However, containers are tidier and make it easier to shield the composting material from pests. Containers can be simple or fancy. Make them from materials such as old pallets, lumber, mesh fencing, or cinder blocks.

Slow Composting

Slow composting is an easy and convenient way to turn yard wastes into a useful soil amendment. It often is the best method for people who do not have the time to tend a hot compost pile. Simply mix nonwoody yard wastes into a pile and let them sit for a year or so. Microorganisms, insects, earthworms, and other decomposers will slowly break down the wastes. A mixture of energy materials and bulking agents provides the best food source and environment for decomposition (see Table 1).

Add fresh wastes by opening the pile, placing the new materials in the center, and covering them. This not only buries the fresh wastes so they do not attract pests, it also helps aerate the pile.

Fruit and vegetable wastes are particularly appealing to pests, so be sure to bury these wastes well within the pile. If pests are still a problem, you may need to screen the pile or use another method of composting these wastes.

The biggest drawbacks of slow composting are the length of time it takes materials to decompose and the related likelihood of pests being attracted to those rotting materials. Also, slow composting does not produce the heat needed to kill many weed seeds or rhizomes. It is best to pull and compost common weeds before they go to seed. If you put seeds in a compost pile, be prepared for more weeding.

Fast Composting

If you create and maintain a balance of air, moisture, and energy for microorganisms in a compost pile, they produce a hot pile that breaks down materials quickly. That heat also kills many weed seeds and disease organisms. Making hot compost takes some extra effort, but it produces a high-quality product relatively quickly. Hot composting requires the proper ratio of energy materials to bulking materials, plus regular mixing of those materials and monitoring for moisture and temperature. One method for starting a hot compost pile is described below.

After initial mixing, a regularly turned pile usually stays hot (120° to 150°F) for several weeks to a month (Figure 5). It will shrink to about half its original volume by the end of this time.

Building a Hot Compost Pile

1. Collect enough material to make a pile at least 1 cubic yard in volume. (An open pile 5 feet wide at the base by 3 feet high holds about a cubic yard.) Use roughly two parts bulking agent to one part energy material (see Table 1). Chop, shred, mow, or smash coarse materials so they will break down faster.
2. Start the pile by adding energy material and bulking agent. Then mix with a pitchfork. If the materials are very dry, add some water to moisten them.
3. Squeeze a handful of the mixed material to check its moisture level. If you can barely squeeze out a drop of water, the moisture level is ideal. If the pile is too dry, add more water and check the moisture again. If it is too wet, mix in some drier material.
4. Continue adding energy material and bulking agent, mixing, and checking moisture until the pile is built.
5. Use a pitchfork to stir and turn the pile weekly, and add water when needed. Turning improves the porosity of the pile and speeds decay. It also mixes cooler material from the outside of the pile into the hotter center. Cover the pile during rainy periods so it will not get too wet.

The pile then needs to sit another 4 to 8 weeks to cure. Curing affects the availability of nitrogen and the microbial activity of the compost. Uncured compost may harm some plants, especially when compost is used in potting soil or to start seeds. Curing is less critical when small amounts of compost are worked into soil. With two compost piles, you can let one batch cure while you start another batch in the second pile.

If anything recognizable remains in your finished compost, pull it out and mix it into your next batch of compost.

Temperatures within a hot compost pile during curing are 80° to 110°F. The compost is ready to use when at least 8 weeks have passed since initial mixing, the pile no longer heats when turned, and the material looks dark and crumbly.

Troubleshooting

If your pile isn't hot, consider the following:

- If the pile is dry, add more moisture.
- If the pile is mostly bulking agent, add energy materials or nitrogen fertilizer.
- If the pile is too wet, add more bulking agent. Cover the pile or build a larger pile during the rainy season.
- If the pile has a foul smell, turn it more often or add more bulking agent to improve its porosity and aeration.
- If the pile is too small, build a larger pile to hold heat better.

Figure 5. With active, hot composting, internal temperatures can rapidly rise above 120°F. This pile is just a week old and was built with fresh grass clippings, shredded leaves, and kitchen scraps.

Sometimes you may have several problems to overcome. If you cannot get the pile to heat, all is not lost. The pile eventually will break down by the slow method anyway.

If a batch of compost is finished but some material remains recognizable (pine cones, large twigs), remove the recognizable material from the rest of the finished compost and simply add it to the next batch to compost again.

Using Compost

The best part about compost is the benefit it provides your garden. Mix compost with soil to add organic matter, or use it as mulch.

Amending Soil

Well-decomposed, earthy compost is a good soil amendment. It makes soil easier to work and creates a better medium for plant growth. You can mix 1 to 2 inches of compost into your soil before you plant a vegetable garden, lawn, flower bed, or cover crop.

Mulching

Compost applied to the soil surface helps control weeds, conserve water, and protect soil from erosion. The best time to apply compost mulch is in early summer, after plants are established and the soil has warmed. Later, the mulch can be dug or tilled into the soil. When mulching perennial plantings, choose compost made from woody bulking agents; it decomposes slowly, resists compaction, and slows weed establishment.

Vermicomposting

Many food wastes can be composted by red worms in **vermicomposting** bins. Kitchen wastes that worms can process include fruit and vegetable peels, grains, pasta, baked goods, coffee grounds, and even coffee filters. Do not feed meat products to these worms.

Place worm bins where temperature and moisture can be controlled. An ideal temperature range for worms is from 55° to 77°F. Worms also need a moist environment, and air circulation is a must in and around a worm bin. Choose a location that is convenient for maintaining the bin.

The size depends on how much waste you generate per week. A bin or box measuring 1 foot by 2 feet by 3 feet can handle 6 pounds of kitchen wastes per week, which is about average for a family of four to six.

Supplies for Vermicomposting

Worm Bins. Many worm bins are made from plywood, but large plastic storage boxes work as well, if some method of ventilation is added. Worms avoid light, so the container should stay dark inside and have a good lid to keep pests out. There should be air holes somewhere on the container—either on the lid, sides, or bottom (if the container is not sitting directly on the ground). If you use a plastic bin, be sure to add both drainage and aeration holes. A drip collection tray under the bin will be necessary if you put drainage holes in the bottom of the bin. Never use a container that has been used for storing toxic chemicals. Worm bin construction plans are available from many Extension offices or municipal solid waste departments.

Type and Quantity of Worms to Use. While nightcrawlers and other garden earthworms are very important for soil improvement, they won't survive in a worm box. Earthworms live only in their burrows in the soil. Two varieties of red worms adapt to a box environment: *Lumbricus rubellus* and *Eisenia foetida*. These red worms feed on the surface of organic matter (Figure 6). Check with master composter volunteers at your local Extension office or solid waste department for sources of worms for composting bins.

The number of worms required depends on the daily weight of food waste added. Measure worms by weight rather than number. Two pounds of worms are needed for each pound of kitchen waste added per day (a ratio of 2:1). For example, if you produce a

Figure 6. Red worms, in particular, can thrive within a contained environment and survive on a diet of kitchen scraps.

half pound of kitchen waste per day (3 1⁄2 pounds per week), use 1 pound of worms.

Bedding. Start by putting bedding in the worm box. Corrugated cardboard, newsprint, and newspaper shredded in 1-inch-wide strips make excellent bedding. Worms need some grit for breaking down their food. Add a little topsoil for this purpose. Put the worms in the bedding with their first feeding.

Worm Bin Management

In order to survive, worms require 75 to 90 percent moisture content in both their bodies and their bedding. To achieve this percentage, add 3 pounds of water for each pound of dry bedding (a ratio of 3:1). An easy way to check the moisture content of bedding is to squeeze some in your hand. If a few drops of moisture are released by squeezing, the bedding is sufficiently moist. If five or more drops are produced, the bedding probably is too wet.

Keep a 4- to 6-inch layer of clean bedding on top of your worms and their food. Tuck each new food addition into the bedding—don't just dump it on top. It is a good practice to vary the location where you bury wastes in the worm box. A worm box 2 feet by 2 feet (big enough to handle food scraps from a family of 4) has approximately 9 locations where you can bury kitchen wastes (each corner, in the middle of each side, and in the box center). That allows 9 feedings before you have to bury again at the first location.

Grinding the scraps is not necessary because kitchen wastes break down very quickly. Do pulverize egg shells, however.

If you need to be away from home, just feed the worms a little extra and leave them undisturbed. They can go 3 weeks or a month without feeding. If you go away for a longer time, make arrangements with someone to feed your worms.

Worms multiply fast. Avoid overpopulation by periodically removing some worms from the bin. Use those "extra" worms to start a new worm box or give them to someone else who is starting a worm composting box. Or, add them to your outdoor compost pile.

Refresh the Bedding. It is not necessary to stir or mix the bedding and food—worms are happy just being fed and left alone. After many weeks, you will notice that the bedding is disappearing as worms and microorganisms decompose the material. The color of the bedding also becomes darker. As these things happen, the favorable worm environment decreases. Also, large amounts of accumulated **castings** might become harmful to the worms, since the castings of each worm are toxic to other worms. Decide when to add fresh bedding based on the condition of the bedding and the quantity of worms in the box. Depending on the amount of room in your worm bin, you may be able to keep adding fresh bedding on top of the old until you are ready to harvest the compost which will accumulate at the bottom.

Odor and Pest Control. Control odors by not overloading the box with waste, keeping out inappropriate waste, and providing adequate fresh bedding. Do not fill the bin with a lot of food waste until the worm population is established. Never add cheese or other animal products to worm composting systems.

Fruit flies are more of a nuisance than a serious problem. Minimize fruit flies in a worm bin by completely covering fresh food waste with several inches of bedding and by covering the bedding with a sheet of newspaper or cardboard tucked in around the edges.

If worm bins are kept outside, rodents and other animal pests may be a problem. The easiest way to keep animals from entering a worm bin is to keep the lid securely shut or latched and meat wastes out.

Harvesting the Vermicompost

Remove worm castings and decomposed bedding at least once a year to keep your worms and their environment healthy. The

> ### Common Vermiquestions
>
> **Can a worm see?**
>
> *No, worms don't have eyes. However, they are very sensitive to light, and they try to hide as soon as they are exposed to light.*
>
> **Where is the worm's mouth?**
>
> *The worm's mouth is in the first anterior segment. There is a small protruding lip just over the mouth. When the worm is foraging, this lip stretches out to sense food.*
>
> **How does a worm chew its food?**
>
> *Worms have no teeth for chewing their food. A worm can take only a small particle of soft, moistened food in its mouth. It ingests the food along with a grinding material such as sand, soil, or limestone. Contractions from muscles in the worm's gizzard compress the particles against each other, thus mixing them with fluid and grinding them into smaller pieces.*
>
> **Do worms need air?**
>
> *Worms need a constant supply of oxygen from the air, even though they do not have a nose or lungs. The oxygen diffuses through the moist tissue of a worm's skin, from the region of greater oxygen concentration (air) to that of lower concentration (inside the worm).*
>
> **How do I use worm compost?**
>
> *Use worm compost like any other compost. Sterilizing is not necessary.*

simplest harvest method is to simply scrape or shake the contents of the worm bin to one side and place fresh bedding and food in the cleared space. Do not put any new food in the old material; place new food only in the new bedding. Wait a month or so until the worms have all migrated to the new feeding ground and bedding, then remove the old material and use it as you would any other compost.

At any time, if there is lots of compost "tea" accumulated at the bottom of the bin, pour it off and water your garden with it.

Summary

Backyard composting reduces the flow of waste to landfills or burn piles and produces valuable organic matter for the soil at the same time. Composting is a natural biological cycle of growth and decay. The benefits are the same whether you compost in carefully tended hot piles or in neglected cold piles, or let worms do the work for you. Backyard composting is a simple, yet important, way to improve our communities and our environment.

Further Reading

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Mansour, N.S. 2003. Gardening with composts, mulches, and row covers. Oregon State University Extension Publication EC 1247. http://extension.oregonstate.edu/catalog/html/ec/ec1247/.

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23

Fire-resistant Landscaping for the Home and Community

Topics covered:

- Introduction
- Wildfire Components
    - Weather
    - Topography
    - Fuel
- Defensible Space
- Fire-resistant Vegetation

Learning Objectives

- Understand how fire spreads and intensifies.
- Understand the concept of defensible space around homes.
- Know practices that property owners and communities can use to decrease the potential for damage to property from wildfire.

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(adapted with permission)

Introduction

The typical home and its surroundings can provide an enormous source of fuel for a wildfire. But through the creation of defensible space around the home, and proper plant selection and care, fire intensity can be decreased. Additionally, the use of fire-resistant materials for the roof, decking, and fencing that may be connected to the house have also been proven to reduce structural damage.

Wildfire Components

There are three components of the fire environment: weather, topography, and fuel. These components affect the likelihood of a fire starting, the speed and direction at which a wildfire will travel, the intensity at which a wildfire burns, and the possibilities for controlling and extinguishing a wildfire.

Weather

Dry, hot, and windy weather increases the likelihood of a major wildfire. These conditions make ignition easier, allow fuels to burn more rapidly, and increase fire intensity. High wind speeds, in particular, can transform a small, easily controllable fire into a catastrophic event in a matter of minutes.

Topography

Homes at the top of hills are the most susceptible to damage by wildfire, and the steeper the slope, the more quickly the fire will spread. Slopes on the south and southwest sides of hills usually have more fires. Steep slopes with narrow drainages can significantly increase the rate of a fire spreading uphill.

Fuel

Fuels for wildfires include all vegetation, both live and dead, including dead trees and shrubs, fallen branches, needles, and leaves. The amount of fuel present on a site and its relative moisture content influence how easily a fire can ignite, how quickly it spreads, and how long it will last. For example, vegetation with a high moisture content will still burn, but may do so at a slower rate.

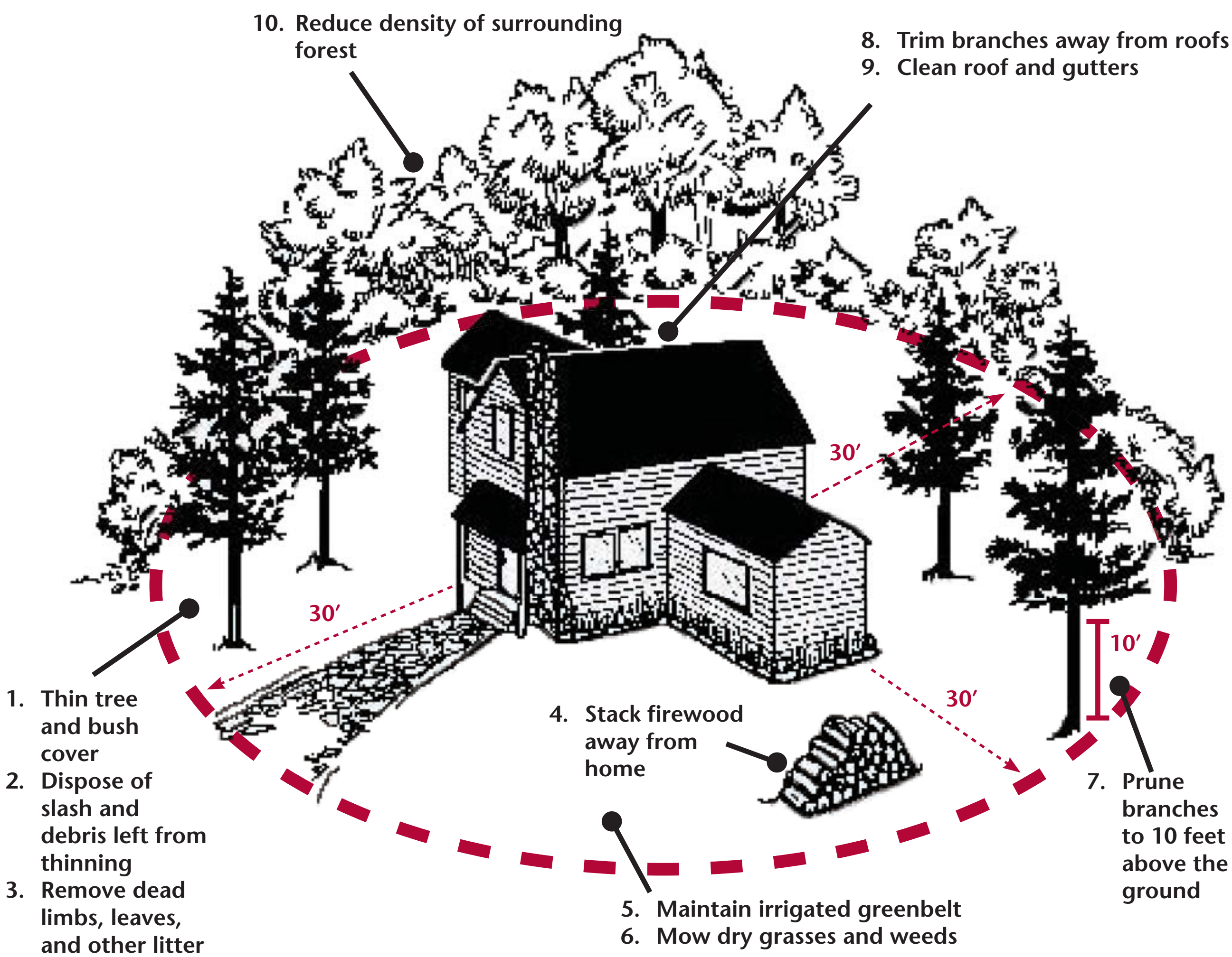
Although property owners can't affect the weather or topography, they can manage the vegetation around their homes to decrease the amount of fuel there is. A good fire-resistant landscape design incorporates what fire service professionals refer to as "defensible space."

Defensible Space

Defensible space refers to the clear area around the home and other structures that reduces the spread of fire and provides a safety zone in which firefighters can work (Figure 1). To create defensible space:

- **Remove hazardous flammable materials,** debris, and dead trees and shrubs near your home. Keep your roof cleared of twigs and needles. Stack firewood and combustible materials well away from buildings. Keep weeds and other debris away from propane tanks and sheds where gasoline or other petroleum products are stored.
- **Thin trees near your house.** A fire that moves independent of the ground in the tree or shrub canopy is referred to as a **crown fire**. When the crowns (upper branched parts) of adjoining trees touch they form a

Figure 1. A fire-resistant defensible space. (Source: U.S. Forest Service)



contiguous fuel ladder and fire can spread quickly from tree to tree. Thinning your woodlands can be very effective in reducing fire risk, but for overall forest health, thinning should be done only between August and December to avoid creating habitat for the *Ips* Beetle. This native bark beetle overwinters in slash and duff on the forest floor. The adult beetles become active in the late winter and seek out fresh slash and trees damaged by ice, wind, or snow. So do not provide any fresh green slash from January through July.

- **Remove ladder fuels.** In unthinned forest stands there are often many little trees in the understory. These small trees act as a "ladder" for fire and help carry it up into the crowns of bigger trees. Once a fire travels into the crown of a tree, that tree almost always dies. These ladder fuels should be removed through thinning.
- **Prune trees.** Tree branches that hang low to the ground are another kind of ladder fuel. Pruning the lower branches of your trees reduces the likelihood that a fire will move from the ground into the crown of a tree. On mature trees, remove branches growing within 10 feet of the ground or understory vegetation. For example, if there are 3-foot-tall snowberry shrubs surrounding many of the trees, remove tree branches to 13 feet. Also, remove branches within 15 feet of roofs and chimneys.
- **Landscape with lawn areas and fire-resistant plants within 30 feet of your house,** or 100 feet if your home is situated in a high risk area. Mow and irrigate lawn areas regularly.
- **Treat slash.** Slash is created after activities such as pruning and thinning. Left on the ground, slash can increase the risk and spread of wildfire. Treating slash usually involves burning in piles or chipping. Many landfills offer designated days when yard debris can be disposed of for little or no cost. If you choose to burn, check local regulations regarding permit requirements and "burn ban" restrictions.
- **Create Fire Breaks.** A fire break is a gap in vegetation or combustible material that will act as a barrier to slow the progression of the fire. Fire breaks can be natural areas such as flowing streams, or installations of hardscaping. Constructed water ponds, fountains, gravel paths, cement sidewalks, rock retaining walls, or courtyards covered with flag stone are just a few examples of hardscaping. (It should be noted that beauty bark, commonly used in northwest garden flowerbeds, will smolder in a fire.)
- **Make sure firefighters can get to you.** Make sure your address is easily visible for firefighters. If necessary, clear your driveway so it is wide enough for a fire truck to enter and turn around. It may not be possible for firefighters to defend your home without good access, an adequate escape route, and defensible space around the home. If the

entrance is too narrow for a fire truck or has an abundance of vegetation that could easily ignite or hinder a safe exit, the fire service will flag that home and move on to the next.

- **Stop sparks before they become fire.** Place screens on your chimney and all the vents in your home to block any burning embers from entering your home. (Note: embers from a nearby fire can travel up to a mile away from the source). If your roof is not made of fire-resistant material, consider replacing it. Face exposed decks, porches, or foundations with skirting. Keep a hose and fire tools readily accessible, especially when you burn debris.
- **Spread the word to your neighbors.** Neighbors working together can create better fire safety than individuals working alone. Ask your neighbors to join you in helping to make your neighborhood safe from wildfire. This is particularly true in housing subdivisions where there is usually less than 30 feet of defensible space surrounding each home. In this case, it becomes even more crucial for entire subdivisions to be involved in fire prevention efforts.
- **Check for neighborhood hazards** such as dead or dying trees or limbs which could fall and break power lines. Notify your power company of potential hazards.
- **Keep fire safety equipment readily accessible inside and outside your home.** Make sure the home has functional smoke detectors and fire extinguishers. Have fire tools and a connected hose readily on hand outside. Make sure all family members know where this equipment is and how to summon help in event of a fire.

In subdivisions, where there is typically less than 30 feet between adjacent houses, it is crucial for neighbors to work together in fire prevention efforts.

Fire-resistant Vegetation

Note: Fire-resistant does not mean fire proof.

How vegetation burns depends on its moisture content, location, distance from other plants, the amount of fuel available, and its exposure to advancing heat and flame. All plants and vegetation will burn if a fire's intensity is high enough.

Generally speaking, trees and shrubs that accumulate a lot of dry or dead needles, twigs or leaves are likely to be highly flammable. Plants with thick, resinous sap, strong odors, and loose, papery bark also tend to be highly flammable.

Water content is a key factor in what makes plants and vegetation resistant to fire. Plants and vegetation with high water content do not readily ignite. These are plants with water-like sap, as opposed to gummy pitch, and with leaves that are moist and supple, like most deciduous leaves. Less intense fires can often pass right through fire-resistant plants causing little or no damage. While fire-resistant vegetation will burn under extreme conditions, the burn will be at a lower intensity and with slower rates of spread.

Fire-resistant landscaping is about proper selection and placement of vegetation—not denuding the property. Proper placement and maintenance (such as thinning, pruning, and watering) are as or more important than selecting a fire-prone vs. fire-resistant plant.

An excellent PNW Extension publication called “Fire-resistant Plants for Home Landscapes” (PNW 590) is available from Washington State University, Oregon State University, and University of Idaho publications departments. While supplies last, you may also contact the Washington State Department of Natural Resources and receive a copy for free. From groundcovers to trees, this colorful publication provides readers with key information on the needs of each plant, such as light, water, and hardiness zone, plus landscaping design tips to make homes less susceptible to fire damage.

Further Reading

WSU Extension Publications available at: http://cru84.cahe.wsu.edu/

Fire education for landowners: Fuel reduction series. Information about fire behavior and fuels reduction methods from Oregon State University. http://www.cof.orst.edu/cof/extended/extserv/wildlandfire/woodlandowners.php.

Fire-resistant home construction. One-page fact sheet from Oregon State University. http://www.cof.orst.edu/cof/extended/extserv/wildlandfire/fwlistsz%5B1%5D.pdf.

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National Firewise. Web site of the national Firewise Communities program with lots of good information and tips. http://www.firewise.org/.

Tolt Firewise. An example of a western Washington FireWise community. http://www.toltfirewise.org/.

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Waterwise Landscaping

Topics covered:

- Introduction
- Planning & Design
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    - Soil Preparation
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    - Irrigation Scheduling
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Learning Objectives

- Understand how to plan and design for water conservation in the landscape
- Know how to prepare and manage soil in waterwise landscapes
- Understand appropriate plant selection and practical turf areas for waterwise landscapes
- Know irrigation and landscape maintenance methods for waterwise landscapes

By

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Introduction

In the western U.S., a majority of municipal water is used for irrigating landscapes. Much of that water is wasted because more is applied than plants need, through inefficiencies in the irrigation system and methods of application. Overspray, due to poor irrigation system planning, operation, and maintenance, causes substantial damage to hardscape materials such as walls, decks, patios, fences, and decorative stone. Excess water use can be reduced by using more efficient irrigation systems and scheduling irrigation according to the needs of the landscape. Besides conserving water, proper irrigation benefits the garden and landscape by encouraging deeper root growth and healthier, more drought-tolerant plants.

Waterwise landscapes are functional, attractive, and efficient.

Besides being economical about water, a waterwise landscape can also be functional, attractive, and easily maintained, and have a cooling effect on its surroundings. The term “xeriscaping,” from the Greek word *Xeros*, meaning dry, is generally synonymous with waterwise landscaping.

Water can be conserved in a landscape by incorporating one or more of Knopf’s principles, outlined in his 1999 book, Waterwise Landscaping with Trees, Shrubs, and Vines. His principles include:

1. planning and design of the landscape;
2. soil preparation and management;
3. appropriate plant selection;
4. using practical turfgrass areas;
5. mulching;
6. proper irrigation planning and practices; and
7. landscape maintenance.

Planning and Design

A landscape plan should meet the needs of the people who will use and maintain the area while incorporating the site’s existing environmental assets and constraints into the design. The planning-and-design stage of landscaping is the time to consider and prepare for all aspects of a landscape’s future use. Designing the landscape to use water efficiently should be a primary objective. Water efficiency can be accomplished by selecting low-water-use plants, designing and scheduling irrigation systems efficiently, grouping plants according to their water requirements, and using hardscaping materials (patios, stone paths, decks, etc.) appropriately to reduce the size of the area requiring irrigation.

Conduct a Site Analysis

Inspect the site and identify the environmental assets and constraints that will influence the design. Take notes on such factors as seasonal effects of sun and shade, soil conditions, slopes, direction of winds, and views from various locations on the site. These will be important in developing the design.

Develop a Plot Plan

Develop a plot plan of the area to be landscaped. This is simply a map of the site with the location of existing structures, trees and shrubs, property lines, driveways, gardens, utility lines, contours of the land, and other possible limitations to the design. Use graph paper to prepare a scale map of the property; let each square on the paper represent a defined unit of measure in the landscape. For instance, if the graph paper has 4 squares per inch, let each square represent 1 foot of landscape area. The map will then have a scale of 1 inch = 4 feet.

Plan the Design

Based on the environmental assets and constraints identified in the site analysis, decide where plants should be placed for optimum aesthetic value, screening of undesirable views, shade or windbreaks, and separation of areas of the landscape. Consider the use of hardscaping materials such as patios, paths, and decks. These materials can enhance the design while reducing the amount of area that needs to be irrigated and maintained.

Minimize Energy Consumption

Deciduous trees should be placed on the south, east and west sides of a building to take advantage of the potential benefits of winter sun and summer shade to heat or cool a building. Evergreens are good insulators but limit sunlight, so try to plant them on the north side of the building. In order to protect a home from cold and snow, use trees and shrubs as insulators or windbreaks along the structure.

Plant According to Water Zones

When choosing plants, identity their water requirements and group those with similar requirements in the same area or irrigation zone. For example, zones can be separated into 0 (no irrigation), 1 (irrigate monthly), 2 (irrigate twice per month), 3 (irrigate weekly) and 4 (irrigate twice per week).

Plants adapted to dry, arid regions should survive with little or no water (zone 0). However, during establishment, plants will need supplemental irrigation. Establish zones according to the amount of water you would like to use or can afford for the landscape, and what you wish to achieve aesthetically and environmentally.

Plants that require more water do not have to be excluded from a waterwise landscape. However, they do need to be grouped together in locations (zones) that suit their needs, with the recognition that more water and attention will be required to maintain them.

Select Plant Material

Select plants that will most effectively achieve the design goals. Use species that are adapted to the soil, water, temperature, light, and pest conditions of not only the region, but of the immediate landscape environment to ensure landscape health and to help minimize maintenance and nutrient and water requirements. When choosing plant material to include in the design, consider:

- Aesthetics—Size, shape, color, and form that will best accomplish the design goals.
- Function—Plant to conserve energy and water, block undesirable views or noise, and control erosion on steep slopes.
- Soils—Most plants do well under a range of soil conditions; however, many plants have an optimum pH range, salt tolerance level, and soil moisture requirement. Check plant labels for more information on specific plant requirements and adaptations.
- Water—Select low water use plants and plants adapted to the water situation in your region. Incorporate smaller plant species into the design – they will use less water at maturity than large species will.
- Climatic adaptation—Choose plants adapted to the local hardiness zone (for the USDA hardiness zone map see http://www.usna.usda.gov/Hardzone/). See Chapter 10: Herbaceous Landscape Plants for a discussion of hardiness zones and choosing suitable landscape plants. Note that microenvironments created by a plant's immediate surroundings can also influence its hardiness in a region.

For more detailed information on planning and designing a waterwise landscape, see http://extension.usu.edu/files/publications/publication/EC_458.pdf and consult other references listed under Further Reading at the end of this chapter.

Soil Preparation and Management

Soil is the most important component of a landscape. Many well-designed landscapes have failed because of inadequate soil preparation before planting, or poor soil management after planting. Proper soil preparation and management also improve landscape water conservation by increasing plant rooting depths and soil water-holding capacity, and by reducing water runoff and evaporation. In choosing plants for landscapes in Washington, remember that soils can vary from alkaline (high) pH with moderate salt levels in the center part of the state, to more acidic (low) pH soils found west of the Cascades.

Soil Preparation

Soils should be tested for pH, salinity (salts), texture, organic matter, and nutrient levels. Any soil problems should be identified and, if possible, addressed before planting. New landscapes offer a unique opportunity to make major improvements in the soil before sprinkler systems and hardscape features are installed and before permanent vegetation is established. Refer to Chapter 3, Soil Science, for more information on soil improvement.

Generally, the better the topsoil, the better the conditions for plant growth. A minimum of 4 inches of topsoil is recommended for turf; 8 inches for trees. Deep, uniform topsoil encourages deeper rooting and provides a larger reservoir for water for plant use. If additional soil is brought to a site, it should be placed in lifts (layers). Lay the first 1/3 of the new topsoil and thoroughly blend with the native soil on site to create a transitional layer. Place the remaining soil on top of this transitional layer.

Compaction is a significant problem in new developments due to the activity of heavy equipment during construction. Break up compacted soil with a ripper blade or heavy-duty tiller before adding new topsoil and planting.

Soil Management

Soil texture dictates the required frequency and duration of water applied in a landscape. Sandy soils absorb water faster but have lower storage capacities than clay soils. In general, sandy soils should be irrigated more frequently, but in smaller amounts, than clay soils. Allowing irrigation water to penetrate deeper into the soil profile encourages deeper, more drought-tolerant root growth. Frequent, light irrigations will lead to plants that have a shallow root system, which are more prone to water stress. But note that for newly planted trees and shrubs, more frequent watering is necessary to promote good root establishment.

Once the landscape is established, various management practices can help maintain good soil conditions and conserve water. Aeration is a common practice to improve water infiltration and gas exchange properties in turf areas. Aeration removes small plugs of soil, creating air spaces and pathways for water movement into the root zone. Aeration should be done once a year in either the spring or fall for soils with a high clay content or for situations of active soil compaction, such as where turf is exposed to heavy foot traffic.

To maintain or improve soil physical conditions, annual planting areas such as flowerbeds and gardens can be amended with ½ to 1 inch of new organic matter each year. In perennial areas such as turf and around trees and shrubs, organic matter cannot be incorporated without damaging roots.

Plant Selection

One of the most pleasurable aspects of landscaping is choosing plants that appeal to you. Whether aesthetically, as with flowering plants, or practically, as with vegetables, plant selection is indicative of your personal taste. Besides choosing plants you like, it is also important to select plant species that are adapted to the soil, water, temperature, light, and pest conditions of your landscape environment to help minimize maintenance and water requirements and to encourage healthier plant growth. One suggested source, developed by the City of Seattle and area water utilities, lists plants that are adapted to the Pacific Northwest (http://www.savingwater.org/docs/plantlist.pdf). The site also provides information on light preferences (sun vs. shade) and mature plant heights. Other references on selecting waterwise plants are listed to the left and at the end of this chapter.

Lists of Waterwise Plants

Utah State University Extension: http://www.waterwiseplants.utah.gov/plants.pdf

City of Olympia's Waterwise Plants: http://olympiawa.gov/city-utilities/drinking-water/conservation/conservation-outdoor/waterwise-plants.aspx

Water Efficient Plants for the Pacific Northwest: http://olympiawa.gov/city-utilities/drinking-water/conservation/conservation-outdoor/waterwise-plants.aspx

Water—Use it Wisely. http://www.wateruseitwisely.com/100-ways-to-conserve/outdoor-tips/plant-lists.php

Some morphological traits, or physical characteristics, are good indicators of plant adaptation to low water situations. Plants with smaller leaves or highly dissected leaves have evolved to lose less water through transpiration. Protective coverings such as thick, waxy cuticles or pubescent (hairy) leaf surfaces also work to conserve water. Dense pubescence often makes the plants appear gray-blue or gray-green. Plants have also evolved various root systems to withstand limited soil water. Some plants have a large taproot to scavenge water deeper in the soil. Others have a dense, fibrous root system to access soil moisture over a large area or volume of soil.

Turfgrass Areas

Turfgrass covers the majority of the landscaped area in Washington. It is also the plant most often over-irrigated in landscapes. For this reason, it is important to consider the placement of turfgrass areas.

Avoid using turfgrass in areas that are hard to irrigate, such as steep slopes or odd-shaped and narrow spaces. Always consider the daily use of the turfgrass areas. If the area only receives traffic when it is mowed, another plant choice may be more appropriate.

One management strategy for low water conditions is to let the turfgrass go dormant during the hottest part of the growing season. Dormancy is a physiological process turfgrass uses to protect itself during drought and heat. Often, turfgrass that has turned a golden or brown color as it enters dormancy is mistaken for dying grass. However, as the temperatures begin to cool and more moisture is available, the grass will recover from dormancy.

If you choose to let turfgrass go dormant, eliminate all traffic on it, including mowing. Mowing will not be necessary anyway, due to the reduced growth rate of the grass. Adjust any automatic irrigation timers or use hose-end sprinklers to apply approximately 1 inch of water per month. This is known as **survival watering** and will be sufficient to maintain turfgrass through the drought period. When drought conditions subside, begin regular watering again to bring the turfgrass out of dormancy. If you let turfgrass go dormant, though, remember that landscape plants nearby still require adequate irrigation.

If the appearance of dormant turfgrass is not acceptable and you wish to maintain a green lawn through the summer, less water will be used if you reduce traffic to minimize wear and soil compaction. Withhold fertilizers (particularly nitrogen) except for small amounts of potassium to aid in root development. Reduce mowing to avoid further stressing the turfgrass.

Mulching

Mulching is the process of maintaining a relatively thick, continuous layer of material such as bark, wood chips, or rock on the soil surface. Mulching is fundamentally different from amending soil with organic matter: amending refers to the incorporation of organic matter into the soil, whereas mulch is layered over the soil.

Mulch reduces moisture loss from the soil and promotes rooting near the soil surface. Greater rooting near the soil surface increases water, nutrient, and oxygen absorption, leading to healthier plants. Mulches can also moderate surface soil temperatures, control annual weeds and grasses, decrease runoff and soil erosion, protect the trunks of woody vegetation from mower damage, and allow easier movement of people through landscapes and gardens during wet periods. Properly used, mulch also adds visually to a landscape (Figure 1).

Organic mulches include plant-derived materials such as bark, straw, leaves, or sawdust. Inorganic mulches include landscape fabric, plastics and rocks. Organic mulches have the advantage of supplying all or part of the nutrients required by plants; however, organic mulches decompose and require replenishing. Inorganic mulches do not provide nutrient benefits but last longer than organic materials. Choice of mulch material should be based on

Figure 1. Landscape plantings without mulch show signs of soil erosion and drying. Besides protecting the soil, insulating plant roots, and conserving soil moisture, mulched areas add visually to the landscape.

cost, availability, and the desired physical, chemical, and visual effects (Table 1).

Mulches are applied after seedling emergence or after transplanting. The thickness of your mulch layer should vary, depending on the material used. To get the maximum benefit of mulching, apply 1 to 2 inches of fine, dense material (less than ½-inch diameter) or 3 to 6 inches of course, fluffy material (between ½-inch and 3 inches in diameter). Note: A 1-inch-thick layer of mulch requires approximately 3 cubic yards of material per 1000 square feet of area. Distribute mulch evenly around the base of plants. Avoid packing down the mulch, especially if the mulch material is wet when applied. Keep as much air space in the mulch material as possible to allow for gas exchange and oxygen movement to roots, while maintaining an effective weed barrier.

Mulch layers should be maintained at their prescribed thickness. As organic mulches decompose (and the layer shrinks), add new material. The decomposition of organic mulch releases nutrients. Also, soil-dwelling insects and other organisms move through and feed in the mulch, incorporating the organic matter into the soil beneath the mulch layer.

Irrigation Planning and Practices

Water is an essential component of, and requirement for, plants and unless plant roots have a continuous supply, the plant will eventually wilt. Some exposure of a plant to water stress can

Table 1. Characteristics of some commonly used mulch materials.

Material	Characteristics
Compost	Test compost for high levels of soluble salts and high pH before using as mulch.
Rocks	May generate high soil temperatures in mid-summer.
Landscape fabrics	Effective in weed suppression; allows for water and air penetration into soil. Spread fabric over the soil; cut holes for existing or new plants; cover the fabric with mulch such as bark, gravel, or other material. Note that mulch materials can blow or wash off the fabric, leaving the fabric exposed.
Lawn clippings	Do not use fresh clippings as mulch. Dry or compost clippings first.
Legume hay	May heat upon wetting. Compost first or mix with other mulches before using.
Peat moss	Acidic (sphagnum) moss is preferred for high pH (alkaline) soils since it will help to lower soil pH. Not environmentally sustainable (depletes peat bogs).
Plastics	May generate excessively high soil temperatures if in direct sunlight in mid-summer. Cover plastic with mulches during hot periods. Not environmentally sustainable because it isn't biodegradable.
Sawdust, wood chips, and barks	These materials can tie up nitrogen in soil and induce a deficiency in plants. Apply 1 lb of available nitrogen per 100 lbs of these materials to prevent nitrogen deficiencies.
Straw, leaves, pine needles, and grass hay	Chop or shred material before using, to create a better mulch.

increase its ability to withstand drought. Eventually, however, if water is not added to reverse the wilting, the plant will die.

Hydrozoning

The first step in properly irrigating plants is grouping and planting them in hydrozones according to their water requirements. This could be a specific area of the landscape or an area under the control of a specific zone of the irrigation system. Once plants are grouped into hydrozones, schedule the irrigation to apply the appropriate amount of water to each of the zones.

Assessing When to Water

The optimum time to water is before you observe any stress on plants from lack of water. Monitoring plant condition and soil moisture can help determine when irrigation is needed before plants show stress.

It is possible to measure or estimate the amount of water lost from a landscape in order to predict how much water needs to be replaced. This is known as irrigating based on **evapotranspiration** (ET)—the sum of the water lost from the soil surface through evaporation plus the water lost through transpiration from the plant. This method is specific for plant species and climatic conditions including temperature, humidity, and wind. Refer to the sources at the end of the chapter for more information on ET.

Visual Signs. Visual signs such as wilting are strong indicators that landscape plants need water. Wilting and leaf scorch are both symptoms of water stress (Figure 2). However, repeatedly over-watering plants can create similar browning symptoms and even cause the leaves to senesce. Roots need oxygen to survive and when the soil is saturated with water, oxygen levels in the root zone are reduced. Without a healthy root system the plant is unable to absorb water and will show signs of water stress. Many gardeners assume the stress symptoms are from a lack of water and will compound the problem by more watering, eventually causing the plant to die.

Figure 2. Leaf scorch involves browning of the margins and tips of leaves. This very common problem can be caused by numerous factors that restrict the flow of water to the leaves, such as drought, salt damage (fertilization), root rot, excessive heat, and chemical injury. Leaf scorch symptoms are shown here on maple (A), poplar (B), and mountain ash (C).

Trees and shrubs have much deeper root systems than turfgrass; therefore, depending on the size and type of tree or shrub, they should be watered to a soil depth of at least 18 to 20 inches. Trees need, on average, one inch of water every seven to ten days, depending on the species. In general, trees and shrubs should be watered less frequently than turfgrass but for longer periods of time (that is, a deeper watering). Frequent, shallow watering does not properly meet the needs of either trees or turf and can be harmful to both.

Trees and shrubs located in turfgrass areas will benefit from normal lawn irrigation. However, during the months of July and August, extra, deep watering 1 to 3 times per month, either by the turfgrass irrigation system or by other sprinklers, may be needed where trees and shrubs are growing in turfgrass areas. Arborists, however, recommend a 2–4 inch layer of mulch under the drip line of trees instead of turf. See Chapter 11, Trees & Woody Landscape Plants for more details.

Feel Method. This method involves feeling a handful of soil to evaluate its moisture level. The texture will be different for each type of soil. Sandy and loam soils are considered dry, with little or no available moisture for the plant, when the soil runs through your fingers and no stain remains on your hands. Clay soils are hard to break apart when they are dry. When moisture levels are optimum for plants, you should be able to form an intact ball of soil and a thin layer of moisture and stain will be left on your hands. If water flows out of the soil ball, it contains more than adequate amounts of moisture and should not be irrigated.

Probe Method. Soil probes can be used to determine soil moisture and watering depth. The advantage of using probes is that they allow rapid inspection of conditions beneath the soil surface with minimal disturbance. Probes can also be used to check for compaction in lawns, tree planting holes, and gardens. There are two main types of simple soil probes (Figure 3).

A tile probe is simply a solid ceramic or metal rod with a pointed tip, fixed to a handle. When the probe is inserted into the soil, any soil moisture will discolor the probe, just as moist soil leaves a mark on your hands when you squeeze a handful. Inexpensive tile probes can be constructed from a ¼-inch-diameter, rolled steel rod welded to a 12-inch-long section of 1-inch diameter metal pipe as a handle.

Use a tile probe 1 to 2 hours after irrigating to monitor the depth of water movement. A tile probe enters moist soil easily. Resistance increases noticeably when the probe encounters dry soil. Stop applying pressure when resistance increases to a level where the probe begins to flex. Grasp the probe at ground level and remove it, noting how much of the probe was below the soil surface. This is an estimate of the depth of water movement. Take samples in several locations to estimate the average depth of water

Figure 3. Both soil probe (top) and tile probe (bottom) indicate similar depths of water movement (about 6 inches indicated here).

movement. Using tile probes takes some practice, but once you are accustomed to these devices you can rapidly and accurately assess the depth of water movement in soil. Do not use probes in areas where underground utility lines are located, and use them carefully around sprinkler lines. If you don't know the location of underground utility lines contact your local utility company.

An open-faced or hollow tube probe can be used to remove intact soil cores. Before irrigating, sample in several locations and inspect the soil to determine if it is dry or still moist from the previous irrigation. Between 1 and 2 hours after irrigating, remove intact soil cores from several locations and look for a color change between wet (dark) and dry (light) soil. This dark/light color change indicates the depth of water content in soil and is known as the **wetting front depth**.

Tile and soil probes can also be used to monitor the uniformity of irrigation and to determine if maintenance or improvements might be needed. Check the wetting front depth around and between sprinkler heads. If the depth varies, inspect sprinkler output rates and water distribution.

When water is applied frequently and for just short periods of time, it is common for soil to be wet to a depth of only a few inches. Over time, short, shallow watering limits plant rooting depth to a shallow surface layer. Additional water is needed to wet the soil to a greater depth and encourage deeper rooting—less frequent but longer irrigation will achieve this. If the depth of wetting exceeds 12 to 18 inches, the water is likely to move beyond the roots of many plants and be wasted. For lawns, 6 to 12 inches of moist soil is sufficient. Gardens and established trees often root deeper than lawns and can tolerate less frequent irrigations with more water to increase the depth of wetting to 24 inches or more.

Hollow tube or open-faced soil probes can be purchased at some agricultural or landscape supply outlets as well as from mail order sources. See sidebar for examples of soil probe retailers.

Some sources for soil probes:

- Ben Meadows Company. www.benmeadows.com
- Forestry Suppliers, Inc. www.forestry-suppliers.com
- Gempler's Supply. http://www.gemplers.com/
- AMS. www.ams-samplers.com

Irrigation Scheduling

An irrigation schedule should be devised and then monitored throughout the year as part of a comprehensive irrigation plan. Less water is lost from plants and soil during the cooler spring and fall months, so less irrigation water is needed at these times. Water is wasted when automatic irrigation systems are programmed for the hottest part of the summer without adjusting for times of day when temperatures are cooler and more natural precipitation is occurring. Websites listed at the end of this chapter provide more information on irrigation scheduling.

Irrigation Equipment

Different types of automated irrigation equipment are available depending on the landscape situation. For instance, turfgrass is most commonly watered using fixed spray or rotary sprinkler heads. Spray heads distribute a fan-shaped water pattern and are the most versatile in landscape coverage area. Rotary sprinklers distribute slowly rotating, high velocity streams of water with lower overall precipitation rates than spray-type heads deliver. Rotary sprinklers cover a larger radius, can be spaced further apart, and are typically used to irrigate larger landscape areas than spray-type heads. Directional models of both spray and rotary heads are available. For either type of sprinkler head, the water from one sprinkler should just overlap the sprinkler next to it. This overlapping pattern provides the most uniform coverage.

Drip irrigation, also known as trickle, micro-irrigation, or low volume irrigation, is an efficient way to water shrubs and smaller trees (with less than 4-inch diameter trunks), but is not appropriate for turfgrass or larger trees. In drip irrigation, water flows through flexible pipes or hoses and is applied directly to the root zone of each plant. Pressure is controlled by flow devices called emitters. Since little water is lost through evaporation or by runoff, drip systems use much less water than sprinklers. The number of emitters used for each plant and the flow rate for each emitter will depend on the size of the plant. Larger trees (with greater than 4-inch diameter trunks) should be irrigated using micro-sprinklers or bubblers that emit larger volumes of water and cover more of the root zone.

See The Irrigation Association's website (http://www.irrigation.org/) for more information on turf and landscape irrigation equipment and management practices.

Irrigation Maintenance

Routine maintenance of an irrigation system is essential. In early spring, prior to using an irrigation system, perform a general inspection to ensure the system is providing uniform coverage of the turfgrass and landscape areas (Figure 4) without leaks or other problems. This is a good time to identify and repair broken or damaged sprinkler heads and nozzles, and adjust sprinkler heads that are tilted away from vertical or are buried too deeply.

Figure 4. These brown patches in a turfgrass area are due to low water pressure and poor uniformity of water application.

Confirm the application rate of the irrigation system to help determine the irrigation run times required to apply the desired amount of water. One way to measure the irrigation rate is to space metal cans or other straight-sided catch cups uniformly around the landscape. Run the irrigation system for at least 15 minutes and then measure the depth of water in each can to determine the output rate (depth in inches ÷ time in minutes) and the distribution uniformity of your irrigation system.

Monthly examination of the irrigation system while in use will help to identify any broken, misaligned, or clogged sprinkler heads that need repair and help keep the system running efficiently.

Other water-efficient irrigation practices include:

- Water between 6 p.m. and 10 a.m. to minimize water losses due to evaporation. Note that to prevent mildew and other wetness-related diseases and problems, watering between 4 a.m. and 10 a.m. minimizes the amount of time for water-foliage contact.

- Set the irrigation system to run in cycles instead of applying all the water at once, to avoid over-saturation and run-off.
- Shut off automatic irrigation systems on rainy or windy days.
- Aim the sprinkler heads correctly: water the landscape, not pavement.
- Hand-water individual plants.

Landscape Maintenance

One of the most important components of a beautiful and lasting landscape is maintenance. Maintenance practices for conserving water in the landscape include:

- Manage and remove weeds to reduce competition for water.
- Cover all bare soil: mulch to reduce water evaporation from the soil and to reduce weeds.
- Fertilize conservatively and use slow-release products to eliminate excessive flushes of growth that require more water.
- Regularly mow turfgrass to reduce leaf surface area and transpiration.
- Aerate to relieve soil compaction and to encourage better water penetration and less run-off.

Portions of this chapter were excerpted and adapted with permission from the following material published by Utah State University.

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Further Reading

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Wateright—An educational and irrigation scheduling resource for water managers. http://www.wateright.org/.

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Greenhouse Construction & Management

Topics covered:

- Introduction
- Planning a Greenhouse
    - Types of Greenhouses
    - Site Selection
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Learning Objectives

- Know principles of basic greenhouse construction
- Know the equipment for hobby greenhouses
- Understand principles of greenhouse lighting, irrigation, heating/cooling, and pest management for optimum plant production

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Introduction

Proper greenhouse construction and management is critical for production of high quality plants. This chapter will discuss the various greenhouse structures, equipment, and methods used for optimum greenhouse plant production. However, this is only an overview of the topics to consider when designing your greenhouse. It is a broad topic to discuss. Consult the references at the end of the chapter for further information.

Planning a Greenhouse

A greenhouse must provide the right environment for growing plants.

A greenhouse project requires some careful advance planning. Your choice of type of greenhouse will depend not only on your primary reason for building the structure—what plants you wish to grow—but also the amount of growing space desired, available building sites and conditions on those sites, access to natural light, surrounding architecture, and costs. But after considering all that, remember that, primarily, the greenhouse must provide the right environment for growing plants.

Types of Greenhouses

There are many different types of greenhouses. They range from “hobby greenhouses” such as a solarium added onto a home, to freestanding commercial greenhouses that produce tons of vegetables and bushels of fresh flowers out of season.

The most common hobby greenhouses are those attached to a building. They provide easy access from the house, garage, or shed and may enlarge the living area of a home.

Attached Lean-to. This structure is “split” along the top of the greenhouse roof, so basically it is a half greenhouse (Figure 1). A lean-to is limited in size, location, and orientation by the structure it attaches to. This also limits the space inside the greenhouse and reduces the amount of natural light that can enter. But, since lean-to structures have a shared wall with another building, they are usually less expensive than a free-standing design. Many lean-to greenhouses can take advantage of home heating systems, saving the expense of purchasing and installing an independent heating system.

Attached Even-span. This type of greenhouse is a full-sized structure. It looks similar to the free-standing structure but is attached on one end to a building. It has more space and natural light than the lean-to attached greenhouse, but is still limited in size by the size of the building it is attached to.

Figure 1. This lean-to hobby greenhouse is "half a greenhouse," attached along its length to another building.

Freestanding. This greenhouse has no common walls with other buildings so its size, shape, and placement are more flexible. The design is also easier to expand or add onto, later. There are a number of different freestanding design styles including gothic, gable, hoop, A-frame, and slant-leg. Heat loss and heating costs are increased for freestanding greenhouses due to the extra open wall area. Plumbing and electrical service will need to be included in the design process of these greenhouses, and independent heating and ventilation systems may be required since a freestanding greenhouse won't be sharing those of an existing building.

Bartock's book, Greenhouses for Homeowners and Gardeners, provides details on sizing and construction of various styles of attached and freestanding greenhouse structures. The plans include dimensions, diagrams, listings of required materials, and heating and ventilation requirements.

Site Selection

There are several factors that need to be considered when selecting the site and orientation of the greenhouse. These factors must be carefully assessed and taken into account before construction work begins, in order to avoid costly adaptations during or after construction. In general, the ideal location for a greenhouse is a well-drained area that is level and has full exposure to sunlight.

Structure Orientation. A greenhouse should be located in a spot where it gets maximum sunlight. Especially aim to maximize winter sun. Remember that in winter the sun is lower and shadows are longer than in the summer. The best location for a greenhouse structure is on the south or southeast side of anything that might cast a shadow on it, such as a building or large tree. This provides the best light levels throughout the day. An east-side location is also good since it captures the November-to-February sunlight most effectively—that is the time of year when natural sunlight is most limited. If a south or southeast location is not possible, then position the greenhouse on the southwest or west side of the building so plants receive sunlight during the afternoon periods. The least desirable site for a greenhouse is on the north side of anything that casts a shadow on the greenhouse.

Plants to be grown. Specific plants have optimum light and temperature requirements. Determine whether the plants and crops you desire can be grown in your climate without excessive environmental modification or production inputs to your greenhouse. For instance, if you plan to grow plants requiring more shade, take this into consideration when choosing a location; maybe the north side of a structure would be the best place to build your greenhouse.

Climate. Evaluate both the overall climate of the region (macroclimate) and the climate conditions of the immediate site (microclimate). The macroclimate gives general information regarding expected temperature extremes and overcast conditions that might occur over the larger region such as Eastern or Western Washington, the Palouse, the Puget Sound region, or the Columbia Basin.

Microclimatic information will provide the specific conditions expected within a small area such as different spots within a single homeowner's landscape. Small differences in elevation and structure proximity can affect sun exposure and shade patterns and influence temperature variations to create frost pockets or to moderate soil conditions and air pollution patterns. A greenhouse, or other structure, located in a **frost pocket** (lower area where cool air pools) will have higher heating costs throughout the winter. However, locating the greenhouse on top of a hill may mean greater wind exposure which can also affect heating costs and may affect the selection of construction materials.

Greenhouse Covering Materials

Materials for greenhouse coverings include glass, fiberglass, rigid plastics, and plastic film (very short-lived). When choosing a type of covering material, remember that, in general, the longer-lived materials cost more but may be more economical in the long run since they don't need to be replaced very often, if at all.

Structural strength of both the framework and the covering material is important to provide the load-carrying capacity of the structure—whether that load is external (snow) or internal (hanging baskets). Local zoning regulations may specify snow load requirements for greenhouse structures. Too, the structure must be strong enough to support the covering and environmental controls such as heaters and supplemental lighting.

Glass is typically installed in single layers but can also be installed as double layers or tempered glass. Tempered glass comes in larger panes and is stronger and safer if broken. The main advantages of glass are the longevity of the panes, high light transmission, and limited expansion and contraction of the material as it heats and cools. The disadvantages of glass are that it is easily broken and both more expensive and heavier than other possible coverings. Because of its weight, glass needs additional structural support which increases construction costs and time. Those supports can also create unwanted shading patterns within the greenhouse.

Fiberglass comes as corrugated panels or flat fiberglass. The greenhouse-grade fiberglass is thicker than other grades of fiberglass and is usually coated with polyvinyl fluoride (one commercial brand is Tedlar®) to slow the breakdown and discoloration caused by ultraviolet light. Fiberglass is lightweight and strong. The main disadvantages are the rapid weathering and discoloration that can occur over time. The weathering and discoloration result in a significant reduction in the light transmission as the sheets weather because the fiberglass fibers become exposed and collect dust. The fiberglass sheets, however, can be given a new coat of resin after 10 to 15 years. Flammability is another concern. Fiberglass panels burn rapidly once ignited, making fire insurance more expensive.

Double-wall plastics, such as acrylics and polycarbonates, are newer types of rigid plastic sheets. The double layer of plastic retains more heat than fiberglass. Acrylic sheets maintain high levels of light transmission for years, while polycarbonate sheets tend to discolor with time, so many are coated with an ultraviolet light inhibitor. Both materials are strong and flexible, making them easier to install over certain types of structures than fiberglass. One disadvantage is that the sheets expand and contract with temperature changes. Special attachments are used to join the sheets together to reduce the expansion problem. If the ends of the sheets are not well sealed, condensation can collect between the layers leading to algae growth and light transmission reductions.

Flexible plastic films are available in rolls, are relatively inexpensive, and easy to install. Polyethylene (PE) is the most common flexible plastic used for covering greenhouses. Simple, inexpensive structures such as greenhouses, hoop houses, or cold frames for over-wintering of plants can be constructed using PE. It comes in various thicknesses (measured in mils) with one mil = 1/1000 of an inch. Most greenhouse PE is 6-mil in thickness. This sheeting requires minimal support, resulting in little shading from structural elements. The sheets can be as wide as 50 feet and special ordered for almost any length. The sheets can easily be removed and the greenhouse recovered, which is especially advantageous since the PE is short lived, compared to other covering materials. On average, the films will last about 3 to 5 years.

Polyethylene transmits infrared or heat radiation from inside the greenhouse significantly more than other coverings and thus increases winter heating costs. Therefore, double layers of the covering can be inflated by a squirrel-cage fan mounted on the structure to blow air between the layers and help to insulate the inside structure. When properly assembled, the structures are tight fitting which helps reduce heat loss. But, because of that tightness, condensation and dripping can be a problem. Types of greenhouse PE treated to reduce condensation and decrease the amount of heat transmitted are available.

Workbenches and Growing Surfaces

Many factors determine the type of workbenches or growing surfaces used in the greenhouse. Some crops, such as cut roses, poinsettias, chrysanthemums, and flats of bedding plants can be grown on the ground to reduce costs. However, the plants are at a more convenient height for care and handling when set on traditional raised benches about 30 inches above the floor. Also, the air temperature is cooler at ground level than at a higher bench level. That difference may only be a few degrees but cooler temperature over several weeks can lengthen the production time and may also cause reduced quality or increased disease problems. A well-designed raised bench system allows better air circulation around the plants and improves disease control. The raised benches are also easier to sanitize than the ground is.

It is important to maximize growing space when designing a bench arrangement, and yet be able to conveniently reach all of the plants without damaging them. The simplest and least expensive benching structures are wooden or steel frames with mesh wire, snow fence, wood slats, or some other type of rigid supports placed across the frames for supporting the plants (Figure 2).

Wood is one of the most common materials used for frames and surface supports of benches in hobby greenhouses. But, remember that the greenhouse environment has high humidity, with irrigation water and condensation commonly present. Wood products such as red cedar and redwood have much longer lives than pine or spruce under these moist conditions.

Whether the wood is used for the benches or greenhouse structure, treatments are available that will help extend the life of the wood. Painting is beneficial for the structure and should be exterior latex, not enamel-based paint. Enamel will tend to peel under the wet conditions and leave the wood unprotected. The paint

Figure 2. Wooden supports are used for the structure while wooden frames with wire mesh serve as workbenches in this hobby greenhouse.

should be white or a similarly reflective color to improve the light reflection into the plants.

Wood preservative treatments are available to extend the life of the wood. There are two general types of preservatives, petroleum-based (penta and creosote) and water-based containing copper salts. Lumber and wood products such as railroad ties that have been treated with petroleum-based preservatives should be avoided. Freshly treated wood can release fumes that may be toxic to the plants. Besides, environmental regulations have restricted the use of these materials and they are of limited availability anyway.

Water-soluble copper preservatives can be used in close proximity to plants without injury. The copper preservatives can either be applied to untreated lumber or lumber can be purchased which has already been treated. Application by soaking the lumber is slightly more effective than brushing because the treatment soaks farther into the wood. The most effective treatment is where the preservative is injected into the lumber by pressure. Pressure-treated lumber can last 3 to 5 times longer than brushed or soaked lumber. And while pressure-treated lumber is more expensive, the extended life justifies the additional costs.

For shelving or workbench tops, galvanized wire mesh or expanded metal are more expensive than wood, but are stronger and can have a much longer life. For more information on types, sizes, and pricing of benches, as well as a list of greenhouse supply companies, visit the National Greenhouse Manufacturers' Association website (http://www.ngma.com).

Heating Systems

A major advantage of crop production in a greenhouse structure is the ability to maintain growing temperatures closer to optimum for the plants and crops. Individual plant species have a temperature range that is optimum for growth and quality. Temperature can affect crop development time, flower initiation and development, and crop height.

When determining temperature control, consider the various temperatures influencing the crop environment, all of which affect plant quality. Air temperature is usually the main temperature considered, but growing media and water temperatures are also worthy of consideration. Air temperature control systems are usually turned on and off by a thermostat that measures changes in the air temperature or by other sensors located somewhere in the greenhouse.

Designing a heating system for a greenhouse or any other structure must include determining the desired temperature to maintain in the structure, calculating how much heat will be lost from the structure during cold weather, and calculating how much heat will have to be replaced by the heating system. Heat is mainly lost from any structure by **conduction** through the covering (about 60%) or **convection** (about 30%).

Conduction is the transfer of heat (energy) through a material from an area with warmer temperatures (greater energy) to an area with cooler temperatures (lower energy). For example, in your house on a winter day, the interior of the house is being heated and is warmer than outside. Heat is being conducted from the warmth inside to the cold outside through the walls, windows, and all other exposed surfaces. The heat actually passes (is conducted) through the body of the structural materials. The amount of heat that is transferred is determined by the amount of exposed surface (the more surface exposed, the more heat is transferred), the difference between the inside and outside temperature (the greater the difference, the more heat is transferred) and the **insulation value** (resistance- or **R-value**) of the structural materials (the more insulation, the less heat is transferred).

Convection is the movement of air (or any gas or liquid) driven by the natural phenomenon of hotter air expanding and rising, causing cooler air to be drawn in below it. Warm air escapes through the leaks in a structure, drawing cold air in from outside to replace the warm air that was lost. That cold air needs to be heated to bring the overall temperature up to the desired level. The more leaks, or the colder the outside air, the more energy is needed to heat the cold air coming in to replace the warm air that escaped.

There are two important factors to consider when selecting a heating system for a greenhouse: the fuel that will be used and the type of heat delivery system that will best suit the situation. Natural gas is often the least expensive of the commercially available fuels. All common greenhouse heating systems can use natural gas as a fuel, as well as other common fuels if natural gas is not available.

The heating systems used in today's greenhouses are basically of three types: boiler systems, forced air units, or radiant heaters.

Boiler Systems. Boilers deliver heat through a system of pipes carrying either steam or hot water—the pipes are hot enough to warm the air around them and the water or steam they carry is recirculated, constantly being reheated and sent out again to keep the pipes (and thus the building) warm. The hot water system is less expensive than steam, and gives less temperature fluctuation. However, in general, boiler systems are expensive and would rarely be used in hobby greenhouses.

Forced Air Heaters. Forced air units, or unit heaters, are hung from supports in the greenhouse with the heated air blowing over the growing area. Most unit heaters are operated together with a tube or fan jet system that delivers the heated air out the tube and mixes the air so the hot, dry air blowing directly on the crop is reduced (Figure 3). A forced air system is the least expensive and most popular of the main greenhouse heating systems. These units will add weight to the structure, so the structural frame must be reinforced and the heating units must be supported. These units can cast shade in the growing area.

Warm air rises and expands, drawing colder, denser air into the void created below it; this movement is known as natural convection.

Figure 3. Forced air heater with an attached polyethylene tube to distribute warm air more uniformly throughout the greenhouse.

Radiant Heaters. Radiant heaters deliver heat as infrared waves. These heaters should be mounted above the crop to encourage the heat to more efficiently cover the production area. The infrared waves pass through air without heating the air and heat only the objects they encounter such as plants, benches, and walks. The initial purchase price of this type of system is relatively expensive compared with other heating systems, but there can be a significant heat savings over time that may offset the high initial cost.

For more specific information on economics of energy sources and types of heating systems see the article, Heating Greenhouses (Buffington et al., 2002). Consult greenhouse heating suppliers for specifics on prices and selecting the appropriate size system for your greenhouse.

Ventilation and Cooling Systems

Ventilation and cooling are important environmental control considerations if quality plants are to be grown during the warm times of the year. Greenhouses are good solar collectors of heat. During the warm, sunny times of the year that heat must be moderated to provide growing temperatures near optimum production temperatures or plant quality will suffer. Temperatures in a greenhouse can be moderated by removing too-hot air, by cooling air that is too hot, or by preventing the air from getting too hot in the first place.

Ventilation is the process of moving, or venting, warm air inside a building to the outside, with cooler outside air entering the building to replace the warm air. The temperature inside the building is lowered, if the outside air is cooler.

Cooling is the process whereby the temperature of air (or water or any material) is lowered. Common methods for cooling air temperatures within a greenhouse structure are shading and fan-and-pad systems.

The amount of heat buildup in a greenhouse is directly related to the amount of sunlight coming into the structure. Most greenhouse plants do not need 100% of summer sunlight to produce a quality plant, so various types of shading are used to reduce the amount of light entering the greenhouse by approximately 50%. Some light-sensitive plants should be grown under even more shade.

Shading. The most common shading materials are woven fabrics that allow different amounts of sunlight through depending on the density of the threads and weaving in the shading materials. Woven shade materials that provide specific percent shade (30%, 50%, etc.) are designed to more accurately control the intensity of light entering the greenhouse. Shade fabrics can be placed either inside the greenhouse (directly over the benches) or outside (over the greenhouse-covering material). Shading placed on the outside of the structure is generally left in place for the entire summer season.

Liquid shading materials may be sprayed on the outside of a greenhouse and are usually cleaned off in the fall, manually. These sprays are typically a mixture of white latex paint and water (Figure 4). A mixture of 1 part white latex paint to 10 parts water would provide heavy shading. Increasing the amount of water in the mixture dilutes the shading effect. The liquid shade will slowly rinse off during the winter in areas with adequate rainfall. With liquid sprays, however, a grower has to estimate the amount of shading being applied. Specific percentages are difficult to achieve.

Figure 4. A mixture of white latex paint and water sprayed on a greenhouse structure will reduce the amount of light and heat penetrating through the glass.

Fan-and-pad Systems. A fan-and-pad system involves mechanical ventilation: fans are located on one wall of a greenhouse with vents and cooling pads on the opposite wall (Figure 5). The fans push air out of the greenhouse, thus drawing air in through the vents and pads. Depending on the temperature of the outside air, the pads may be dry or have water circulating through them for **evaporative cooling**. With evaporative cooling, the humidity level of the air increases, which improves water relations within plants. When water stress is thus decreased, the plant's photosynthetic activity is increased. With ventilation alone, the humidity of the air entering the greenhouse is similar to the humidity of outside air; the humidity of the incoming air decreases when the air warms as it moves through the greenhouse. See Bucklin's 2004 article, Fan-and-Pad Greenhouse Evaporative Cooling Systems, for more specific information.

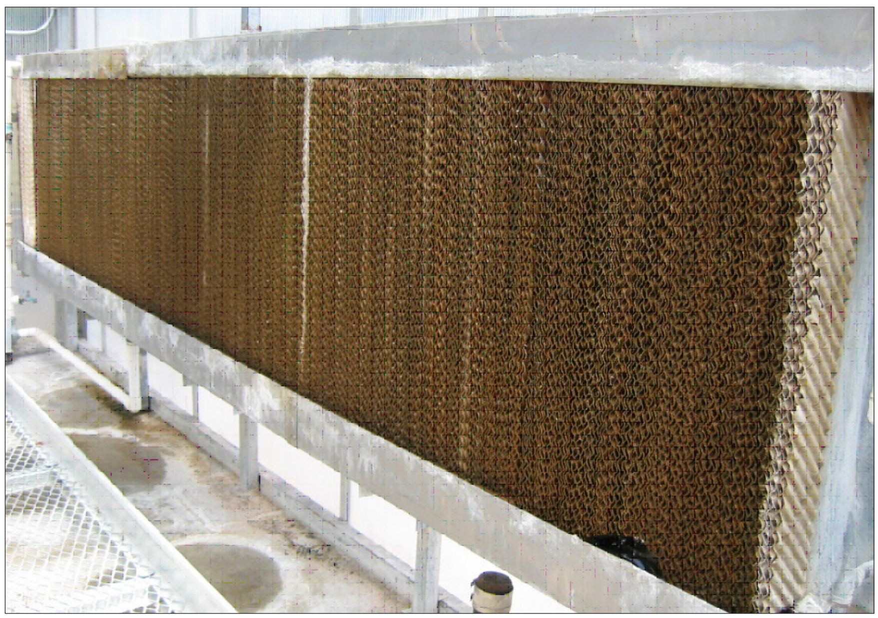


Figure 5. The fan system (top) and pad system (bottom) work together to ventilate and cool a greenhouse.

The National Greenhouse Manufacturers' Association has developed standards and procedures for determining the amount of air that should be moved by a ventilation system to give the desired temperature control. These calculations are based on achieving one **air change** per minute with the system at maximum ventilation. (One air change is the replacement of an amount of air equivalent to the volume within the room or structure.) Based on this, the number of cubic feet per minute of air to be moved through the greenhouse can be determined. The volume (cubic feet) of air to be moved in a greenhouse must be adjusted for various location and environmental factors. Consult greenhouse cooling and ventilation suppliers for specifics on selecting the appropriate size system for your greenhouse.

Air circulation is simply movement of air within a structure to eliminate hot and cold spots. No air exchange with the outside air is required. Circulation helps maintain a more uniform growing temperature throughout the greenhouse, reduces humidity around the plants, and improves carbon dioxide levels around the plants. Common greenhouse air circulation systems include fan-and-tube distribution systems and horizontal air flow fans.

Fan-and-tube Systems. These distribution systems consist of a fan jet mounted in the peak of the greenhouse. The air is blown through one long polyethylene tube with openings spaced evenly throughout. This system cannot only provide ventilation but can also distribute heat from forced air burners depending on the design of the system.

Horizontal Air Flow (HAF) Fans. These involve a system of fans mounted above the plants in a greenhouse. The fans are positioned so that they blow horizontally through the greenhouse, and adjacent fans will blow in opposite directions. This creates a circular flow of air throughout the area where the fans are mounted.

Humidity Control

One of the more important environmental factors affecting plant growth and health is the **humidity** level, or amount of water vapor, in the air. Problems can occur either when the humidity is too low or when the humidity is too high.

Low humidity can increase plant water stress because under conditions of low **relative humidity** more water is transpired (lost) from plant leaves. If too much water is transpired, water absorption and translocation within the plant cannot keep up.

By contrast, high humidity with resulting condensation can lead to increased disease problems. At night or under cloudy conditions during the day, a plant's temperature can be a few degrees cooler than the surrounding air. This temperature difference will result in condensation on the plant if the humidity is high enough.

To reduce the humidity in a greenhouse, a fan from the ventilation system can be used to exhaust the warm, humid air from the greenhouse and bring in cooler outside air. When that air is warmed the relative humidity goes down and the air feels drier.

High humidity is important in propagation facilities, both for seed germination and for rooting of cuttings. For seed germination, special germination chambers are often used to maintain high humidity and warm temperatures. These conditions speed the

Humidity vs. Relative Humidity

Humidity is the amount of water vapor in air.

Relative humidity is a measure of how saturated the air is with water vapor. Relative humidity changes with air temperature, without changing the amount of water vapor actually present. Warmer air can "hold" more water than cold air can. This is why muggy summer weather makes us feel sticky, and why our skin dries out in the winter.

germination process and result in higher quality seedlings. High humidity can be maintained by a mist system or just by having an air-tight structure with air moisture levels elevated by watering the germination flats plus infrequent misting by hand as needed.

Another environmental control that increases the humidity in a greenhouse is evaporative cooling. The cooling system decreases the air temperature by evaporation of water as the fans pull outside air into the greenhouse through the wet pad system. Evaporation takes energy and that energy, in this case, comes from the heat in the warmer air.

Irrigation Systems

Irrigation is one of the easier systems in the greenhouse to automate. The degree of automation and accuracy will dictate the cost of the system. The simplest automated irrigation system consists of plumbing, a timer, and a solenoid valve (used to turn the water on and off) controlled by the timer. More sophisticated computerized control systems are available to monitor moisture in the growing medium, salinity levels in the soil, solar radiation, and other parameters. However, even though the control may be automated, the requirements of the crop and influences of the environment and growing media must be understood to operate the system correctly.

In hobby greenhouses, growers typically use a hose to hand-apply water. Spray, drip, and capillary mat systems are common types of automated greenhouse irrigation systems.

Spray systems apply water from overhead nozzles. Each nozzle creates a circular water pattern over plants. This system is commonly used for germinating seeds and for bedding plant production.

Drip irrigation systems slowly apply water to individual pots or localized areas of a bench. The drip ("spaghetti") tubes are small plastic tubes connected to a larger supply tube. The tubes and emitters (tube-end nozzles) come in various types and sizes depending on the size of the plants being watered. Due to the slow trickle of water applied directly to the soil, water is conserved with this system.

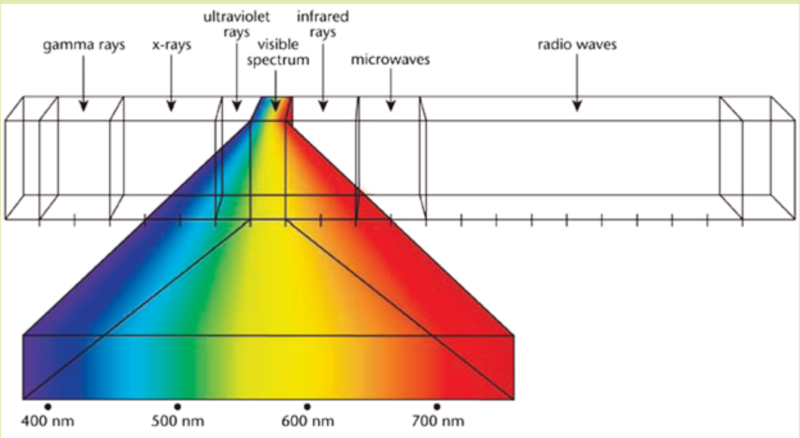
Capillary mats are a subsurface irrigation system. A special fibrous cloth mat is placed on a plastic liner or tray on top of the workbench. Pots sit directly on the capillary mat, so that as water is applied to the mat, the water is taken up by capillary action through holes in the bottom of the pots. It is important that the benches are level so the water does not all drain to one side, allowing some pots to be over-watered and others to dry out.

Lighting Systems

The amount of light in a greenhouse is primarily determined by the amount of sunlight that shines on the greenhouse. Artificial lighting can supplement the amount of light received on shorter or darker days.

There are two main reasons for using artificial lighting systems: to stimulate photosynthesis, resulting in increased plant growth; and

Aspects of Light



Light is a form of electromagnetic energy released as photons. The terms quantity, duration, and quality are used when describing light.

Light quantity relates to the intensity or the energy output of a light source. This is measured or described in terms of foot candles (fc).

Light duration indicates the photoperiod or length of time that the light source is emitting light.

Light quality refers to the color of the light emitted by a source. A light's color is determined by the light's wavelength (measured in nanometers, nm). Sunlight is energy of wavelengths from the entire electromagnetic (EM) spectrum. The wavelengths of light that humans can see make up the **visible spectrum**—just a small portion of the EM spectrum, from violet to red light. Wavelengths within the visible spectrum are most effective in stimulating photosynthesis and are referred to as the **photosynthetically active radiation** (PAR).

Objects appear colored because of reflection: they reflect light of a certain wavelength. Green plant leaves appear green to our eyes because they reflect green wavelengths while absorbing the other wavelengths of light. A black object absorbs all wavelengths of light and reflects almost none, while a white object absorbs almost no light and reflects nearly all wavelengths.

for photoperiodic control. Lighting to stimulate photosynthesis and growth must be relatively high to affect the processes. Many plants will show a significant growth response when supplemental lighting is used during the dark winter months. Manipulation of the photoperiod (length of daylight) is used with ornamental plants primarily to control flowering, as with poinsettias.

Three types of light tubes or bulbs are commonly used for supplemental lighting in greenhouses: fluorescent tubes, incandescent bulbs, and high intensity discharge (HID) bulbs. They each have different uses and benefits.

Fluorescent tubes have been used for plant lighting systems for years and are still used in germination chambers and growth rooms. Several different types of fluorescent tubes are available including plant grow lights, daylight, cool white, and others. The main differences among these various bulbs are the quality (color) and the intensity of light emitted. Because of the linear shape of fluorescent bulbs, they provide more uniform lighting than incandescent bulbs.

Incandescent bulbs are commonly used for photoperiodic control since only low intensity light is needed for that. Light levels of about 10 fc (foot-candles) will produce the desired photoperiodic responses. Typically, a row of 60-watt bulbs spread 4 feet apart and 5 feet above plants on a 4-foot-wide bed or bench is recommended. Aluminum pie plates may be set or hung between plants to increase the amount of light that reaches them. Incandescent lights are not used as growth lights because their low intensity tends to cause legginess (stretching of plant internodes).

High intensity discharge bulbs (HID) have longer life and higher efficiency, and produce much higher light intensities than either fluorescent or incandescent bulbs (Figure 6). High intensity bulbs

Figure 6. High intensity discharge lights can be used for supplemental lighting in a greenhouse during dark winter months.

are used for supplemental lighting especially during the winter months. Two common types of HID bulbs are metal halide and high pressure sodium lights. Metal halide bulbs contain a mixture of gases that produce a light quality that is mainly in the blue-green region of the spectrum. High pressure sodium lights are probably the most widely used supplemental light source in the U.S. These lights emit a quality of light located in a narrow region of the spectrum, primarily in the yellow region, and produce high intensity light.

Greenhouse Supplies

Greenhouse conditions require sterile growing media, clean water, and tools for irrigation and pest management.

Soilless Media

All growing media should provide oxygen, nutrients, water, and physical support for the plant. Each of those items becomes a major concern with greenhouse production since, in contrast to yard and garden ("field") situations, the growing medium is used in pots or growing benches with restricted depths and volumes.

Most greenhouses use premixed commercial media for plant production that consist mainly of peat moss or bark plus inorganic components added to increase aeration, bulk density, or water holding capacity. Wetting agents, limestone, and a nutrient "starter charge" are also added to commercial mixes. Wetting agents allow for more rapid water absorption by the medium. Limestone is added to adjust the pH to 5.5 to 6.5, the optimum pH level for production of most greenhouse crops. A nutrient starter charge provides a small amount of initial nutrients for the plants, but additional fertilizer must be applied throughout a plant's life to satisfy its requirements.

For mixing your own media, various inorganic and organic components can be used to produce a high quality potting mix. Commonly used inorganic components include sand, perlite, and vermiculite. Potential organic components include peatmoss, bark, and coconut coir.

Table 1. Uses and components of commonly used greenhouse mixes.

Media Use	Components
General purpose media	75–85% sphagnum peat moss (by volume), perlite, vermiculite, wetting agent, limestone to adjust pH, and a nutrient starter charge
General purpose media with less water retention	55–65% composted bark (by volume), sphagnum peat moss, perlite, wetting agent, limestone to adjust pH, and a nutrient starter charge
Plug and germination media	65–75% sphagnum peat moss (by volume), vermiculite, wetting agent, limestone to adjust pH, and a nutrient starter charge

Sand is added to improve the porosity of the medium, which results in better aeration. However, sand is heavy and can vary considerably in particle size. A medium to larger (coarser) size should be used since small particle size can reduce porosity rather than improve it, causing drainage and aeration problems. Sand is chemically inert and has limited nutrient-holding capacity.

Perlite is an expanded silicate material. It comes in various sizes but the horticultural grade works best in potting mixes. Perlite is very lightweight and tends to float to the surface in pots. While perlite provides good aeration properties for growing media, it has only limited water- and nutrient-holding capacity. Another potential problem with perlite is that it contains some fluoride, which can adversely affect the growth of some plants.

Vermiculite is an expanded mineral product produced by heating mica to extremely high temperatures. The vermiculite particles hold water and have a relatively high cation exchange capacity. If the medium is mixed or handled too much though, the particles will tend to compact and lose some aeration benefits.

Pumice is a volcanic rock and is mined in eastern Oregon, among other places. This is a common constituent of commercial mixes in the Northwest. Pumice is heavier than perlite but not as heavy as sand, and adds water and nutrient-holding characteristics to the mix.

The only organic constituents that should be considered are materials that have been fully composted or those that are resistant to decomposition. Manures, sawdust, and other fresh organic materials will decompose as they sit in the mix and can tie up nitrogen, causing nitrogen deficiencies in plants. They can also introduce disease and other pests. Be cautious when using fresh organic matter such as manure because it can carry weed seeds and herbicides, and have high soluble salt levels.

Peat moss is the most common organic component in soilless growing mixes. Peat moss characteristics vary, depending on the source, type of parent plant material, and degree of decomposition. Sphagnum peat is resistant to further decomposition. Lower or inferior grades of peat include **hypnaceous** (moss), reed, sedge, and humus or muck. Although peat tends to be acidic, there can be quite a variation in pH among them.

Bark, especially Douglas fir bark, is used by growers in the Northwest. This bark is fairly resistant to decomposition and is chemically inactive. Hardwood barks should be thoroughly composted before using.

Coir (coconut fiber) has become available as a substitute for peat. This fiber is the remaining waste from processed coconut husks. The fibers are compressed into blocks for shipping. When the blocks are placed in water, the fibers will expand to about 8 times their initial volume. Some coir sources originate near the ocean and high soluble salt problems have occurred when that coir is used in growing mixes. The soluble salt content of any coir should be checked before using.

Table 2. Characteristics of commonly used soilless media components.

Component	pH	Moisture retention	Aeration	Stability	Density
Peat moss	3.0–4.0	+	+	+	low
Composted bark	5.0–7.0	-	++	++	medium
Coconut coir	5.5–6.5	+	+	+	low
Vermiculite		+	+	-	low
Perlite		-	++	+	low
Sand		-	++	++	high

Water

The importance of using good quality water to irrigate any plant cannot be overemphasized. Optimum water pH is 5.5 to 7.0. Optimum soluble salt concentrations are 0.2 to 0.5 mS/cm. Young seedlings and certain plants are sensitive to even lower concentrations. Water softeners should never be used to remove soluble salts from irrigation water because they result in levels of sodium in the water that are toxic to plants. More expensive methods of salt removal include deionization or reverse osmosis. Some waters, especially well waters, may be high in ions such as sodium, chloride, or boron. Bicarbonate (HCO_3) and carbonate (CO_3) can be present in relatively high concentrations in water having a pH above 7. Over time these ions will raise the pH of the growing media, causing problems with nutrient uptake and availability. They can also cause unsightly white spots on plant foliage.

Some surface and recirculated waters may transmit plant disease, cause algae buildup, or have other biological problems. Occasionally, water might also carry weed seeds and insects that could pose problems. Water disinfection systems are becoming more important as growers turn to recirculating irrigation systems. There are several methods for disinfecting water. Methods available to home gardeners include heat treatment and filtration.

Fertilization Practices

There are various ways to supply essential nutrients to plants. Slow-release granular fertilizer can be mixed into soilless media at the time of planting or added periodically throughout a plant's life, or a liquid fertilizer can be applied through the irrigation system. Most greenhouses use some type of fertilizer proportioner system to apply a liquid feed to plants. One of the simplest and most commonly used types of proportioners for hobby greenhouses is a Hyponex Siphon injector, or similar hose-on types (Figure 7). This type of system is available at any garden center. It attaches directly to a hose and mixes at a dilution rate of 1 gallon of concentrated fertilizer to 15 gallons of water. Other, more sophisticated injectors that proportion at much higher rates are available. This reduces the number of times you have to make up fertilizer solutions. See Greenhouse Fertilizer Injectors: Selection, Maintenance, and Calibration, for complete information and diagrams for setting up a proportioner system: http://www.aces.edu/pubs/docs/A/ANR-1243/ANR-1243.pdf.

Figure 7. A simple hose-on–type proportioner is commonly used in a system for applying liquid fertilizer in a greenhouse.

Note that **backflow** can occur in a fertilizer injection system when there is a pressure drop in the supply line, creating suction and drawing the liquid from the concentrated fertilizer tank or other source backwards into the water supply line and contaminating the water line. Various types of backflow prevention devices are available. Consult irrigation companies and county health departments for recommendations and requirements.

In large scale greenhouse operations, fertilizer solution runoff and groundwater contamination have become a concern because (commercial) greenhouses use high rates of fertilizer and other chemicals. Some of these chemicals may be leached through the pots or root zones and end up in the ground water. Regulations are proposed or in place in some states and/or counties to prevent this contamination by runoff containment at the source. Recirculating systems in which water is reused are also becoming more common.

Various formulations of slow release fertilizers are available, usually coated with a resin or some material that allows the nutrients to escape slowly from the fertilizer pellets into the growing medium over an extended period of time. Release times range from just a few weeks or months to over a year. Temperature and moisture can affect release patterns of the nutrients.

The fertilizer type and concentration or rate depends on the plant species being grown. (See Chapter 5, Plant Mineral Nutrition and Fertility, for more information on essential plant nutrients, nutrient deficiency and toxicity symptoms, fertilizers, soil pH, and soil salinity). Potted bulb crops will require little, if any, additional fertilizer while petunias, chrysanthemums, and poinsettias are heavy feeders and will require high rates applied consistently throughout their life cycle. It may be necessary to periodically check the status of the fertilizer program by having an analysis made of the growing medium and/or plant tissue. For an up-to-date listing of labs conducting soil tests in Washington, see WSU Extension webpage for Analytical Laboratories and Consultants Serving Agriculture in the Pacific Northwest (http://www.puyallup.wsu.edu/analyticallabs/instructions). It is best to use a lab that routinely tests greenhouse media rather than just field soils. Analyses and recommendations can be different for peat-based or other soilless media compared with soil-based media.

Pest Control

Sanitation is important not only for disease control but for the control of insects and weeds—it is the first line of defense against pests and diseases in a greenhouse. Sanitation relates to the cleanliness of the growing facility and ensuring that only clean plant material, tools, supplies, and irrigation water enter the greenhouse.

When considering pest control methods, the use of pesticides should represent only one tool in a whole array of pest control procedures. Besides the environmental concerns about pesticides, their overuse has encouraged the development of pesticide resistance in certain greenhouse insects and diseases. Always read pesticide labels carefully before using, and rotate the classes of pesticides used in the greenhouse. Note that some products labeled for outside use may not be labeled for greenhouse use.

Integrated pest management (IPM) strategies should be used whenever possible. For more information on specific insects, diseases, pesticides, and IPM see the chapters in the Plant Health Care Section of this manual.

Good Greenhouse Sanitation Practices

- Wash and disinfect any greenhouse tools, containers, or equipment that might come in contact with growing media or be reused for plants.
- Wash your hands before beginning any work with plant materials, media, or containers.
- Inspect new plant material and supplies before bringing them into the greenhouse to make sure they won't introduce pests or pathogens.
- Keep dirty equipment, shoes, gloves, etc. off the workbenches.
- Keep hose ends and sprayer nozzles off the floor.
- Avoid wearing bright colored clothing that might attract insect hitchhikers and allow them to sneak into the greenhouse.
- Exclude pets and rodents from the greenhouse, as they can bring in insect and diseases on their feet or in their fur.
- Remove all weeds that sprout in containers or from the floor.
- Bag and remove infected, diseased, or suspicious plants carefully, to prevent spreading of inocula.
- Use trash cans and remove trash promptly and regularly.
- Periodically sweep or vacuum and wash the floor, windows, and walls.
- Keep the area around the greenhouse free of debris and consistently weeded and mowed.

Adapted from Greenhouse Sanitation by J. R. Kessler.

Further Reading

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The Hobby Greenhouse Association. http://www.hobbygreenhouse.org/.

Glossary

Portions excerpted from WSU Extension Publication MISC0175: Introduction to Insect and Disease Management; and Gardening in Western Washington: Native Plants (http://gardening.wsu.edu/text/nvglossr.htm).

A

abiotic. Literally, "without life." Inanimate or nonliving.

abscise. To fall off, as with leaves.

abscission. Shedding of plant body parts such as leaves in the fall.

abscission layer. Layer of cells between a leaf and the stem that is killed by hormones to make the leaf fall off the plant.

acclimate. To adapt to new growing or environmental conditions.

active ingredient (ai). A component of a pesticide that has pesticidal (prevention, destruction, repellant, etc.) activity; primary chemical of action in a product. Must be listed on any pesticide labels.

adventitious buds. Buds that form in an unexpected place on a plant, such as an internode. May be stimulated by extreme pruning or other wounding.

acute toxicity. A measure of the capacity of a pesticide to cause injury as a result of a single exposure.

aeration. Oxygenation; ventilation to expose something to air.

aerobic. Requiring or using oxygen to live or proceed.

aesthetic threshold. In pest management, the point at which visible or aesthetic damage becomes intolerable, requiring action to control the pest causing the damage.

aggregation. Process by which individual particles of sand, silt, and clay cluster and bind together to form peds.

agronomy. Study and practice of field crop production and soil management.

air change. Replacement of a given volume of air within a given amount of time; method of calculating and rating a ventilation system's capability.

allelopathy. The release of biochemicals, by some plants, to discourage or suppress the growth of other, competing plants nearby.

alternate host. A secondary host required by an insect or disease-causing organism to complete its life cycle.

ametabolous. Little or no body form change during growth development, in arthropods. *See also* metamorphosis.

anaerobic. Literally, “without oxygen;” living or active in the absence of oxygen.

angiosperms. Flowering plants; plants which produce seeds in a closed or covered ovary (fruit). *Contrast* gymnosperms.

anion. A negatively charged ion. Plant nutrient examples include nitrate (NO_3^-), phosphate ($H_2PO_4^-$), and sulfate (SO_4^{2-}).

annual plants. Plants that die after a single growing season and reproduction cycle. Also called simply, “annuals.”

anther. Plant reproductive structure that holds pollen.

apical. Situated at the highest point (apex) or end point.

apical dominance. Growth at the terminal, or apical, bud at the expense of lateral bud growth.

apical meristem. Area at the tips of twigs and roots from which new plant growth arises; the highest growing meristem on a plant.

arborize. To make tree-like; pruning lower branches of a shrub so they don’t drag on the ground.

arthropod. Invertebrate members of the Phylum Arthropoda; having a segmented body, jointed limbs, and **exoskeleton**.

aspect. Direction of exposure to sunlight.

attractant. Bait or other material that lures insects or animals.

avoidance. Planting at a time or in an area when or where insect or disease pathogens either are not found or are found only in low numbers.

awn. Single bristle or hair as on grains or a grass seed.

axillary bud. Bud located in the axil of a leaf. *See also* lateral bud.

B

backflow. In a plumbing or irrigation system, backward movement of water caused by suction instead of outflow of water. Can lead to contamination of water supplies.

bacterial ooze. Sticky liquid containing pathogenic bacteria, which seeps from cankers or lesions.

bait. A food or other substance that attracts insects or animals to a trap.

banding. Fertilizer application method in which the fertilizer is placed in a concentrated row or strip adjacent to plants.

bare root. A dormant plant that is shipped with no soil or other growing medium around its roots.

bark. Outermost layer of stems and roots of woody plants.

bark inclusion. Bark pinched between closely adjacent tree limbs or between a branch and the trunk in a tight crotch. Can serve as a wedge over time, leading to the splitting of the branch and trunk.

Batesian mimicry. With insects, physical resemblance to another species in order to stymie enemies. *Contrast* cryptic mimicry and Muellarian mimicry.

bearded. Having a long awn, or stiff hairs, as on the lower petals of some iris.

bedding plants. Plants grown indoors for transplanting to (usually) large, temporary display beds.

beneficial insects. Insects that benefit plants by preying on, parasitizing, or otherwise destroying pest insects or other arthropods. Often referred to as biological control agents or natural enemies.

biennial plants. Plants that take two growing seasons to complete their life cycle.

bilateral symmetry. In biology, a body that is symmetrical across a plane, that is, one side is a mirror image of the other. Humans have bilateral symmetry around a vertical plane bisecting the body into left and right sides.

biocide. A pesticide that is effective against living organisms in general.

biological control. The use of living organisms to suppress pest organisms.

biological control agent. A predator, parasite, or disease agent that feeds on, or in some other way destroys, a pest species. Biological control organisms may be native to the area or introduced.

biosolids. A by-product of wastewater treatment sometimes used as a fertilizer.

biotic. Literally, “of life.” Related to or caused or produced by living organisms.

blight. Pathological condition of plants in which portions of a plant become necrotic and die. May be caused by a variety of agents and conditions.

bolt. Sudden growth of some herbs or vegetables, in which the plants quickly send up flower stalks, bloom, and set seed. May be brought on by heat stress.

botanical name. Scientific name, plus any race, subspecies or variety specifier. *See* scientific name.

botanical pesticide. A pesticide that is extracted or derived directly from plants.

botany. The study of plants.

bract. A modified leaf structure, usually associated with a flower or cone scale.

brand name. The specific, registered name given by a manufacturer to a product; same as trade name or proprietary name.

broadcast application. Distributing seed, fertilizer, or pesticide uniformly on the surface of the ground.

broadleaf. Having wide leaves, as opposed to needles or grasses.

broad spectrum pesticide. A pesticide that affects a wide variety of pests.

bud. undeveloped plant shoot that will produce a leaf, a flower, or both, but has not unfolded yet. Buds are classified by location, status, morphology, or function. *See also* axillary bud, mixed bud, lateral bud, simple bud, terminal bud, reproductive bud, vegetative bud. Note: “fruit bud” is poor usage—all plants must flower before setting fruit; therefore there is no such thing as a “fruit bud.”

bud dormancy. Waiting period for buds in which they do not mature or progress; may be indefinitely long.

bud scales. Modified leaf structures that protect buds.

bud scale scar. Place on a twig where there used to be a bud scale.

bulb. Modified stem tissue, forming an underground storage organ of perennials such as tulips and daffodils.

bulbil. A small bulb that forms along the stem of certain plants such as tiger lilies.

bulblet. A small bulb that forms around a parent bulb and can be separated to propagate new plants.

burrknot. Condition where apple branch tissue starts producing roots instead of more branch tissue.

button. Small heads of broccoli or cabbage that form as a result of seedlings being exposed to freezing temperatures.

C

C:N ratio. The ratio of carbon to nitrogen in organic materials. Materials with a high C:N ratio are good bulking agents in compost piles, while those with a low C:N ratio are good energy sources.

calyx. Flower petals and sepals grouped together; usually green and formed in multiple parts.

cambium. The living layer of cells of a woody plant, producing phloem and xylem cells for those layers.

candle. Bright spring growth at the tips of branches of pines and other needle-leaved evergreens.

cane. Long flexible stem, typical of some berries.

canker. A defined necrotic area, often sunken, on woody plant parts.

canopy. The topmost layer of a garden, orchard, or forest formed by the leaves and branches of the tallest plants.

capillary action or force. Intermolecular attractive forces causing water molecules to attract and stick to each other and the surfaces surrounding them; these forces can draw water up against the pull of gravity to a certain degree. For instance, holding water in fine soil pores against the force of gravity.

carbon dioxide fertilization. The process of increasing the atmospheric CO_2 level in a greenhouse in order to increase the photosynthetic rate of plants growing there.

carotene. Yellow-orange pigment of plants.

carrying capacity. In a habitat, the number of members of a species that can be supported by the available resources.

castings. Worm excrement.

cation. A positively charged ion. Plant nutrient examples include calcium (Ca^{++}) and potassium (K^{+}).

cation exchange capacity (CEC). A soil's capacity to hold cations as a storehouse of reserve nutrients.

causal organism. The pathogen responsible for a specific disease.

cell. The basic functional structure of living organisms. May exist as an independent living organism, as with Protista, or group together in colonies, or as tissues and organs in higher plants and animals.

cerci. (singular: cercus) Paired appendages on the abdomen of some insects. May be sensory organs, weapons, copulatory tools, or merely vestigial.

certified pesticide applicator. A person trained and certified, per standards of the EPA, in the handling and application of restricted pesticides. Certification is required for commercial pesticide use.

certified seed. Commercially available seed that

chemical drought. Chemically induced drought; high levels of soluble salts in soils induce drought-like conditions for plants growing in that soil.

chemigation. Application of chemicals (pesticides and fertilizers, etc.) to crops and soils via the water in an irrigation system.

chlorophyll. Pigment that gives green plants their color and absorbs sunlight, allowing photosynthesis to occur.

chloroplast. Plant cell organelle containing chlorophyll and in which photosynthesis takes place.

chlorosis. Distinctive yellowing of green plant tissues, often indicating iron deficiency.

clay. The smallest type of soil particle (less than 0.002 mm in diameter).

cline. A gradual change in the characteristics of a species over a continuous distance.

clone. An individual plant or plants that have been asexually propagated from one individual.

coir. Coconut fiber used as mulch or a component of soilless growing media.

cold composting. A slow composting process that involves simply building a pile and leaving it alone until it decomposes. This process may take months or longer. Cold composting does not kill weed seeds or pathogens.

cold stratification. A chilling treatment used on seeds to make them break dormancy and get ready to germinate.

commensal rodents. Rodents that live in close proximity to humans; typically, rats and mice.

common name. 1. A familiar or colloquial name for a particular plant, insect, disease, or pest organism. Any particular organism may have several common names. 2. The standard, accepted name of a pesticide's active ingredient, which is established by the appropriate professional societies. *See also* brand name.

compaction. Pressure that squeezes soil into layers that resist root penetration and water movement. Often the result of foot or machine traffic.

compartmentalization. Isolation of infected or damaged tissue by forming specialized tissue around the afflicted area.

competitive exclusion. In a community or habitat, the use or defense of a nutrient or other resource by one group or individual so that no other group or individual can access that commodity or resource.

complete fertilizer. A fertilizer containing all three macronutrients: nitrogen, phosphorus, and potassium (N, P, K).

complete flower. A flower with both male and female parts, plus the petals and sepals.

complex (complete) metamorphosis. A series of changes and stages of maturity in certain insects, involving easily visible changes in shape, form, and size. Normally includes stages as egg, larva, pupa, and adult. *Contrast* simple metamorphosis.

compost. The product created by the natural decay and breakdown of organic waste material under conditions manipulated by people.

conduction. Transfer of heat energy through material, from areas of higher energy (warmer) to areas of lower energy (cooler).

conifers. Gymnosperms that produce naked seed in cones.

contact herbicide. Chemical product applied directly to foliage, damaging or killing that foliage.

controlled release fertilizer. Fertilizer that releases nutrients at a prescribed rate over time.

convection. Movement of fluid material (gaseous, liquid, or semi-liquid) driven by the natural phenomenon of warmer materials being less dense and therefore rising above cooler, denser material. Rising warmer material creates a void underneath where cooler material is then drawn in.

corm. Short, enlarged underground stem tissues that provide food storage for a plant.

corolla. The collection of petals in a flower.

cotyledon. Embryonic or seed leaf; the first proto-leaf or leaves sprouting out of a seed. Contains the food for the sprouting plant.

cover crop. A crop planted to protect soil from erosion or to control weeds, and that may be turned into the soil to return organic matter and nitrogen to the soil (then referred to as a green manure).

cross pollination. Transfer of pollen from one flowering plant to another flowering plant. *Contrast* self pollination.

crown. 1. The uppermost part of a tree canopy, including its limbs, twigs, and leaves. 2. Stems compressed to a very short form, as in strawberry plants or African violets.

crown die-back. In trees, the death of the upper-most parts of the canopy.

crown fire. A wildfire spreading from tree to tree via their branches or crowns, and not involving the ground or low-growing vegetation.

cryptic mimicry. With insects, physical appearance mimicking surrounding environmental elements such as twigs, leaves, rocks, etc. as camouflage for defense. *Contrast* Batesian mimicry and Muellarian mimicry.

cultivar (cultivated variety). A variation of a species that originated in cultivation and persists under cultivation. May arise by chance or through mutation or selective breeding. Usually propagated asexually to preserve the variation characteristics.

cytoplasm. Everything inside a cell, except for the nucleus.

cytoplasmic streaming. Method of movement or flow of the cytoplasm within a plant or animal cell.

D

damping-off. rotting of seedlings at or below the soil line.

day-neutral plants. Plants whose reproductive cycle is not affected by length of day and night.

deciduous. Plants whose leaves only last one growing season.

decomposition. The breakdown of organic materials by microorganisms.

degree-day, or, growing degree-day (GDD). A 24-hour period during which temperatures reach at least one degree above the lower limit of an organism's developmental threshold. That is, the combination of time and temperature required for an organism to develop. *Also*, heat unit.

determinate. Plant growth that has a limit; pattern of growth in which a plant flowers and sets seed all at once.

diagnosis. The positive determination of the nature and cause of plant damage. The positive identification of an insect or other pest.

dicotyledon. Member of the Dicotyledones class; flowering plants with two embryonic leaves per seed. Also known as "dicots." *Contrast* monocotyledon.

dioecious. From the Greek "two" + "houses." Plants that have male flowers on one plant and female flowers on another plant; therefore, both a male plant and a separate female plant are needed for seed production.

dormancy. State of biological inactivity; seasonal nongrowth; suspended animation.

drip line. A rough circle under a tree, marking the outer edge of the reach of its branches; the circle on the ground drawn by rain shed from a tree.

E

economic threshold. In pest management, the point at which the cost of crop losses equals the cost of controlling the pest that is causing the loss.

ecosystem. A community of interacting organisms, and the physical environment they occupy.

ecotype. A subdivision of a species, genetically adapted to local environmental conditions.

ectoparasite. A parasitic organism that attaches to the outside or surface of a host. For instance, fleas. *Contrast* endoparasite.

elepidote. Having no scales.

eluviation. Downward movement of chemicals or other materials as they are leached from a site; especially nutrients from the A horizon in soil.

elytra. With coleopteran insects, the outer pair of wings.

endoparasite. A parasite that enters the body of its host to live and feed. *Contrast* ectoparasite.

endophyte. An organism living within a plant in a parasitic or symbionic relationship.

English hedgerow. Style of planting, growth, and trellising for cane berries or landscape barrier plants, in which plants are allowed to grow continuously along a row.

environmental carrying capacity. The number of organisms an environment or habitat can support. The population size that can be supported indefinitely, given the resources available.

ephemeral. A plant that grows and flowers in one season then dies back for the rest of the year. For instance, spring ephemerals such as trillium or lady's slipper.

epidermis. Outermost layer of plant tissue, somewhat analogous to skin. May be covered with a waxy substance to reduce water loss.

epigeous germination. Style of germination in which the seed leaves push out of the ground, as with tomatoes, for example. *Contrast* hypogenous germination.

eradication. The complete elimination of a pest from a site, an area, or a geographic region.

espalier. A plant pruned and trained to grow flat against a fence, trellis, or wall.

evaporative cooling. The process by which evaporating water cools surfaces of objects. When water evaporates (turns to vapor), it consumes heat energy, thus cooling the object it has evaporated off of. Sweat is an evaporative cooling process.

evapotranspiration. Evaporation + transpiration. The biological process of plants taking in CO_2 and releasing water vapor into the atmosphere as they live and grow.

evergreen. Plants that do not drop all their leaves at the end of the growing season.

exclusion. Preventing the establishment of a pest in a previously uninvaded area.

exfoliation. Automatic shedding or self-stripping of bark or outer layers of material. Diagnostic for some species.

exoskeleton. Literally, an exterior skeleton. Tough outer shell, typically made of chitin, for protection and support on many creatures including insects and crabs.

F

fallow. Cultivated ground that is allowed to rest unplanted for one season.

fasciation. Distorted plant tissue growth resulting in flattened, rather than round, twigs and stems.

fascicle. Paper wrapper holding each bundle of needles on a conifer branch; each bundle of needles on a conifer branch.

fertigation. Application of fertilizer via irrigation water.

fertilizer. Any material used as a source of plant nutrients. Commonly used to correct deficiencies in nitrogen, phosphorus, and potassium.

fertilizer analysis. The amount of nitrogen, phosphorus (as P_2O_5), and potassium (as K_2O) in a fertilizer expressed as a percent of total fertilizer weight. Nitrogen (N) always is listed first, phosphorus (P) second, and potassium (K) third.

fibrous roots. A many-branching root system with no central axis or tap root.

filament. Portion of the stamen that supports the anther.

fire break. A gap in vegetation or combustible material that will act as a barrier to slow the progression of a wildfire.

fission. In biology, a style of reproduction for one-celled organisms by simple cell division.

floricane. A flexible stem that lives for two years, producing flowers and fruit the second year. Typical of *Rubrus* genus members.

flower. Reproductive structures of members of the phylum Anthrophyta.

Flower bract. Modified leaf structure that protects the flower bud; may be quite showy and overshadow the flower itself, as with poinsettia, for example.

foliage. Plant leaves.

foliar. Having to do with foliage, that is, leaves.

foliar-applied pesticide. Chemicals in solution that are applied to, and absorbed through, plant leaves.

foliar fertilizer. Nutrients in solutions that are applied to, and absorbed through, plant leaves.

foliar necrosis. Death of leaves or parts of leaves.

folly. A landscape structure installed for visual effect.

forbs. Herbaceous flowering plants other than grasses, sedges, and rushes.

foundation planting. Plants along the base of a house or other building that provide a visual transition to the surrounding landscape.

frass. Excrement left by insects.

frond. Leaf-like structures of ferns.

frost heave. Action by which plants, rocks, and small structures are pushed up out of the soil from repeated freezing and thawing of the soil.

frost pocket. Microclimate area, typically a low spot, where cold air tends to pool producing frost when the higher surrounding area has no frost.

fruit bud. Since plants must flower before they set fruit, this term is incorrect; do not use it. Preferred term is “reproductive bud.”

fruiting body. Reproductive structure (spore-producing part) of a fungus.

fruiting precocity. Ability of relatively young trees and plants to produce fruit.

fungus. The largest group of known plant pathogens; these organisms lack chlorophyll and cannot produce their own food; therefore, they live either on host plants as symbionts or on dead matter. Reproduce by spores.

G

gall. A swelling or outgrowth, typically on a branch or tree trunk, caused by a pathogen, insects, or other pests.

garbage stream. The trail an item traces from its place of use where it was discarded, to its end at a garbage incinerator or landfill. Also, the aggregate of discarded items moving through a waste disposal system.

germinate. To sprout from seed.

girdling. Removal or strangling of the cambium layer completely around the trunk of a woody plant or tree, resulting in restriction of the flow of water and nutrients between the roots and crown.

green manure. Plants grown just to be tilled into the soil to become a source of nutrients for future crops. *See also* cover crop.

green sand. Soil amendment (0-0-3) containing glauconite mined from the ocean floor.

growing degree days. A heat index, relating timing and development of plants to ambient air temperatures. *See also* heat unit.

growing season. Time between last frost in the spring and first frost in the fall; average number of frost-free days in a location.

grub. Worm-like larva, especially of beetles.

guano. Bird or bat excrement used as fertilizer.

gummosis. Gummy sap exuded from trees, especially fruit trees; usually associated with pathological conditions such as mechanical wounds, insect infestations, and bacterial infection.

gymnosperms. Plants that produce unenclosed, or naked, seed. *Contrast* angiosperms.

H

habit. General shape and appearance of a plant.

haemolymph. Internal bodily fluid of insect groups that have an "open" circulatory system; somewhat analogous to blood in arthropods.

harden off. Practice of gradually getting a plant used to a more difficult living environment.

hardiness. Tolerance of a plant to cold and heat.

hardscape. Permanent, non-living elements of a landscape, such as sidewalks, retaining walls, or natural rock formations.

hardwood. Dicotyledonous, deciduous trees and the wood from those trees (but unrelated to the actual density or hardness of that wood).

heading cut. Removal of a terminal bud; removal of the outermost portion of a twig or branch. *Contrast* thinning cut.

heartwood. Nonliving older wood in the center of a tree trunk or limb. It is usually denser and harder than the living sapwood.

heat unit. The combination of time and temperature required for an organism to develop. *See also* degree-day.

heave. Bulging of soil caused by alternating cycles of freezing and thawing. Can uproot plants.

heel in. Short-term plant storage where the plants are kept with their roots shallowly in soil or sawdust until they can be permanently placed.

herbaceous. Lacking permanent woody stems; plants that do not add to the diameter of their stems each year, and typically die back to the ground at the end of the growing season. May be ephemeral, annual, biennial, or perennial.

herbivores. Insects and other animals that only eat plant-based foods.

hidden hunger. A plant nutrient deficiency with no visual symptom.

higher insects. Insects that undergo complex metamorphism. *Contrast* primitive insects.

higher plants. Complex plants that have internal vascular systems; also called trachyophyta or "trachyophytes."

horizon, soil. A layer within a soil profile. Denoted by letters A, E, B, or C based on physical characteristics and chemical components present.

hormone. An internally synthesized chemical that controls the internal functioning of living organisms. In plants, phytohormones are produced not in glands but in each cell of a plant and affect every aspect of metabolism.

host plant. A plant on which a particular disease can develop or a species of insect lays its eggs, or that is the source of nutrients for insects or a parasitic plant. *Contrast* non-host.

host range. All plants or cultivars of a plant on which a particular disease can develop.

hot composting. A fast composting process that produces finished compost in 6 to 8 weeks. High temperatures are maintained by mixing balanced volumes of energy materials ("greens") and bulking agents ("browns"), keeping the pile moist, and turning it frequently to keep it aerated.

humidity. Amount of water vapor in the air. *Contrast* relative humidity.

hummus. [HUM us] Middle-eastern dish of mashed chickpeas and spices; used as a dip or spread on pita bread. Not to be confused with humus, which does not taste so nice. *Contrast* humus.

humus. [HYOO mus] The end product of decomposed animal or vegetable matter. *Contrast* hummus.

hybrid. A first generation cross between two genetically different parents.

hydraulic excavation. Use of high-pressure water flow and a vacuum to remove soil and rocks.

hydrozone. Area of a landscape in which all plants have similar water requirements.

hypha. (plural: hyphae). With fungi, the thread-like growth of elongated cells. *See also* mycelium.

hypnaceous. Moss-like; of the family Hypnaceae.

hypogenous germination. Style of germination in which seed leaves remain underground, as with oaks, for example.

I

illuviation. Process whereby material accumulates in a lower soil horizon; for instance, moving silt to accumulate in the B horizon.

imbricate. Flower bulbs that develop no outer protective layer; for instance, true lilies. *Contrast* tunicate.

immobile (non-mobile) nutrient. A plant nutrient that, once entering a leaf, will not move again.

immobilization. Process by which soil microorganisms use available nitrogen as they break down materials with a high C:N ratio, thus reducing the amount of nitrogen available to plants.

indeterminate. A plant with the potential to grow without limit.

indicator plants. Plants that show nutrient deficiency or disease symptoms before the majority of other plants.

infectious disease. Contagious disease; disease caused by microscopic pathogens that can spread rapidly. *Contrast* non-infectious disease.

infiltration. Movement of water into soil.

infiltration rate. The speed at which water moves down through soil. Measured in minutes per inch, via a percolation ("perk") test.

inflorescence. A group of individual flowers arranged in a cluster. Examples: lilac, daisy, sunflower.

inoculum. The part of a pathogen, such as spores, bacterial cells, or virus particles, that cause an infection.

inorganic fertilizer. Fertilizer that does not contain nutrients bound to carbon-based molecules; often refers to fertilizer manufactured in industrial processes.

inorganic pesticides. Pesticides of mineral origin—they do not contain carbon.

insect. A small invertebrate animal having three body regions, six jointed legs, and antennae.

instar. A development stage of insect larvae between molts. A species may have several instars. Newly hatched larvae before their first molt are first instars or first instar larvae.

insulation value. A material's resistance to heat transfer. Given as a value of R ("R-Value").

integrated pest management (IPM). A multi-pronged and unified pest control system that uses all available, necessary techniques and tools to manage pest populations and resulting problems, while striving to minimize adverse effects on other species and the environment.

internode. The regions on a stem between nodes. *See also* node.

invasive weed. A non-native plant species that negatively affects the environment that it is introduced to, by crowding out native plants and other, less competitive species.

ion. An atom or molecule with either a positive or negative charge.

J

K

key pests. Common and chronic trouble-makers for plants in a landscape or garden.

key plants. Plants in a landscape or garden that are problem-prone and likely to require the most attention.

key problems. The abiotic or biotic problems in a landscape or garden that are most likely to impact plant health and require attention and intervention.

L

lateral bud. Embryonic plant shoot arising along the sides of stems. Brussels sprouts are edible lateral buds. *See also* axillary bud.

leaching. Movement of soluble nutrients, carried by water down through the soil profile.

leaf axil. Angle between a stem and an attached leaf.

leaf scar. Place on a stem where there used to be a leaf attached.

lenticels. Small openings along a stem that allow gas exchange. Often seen as small bumps. Distinctive size, color, or shape may be diagnostic for species identification.

lepidote. Having scales; rough to the touch. *Contrast* elepidote.

light compensation point. The level of light intensity at which the rate of photosynthesis (and a plant's CO_2 requirement) equals the rate of respiration (the plant's CO_2 output). A balanced light level for plants.

light saturation point. The amount or intensity of light above which a plant's photosynthetic rate will not change.

line. An inbred group of plants with homogeneous genetic material whose seed give very uniform progeny.

loam. A soil with roughly equal parts of sand, silt, and clay particles.

long-day plant. Plants that require longer days and shorter nights in order to produce flowers. For example: peas, bellflower. *Contrast* short-day plant. *See also* photoperiodism.

lower insects. *See* primitive insects.

M

macropore. A large soil pore. Macropores include earthworm and root channels and benefit a soil's permeability and aeration.

male confusion. In pest management, an effect of pheromone-impregnated lures to obscure the scent of live females so that mating does not occur.

mating disruption. In pest management, the use of species-specific pheromones to keep male insects from finding female insects, thereby preventing mating.

meiosis. Specialized cell division that produces reproductive cells (egg and sperm cells). *Contrast* mitosis.

meristem. Collection or area of undifferentiated plant cells from which new growth arises.

mesophyll. Spongy layer of cells in dicot leaves where photosynthesis and gas exchange occurs.

metabolism. The sum total of the biochemical activity within a plant.

metamorphosis. A change in the size, shape, or appearance of an insect as it matures. *See also* complex metamorphosis and simple metamorphosis.

microclimate. A very localized habitat or area in which the climate varies from the greater surrounding area; may be as small as a garden bed.

microhabitat. A small geographic area with unique conditions that make it distinct from the larger surrounding area. Those distinct conditions may lead to development of local species of flora and fauna that are adapted to, and then require, those conditions.

micronutrient. A nutrient used by plants in small amounts (for example, iron, zinc, molybdenum, manganese, boron, copper, and chlorine). Also called a trace element.

micropore. The tiny space between soil particles, typically a fraction of a millimeter in diameter. Micropores are responsible for a soil's ability to hold water.

mildew. A fungal disease in which the mycelium and spores of a fungus can be seen as a growth on a plant surface.

mineral nutrients. Plant nutrients absorbed from soil in the form of inorganic ions.

mitochondria. Cellular structure responsible for power generation in plant cells.

mitosis. Cell division producing daughter cells that are identical to the parent cell. *Contrast* meiosis.

mixed bud. Embryonic plant shoot containing both vegetative tissue (leaves) and reproductive tissue (flowers).

mobile nutrient. A plant nutrient that can relocate within a plant. *Contrast* immobile nutrient.

mode of action. The way in which a pesticide exerts a toxic effect.

monocotyledon. Member of the Monocotyledones class; flowering plants with only one embryonic leaf per seed, for instance, grasses. Also known as "monocots." *Contrast* dicotyledon.

monostand. A field or space with a single species of plant growing.

mosaic. Random pattern of colors, primarily shades of green, produced in leaf tissue; may be symptomatic of viral infections.

Muellarian mimicry. With insects, physical appearance evolved to appear like more dangerous species, as a form of defense. *Contrast* cryptic mimicry and Batesian mimicry.

mycelial fans. Masses of fungal mycelia; named for the shape produced by certain species of fungus.

mycelium. (plural: mycelia) Bunches of thread-like fungal hyphae.

mycorrhizae. Beneficial fungi that infect plant roots and increase their ability to take up nutrients from the soil.

N

naiad. Immature, stages of insects that undergo incomplete metamorphosis; analogous to nymphs, but occurs under water.

narrow spectrum pesticide. A pesticide that is effective against only one or a few pest species. The term is usually applied to insecticides and fungicides.

natural enemies. Predators and parasites that attack pest species.

necrosis. Death of living tissue, usually resulting in discoloration of the affected area.

nematodes. Plant–parasitic nematodes are small aquatic worms that feed on plant tissue.

niche. The job an insect species performs in its living space or microhabitat.

nitrifier. A microbe that converts ammonium to nitrate.

nitrogen. Most commonly required macronutrient for plants. Often applied in nitrate form (NO_3^-).

nitrogen cycle. The sequence of biochemical changes undergone by nitrogen as it moves from living organisms, to decomposing organic matter, to inorganic forms, and back to living organisms.

nitrogen fixation. Conversion of atmospheric nitrogen into plant-available forms by Rhizobia or Frankia bacteria.

node. The area on a stem from which a leaf or twig sprouts.

non-host. A plant that is not susceptible to a pathogen or is inhospitable to an organism.

non-infectious disease. Physiological disease caused by adverse chemical, environmental, or soil conditions. *Contrast* infectious disease.

non-mobile (immobile) nutrient. A plant nutrient that, once entering a leaf, will not move to another part of the plant. *Contrast* mobile nutrient.

non-selective herbicide. An herbicide that damages or kills all types of plants.

noxious weed. A plant (usually non-native) listed by the state noxious weed board as a problem plant that must be controlled if not eradicated.

nutrient cycles. Pathways of nutrient inputs and outputs, transformations, and flows through soil–plant systems.

nymph. An immature stage of insects that undergo simple metamorphosis, in which the insect body resembles the adult.

O

organic fertilizer. Fertilizer material in which nutrients are bound to carbon-based molecules; often refers to naturally-occurring sources of plant nutrients, that is, fertilizer material that has undergone little or no processing. Can include plant, animal, and/or mineral materials.

organic matter. Soil component made of any material originating from a living organism (straw, peat moss, compost, wood chips, manure, etc.).

organic pesticide. A pesticide that contains carbon. Most organic pesticides are synthesized or derived from plants.

ovary. Reproductive structure containing first the unfertilized ovum, then, if fertilized, the developing seed.

ovum. Egg; unfertilized female reproductive material.

P

palisade cells. In dicot leaves, chlorophyll-rich, elongated cells arranged perpendicular to the plane of the leaf.

palmate. Radiating out like fingers from the palm of the hand.

parasite. An organism that invades or attaches to a host organism's body, feeding on it without killing it.

parasitoid. An organism that invades or attaches to a host organism's body, feeding on it until the host dies.

parenchyma. Plant tissue with thin-walled, simple cells that are responsible for photosynthesis.

pathogen. A disease-causing organism. Pathogenic organisms include bacteria, viruses, fungi, parasitic plants and nematodes.

peat moss. The product of peat bogs used as an acidifying soil amendment. Also known as sphagnum peat moss or peat humus. Peat bogs are ancient carbon sinks, therefore use of peat moss as a commercial soil amendment is not considered a sustainable practice.

ped. A cluster of individual soil particles.

perennial plants. Plants that grow and continue to reproduce over multiple years. May be long-lived or short-lived, hardy or tender, flowering or non-flowering.

perfect flower. A flower that contains both male and female parts. *Contrast* complete flower.

perlite. Lightweight, white volcanic rock used in potting media or as a soil amendment for aeration.

permeability. The rate at which water moves through a material such as soil.

persistence. A measure of how long a pesticide remains active at the site of application or in the environment.

pesticide. A chemical used to control pest populations and to prevent or reduce pest damage. An insecticide is one type of pesticide, made specifically to control insects.

pest resurgence. In pest management, the rebound of a pest population after a broad-spectrum pesticide has been applied and killed not only some of the target pest, but also other beneficial organisms that had kept the pest in check. The beneficial agent is no longer there to help keep the target pest in check, so that pest can recover and expand.

petiole. The stalk of a leaf, attaching the leaf to a stem.

pH. A measure of acidity or alkalinity. Values from 0 to 7 indicate acidity, a value of 7 is neutral, and values from 7 to 14 indicate alkalinity. Most garden plants and crops perform best in soils with pH of 5.5 to 7.5.

phenology. The study of life cycle events (for either plants or animals) as related to seasonal and climatic changes.

pheromone. A volatile chemical substance secreted by animals to stimulate a response in, or convey information to, others of its species.

phloem. Type of living plant tissue responsible for movement of .nutrients throughout the plant. In trees, located within the cambium layer.

phloem-immobile. Nutrients that cannot relocate within a plant via the phloem.

phloem-mobile. Nutrients that can relocate within a plant via the phloem.

phosphate. The form of phosphorus listed in most fertilizer analyses (P_20_5).

photoperiodism. Changes in a plant's growth and development induced by the relative length of light and dark periods (length of day and night).

photosynthesis. Chemical reaction involving chlorophyll within plant cells that converts sunlight plus carbon dioxide into sugar (energy) the plant can use.

photosynthetically active radiation (PAR). Wavelengths of visible light that are most effective in stimulating photosynthesis in plants.

physical drift. Movement of herbicide mist away from the target at the time of application due to high winds or very still wind that allows the mist to hang too long in the air.

phyto-. Prefix meaning "plant."

pinching back. Removing the growing tips of twigs to encourage bushier growth.

pinnate. Feather-like in structure.

pistil. Female portion of a flower, made to catch pollen. *See also* stigma and style.

pistillate flower. A flower having no male parts. *Contrast* staminate flower.

pith. Spongy, nonvascular tissue in herbaceous dicot stems.

plant disease. A condition in which a plant differs in structure or function from a healthy plant.

plant growth regulators. Synthetically produced chemical that mimics a plant hormone to regulate a plant's growth.

plant health care. A holistic approach to managing gardens and landscapes, focusing on improving overall plant health in order to prevent or avoid plant diseases and problems.

plant injury. Nearly instantaneous damage to a plant caused by mechanical impact or sudden, short-term environmental changes. *See also* plant disease.

plant pathology. The study of plant diseases and their management.

pollination. Transfer of pollen from male parts of a flower (stamen) to the female parts of a flower (pistil); fertilization, required for most fruit and nut production.

pollinator. One who carries or transfers pollen. *Contrast* pollinizer.

pollinizer. A pollen producer. A plant variety specially planted to be a source of pollen. *Contrast* pollinator.

population dynamics. The science or study of how a population's size grows and shrinks over time as related to births, deaths, and migration, and the study of the factors affecting those changes.

postemergence. Time period for pesticide applications: a treatment applied to a plant or the soil after a plant has emerged from the ground.

potash. A (somewhat archaic) term for potassium fertilizer. Listed in most fertilizer analyses as K_20.

predator. An animal that attacks, feeds on, and kills other animals.

preemergence. Time period for pesticide applications: a treatment applied to soil or seeds before the seeds sprout and emerge from the ground.

profile, soil. Cross-sectional view of soil layers, as they occur at a site.

primary nutrient. A nutrient required by plants in a relatively large amount (nitrogen, phosphorus, and potassium).

primitive insects. Insects that do not undergo complex metamorphism, but merely get larger as they mature. Most primitive insects have external mouthparts. *Contrast* higher insects.

processed fertilizer. A fertilizer that is manufactured or is refined from natural ingredients to be more concentrated and more available to plants.

product brand name. Commercial title of a product; the trade name.

profile. *See* soil profile.

prolegs. Unjointed legs of insects; distinguished from "true legs" which are jointed.

propagule. Any part of a plant that can propagate or grow a new entire plant.

protoplasm. Archaic term for the entire contents of a living cell.

pupa. (pl. pupae). An intermediate stage of development for insects that undergo complex metamorphosis. Insects generally do not feed during the pupal stage. Usually involves a chrysalis or cocoon.

Q

quick-release fertilizer. A fertilizer that contains nutrients in plant-available forms such as ammonium and nitrate.

R

R value. Insulation rating of a material; how resistant a material is to heat transfer.

radial aeration. Narrow trenches dug in a radial pattern out from the base of an established tree or shrub, then filled with top soil or compost to compensate for compacted soil or to improve aeration.

rank growth. Wild, unchecked growth that is often weak and prone to disease or insect attack; may be spurred by over-enthusiastic fertilizing or pruning late in the growing season.

ray cells. Specialized xylem cells that move water and nutrients laterally rather than vertically within a plant.

recyclers. Also known as decomposers; organisms such as worms, insects, and fungi that ingest or otherwise break down organic matter, releasing the carbon, nitrogen, and other raw materials from the organic matter.

relative humidity. How saturated the air is, relative to how much water vapor it is capable of holding, given as a percent.

release. In horticulture, a growth spurt reaction of remaining trees, after their competitors have been removed (thinned).

reproductive bud. embryonic plant shoot containing reproductive tissue (flowers).

resistance. The ability of a plant to avoid or repel infection from a specific pathogen; the ability a pest develops to withstand pesticides.

respiration. Transport and exchange of oxygen from outside an organism, into its cell, concurrent with production of energy and release of carbon dioxide.

reticulate. Net-like, as in leaf veining.

Rhizobia bacteria. Bacteria of the genus *Rhizobium* that live in association with roots of legumes and convert atmospheric nitrogen to plant-available forms. *See also* nitrogen fixation.

rhizome. Creeping horizontal stem, usually underground, with roots below and stems above; not a true root.

rhizomorphs. Dark clumps or strands of fungal mycelia that resemble roots, on or just below the soil surface.

rhizosphere. The thin layer of soil immediately surrounding plant roots.

riparian. Of or relating to river banks and stream edges.

roguing. Simple removal and destruction of problem plants.

root. specialized underground portion of a plant, responsible for uptake of water and nutrients as well as support of the plant.

root cap. A group of tough cells produced by the apical meristem at the tip of a root that serves as a battering ram to allow the root to force its way down into the soil.

root flare. *See* trunk flare.

root hair. Small extensions of epidermal cells in a plant root that take up water and nutrients for a plant.

rootstock. On a grafted tree, the root and collar system to which the scion is grafted. Rootstock controls tree size, fruiting precocity, and soil moisture tolerance and may provide some resistance to soil insect pests and diseases.

root system. The underground portion of a plant.

rosette. Plant growth form in which many leaves emerge radially on very short stems.

S

sand. The coarsest size of mineral soil particle (0.05 to 2 mm in diameter).

sanitation. Elimination of potential sources of infection and infestation to prevent the development of a disease or pest problem.

saprophyte. Organism that obtains nutrition from dead and decomposing organic material, often aiding in their decomposition. *See* recycler.

sapwood. Portion of a woody stem containing live xylem; the portion of a woody stem where active movement of water and nutrients takes place.

scarification. A buffing, cutting, or scarring treatment used on seeds to make them break dormancy.

scientific name. Latin name, consisting of genus and a specific epithet for the species. May also include the name of a recognizable race, subspecies, or varietal.

scion. Grafted material on a tree; a cutting destined to be grafted onto another rootstock.

sclerenchyma. Plant cells with thick walls to provide support for the plant.

secondary nutrient. A nutrient needed by plants in a moderate amount (sulfur, calcium, and magnesium).

secondary pest. Pests that follow a primary pest and are usually less important, such as mites, aphids, and leafhoppers.

secondary pest explosion. In pest management, a consequence of applying a broad spectrum insecticide that kills not only the primary target, but also beneficial agents that had been keeping another (secondary) pest in check.

seedling rootstock. The original rootstock of a tree grown from seed.

selective pesticide. *See* narrow spectrum pesticide.

self-fruitful. Fruit varieties that can set fruit when pollinated with their own pollen.

self pollination. Transfer of pollen from the anther to the stigma of the same plant. *Contrast* cross pollination.

self-unfruitful. Fruit trees that cannot be fertilized by their own pollen to produce fruit. These trees require pollen from another variety for fruit production.

senescence. Aging; biological processes and changes involved in aging; expected decline and death.

sepal. Modified leaf structure that encloses and protects a flower bud.

shearing. A method of pruning that involves clipping off all the growing tips of a tree or shrub, to give a smooth appearance. Commonly done for hedges.

shoot system. The stem and leaves of a plant (all the parts of a plant except for its roots).

short-day plant. Plants that require longer nights and shorter days in order to produce flowers. For example, strawberries, poinsettia.

shuck. A papery sheath surrounding newly developing fruit in some plant species such as stone fruits and tomatillos.

sign. The vegetative or reproductive structures of a pathogen or pest that are either individually or collectively large enough to be visible without a microscope. *Contrast* symptom.

silt. Size of mineral soil particles intermediate between sand and clay (0.002 to 0.05 mm in diameter).

simple bud. embryonic plant shoot containing either vegetative tissue or reproductive tissue, but not both. Also, a flower bud containing reproductive tissue for a single flower.

simple metamorphosis. A set of changes or stages of maturity during the life cycle of certain insects that involve little more than changes in size; typically includes egg, nymph, and adult stages. *Contrast* complex metamorphosis.

simple plants. Single-celled or few-celled plants that do not have an internal vascular system.

slow-release fertilizer. A fertilizer material that must be converted into a plant-available form by soil microorganisms.

snag. A standing dead tree or tree trunk, left in place to provide wildlife habitat.

soil. A biologically active mixture of weathered rock fragments and organic matter at the earth's surface; ranges in depth from inches to several feet. Provides nutrients, water, and physical support for plants, plus air for plant roots.

soil frost line. Average depth to which soil freezes each winter.

soil horizon. A layer of soil within a soil profile; defined by its material make-up and its position in the profile.

soil profile. Cross-section view of in situ soil layers, as they occur on a site.

soil salinity. A measure of the total soluble salts in a soil.

soil solarization. Partial sterilization of in-situ soil through the use of clear plastic mulch covering the ground.

soil solution. The solution of water and dissolved minerals found in soil pores.

soil structure. The arrangement of aggregates (peds) in a soil.

soil texture. How coarse or fine a soil is. Texture is determined by the proportions of sand, silt, and clay in the soil.

soluble salt. Inorganic compounds dissolvable in water. A compound often remaining in soil from irrigation water, fertilizer, compost, or manure applications.

specialty fertilizer. Nutrient source with unique properties or behaviors such as slow release, low pH, or plant-specific formulations of nutrients.

species. The basic unit of taxonomy, designating a group of individuals that are capable of interbreeding.

spiracle. Opening in an exoskeleton to facilitate gas exchange; opening to a respiratory tube.

split applications. For fertilizers, applying part of the nutrient rate in one application and the remainder in one or more subsequent applications.

spur. On woody flowering plants, a specialized branch with very short, compressed internodes that give rise to flower buds. Typical of apple, chokeberries. Also known as fruiting spurs.

spur-type tree. In apples, least vigorous growing varieties.

stamen. Male part of a flower.

staminate flower. A flower with no female parts. *Contrast* pistillate flower.

stolon. Modified stems that spread laterally across the ground surface, rooting at their joints to form new plants.

stoma (plural: stomata). Pores on leaves and stems that control gas exchange in plants. From the Greek word for “mouth.”

stool method. Planting pattern that spaces plants so they are maintained as discrete bushes or “stools” for easier maintenance. Typical of raspberries. *Also known as* the Scottish stool system.

stylet. Small, hard, piercing mouth-part of an insect, used to extract fluids.

sub-shrub. Horticultural, rather than botanical, term for a low-growing, semi-woody perennial plant.

sucker. A young plant sprouting from the horizontal roots of a parent plant.

sun scald. Winter damage, particularly on south sides of young tree trunks, from overheating by solar radiation during extreme cold weather.

surface area. A measure of the outside area of a three-dimensional object, expressed by a two-dimensional unit such as square inches. For instance, a one-inch cube has a surface area of 6 square inches.

susceptibility. The degree to which a plant is vulnerable to infection by a specific pathogen.

symptom. Any detectible change in an organism resulting from the activities of a pathogen, other pest, or environmental conditions. *Contrast* sign.

systematists. Taxonomists; scientists who specialize in the classification of organisms.

systemic pesticide. A pesticide that is absorbed by a plant or animal and translocated within that plant or animal.

T

taproot. One main fleshy root that grows straight down into the ground.

taxonomy. The classification of items.

terminal bud. Embryonic plant shoot located at the tip of a stem.

thermophilic. Heat loving. Type of bacteria that require high temperatures to thrive.

thinning cut. Removal of a branch back to its origin; a cut made at the base of a limb, at the branch collar. *Contrast* heading cut.

tilth. Soil condition defined by ease of tillage.

tracheophyta. Vascular plants; plants with internal structures that move water and nutrients internally. Plants in this division are known as "tracheophytes."

trade name. Commercial title of a product; a product's brand name.

translocating herbicide. Chemical product that is absorbed by one part of a plant and then moved within the plant to the site of action.

transpiration. The giving off of water vapor through a plant's leaves or stomata. This causes water to be drawn up through a plant's roots, thereby moving water and nutrients through a plant.

transplant shock. A trauma-induced condition of plants that have been transplanted; symptoms include wilting and reduced growth and vigor.

tree valuation. Process of assessing landscape plants and assigning dollar values to them.

tree vault. Underground container, typically concrete, placed to contain growing medium and tree roots in urban settings.

tree vigor. The potential for a tree to become a large tree. The greater the vigor, the larger the tree at maturity. *See also* vigor.

trunk flare. On a tree, the swelling at the base of the trunk, signaling the change from stem tissue to root tissue. Sometimes called **root flare**.

tubers. Enlarged underground stems that provide nutrient storage for the plant.

tunicate. Flower bulbs that have a protective outer layer; for instance, tulips and daffodils. *Contrast* imbricate.

turgor pressure. Outward force on a cell wall from water contained within the cell. The more water, the higher the turgor pressure. Signs of low turgor pressure include limpness and flaccidity.

U

V

vapor drift. Movement away from the target plant, of herbicide components that have volatilized because of environmental conditions such as high humidity or temperature.

variegated. Plant parts with varying pigments, causing multiple distinct colors and shades within the foliage.

variety, botanical. A fairly consistent natural variation of a species that will usually breed true. *Compare to* cultivar.

vector. An agent that carries disease inoculum from one host to another.

vegetative bud. Embryonic plant shoot containing only vegetative tissue.

vegetative growth. Growth of plant leaves, stems and roots.

vegetative reproduction. Asexual plant reproduction. May be via cuttings, runners, bulbs, stolons, etc. New plants will have the same genetic material as the single parent plant.

vein. A strand of conducting tissue extending into the leaves, often easily visible. *See also* phloem and xylem.

venation. Pattern of veining in leaves.

vermicomposting. Composting done by red worms; typically done in a controlled environment such as a worm bin for the most efficient job.

vermiculite. An expanded mica (mineral) product used as a component of potting media.

vernalization. The process or stimulus which causes a plant to produce a flower bud, such as the chill of winter. (*verb*: vernalize).

vertical mulching. Method of backfilling drilled holes in the ground to improve aeration and drainage for established trees and shrubs that have extensive root systems.

viable. Capable of growing or developing.

vigor. The likelihood that a tree will get very big at maturity. Determined by species, but strongly influenced by grafted rootstock.

visible spectrum. Wavelengths of electromagnetic radiation that are visible to the human eye: violet to red light.

W

water-holding capacity. The ability of a soil's micropores to hold water for plant use.

weed. A plant that is competitive, persistent, invasive, and interfering with human activities, thus undesirable; any plant growing where it is unwanted.

weed-and-feed products. Commercially available products that are a combination of herbicide (plant killer) and fertilizer.

wetting front depth. Depth in the soil profile to which surface-applied water has soaked in.

whip. Very young tree that still has a flexible trunk.

wilt. Loss of rigidity and drooping of plant parts, usually resulting from insufficient water transport to the aerial portions of the plant.

windbreak. Rows of large shrubs or trees that block or deflect wind and weather.

woody plants. Plants that retain woody stems and branches from year to year and add growth to their diameters each year. May be evergreen or deciduous. *Contrast* herbaceous plants.

X

xylem. In vascular plants, the internal structure through which water and dissolved nutrients are moved. As a plant grows, old xylem is retained and becomes the woody part of a plant.

Y

Z

zone of differentiation. In plant shoots, twigs, and roots, the region below or behind the zone of elongation; cells here are maturing and differentiating for the different tissues they will be part of. Another name for the zone of maturation.

zone of elongation. Region near the tip of a twig or root just behind the meristem, where new cells are elongating to move the meristem farther out from previous growth.

zone of maturation. In plant shoots, twigs, and roots, the region below or behind the zone of elongation; where plant cells are maturing and differentiating for the different tissues they will be part of. Another name for the zone of differentiation.

zoophytes. Invertebrate aquatic animals that look like plants. For example, corals and sponges.

Zyzzyva. Genus of tropical American beetle. Often, the last entry in a dictionary.