



Growing Under Cover

A Kansas Grower's Guide

KansasRuralCenter.org



KRC
KANSAS RURAL CENTER



Growing Under Cover

A Kansas Grower's Guide

A Kansas Rural Center publication
prepared by:

Tom Buller, Kansas Rural Center

Dr. Cary Rivard, Kansas State University, Fruit and Vegetable Extension Specialist
Department of Horticulture and Natural Resources

Kimberly Oxley, Research Extension Associate, Kansas State University,
Department of Horticulture and Natural Resources

Funding was provided by:

The Specialty Crop Block Grant Program at the U.S. Department of Agriculture (USDA) through grant number 15-SCBG- KS-0031. The report contents are solely the responsibility of the authors and do not necessarily represent the official views of the USDA.



This manual is intended as a brief introduction for those interested in using high tunnels. It is informed by a rich body of information on high tunnel usage around the state of Kansas. The appendix provides additional tools and resources for those looking to push their high tunnel knowledge further.

Suggested Citation: Buller, Tom et al. 2016. Growing Under Cover: A Kansas Grower's Guide, a Kansas Rural Center Publication, Topeka, KS.

Copyright © 2016

Guide designed by Kimberly Oxley, Research Associate, Kansas State University.

Growing Under Cover

A Kansas Grower's Guide

Table of Contents

I.	Introduction	1
II.	Grower Profiles	3
	A. C and C High Tunnels, <i>Chris and Christi Janssen</i>	
	B. Gieringer's Orchard, <i>Brice Wiswell</i>	
	C. Griggs Bros. Farms, <i>Todd Griggs</i>	
	D. Jay's Jellies, Produce and More, <i>Jay Schleicter</i>	
	E. Moon on the Meadow, <i>Jill Elmers</i>	
III.	General Management Strategies	11
	A. Layout	
	B. Crop Support/Trellising	
	C. Ventilation	
	D. Integrated Pest Management	
	E. Grafting	
	F. Soil Management	
	G. Water Management	
	H. Winter Cropping	
	I. Storm Proofing	
IV.	Crop Production Guides and Enterprise Budgets	20
	A. Tomatoes	
	B. Head Lettuce	
	C. Spinach	
	D. Cucumbers	
	E. Bell Peppers	
	F. Leafy Greens	
	G. Roots	
V.	Appendix/ Additional Resources	39



Gieringer's Orchard, Edgerton, Kansas

INTRODUCTION

High tunnels, also called hoop houses, are unheated greenhouse-like structures that provide additional control over the environmental conditions for production. High tunnels not only offer the ability to extend the season by approximately 30 days in spring and fall, but also add a level of environmental control over factors such as temperature, ventilation, and soil moisture that can help provide higher crop productivity and quality when managed correctly. Typically, high tunnel production space is the most valuable growing area on the farm, but is not a “cure-all” for farmers. As stated by a grower in the first volume of *Growing Under Cover, A Guide to Polyunnel Options for Kansas Growers*, “High Tunnels are a great tool, but they are just a tool. If you are doing a poor job raising produce now, putting up a tunnel will not fix that.”

Kansas Rural Center’s first volume of *Growing Under Cover* focuses mostly on the benefits and challenges of high tunnels and low tunnels. It explores various types of structures, construction, maintenance and planning strategies. This second volume, *A Kansas Grower’s Guide*, provides success stories from Kansas farmers who use tunnels on their farms, additional general management strategies, and specific cropping advice for some of the most successful crops grown in high tunnels in Kansas. This volume is for growers who are looking to start growing in high tunnels, as well as those who already have a high tunnel and are seeking to optimize its use. It will also provide a foundation for growers seeking to understand the basic management practices and needs of various crops within high tunnels.

A note should be made about Kansas geography and the dramatic differences in climatic conditions from the east to the west. Most of the stories found in these pages are from the eastern half of the state. High tunnels are currently being used in western Kansas as well, although they must overcome extreme environmental conditions that can be challenging for high tunnels. Challenges include reducing structural damage from high winds, coping with temperature extremes and water scarcity. However, if the high tunnel is well-constructed and managed, it can help grow more successful crops, and overcome these extreme environmental conditions.

This volume will begin by profiling five growers from the state of Kansas who are successfully using high tunnels: Chis and Christi Janssen of C and C High Tunnels; Brice Wiswell of Gieringer’s Orchard; Todd Griggs

of Griggs Bros. Farms; Jay Schleicter of Jay's Jellies, Produce and More, and Jill Elmers of Moon on the Meadow Farm.

“High Tunnels are a great tool, but they are just a tool. If you are doing a poor job raising produce now, putting up a tunnel will not fix that.”

Kansas grower and high tunnel owner

All of these operations use high tunnels expertly, but in different ways that are adapted to fit their overall farming system and production goals. Both Gieringer's Orchard and Griggs Bros. Farms use high tunnels primarily to grow tomatoes. The other three farms also grow tomatoes in their tunnels, but as part of a diverse mix of crops being grown. Three of the growers profiled are in urban or populated areas (Moon on the Meadow in Lawrence, Griggs Bros. in Augusta, and C and C in Scandia) and the other two are considered peri-urban or rural. All of these growers have found tunnels to be a successful tool in their operation and have expanded production area since building their first high tunnel. Each of these farms have five to twelve tunnels of various sizes in production or under construction.

The five operations chosen as examples are by no means the only successful high tunnel users in the state. However, their different management styles, crops being grown, and markets being served offer models for other high tunnel growers.

After exploring the work of five successful farms using high tunnels in Kansas, the focus will turn to specific information on management. Topics such as layout, ventilation, integrated pest management (IPM), soil management, irrigation, winter cropping and storm protection will be discussed. Other production practices such as trellising, staking and grafting will also be discussed for specific crops in this section.



C and C High Tunnels, Scandia, Kansas

Finally, this volume also includes specific growing information on seven different groups of crops, with analysis of their economic potential. These crops include tomatoes, spinach, cucumbers, peppers, leafy greens, roots, and head lettuce. The crops were chosen from a survey of the most commonly grown crops in high tunnels in Kansas conducted by the Kansas Rural Center in 2013 and by a similar survey published by Kansas State University Research and Extension in 2010. Growers also have found success producing other crops in tunnels. Several crops such as tomatoes or baby leaf salad mix, may provide impressive per square foot profit potential in enterprise budgets, but other crops can also prove valuable. Growers might still consider producing additional crops as part of their overall marketing/tunnel management strategy, if they find a benefit in producing those crops, or are able to adjust their production costs or market price to grow them profitably. An estimate of the crop economic potential was compiled by Kansas growers and other economic research results that were available.



Moon on the Meadow Farm, Lawrence, Kansas

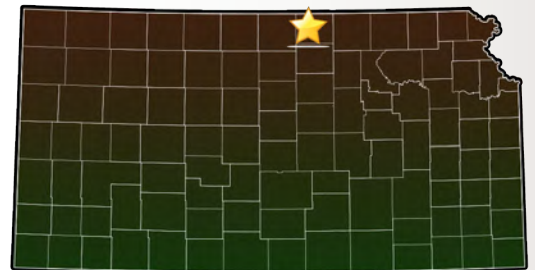
GROWER PROFILES

C AND C HIGH TUNNELS: *Chris and Christi Janssen*

Chris and Christi Janssen started growing produce commercially in Scandia, Kansas in 2009, when they built their first two 30'x140' high tunnels on two lots on the edge of town. In 2011, they brought additional land into cultivation for outdoor fruit and vegetable production. In 2012, they expanded their high tunnel space, adding a third 30'x140' high tunnel. They also have a smaller tunnel (20'x30') near their residence for transplant and winter greens production. This year C and C added a 14' x 50' movable high tunnel. The movable tunnel is a farm-based creation that can roll across the ground on wheels and is anchored by steel pipes. Between these five tunnels, Chris and Christi have over 14,000 feet of covered growing space. C and C High Tunnels is a major producer of local foods serving broad regions of North Central Kansas. They serve farmer's markets in Mankato, Beloit, Concordia, Phillipsburg, Salina and Belleville, in addition to running their year-round Community Supported Agriculture (CSA) subscription service that covers a 50 mile radius, and working with a cooperative CSA out of Salina. They also sell to wholesale accounts in the area. In spite of this broad market scope, they view themselves as a middle-sized produce farm, as Chris puts it, "too big to be small and too small to be big."



Chris and Christi Janssen, C and C High Tunnels, Scandia, Kansas



GROWING PRODUCE ON TWO CITY LOTS

The Janssens plant their high tunnels to a diverse blend of cool season crops including spinach, baby kale, and a mix of spring salad greens starting around the first week of October. They till the tunnel using their

tractor, and direct seed these crops into the soil. They irrigate by using an overhead watering system. As the plants mature, Chris and Christi sell the vegetables throughout the winter to CSA customers and also wholesale markets. They harvest their greens at leaf stage, rather than growing head lettuce or other full-sized mature heads, due to the hardiness of the younger plants. They tend to plant their three tunnels in succession from the first through the third week of October, spreading the planting to minimize the lull between the removal of warm-season crops and the onset of cool-season vegetables. For them, getting the crops established with a solid root system before day length becomes too short in November is critical.

Around the first of April, they replace the winter greens with summer products, such as tomatoes, peppers and cucumbers, in addition to other warm-season crops. Chris and Christi create plasticulture beds for their summer products using a mulch layer to place the plastic mulch and drip irrigation lines. They are able to use the machinery to cover most of the length of the tunnel, the last few feet being buried by hand. These crops are the mainstays of their summer high tunnel production, but also grow a broader mix of crops outside to provide diverse offerings to their customers.

C and C uses natural farming practices which incorporate the use of beneficial insects, organic methods, and hands-on labor. Growing just inside of town pushes them towards efficiency, and they are innovative in the use their production space. They squeeze strawberries along the edge of their tunnel, plant asparagus between two closely spaced high tunnels, and plant rhubarb on the hillside created when the land was raised to keep the tunnels above flood level. They have also converted their home lawn into a vegetable garden. In addition to the use of intensive cultivation practices, C and C maximizes their location in town by having neighbors drop off organic wastes, such as lawn clippings to use as mulch, and by employing local youth for summer help.

When asked what is the main lesson they have learned since starting their farm, they both agreed the key is to, “work smarter, not harder.” Growing vegetables is physically demanding work, therefore planning is essential for efficient and successful production. For example, on their newest 30’x140’ tunnel, they installed ten foot wide doors instead of eight foot, so they can fit their tractor in the tunnel easily. Their investment in machinery, a plastic mulch layer and a mulch lifter, helped improved labor. They had previously installed plastic mulch by hand in the tunnel, and now the efficiency of the machines decreases labor and limits physical strain.

The 2016 summer growing season emphasized the value of high tunnel growing for the Janssens. While weather conditions kept most growers in the region from being able to produce many tomatoes, the environmental control of the high tunnels allowed C and C to successfully produce a tomato crop. This guaranteed them a steady flow of customers and high prices through the main market season.



Strawberries grow along the edge of a tunnel while tomatoes growing to the right.



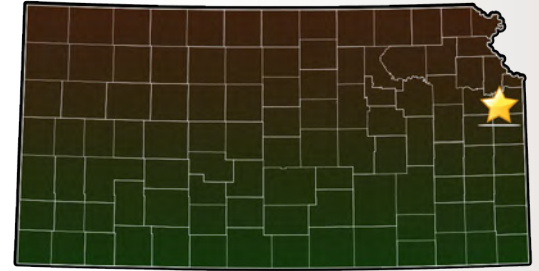
Movable high tunnel

GIERINGER'S ORCHARD: *Brice Wiswell*

Gieringer's Orchard, located northwest of Edgerton, Kansas, is owned and operated by Frank and Melanie Gieringer along with their son Brice Wiswell. Gieringer's is a diversified operation that includes blackberries, peaches, strawberries, blueberries, tomatoes, sweet corn, and other vegetables along with traditional row crops and cattle. All of their tomatoes are grown in six high tunnels, with a total covered growing space of over 18,000 square feet. In the past two seasons, they experimented with integrating cauliflower in one high tunnel as an early crop, then followed with a later planting of tomatoes in mid-June. Otherwise, tomatoes are grown exclusively in their high tunnels. The tunnels are not utilized during winter (November-March) for cool season production other than the cauliflower. The Gieringer's have a major u-pick operation (strawberries, blackberries, pumpkins and peaches), an on-farm store, and sell at the Overland Park and Lawrence farmer's markets.



Brice Wiswell, Gieringer's Orchard, Edgerton, Kansas



While the on-farm sales create some challenges, such as unexpected visitors at all hours, Brice emphasized the value in being open to the public, "I like people seeing how we grow and what we do." They also service several grocery stores and some restaurants with their high-quality, high-value crops. They have planned their operations to integrate their specialty crop production with the seasonal work of row cropping and raising cattle.

TOMATO PRODUCTION AT GIERINGER'S ORCHARD



Laying landscape fabric and assembling the trellis system in a tunnel at Gieringer's Orchard during the winter

The Gieringers focus their high tunnel production on tomatoes and tailor their growing practices to fit with their overall farm system. A big part of that comes from their efforts to minimize labor during the growing season while producing a high volume of large, red slicing tomatoes for their markets. To accomplish this, they use a very specific production protocol. In the winter, composted cow manure is spread in a fairly heavy application. Afterwards, a high pressure drip irrigation system is installed, and landscape fabric (aka woven groundcover) with precut holes for the tomato plants is laid down to prevent weeds. Both the drip systems and fabric can be reused every year. The entire tunnel floor is covered with groundcover, which prevents weed growth throughout the season, and minimizes the in-season labor. The trellis system, which is a modification of the stake-and-weave method, is

set up just after planting the tomatoes. All twine is strung onto the stakes when the plants are small and 3/4" plant clips are used to attach the vines to the trellis. After planting in the spring (March 25 – April 10), the plants are pruned to the first fruit hand and then allowed to grow freely. The vines are attached to the trellis with plant clips weekly. The tunnel rows are laid out in double rows, where two rows are close together (roughly three feet on center) with more space between the next two rows (roughly four foot, six inches on center) that is used as an aisle to access the plants for maintenance and harvesting.

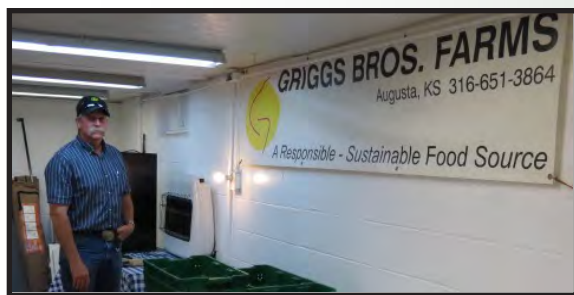
The tomato variety the Gieringers plant is BHN589 grafted onto Maxifort rootstock. They feel that the grafted plants are superior in terms of yield. Frank has conducted on-farm research trials with Kansas State University for several years and has gathered data to identify rootstocks that perform well in their production system. In some years, per plant yield has surpassed 40 pounds, significantly higher than non-grafted BHN589. The secret of their success is not solely in using grafted plants, but also the careful management that they give to their crops. During a tour of the high tunnels, Brice mentioned he did not have his drip lines on a timer like many growers, because when he turned them on, he wanted to manually check that the lines were functioning correctly. Another example of careful observation and management is the use of shade cloth on the tunnels. Despite the high additional investment needed, the shade cloth helps keep temperatures down in the high tunnel during the hot summer months, encouraging fruit set and even ripening.



40% shade cloth installed on a high tunnel

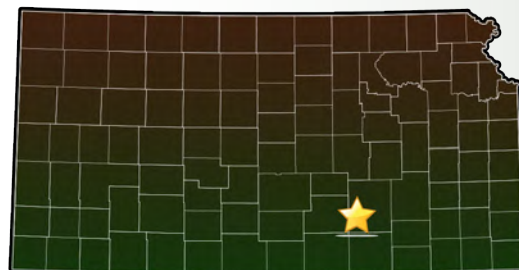
GRIGGS BROS. FARMS: *Todd Griggs*

Todd Griggs, of Griggs Bros. Farms, operates four high tunnels in his backyard in Augusta, Kansas with six acres of open-field growing space outside of town. Todd began using high tunnels in 2012 by moving used greenhouse structures he purchased from a nursery, so his high tunnels are equipped with large exhaust fans. He has two tunnels (21'x72') that are gutter-connected and two additional tunnels (21x72') that are free-standing, for a total of 8,640 square feet of covered growing space. Recently, Griggs purchased and has begun construction on an additional eight 30'x96' high tunnels on his land.



Todd Griggs, Griggs Bros. Farms, Augusta, Kansas

Todd sells to five area farmer's markets: Winfield, El Dorado, Augusta, Arkansas City, and the Kansas Grown Market in Wichita. Todd also has an innovative farm stand in his driveway that helps



local customers find fresh produce. The farm stand is helpful for selling produce that does not grade out for other markets. His stand uses an honor system whereby people weigh their own produce and pay into a secure box. Given his location in town, he does good business with a steady stream of customers during the growing season. Todd says that his booth outperforms his lower revenue markets on some days.



Griggs Bros. Farms honor system market stand in his driveway.

TOMATO PRODUCTION AT GRIGGS BROS. FARMS

Todd's main crop is large, red slicing tomatoes that are grown in tunnels and in the field. Other major crops grown in the open-field include peppers, cucumbers, squash and onions. High tunnels provide early tomatoes before his field plantings and allow an extended marketing season as well as improved year-to-year consistency.

In the high tunnels, Griggs grows mostly tomatoes although he uses one tunnel for growing transplants in the spring and he has experimented with growing squash in the late season. Todd's goal is to complete the eight additional high tunnels by the fall of 2016 so he can move most of his tomato production indoors in the future to improve fruit quality and decrease the amount of time he spends in weed management.



High tunnel layout with solid ground cover and stakes after plants have been removed

In the past, Griggs has used plasticulture beds in the tunnels, but in 2016 he switched to fabric mulch. The one problem he noted with the fabric mulch is that it provided an ideal environment for crickets, which were damaging to the plants. He also noted the fabric mulch reduced labor for weeding, especially important since his sons have gone off to college. Todd prefers growing determinate varieties like Red Deuce and uses the stake-and-weave method for trellising the vines.



Transplants grown in the spring in one of Griggs Bros. Farms high tunnels

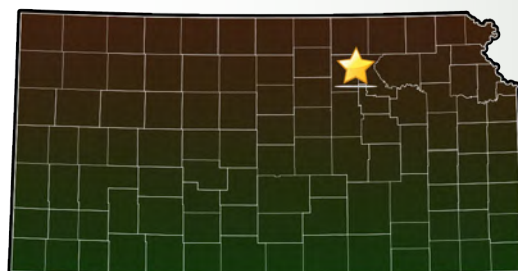
Todd has had recurring problems with spider mites and has tried chemical control options, although they have not been very successful for him. He routinely integrates a second planting of either tomatoes or another warm season vegetable in his four tunnels. He will then replant some of the houses to a second tomato crop and squash, for a late season harvest.

JAY'S JELLIES, PRODUCE AND MORE: *Jay Schleichter*

On a scenic hilltop just north of Clay Center, Kansas, Jay's Jellies, Produce and More grows a diverse mixture of vegetable crops using high tunnels year-round. Jay's operation is on a five acre property, and he is producing vegetables for market on a small portion of that. Jay started growing in high tunnels in 2008 in a model he designed and built. Based upon the success of that initial tunnel, he built two more in 2009 and two more in 2010. Jay grows year-round and produces a mixture of greens, lettuces, herbs, cucumbers, tomatoes, peppers, onions, carrots and other crops. Jay is a teacher in Clay Center, so major periods of work in the high tunnels are scheduled around school breaks. Transitioning the tunnel from winter greens to summer plantings of tomatoes and summer crops occurs over his spring break, roughly during the middle of March. The summer crops are taken out of the high tunnel and fall and winter crops are planted over the Labor Day weekend. Jay's Jellies, Produce and More sells at farmer's markets year-round in Manhattan, Junction City and Clay Center.



The Schleichter Family, Jay's Jellies, Produce and More, Clay Center, Kansas



DESIGNING AND BUILDING HIGH TUNNELS TO SUIT

Aside from the diverse way Jay uses his high tunnels, the outstanding feature of his farm is the ingenuity that is demonstrated in high tunnel construction and other farm-built tools. While he has two pre-manufactured high tunnels (30'x48' and 26'x72'), there are four tunnels that Jay has built himself of various sizes. His first homemade tunnel was an 18'x48' Quonset style structure built from PVC and wood. Seeing how much it improved his growing ability, he built a similar tunnel with a few modifications to improve the design. He then added two additional 16'x32' movable high tunnels that he designed and fabricated. The movable tunnels can transition between three different positions, sliding on wooden rails. Although the tunnels move up and down a significant hill, Jay insists the tunnels move easily enough that he can move them by himself in either direction. The movable tunnel allows Jay to start a cold-tolerant crop early in the spring and then move the tunnel into another position as the weather begins to warm up. In 2016, he began with onions, moved the tunnel to start summer squash, and followed with a fall crop of carrots. Thus, while the movable tunnel gives valuable benefits like the ability to rotate crops and expose the



One of Jay's movable tunnels. It has metal pins that slide on top of the wooden rails. Once the tunnel is in position it is secured to the rails by bolts.



This tunnel pictured in May shows some of the diverse production at Jay's Jellies, Produce and More. On the left garlic, in the middle, head lettuce and cucumbers are growing side by side and on the right cherry tomatoes are getting ready to start producing.

soil to natural precipitation, it can also be used to start crops and move onto another crop as they mature. Jay has also built a variety of other farm tools to improve his production efficiency such as barrel washer and plastic mulch layer.

Jay's farm is located on a hilltop in central Kansas. Consequently, he battles wind on a regular basis and has devised management practices for dealing with such issues. To prevent damage, Schlechter is diligent about battening down his sidewalls and vents when the wind picks up. One noticeable difference between his tunnels and commercial designs are how low they are to the ground. Although people can still stand inside, he believes the lower height makes them more secure during high winds.

MOON ON THE MEADOW FARM: *Jill Elmers*

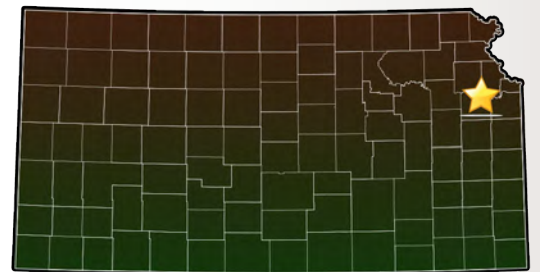
Moon on the Meadow Farm is a certified organic farm that produces vegetables, fruits and flowers in the Kansas River Valley, on the east side of Lawrence, Kansas. Jill Elmers began Moon on the Meadow in 2000 on rented land near Lawrence. In 2006, she purchased one of the locations she was renting and settled Moon on the Meadow into its permanent home, just inside the city limits of Lawrence. In 2010, Jill partnered with another local grower to purchase an additional 30 acres of production space that was adjacent to her property.



Jill Elmers, Moon on the Meadow Farm, Lawrence, KS

Moon on the Meadow markets produce through a variety of channels in Northeast Kansas including a CSA in Lawrence and Kansas City, the Lawrence farmer's market, and a number of wholesale accounts with restaurants and grocery stores in Lawrence. Jill bought her first high tunnel (20'x96') in 2007, added a second in 2010, and in 2016 she added a third 20'x 96' high tunnel.

Additionally, there are two smaller high tunnels that were made on site using a pipe bender (from Johnny's Selected Seeds) that bends tubing from chain link fencing into hoops, and a third small tunnel purchased from a hardware store that had used it to house retail bedding plants in the spring.



DIVERSIFIED HIGH TUNNEL MANAGEMENT

At Moon on the Meadow Farm, each of the different high tunnel types are managed differently. The larger high tunnels are used for year-round production focusing on spinach, lettuce and other cool season greens in the winter; tomatoes in the summer; and some plantings of tender perennial herbs like rosemary. Two smaller tunnels have been utilized primarily for transplant production, and prior to 2016, Jill used one of them to produce microgreens. The third small high tunnel (12'x32') is used specifically for cut flower production. From 2015-2016, she overwintered larkspur, anemone, and ranunculus in that tunnel, providing a jump on early spring production. In 2016, Jill was able to lease space in a commercial greenhouse to increase transplant production capacity and serve as a site for scaling up her microgreen enterprise, so this will change the way the smaller tunnels will be used at Moon on the Meadow Farm in the future.

Throughout the season, Elmers grows different crops in the tunnels including herbs, heirloom tomatoes, cherry tomatoes, greens (baby greens and larger varieties), spinach, and radishes. The diversity of crops that she grows in the high tunnels allows her to provide the many crops desired by customers at the farmer's markets and the CSA from early April through November. Winter production in the high tunnels at Moon on the Meadow allows Elmers to generate some income through the off-season, selling mostly to wholesale accounts and CSA customers.

Spinach is the primary winter crop at Moon on the Meadow due to market demand and its high tolerance of many freeze and thaw cycles. Elmers' production system begins with sowing the spinach in the fall to promote growth while there is adequate day length and then harvesting throughout the winter. Inside the tunnels, row covers (0.55 oz/yard, Agribon Ag-19) are used over the spinach to protect the crop for temperature variations on the coldest days.

An innovative way Elmers uses high tunnels is to overwinter tender perennials, such as rosemary, that would normally not survive the Kansas winter. This type of production is becoming more popular nationwide for high value crops such as figs, but it is still relatively rare in Kansas.

The rule of thumb is that a tunnel can change the growing environment by three hardiness zones. Elmers mulches her rosemary heavily during the winter to protect it. While the tunnel may not change the minimum temperature very much on a cold, clear night, it can protect the soil from freezing, which can increase overwintering survival for many perennial plant species.



This tunnel has rosemary growing next to the sidewalls and young cool crops in the middle covered with row cover. This is to stop the rabbits from eating the tender leaves



Transplant production at Moon on the Meadow



Kale growing at Moon on The Meadow

GENERAL MANAGEMENT STRATEGIES

This section provides a basic introduction to some of the fundamental growing and management practices used in a high tunnel, synthesized with information from the profiled Kansas growers and other resources. For more information on any of the selected topics, view the additional high tunnel growing manuals listed in the Appendix.

LAYOUT

Given that high tunnels are some of the most valuable space a grower will have access to, layout for maximum value is very important. The two main layout concerns are maximizing usable growing space and designing for ease of access to the crop.

The two main layout styles include long rows/beds that run parallel to the length of the house and ones that are perpendicular to the long axis with either a central row running down the middle of the high tunnel or paths along the sidewalls. The former layout, parallel rows, seems to be most common in Kansas and is well-suited to tall crops like tomatoes and cucumbers. Both of these layouts can be optimized for usable space, so the decision should be based upon the needed access for equipment, crop maintenance, and harvesting.



Parallel bed layout at Griggs Bros. Farms

If a tractor is used for tillage or bed-shaping, then having long rows parallel to the sidewalls typically makes the most sense. If hand tillage or small equipment (e.g. walk-behind tillers) is being used, growers may find that having shorter, perpendicular rows may be ideal especially, if a diverse mix of crops are being grown. Depending on the growing system used and crop being produced, beds can be raised or level with the ground. Raised beds tend to warm up faster in the spring, while



Perpendicular crop layout in a tunnel at Growing Home, Chicago, Illinois

level beds tend to retain heat more efficiently in the winter. The toughest areas to utilize are directly along the sidewalls, particularly if the high tunnel has short sidewalls. Many growers are building tunnels that have 5' to 8' sidewalls in order to increase production space, but the location along the sidewall makes it cooler and damper in the winter than the rest of the tunnel. Similarly, growers may find more disease on plants along the sidewalls, especially if they are not closed during rain events. If the surrounding area outside is not graded to drain away from the tunnel, the area around the sidewalls is prone to water infiltration during heavy rains. Planting crops that

can handle these conditions, or leaving footpaths are good use of this space (see C and C High Tunnels grower profile).

It is important to have a strong support system to support the weight of the plants when using the string trellis system. Plants can weight up to 30lb including fruit during peak season.

CROP SUPPORT/TRELLISING

Maximizing production space in high tunnels is a high priority for growers and trellising helps plants grow vertically, hence producing a higher crop yield. Trellising also helps keep plants off the ground and therefore decreases the chance for fruit diseases, uneven ripening, and unwanted pests. This ultimately allows for cleaner, higher quality fruit for the market. There are many options for trellising in tunnels, which include: European string trellis, Florida/California stake-and-weave, and mesh fencing trellis.

European string trellises are a very efficient use of space and work well in high tunnels that have the structure to support them. This method is common for indeterminate tomatoes and cucumbers. A string is run from floor to ceiling and the vines are attached with plastic clips or other methods. Tomato plants are traditionally pruned down to a single leader, but can be managed with two or more, particularly if grafted plants are used.



String trellising at C and C High Tunnels

To construct a trellis, tie one string overhead per vine, making sure it is long enough to reach all the way to the floor. Secure the string near the base of the vine, keeping the line tight, but make sure it is not so tight as to damage the vine. It is important to have a strong support system to support the weight of the plants, as each plant can be up to 30 pounds or more during peak fruiting season. High tensile wire is frequently secured to the end walls or any rafters supporting the bows of a high tunnel and the strings are attached to the wire or the rafters. As plants grow, the string can either be twisted around the stem, or the plant can be attached with twine



Stake-and-weave on tomatoes at John C. Pair Center, Haysville, Kansas



Mesh trellis used on cucurbits at C and C High Tunnels

The **Florida/California stake-and-weave** technique, is commonly used for tomatoes, peppers and eggplant grown in high tunnels. Wooden or metal posts, usually 5' to 8' tall, are set about a foot deep in line with the row between every other plant. Once the plants are about 10 to 12 inches tall, strings need to be added roughly once per week until the plants shift to fruit production. This should be done so that each string added is placed just below the top of the canopy of the plant. Tie twine to the end stake and run it down the row, wrapping it around each stake as you go. Do not "weave" the plants and be sure to keep the string between yourself and the plants at all times. At the far end of the row, wrap the twine a couple of times around the end stake, and return up the other side of the row in the same fashion. Put a pair of lines like this on each side of the row as the plants grow, usually every eight inches or so.

Meshed trellis is commonly used for cucumber production and allows for easier harvesting. Some growers use cattle panels or other wire mesh to support plant growth, but frequently growers use a disposable PVC mesh, such as Trellinet. The mesh is either supported from stakes in the ground or from the rafters of the hoop house. Clips can be used to help support the plants, if needed.

VENTILATION

Ventilation is a significant challenge for high tunnel users, particularly in areas that do not maintain consistent wind. There are a number of systems to improve ventilation. The structure can be ventilated with roll-up or drop-down sidewall ventilation combined with gable vents on the peaks of the end walls. Gable vents are very important as the rising hot air creates a current that can move a greater volume of air than would be suggested by the size of the vent. Additionally, in the winter, one of the main goals of ventilation



This tunnel at Gieringer's Orchard has a drop-down sidewall and open peak vent on the end wall.

on cold days is to prevent excessive moisture build-up. Opening gable vents can allow this moisture to flow out without allowing cold air to enter the tunnel at crop level. Drop down sidewalls can also be more effective at protecting crops at ground level from cold air early in the season, as they can be cracked at the top to let

out warm, moist air, while colder air does not flow directly onto the plants. The drawback of drop down sidewalls versus roll up is increased cost, mechanical complexity, and maintenance.

High tunnels might seem like an ideal tool for any farming operation but ventilation is one area where people tend to underestimate the amount of labor and time required. Tunnels can heat up extremely quickly during sunny days and need to be vented promptly to avoid damage to the plants. Similarly, in cold weather they will need to be closed promptly as light fades to minimize temperature loss. There are some automatic sidewall systems on the market but they are expensive, so manual ventilation remains the most common method for growers.

A homemade automatic gable vent at Moon on the Meadow Farm (pictured right) is a nice way to add automation to ventilation. Even with automation, these vents still requires someone to monitor the automated ventilation in the mornings and the evenings. Even though the labor of ventilation is just a few minutes a day of labor, it can create a certain scheduling hassle and yet it is absolutely critical.



A farm-built automatic peak vent using a UniVent opener

INTEGRATED PEST MANAGEMENT

High tunnels can create unique opportunities for pests and therefore, a need for specialized pest management. A key to a profitable enterprise is minimizing expenses, and in the realm of pest control the best strategy is using Integrated Pest Management (IPM). IPM is a pest management approach that is well-suited for the confines of a high tunnel.

The goal of an IPM program is to manage pests at a level that is economically acceptable. Rather than eliminating all pests, the target is to control the amount of damage done. This is achieved using multiple lines of defense, first to minimize potential problems, second to treat as needed. This approach balances the ecological and financial impact on the farm. The primary layer of defense is preventive cultural practices. This means selecting the best varieties for the growing conditions, with the best possible resistance to existing pest and disease pressure and maintaining cleanliness in the tunnel. Other cultural practices, such as pruning tomatoes or increasing plant spacing, can improve airflow and help minimize disease pressure.



Tomatoes pruned to first hand to help increase airflow at Kansas State University Olathe Horticulture Research and Extension Center.

The most important step in IPM is scouting. This involves regular observation of the crop, looking for insects or damage, and identifying the culprits. Many growers use sticky cards to aid in observation. Regular observation is critical. Once pests reach a critical threshold there are a variety of treatments available, but

chemical pesticides are usually considered the last line of defense. A grower can use mechanical controls, from simple methods such as pest barriers or hand picking to more advanced methods like insect vacuums. At Michigan State University, researchers have been particularly successful experimenting with insect netting to eliminate cucumber beetles from high tunnels. Row cover can be used to exclude flea beetles which are a common problem in arugula and eggplant production.

A second line of defense is biological controls, like beneficial insects or biologically-based insecticides such as Bt and spinosad. In the closed environment of a high tunnel, they can be more effective since the product is not washed off the plants by rain. A release of ladybugs or other beneficial insects in the fall can provide a defense against aphid buildup over the winter and into the spring.

The last line of defense is usually conventional pesticides. If the problem hasn't been reduced or eliminated with the other management steps, these can provide a route to saving a crop. Be sure to follow all requirements identified by the label on the pesticide. View the resource section at the end of the manual for more information guides that can be extremely helpful for managing insects and diseases.

Another problem that can be more noticeable in high tunnels than in the field is the presence of animal pests such as moles, voles and mice. The covered environment is a nice habitat for them in the winter, with generally fewer predators and they are provided food by the vegetables you are working hard to produce. These are best trapped mechanically with live or killing traps, since chemical control could leave poisoned animals laying among the crops, which is a food safety concern.

For Kansas high tunnel tomato growers, a particular challenge related to preventative IPM practices is crop rotation. Given the profit potential of tomatoes in local markets and the significant benefit of growing them in high tunnel systems, rotation becomes a practice that is often overlooked. Realizing many growers will either ignore rotation or have very short rotation intervals, paying attention to other preventative practices that might mitigate the impact of soilborne disease is critical. Examples of such practices include bringing in additional organic material such as compost in the offseason, strict sanitation methods including removal of all plant debris, and growing plants that are grafted with disease resistant rootstocks. Some growers, like Gieringer's Orchard, have grown tomatoes continuously in the same tunnels for many years. Although this is typically not recommended, they have had good success thus far due to bringing in additional compost in the winter and using grafted tomato plants.



Scouting for pests



Tomato fruit worm on a tomato



Example of crop rotation in a high tunnel. Tomatoes are shown on the left and buckwheat is used as a cover crop on the right. The crops were switched the next year. Kansas State University Olathe Horticulture Research and Extension Center.

“The [grafted tomato] plants are significantly more expensive and challenging to find but the boost in yield makes up for the difference.” Brice Wiswell, Gieringer’s Orchard

GRAFTING

Many growers locally and worldwide are finding the advantages of using grafted plants, particularly when used in high tunnels. Grafted plants help overcome abiotic and biotic crop stress, help with nutrient plant uptake, and increase fruit yield per plant. The most commonly grafted vegetable plants in the United States are tomatoes, but grafting is possible with a variety of other vegetables. Grafted plants are produced by attaching the scion of a variety with good fruit production characteristics to a rootstock that adds vigor and resistance to root-infecting pathogens. The grafting process occurs when the plants are small seedlings and can add significant cost to the price of a transplant. However, high tunnel growers in Kansas are finding that certain rootstocks can increase yield by 20 to 50% and sometimes more. “The [grafted tomato] plants are significantly more expensive and challenging to find but the boost in yield makes up for the difference.” says Brice Wiswell of Gieringer’s Orchard who plants only grafted plants in their high tunnels. The process of grafting is somewhat complicated and requires careful management in the healing stages. To get more information, refer to the resources section in this manual.



Tomato grafting at Kansas State University Olathe Horticulture Research and Extension Center

SOIL MANAGEMENT

Managing soil in high tunnels provide numerous challenges compared to the open-field. Due to the intensive cultivation often utilized in tunnels, soils can become depleted of nutrients and organic matter. Furthermore, the covering on the high tunnel structure excludes natural precipitation and can lead to buildup of salts over time.

One solution to maintaining good soil health is to add organic material. This is mentioned in the grower profiles. Using finished compost can add critical nutrients as well as organic material and can be a source for beneficial microbes. Excessive use of compost, however, can contribute to salt buildup, which can become a serious issue and difficult to remediate. To address concerns of salt buildup and disease, some growers across the nation have removed soil and replaced it, but that is not a common strategy in Kansas. To reduce soil salinity,



Oilseed radish used as a cover crop in a three season high tunnel at Kansas State University Olathe Horticulture and Research Center

removing the covering of the tunnel for a period allows precipitation to wash away salt buildup. This may be a practical and labor saving strategy when coordinated with the replacement of the cover. Some growers will grow a cover crop during this fallow period to add additional organic matter and promote soil health.

WATER MANAGEMENT

Water management is critical in high tunnels. Any large fluctuations in watering can reduce the yield and fruit quality of the crop. Depending on the crop being grown and the type of irrigation system in place, this can occur through frequent though short irrigation cycles or less frequent but longer cycles. The optimal type of irrigation system to use depends upon the crops grown.

Drip irrigation is widely used because it does not wet the leaves, which leads to less disease pressure on many crops. It is also common to water tomatoes after picking, as the ripest fruits will be most prone to splitting. Other crops like greens and baby leaf salad mix can benefit from sprinklers or micro-sprinklers because of the even water distribution over the soil surface.

It's important to plan your irrigation system before the plants are in the tunnel. Planning includes thinking about: plant row layout, in-row spacing, water supply, fertility needs, water use at peak demand, and choosing the specific irrigation system. Tensiometers and/or other electronic soil moisture sensors can be helpful to ensure optimal watering.



Emitter shown on drip irrigation tube watering tomatoes in a tunnel



Irrigation manifold with timer at Griggs Bros. Farms.

WINTER CROPPING

There are unique benefits and challenges when using high tunnels during the winter in Kansas. For instance, weeds are a challenge in the summer growing season, but are generally less troublesome in the winter. Another benefit to winter cropping is that competition at local markets can dramatically decrease during this time. Some of the challenges of growing during the winter are apparent, such as preserving crops from cold damage and working in colder weather.

An equally significant challenge is the shortage of daylight. When day length falls below about ten hours, lack of light can limit crop growth. The period of short daylight occurs from around November 7 to February 1 in northern Kansas and November 15 to January 23 on the southern border. Studies indicate that production slows during the winter due to lack of light intensity, hence lower temperatures in high tunnels, rather than

inadequate light for growth. As noted in the ventilation section, winter growing can necessitate a serious investment in either mechanized ventilation options or the time to manage ventilation daily through a longer season. Sidewalls and other vents will need to be closely monitored and managed throughout the day in order to provide the best possible growing environment that the high tunnel structure can provide.

Most production in tunnels in the winter is reliant upon multiple layers of cover, including not only the poly skin of the tunnel, but also floating row cover placed directly



Floating row cover in a tunnel at Griggs Bros Produce

over the crops or suspended above them. This provides additional protection to the crops from cold nights and also helps to trap warmth from the ground. Floating row cover should be laid over metal hoops or a similar apparatus to keep them from contacting leaf surfaces. Otherwise the leaves of sensitive crops could get damaged by the freezing covers. Similarly, if row cover is placed directly on the plants, the microclimate underneath can quickly warm up and damage some

crops when the sun comes out. In trials at Michigan State University, researchers have had success using row covers that span the width of the high tunnel. This method insulates more effectively than covers over single rows as there are fewer edges to leak heat and a larger thermal mass that is under the cover.

There are two distinct methods of using tunnels to grow in the winter but usually similar crops are used. The first method is overwintering, which is common for spinach, kale, and other cold-tolerant crops. Crops are planted and raised to a stage below maturity prior to the critical period of short daylight. These crops are essentially held in dormancy until the weather begins to warm in the early spring. This type of growing can be somewhat problematic in Kansas, depending on available markets, as warm spells in February and March can often finish the crops before seasonal farmer's markets are open.

The second method to using a tunnel during cold weather is to harvest throughout the winter. This method is common for crops such as leafy greens, spinach and other cold-tolerant greens in Kansas. Crops must be planted earlier than those overwintered, so that they are at or close to marketable size when the days shorten enough to limit growth. Supplemental heat can encourage some growth, but daylight becomes a serious limiting factor in late December, January and early February. Crops must be selected that can handle multiple freeze and thaw cycles, and multiple layers of covering can be used to keep the crops sufficiently warm. Spinach and baby leaf salad greens in particular can be harvested and will continue to grow, albeit slowly, throughout the winter.



Metal hoops being utilized to protect the spinach when row covers are used at Kansas State University Olathe Horticulture and Research Center.

If harvesting through the winter or even in late fall/early spring, scheduling becomes an issue. Winter harvest scheduling is more challenging than summer, as it is weather dependent. Crops cannot be harvested if the temperature in the tunnel is below freezing or has not risen enough for crops to thaw. Careful planning must occur to ensure crops are harvested and stored to meet delivery deadlines if cold weather is forecasted.

If crops are harvested while frozen, they won't be marketable when they thaw. However, if crops are allowed to thaw prior to harvest, they can be marketable. For example, a crop may have to be harvested on a Tuesday for Saturday market if it's the only day of the week temperatures are expected to be above freezing inside the tunnel.

Crops that are more tolerant of multiple freeze and thaw cycles include leafy crops such as kale, spinach and Swiss chard as compared to heading crops such as head lettuce or Chinese cabbage or crops with semi-exposed roots such as radishes or turnips. Carrots are also tolerant of the freeze thaw cycles since they are mostly under the soil. Such tolerant crops are excellent for winter production.

STORM PROOFING

Storm proofing high tunnels should be a priority for growers in Kansas. High tunnels are an investment and keeping them from being destroyed by winds or snow is important. Furthermore, the loss of a high tunnel can lead to significant loss of value not only to the structure, but the crops inside as well.

Movement under periods of high wind can bend metal, tear the poly cover off the bows, or destroy end walls. Wind has been known to lift tunnels out of the ground and destroy the frame, particularly if the structure was not installed correctly. There are important steps to ensuring a secure high tunnel. First, make sure the tunnel is solidly constructed. It's typically recommended to put at least the corner posts in concrete and to be sure that the baseboards are secure to prevent vertical movement of the footers. Second, stretch the poly cover tight to prevent wind from pulling on it. Volume One of *Growing Under Cover* provides a detailed description of the best way to pull plastic to provide a tight fit (page 14). Finally, lifting or other frame damage is best managed by closing the tunnel during high wind events. This can be especially challenging in the summer, as a tunnel closed prematurely on a sunny day will quickly cook the produce inside. In a completely closed structure, the wind should flow over the tunnel rather than lifting it.

Snow loads can also become a problem. Snow can be light and fluffy or wet and heavy depending on the conditions. To keep a tunnel from caving in from the snow requires preparation. Make sure diagonal bracing is intact to help with the load. If you have a heating system, maintain a warmer temperature to help melt the snow. Keep long-handled brooms on-hand to help brush off the snow, lumber to brace your tunnel bows and back-up poly for needed repairs. Many growers have also had success using ropes with large knots tied into them that are drawn back and forth across the peak of the tunnel to "knock" the snow down the roof.



2' x 4' wood posts to hold bows in place on a three season high tunnel during a snow storm



Gieringer's Orchard, Edgerton, Kansas

CROP PLANNING & PRODUCTION GUIDES

The crops discussed in this section were chosen based on the results from two surveys about high tunnels in Kansas. The results from one survey are shown in Figures 1-2. *Growing Under Cover: Volume One* has information on the other survey conducted by the Kansas Rural Center. See Appendix for reference.

Along with suggested plant varieties and recommended management, this section includes economic analysis and crop enterprise budgets for each type of crop. One thing to note, while several crops, including tomatoes and baby leaf salad mix, have impressive per square foot profit potential, others may seem less impressive. However, growers should still consider growing these crops as part of an overall marketing and tunnel management strategy if they find value in producing them. This value might include crop rotation or profitably from market demand. If a grower is targeting wholesale markets, tunnels planted to single crops might be feasible. For growers who market to farmer's markets, CSA subscriptions, or serving smaller wholesale outlets, there is often a great value in having a wide diversity of products, rather than just lots of tomatoes or salad mix.

Iowa State University has produced an enterprise budget for a mixed-use tunnel. The overall per square foot revenue of the tunnel is quite good, \$3.18 per square foot (see Appendix for link). They also have a Decisionmaker tool that allows a

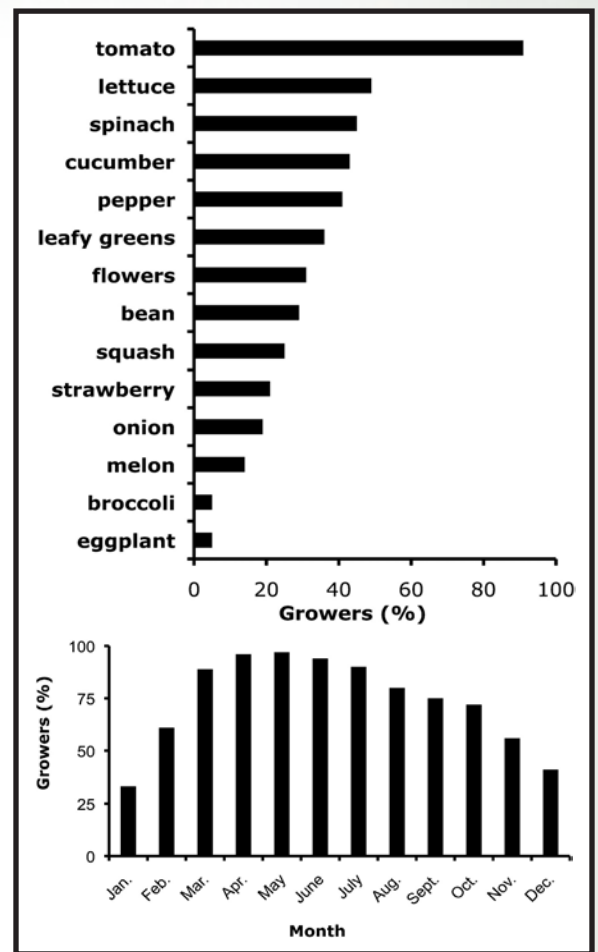


Fig. 1. (top graph) Proportion of growers that reported producing various crops in high tunnels during the previous 4 years. Results of a survey of 81 growers from Iowa, Kansas, Missouri, and Nebraska conducted from 2005 to 2007.

Fig. 2. The number of producers reporting a crop in a high tunnel during each month of the year. Results of a survey of 81 growers from Iowa, Kansas, Missouri, and Nebraska conducted from 2005 to 2007.

grower to consider multiple cropping mixes when determining how to allocate a tunnel for maximum profit. While some growers use the entire tunnel for one crop per season, a number of Kansas growers produce multiple crops simultaneously or over the course of a year. Diverse cropping mixes might make the financial picture presented in a basic crop enterprise budget look dramatically different, if, for example, a root crop is grown prior to tomatoes in the spring and followed by spinach in the fall. These types of decisions depend on market availability and a farm's ability to successfully grow different crops.

Another note about the high tunnel budgets: the construction cost of the tunnel structure used in all the example budgets is based upon a 20'x100' tunnel using numbers derived from a 2013 article in HortTechnology (see Appendix). A detailed chart is included on the next page. One way to improve the profitability of all high tunnel crops is by reducing fixed costs. Three of the profiled farms have constructed their own high tunnels, which can have a lower per square foot cost. Also, National Resources Conservation Service (NRCS) Environmental Quality Improvement Program funding in recent years has provided opportunities to offset some construction costs. For growers who take advantage of such opportunities, the fixed costs can be lower than is shown in the budgets.



Photo credit: nrcs.usda.gov/programs

The National Resources Conservation Services (NRCS) Environmental Quality Improvement Program is providing funding opportunities to help offset high tunnel construction costs. Learn more at ks.nrcs.usda.gov/programs

Analysis of the economic potential of crops was tailored as much as possible to Kansas. The enterprise budgets were based upon data from the profiled farms for tomatoes, cucumbers and spinach. Other information came from a variety of national sources (see the Appendix for references). The profit potential of a crop in one environment does not always transfer to other regions and production systems, and even the information developed from Kansas data is meant for educational purposes only, as different farms have vastly different production costs, sales channels, and pricing. The best method to determine the enterprise potential on your farm is to tailor the budgets to your situation, explore local prices and market opportunities, and ultimately to track your own information.

FIXED COSTS FOR CROP ECONOMIC BUDGETS

Construction Cost Component	Labor (\$/tunnel)	Machinery (\$/tunnel)	Materials (\$/tunnel)	Total per component (\$/tunnel)	Share of total costs (%)	Useful life (yr)	Annual costs per component (\$/tunnel)	Share of total annual costs (%)
Site Evaluation and Soil Preparation	312.88	69.85	-	382.73	3.34%	10	38.27	3.04%
Trenching and laying water pipes	14.20	-	100.00	114.20	1.00%	10	11.42	0.91%
Inserting poles and setting posts	283.92	159.24	211.20	654.36	5.70%	10	65.44	5.19%
Assembling the frame	283.92	-	7,048.80	7,332.72	63.90%	10	733.27	58.19%
Treating and setting baseboards	94.64	-	119.64	214.28	1.87%	10	21.43	1.70%
End and sidewall installation	473.20	-	337.00	810.20	7.06%	10	81.02	6.43%
Pulling plastic	94.64	-	656.00	750.64	6.54%	4	187.66	14.89%
Channel Lock Installation	23.66	-	-	23.66	0.21%	10	2.37	0.19%
Shutter vents	-	-	612.00	612.00	5.33%	10	61.20	4.86%
Trellis purlin installation	141.96	-	221.30	363.26	3.17%	10	36.33	2.88%
Electrical	116.56	-	-	116.56	1.02%	10	11.66	0.93%
Miscellaneous hardware and tools	-	-	100.00	100.00	0.87%	10	10.00	0.79%
Total Construction Costs	1,839.58	229.09	9,405.94	11,474.61	100%		1,260.06	100%

Monthly Fixed Cost \$105.01

Marketing Expenses	Labor (hrs)	Price (\$)	Total
- Marketing Labor	60	12.00	\$ 720.00
- Farmer's Market Stand (Lawrence)	1	260.00	\$ 260.00
- Marketing Materials	1	500.00	\$ 500.00
Yearly Total Marketing Expense			\$ 1,480.00

Monthly Marketing Cost \$123.33

TOMATOES

Tomatoes are the most commonly grown crop in high tunnels in Kansas and with good reason. There is a high market demand for fresh tomatoes, and high tunnels can produce fruit both earlier and later, with superior productivity and marketability compared to field-grown crops. Tomatoes are generally the most valuable per square foot crop produced in high tunnels, although some argue a succession of crops with a shorter production cycle, such as baby lettuce salad mix can, match the profitability of tomatoes.

Some of the challenges of growing field tomatoes include leaf diseases and fruit cracking, both of which are driven by rain events. These are mitigated by the tunnel's controlled soil moisture. All of the farms presented in the case studies dedicate a significant portion of their summer high tunnel space to growing tomatoes.

SUGGESTED VARIETIES

High tunnels produce superior tomatoes of all types. Growers will produce slicers, cherry tomatoes, and heirloom tomatoes, or all three, depending on the market demand. In general, most tomatoes that grow well in the open field will perform better in a high tunnel, but there are a few types that perform particularly well. Below are varieties Kansas growers have successfully grown in tunnels.

Red Slicers: BHN589, Red Deuce and Primo Red had highest marketable yield in trials at the K-State Olathe Horticulture Research and Extension Center from 2013-2016.

Cherry Tomatoes: Sungold, Black Cherry, Yellow Pear. All cherry tomatoes grow well in a tunnel. High tunnels can provide an advantage for the very tender, flavorful cherry tomatoes such as Sungold, which is prone to splitting. The ability to control moisture leads to significantly increased marketable yields.

Heirlooms: Any heirloom will more than likely perform better in a high tunnel. Commonly grown varieties, include Cherokee Purple, Brandywine, Striped German, Green Zebra, and Black Krim but the options are almost limitless. Heirlooms frequently suffer in the field due to high susceptibility to diseases. High tunnels can tremendously help reduce the incidence of foliar diseases.



Red slicers grown in high tunnels at Griggs Bros. Farms.

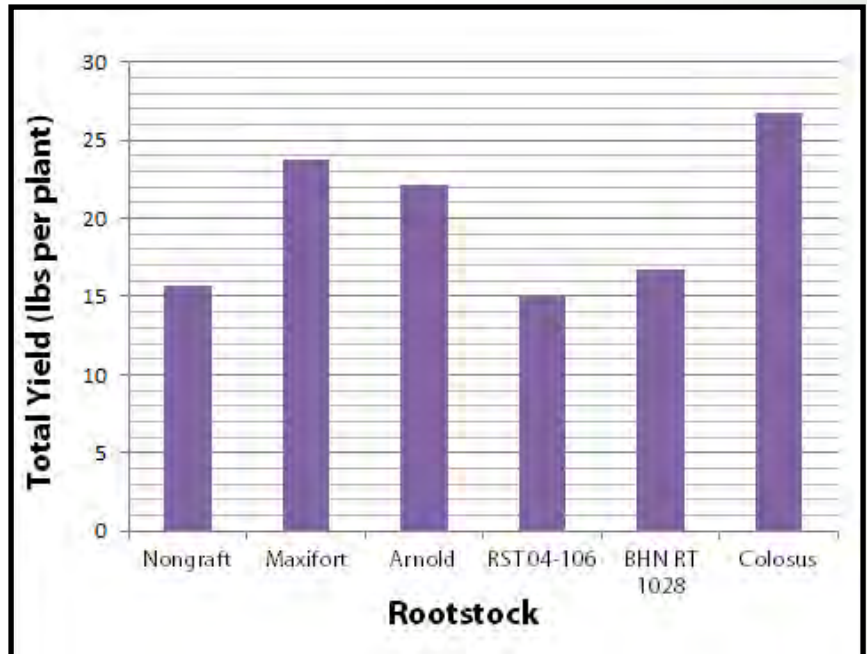


Cherry tomatoes grown in a high tunnel at Kansas State University Olathe Horticulture Research and Extension Center



Cherokee Purple heirloom grown in a high tunnel at North Carolina State University

Rootstock: Grafted tomatoes, as discussed in the General Management Strategies section, can perform very well in high tunnels. Research at Kansas State University has been done to evaluate rootstocks for their use in high tunnels. Replicated on-farm and research station trials have shown positive results for determinate tomatoes grown in high tunnels with Maxifort, Multifort, Arnold and Colosus rootstocks, where little disease pressure is evident. Others may be valuable for managing certain soilborne pathogens in the high tunnel such as root-knot nematodes (*Meloidogyne spp.*) and southern bacterial wilt (*Ralstonia solanacearum*) although the latter is only a problem in southern regions of the United States and not present in Kansas. Grafted plants with inter-specific hybrid rootstocks have been shown to outperform non-grafted plants in regards to yield as a result of added vigor. Additional cultural considerations should be made (e.g. plant spacing, pruning) when using vigorous rootstocks.



Grafted tomato total yield in a high tunnel at Gieringer's Orchard, 2015. The scion variety used in this trial was BHN589.

MANAGEMENT



Spider mite damage on a tomato

Tomatoes are generally spaced between 18" to 24" in row, with rows spaced from 4 to 5 feet apart depending on how they are trellised and harvested. In southern Kansas, tomatoes can be planted in a hoop house as early as mid to late March. The earlier the plants are transplanted to the tunnel, the more likely it is that there will be a few nights when protection with row cover and supplemental heat is needed. Tomatoes need to be monitored during the growing season for hornworm and spider mites (see Grower Profile of Griggs Bros. Farms). Hornworms can do significant damage and can be removed by hand or killed with a spray. Beneficial mites can also be released to combat spidermites or miticides can be used.

Trellising and Support: Tomatoes need support, and this is especially true in high tunnels where growing under poly encourages vegetative growth by the plants. There are two main ways tomatoes are typically trellised in tunnels: string trellis and stake-and-weave. These techniques are explained in the General

Practices section of this volume. Typically, stake-and-weave is recommended for determinate tomatoes but can also be used for indeterminate varieties. String trellis systems work well for indeterminate varieties like those bred for greenhouse production systems, but should not be used for determinate varieties.

ECONOMICS

High tunnel tomatoes yield anywhere from 10 to 30 plus pounds per plant, but yield can vary greatly depending on cultural methods, soil quality, season length and disease pressure. Tomatoes are the most-studied crop in high tunnels and enterprise budgets have been published by Kansas State University, Iowa State University, North Carolina State University, Cornell, the University of Minnesota and others. Many enterprise budgets use 1.5 to 3 pounds per square foot for yields.

The value of tomatoes can vary dramatically over the course of a season and by market. Direct to retail early season tomatoes might get up to \$4.00 per pound (more for heirlooms), while peak season wholesale markets might pay less than \$1.00 per pound. One of the benefits of high tunnels is the ability to capture more of the early season demand along with the high prices. In conclusion, high tunnel tomato production is profitable for most scenarios, particularly where higher market price is provided for the fruit.

The data in the tomato enterprise budget is derived from information provided by Gieringer's Orchard, Griggs Bros. Farms, and C and C High Tunnels. 2016 was a challenging year for tomato production and the yield calculated is thus far on the lower end of the generally expected range.



Tomatoes at Moon on the Meadow on display at a farmer's market.

CROP ENTERPRISE BUDGET FOR HIGH TUNNEL TOMATOES

Category	Task	Materials			Hired Labor			Owner Labor			Total Cost	\$/sq ft.	
		Unit	Qty	Price	Hours	Rate	Total	Hours	Rate	Total			
Preparation	Soil Test	each	1	\$ 10.00	\$ 10.00		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 10.00	\$ 0.01
	Tilling			\$ -	\$ -	0	\$ 10.85	\$ -		\$ 14.34	\$ 14.34	\$ 14.34	\$ 0.01
	Lay Beds			\$ -	\$ -	3	\$ 10.85	\$ 32.55		\$ 14.34	\$ -	\$ 32.55	\$ 0.02
	Plastic Mulch	feet	400	\$ 0.03	\$ 13.12		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 13.12	\$ 0.01
	Drip Tape	feet	400	\$ 0.03	\$ 10.76		\$ 10.85	\$ 10.85		\$ 14.34	\$ -	\$ 21.61	\$ 0.01
	Transplants	each	266	\$ 0.26	\$ 69.16		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 69.16	\$ 0.03
Production	Planting			\$ -	\$ -	2	\$ 10.85	\$ 21.70		\$ 14.34	\$ 14.34	\$ 36.04	\$ 0.02
	Staking	posts	83	\$ 1.58	\$ 131.14	10	\$ 10.85	\$ 108.50		\$ 14.34	\$ -	\$ 239.64	\$ 0.12
	Pruning and clipping			\$ -	\$ -	23	\$ 10.85	\$ 249.55		\$ 14.34	\$ -	\$ 249.55	\$ 0.12
	Weeding			\$ -	\$ -	2	\$ 10.85	\$ 21.70		\$ 14.34	\$ -	\$ 21.70	\$ 0.01
	Irrigation (setup and Maintenance)			\$ -	\$ -		\$ 10.85	\$ -	3	\$ 14.34	\$ 43.02	\$ 43.02	\$ 0.02
	Fertigation			\$ 37.00	\$ 37.00	2	\$ 10.85	\$ 21.70		\$ 14.34	\$ -	\$ 58.70	\$ 0.03
	IPM (Scouting/Application)			\$ 4.80	\$ 4.80	1	\$ 10.85	\$ 10.85	10	\$ 14.34	\$ 143.40	\$ 159.05	\$ 0.08
	Harvesting (12 weeks)			\$ -	\$ -	42	\$ 10.85	\$ 455.70		\$ 14.34	\$ -	\$ 455.70	\$ 0.23
	Washing/Grading/Packing (12 weeks)			\$ -	\$ -	10	\$ 10.85	\$ 108.50		\$ 14.34	\$ -	\$ 108.50	\$ 0.05
	Boxes and Other Supplies			\$ -	\$ -	4	\$ 10.85	\$ 43.40		\$ 14.34	\$ -	\$ 43.40	\$ 0.02
Marketing	See Fixed Costs Spreadsheet		4	\$ 123.33	\$ 493.33						\$ 493.33	\$ 0.25	
Total Variable Costs											\$ 2,069.41	\$ 1.03	
Monthly Fixed Costs (6 months)											\$ 630.60	\$ 0.32	

Revenue	Unit	Qty	Price	Total	\$/sq ft.
Marketing Channels: farmers market, retail (Yield 11lbs per plant)	lbs	2926	\$ 2.50	\$ 7,315.00	\$ 3.66

Net Income \$ 4,614.99 \$ 2.31

HEAD LETTUCE

High tunnels are well suited for head lettuce production (for baby leaf salad green production see page 35). The lettuce can be grown as small heads, and baby heads have become popular in recent years. Fully mature lettuce heads are typically more susceptible to frost damage than leaf lettuce. This can make them more suitable to fall and spring production rather than in winter.

SUGGESTED VARIETIES

Winter: Tin Tin, Spretnek, Winter Density, New Red Fire

Summer: Simpson Elite (loose-leaf), Ermosa (butterhead), Kalura (Romaine)

MANAGEMENT

High tunnels can produce headed lettuce of excellent quality. Head lettuce is a short season crop (60 to 80 days) and can be produced multiple seasons in the high tunnel system.

Heads can be produced in fall and spring, or overwintered using similar techniques as discussed earlier in this volume. Head lettuce is normally transplanted, but it can be grown via direct seeding and heavy thinning to 12 inches in and between rows. Plants are spaced from six inches to one foot apart, depending size of heads



Example of head lettuce plant spacing in a high tunnel



Head lettuce being grown in a high tunnel at Moon over the Meadow farm

heads desired. Rows are usually spaced at the same interval to fill the bed. If temperatures drop below freezing, lettuce should be protected with row cover. Heads that are fully developed are more susceptible to cold temperature injury than plants that are not yet mature.

The enclosed environment of the tunnel can also be used to provide shade and grow summer lettuces. Studies in the early 2000's at the Kansas State University Olathe Horticulture and Research Extension Center compared summer lettuce production between a shaded (39%) high tunnel and the open field. Certain

cultivars in the tunnels were shown to be best suited to slower bolting and reduced bitterness. The field heads were bigger than the shaded heads, but the shaded tunnel improved the proportion of marketable heads.

Lettuce and most leafy crops are susceptible to aphids. Release of ladybugs or other biological controls can be an effective way to prevent an outbreak.

ECONOMICS

Lettuce grows relatively quickly, and can be closely spaced to have good yields in high tunnels. Lettuce usually yields between \$1.00 to \$2.00 per head depending on wholesale or retail markets, resulting in decent returns from a short growing period in the high tunnel. Market demand is usually high for lettuce and is particularly suited for direct markets. Farmers can grow specialty lettuces, such as bibb and butter crunch, that do not ship as well. These varieties are frequently unavailable in grocery stores and can command a premium price. The major labor requirements are planting, cultivation for weed management, harvest and washing prior to sale. This budget was derived from labor and management times from Kansas growers and yield numbers from several productions across the country, including Washington and Utah (see Appendix).

CROP ENTERPRISE BUDGET FOR HEAD LETTUCE

Category	Task	Materials				Hired Labor			Owner Labor			Total Cost	\$/sq ft.
		Unit	Qty	Price	Total	Hours	Rate	Total	Hours	Rate	Total		
Preparation	Fertilizer (compost)	Yards	6	\$ 5.00	\$ 30.00	3	\$ 10.85	\$ 32.55		\$ 14.34	\$ -	\$ 62.55	\$ 0.03
	Row Cover	Sq Foot	2000	\$ 0.03	\$ 60.00		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 60.00	\$ 0.03
	Hoops	each	75	\$ 0.40	\$ 30.00		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 30.00	\$ 0.02
	Tilling				\$ -		\$ 10.85	\$ -	1	\$ 14.34	\$ 14.34	\$ 14.34	\$ 0.01
	Lay Beds				\$ -	1	\$ 10.85	\$ 10.85		\$ 14.34	\$ -	\$ 10.85	\$ 0.01
	Seeds	Thousand	3	\$ 2.44	\$ 7.32		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 7.32	\$ 0.00
	Media		2	\$ 15.00	\$ 30.00		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 30.00	\$ 0.02
	Equipment (pots)		1	\$ 20.00	\$ 20.00		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 20.00	\$ 0.01
	Transplants				\$ -	2	\$ 10.85	\$ 21.70		\$ 14.34	\$ -	\$ 21.70	\$ 0.01
Production	Planting				\$ -	5	\$ 10.85	\$ 54.25		\$ 14.34	\$ -	\$ 54.25	\$ 0.03
	Weeding				\$ -	3	\$ 10.85	\$ 32.55		\$ 14.34	\$ -	\$ 32.55	\$ 0.02
	IPM	Insecticide	1	\$ 25.00	\$ 25.00		\$ 10.85	\$ -	2	\$ 14.34	\$ 28.68	\$ 53.68	\$ 0.03
	Venting				\$ -		\$ 10.85	\$ -	2	\$ 14.34	\$ 28.68	\$ 28.68	\$ 0.01
	Other				\$ -		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ -	\$ -
Harvesting	Harvesting and washing				\$ -	28	\$ 10.85	\$ 303.80		\$ 14.34	\$ -	\$ 303.80	\$ 0.15
	End of season clean up				\$ -	2	\$ 10.85	\$ 21.70		\$ 14.34	\$ -	\$ 21.70	\$ 0.01
Marketing	See Fixed Costs Spreadsheet		2	\$ 123.33	\$ 246.67							\$ 246.67	\$ 0.12
Total Variable Costs											\$ 998.09	\$ 0.50	
Monthly Fixed Costs (2 months)											\$ 210.02	\$ 0.11	

Revenue	Unit	Qty	Price	Total	\$/sq ft.
Marketing Channels: farmers market, retail	head	1300	\$ 2.00	\$ 2,600.00	\$ 1.30

Net Income \$ 1,391.89 \$ 0.70

SPINACH

Spinach is an excellent crop to grow during the winter season because it is extremely tolerant of multiple freeze/thaw cycles and continues to grow slowly even in periods of low light. If established early enough, it can be used for continuous harvest throughout the winter and spring until the temperatures begin to rise and the spinach begins to bolt.

SUGGESTED VARIETIES

Interceptor, Highpack, Lombardia, Olympia, PVO170, Tigercat, Space, Corvair, Tyee, Regiment

MANAGEMENT

If planning for a continuous harvest during the winter, plant the spinach in the high tunnel between September and early October. Early planting allows for the plant to grow large enough for a continuous winter harvest. If spinach is planted during the winter months, the growth will not be significant enough for harvesting until spring.

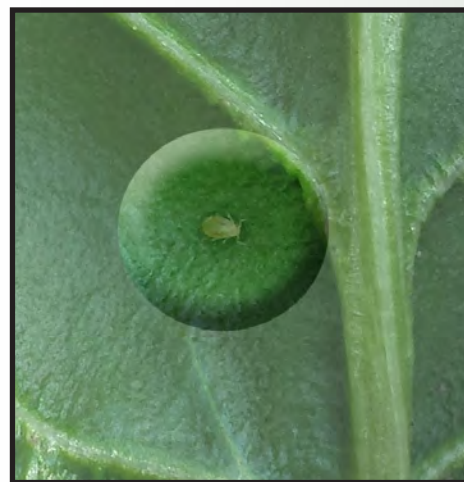
The picture on the right taken in early January, shows the difference in size between crops sown in early October versus early November. Spinach sown too early in the fall or too late in the spring can have poor germination because spinach does not germinate well in high soil temperatures. Maximum spinach growth happens when temperatures range from 60 to 75°F. Spinach is more tolerant of frost burning than many other greens. Plant growth will slow as the temperature decreases and will cease at 36°F. Therefore, the crop should be kept under row cover inside the tunnel when temperatures drop below freezing. Removing the cover in above freezing weather will increase light transmission to the crop as well as increase the growth rate and reduce the humidity, which can help prevent disease.

Spinach can be direct sown with an Earthway's or Planet Junior Seeder or a four to six row pinpoint seeder. Planting is efficient when direct seeding. Soil temperatures between 45 to 75°F are recommended for optimal direct seed germination. Transplants are also an option, and although there is an additional cost in materials and labor, plants will reach harvest peak sooner. Transplants can also be useful because seed can be germinated indoors, where cooler conditions may be more attainable.



Spinach planted on different dates at Kansas State University Olathe Horticulture Research and Extension Center

Spinach is susceptible to aphids. Moon on the Meadow Farm releases ladybugs in the fall to prevent a buildup of the pests and this is a common control strategy.



Aphid on a spinach leaf

ECONOMICS

Typical yields of spinach grown and harvested through the winter are around 1 to 1.5 pounds per square foot. Growers in this area usually sell spinach in leaf form by the pound, rather than bunched. The main demand of labor in spinach production is in picking it. Market pricing can be quite variable, ranging anywhere from \$5.00 to \$12.00 per pound in Northeast Kansas over the past few years, depending on factors such as wholesale versus retail, organic certification, and specific market.

The enterprise budget for spinach is derived from information gathered at Moon on the Meadow Farm in the 2016 season. To note on this budget, spinach was harvested for specific market demand, so the overall yield would be above that which is shown below.

CROP ENTERPRISE BUDGET FOR SPINACH

Category	Task	Materials			Hired Labor			Owner Labor			Total Cost	\$/sq ft.	
		Unit	Qty	Price	Total	Hours	Rate	Total	Hours	Rate			Total
	Row Cover	Sq Foot	2000	\$ 0.03	\$ 60.00		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 60.00	\$ 0.03
	Hoops	each	75	\$ 0.40	\$ 30.00		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 30.00	\$ 0.02
	Tilling				\$ -		\$ 10.85	\$ -	0.5	\$ 14.34	\$ 7.17	\$ 7.17	\$ 0.00
	Lay Beds				\$ -	1	\$ 10.85	\$ 10.85		\$ 14.34	\$ -	\$ 10.85	\$ 0.01
	Seeds	Thousand	50	\$ 1.12	\$ 56.00		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 56.00	\$ 0.03
Production	Planting				\$ -	0.5	\$ 10.85	\$ 5.43		\$ 14.34	\$ -	\$ 5.43	\$ 0.00
	Weeding				\$ -		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ -	\$ -
	Hand Irrigation				\$ -	3	\$ 10.85	\$ 32.55		\$ 14.34	\$ -	\$ 32.55	\$ 0.02
	Venting				\$ -		\$ 10.85	\$ -	5	\$ 14.34	\$ 71.70	\$ 71.70	\$ 0.04
	Lady Bug release		1	\$ 37.67	\$ 37.67		\$ 10.85	\$ -	0.25	\$ 14.34	\$ 3.59	\$ 41.26	\$ 0.02
Harvesting	Harvesting and washing				\$ -	40	\$ 10.85	\$ 434.00		\$ 14.34	\$ -	\$ 434.00	\$ 0.22
	End of season clean up				\$ -	2	\$ 10.85	\$ 21.70		\$ 14.34	\$ -	\$ 21.70	\$ 0.01
Marketing	See Fixed Costs Spreadsheet					1	\$ 123.33	\$ 123.33		\$ 83.33	\$ -	\$ 123.33	\$ 0.06
Total Variable Costs											\$ 893.98	\$ 0.45	
Monthly Fixed Costs (6 months)											\$ 630.06	\$ 0.32	

Revenue	Unit	Qty	Price	Total	\$/sq ft.
Marketing Channels: mixed wholesale avg price \$5.50/lb	lbs	398	\$ 5.50	\$ 2,189.00	\$ 1.09

Net Income \$ 664.96 \$ 0.33

CUCUMBERS

When grown vertically, cucumber plants do well in high tunnels by taking advantage of the light and space. They are a quick, short season crop (~60 days), and are frequently grown in rotation with tomatoes. While they typically offer a lower net profit per square foot yield than tomatoes, they can be used as a successor to an early planting of fall crops or cover crop.

SUGGESTED VARIETIES

Due to the hot, dry summer environment in Kansas, cultivars that are resistant to powdery mildew should be used. English style or greenhouse cucumbers are not often recommended for high tunnel production as a hoop house does not provide adequate protection from pollinators and the long fruits may become misshapen. However, many growers in Kansas have realized good yield with certain varieties.

Slicing Cucumbers: Tamazula, Dasher, Sprint, Marketmore, Sweet Slice

Beit Alpha: Socrates, Diva

Pickling: Northern Pickle

Small Snacker: Unistars (heavy yield)



Cucumbers grown in a high tunnel

MANAGEMENT

Cucumbers need adequate space to grow for maximum yield. Recommended plant spacing is 12 inches apart and row spacing is four to six feet apart. They are also a water-demanding crop and daily watering is recommended. Cucumbers grow quickly in high tunnels, but do not grow well in cool soils and will not survive any type of frost or freeze event. Early planting may not benefit the grower if soil temperatures have not adequately warmed up above 60°F.



Cucumbers growing on a mesh netting at C and C High Tunnels

Trellising: Cucumbers are usually trellised in high tunnels in order to maximize the growing space, reduce yellowing of the fruit and make harvesting easier. They can be pruned as a single leader and hung with string trellis, or plastic or metal wire mesh can be used for the vines to grow on.

For more information about trellising, refer to the General Management Strategies section of this volume.

Pruning: Pruning can be beneficial for cucumbers. Andrew Mefferd of *Growing for Market* suggests pruning the buds of larger fruited varieties to one fruit per node to increase size and consistency of fruit (May 2014). Only parthenocarpic cucumbers should be pruned to single leader. Traditional field cucumbers fruit on runner shoots, and if these are removed fruiting will not occur.



Cucumbers growing on cattle panels in a high tunnel

ECONOMICS

Cucumbers usually yield anywhere from 5 to 30 pounds per plant. Market prices vary, but can range from a low of around \$0.75 to \$2.00 per pound. Enterprise budgets for cucumbers developed by the University of Minnesota, show that cucumbers that have a moderate yield and receive a moderate price can still be profitable when crop grown in high tunnels. Cucumbers are frequently a part of a mixed use high tunnel, rather than being grown as a monoculture within an entire tunnel. The management numbers on this budget are based upon information gathered by C and C High Tunnels and Iowa State.

CROP ENTERPRISE BUDGET FOR CUCUMBERS

Category	Task	Materials				Hired Labor			Owner Labor			Total Cost	\$/sq ft.		
		Unit	Qty	Price	Total	Hours	Rate	Total	Hours	Rate	Total				
Preparation	Soil Test	each	1	\$ 10.00	\$ 10.00		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 10.00	\$ 0.01		
	Fertilizer (Compost)	yards	6	\$ 5.00	\$ 30.00	3	\$ 10.85	\$ 32.55		\$ 14.34	\$ -	\$ 62.55	\$ 0.03		
	Tilling				\$ -		\$ 10.85	\$ -	1	\$ 14.34	\$ 14.34	\$ 14.34	\$ 0.01		
	Lay Beds				\$ -	3	\$ 10.85	\$ 32.55		\$ 14.34	\$ -	\$ 32.55	\$ 0.02		
	Plastic Mulch	feet	400	\$ 0.03	\$ 13.12		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 13.12	\$ 0.01		
	Drip Tape	feet	400	\$ 0.03	\$ 10.76		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 10.76	\$ 0.01		
Seeding/Transplants	Seeds		1	\$ 30.00	\$ 30.00		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 30.00	\$ 0.02		
	Media		2	\$ 15.00	\$ 30.00		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 30.00	\$ 0.02		
	Equipment (pots)		1	\$ 20.00	\$ 20.00		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 20.00	\$ 0.01		
	Transplants				\$ -	2	\$ 10.85	\$ 21.70		\$ 14.34	\$ -	\$ 21.70	\$ 0.01		
Production	Planting				\$ -	3	\$ 10.85	\$ 32.55		\$ 14.34	\$ -	\$ 32.55	\$ 0.02		
	Stringing		1	\$ 50.00	\$ 50.00	12	\$ 10.85	\$ 130.20		\$ 14.34	\$ -	\$ 180.20	\$ 0.09		
	Weeding				\$ -	4	\$ 10.85	\$ 43.40		\$ 14.34	\$ -	\$ 43.40	\$ 0.02		
	Irrigation (setup and Maintenance)				\$ -	4	\$ 10.85	\$ 43.40		\$ 14.34	\$ -	\$ 43.40	\$ 0.02		
	Fertigation	Fertilizer	1	\$ 37.00	\$ 37.00	2	\$ 10.85	\$ 21.70		\$ 14.34	\$ -	\$ 58.70	\$ 0.03		
	IPM (Scouting/Application)	Insecticide	1	\$ 119.00	\$ 119.00	10	\$ 10.85	\$ 108.50		\$ 14.34	\$ -	\$ 227.50	\$ 0.11		
Harvesting	Harvesting (6 weeks)				\$ -	24	\$ 10.85	\$ 260.40		\$ 14.34	\$ -	\$ 260.40	\$ 0.13		
Post Harvest	Washing/Grading/Packing (6 weeks)				\$ -	24	\$ 10.85	\$ 260.40		\$ 14.34	\$ -	\$ 260.40	\$ 0.13		
	Boxes and Other Supplies				\$ -	4	\$ 10.85	\$ 43.40		\$ 14.34	\$ -	\$ 43.40	\$ 0.02		
	Utilities/Storage				\$ -		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ -	\$ -		
Marketing	See Fixed Costs Spreadsheet		2	\$ 123.33	\$ 246.67							\$ 246.67	\$ 0.12		
Total Variable Costs											\$ 1,641.64	\$ 0.82			
Monthly Fixed Costs (2 months)											\$ 210.02	\$ 0.11			
Revenue											Unit	Qty	Price	Total	\$/sq ft.
Marketing Channels: farmers market, retail (Yield 6lbs per plant)											lbs	2160	\$ 1.50	\$ 3,240.00	\$ 1.62

7

Net Income \$ 1,388.34 \$ 0.69

BELL PEPPERS

Bell peppers are a heat-loving crop and weather conditions in a Kansas high tunnel in the summer are well-suited for their production. Since peppers are in the same family as tomatoes, they will not provide a valuable rotation crop. However, the warm soils that typically exist in high tunnels in Kansas can allow for a dramatically earlier crop as well as larger fruit size and higher marketability.

SUGGESTED VARIETIES

Vanguard, Chesapeake, Currier, Karisma, Red Knight (Kansas State University Variety Trials in 2014 and 2015) Sprinter, Sympathy, Moonset

MANAGEMENT

Peppers are a heat loving crop, and should be planted after the danger of frost. In high tunnels, they can be planted four to six weeks earlier than they would be planted outside. In most parts of Kansas, this would be early April to mid-April. Peppers are sensitive to cold temperatures, so care must be taken to manage them if the cold weather in the spring, and supplemental heat may be necessary. They are usually planted in a staggered pattern with two rows to a bed. The plants are spaced 12 to 18 inches apart, with rows space 15 inches apart. As plant spacing increases, the yield per plant and size of fruit increases, but overall yield for the tunnel will decrease.

Trellising: Pepper plants are not particularly strong. Support is sometimes needed in high tunnels where they can become quite large over a long growing season. They can be supported by using the stake-and-weave method or the string trellis method.

Pruning: Pruning can be done for peppers to help fruit development and yield, but may not be as important as with tomatoes. Andrew Mefferd recommends keeping pepper blossoms pruned to one per plant node to encourage adequate fruit size. Many growers do not prune peppers at all.



Peppers using the stake-and-weave method for support at Kansas State University Olathe Horticulture Research and Extension Center

ECONOMICS

Peppers have the potential to yield between three to ten pounds per plant and are typically sold somewhere between \$1.50 and \$4.00 per pound. The higher end price is for colored bells in a retail setting. Analyses conducted by the University of Minnesota indicate that if producers can achieve the mid-range or better in both production and price, peppers can be profitable when grown in high tunnels. The enterprise budget was compiled using information from Kansas growers, and Iowa State.

CROP ENTERPRISE BUDGET FOR BELL PEPPERS

Category	Task	Materials				Labor			Labor			Total Cost	\$/sq ft.
		Unit	Qty	Price	Total	Hours	Rate	Total	Hours	Rate	Total		
Preparation	Soil Test	each	1	\$ 10.00	\$ 10.00		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 10.00	\$ 0.01
	Fertilizer (Compost)	ton	6	\$ 5.00	\$ 30.00	3	\$ 10.85	\$ 32.55		\$ 14.34	\$ -	\$ 62.55	\$ 0.03
	Tilling				\$ -		\$ 10.85	\$ -	1	\$ 14.34	\$ 14.34	\$ 14.34	\$ 0.01
	Lay Beds				\$ -	3	\$ 10.85	\$ 32.55		\$ 14.34	\$ -	\$ 32.55	\$ 0.02
	Plastic Mulch	feet	400	\$ 0.03	\$ 13.12		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 13.12	\$ 0.01
	Drip Tape	feet	400	\$ 0.03	\$ 10.76		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 10.76	\$ 0.01
Plants	Transplants	each	512	\$ 0.27	\$ 138.24	0	\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 138.24	\$ 0.07
Production	Planting				\$ -	3	\$ 10.85	\$ 32.55		\$ 14.34	\$ -	\$ 32.55	\$ 0.02
	Staking		1	\$ 104.00	\$ 104.00	12	\$ 10.85	\$ 130.20		\$ 14.34	\$ -	\$ 234.20	\$ 0.12
	Weeding				\$ -	4	\$ 10.85	\$ 43.40		\$ 14.34	\$ -	\$ 43.40	\$ 0.02
	Irrigation (setup and Maintenance)				\$ -	4	\$ 10.85	\$ 43.40		\$ 14.34	\$ -	\$ 43.40	\$ 0.02
	Fertilizer/Fungicide (Drip)				\$ -		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ -	\$ -
	Fertigation	Fertilizer	1	\$ 37.00	\$ 37.00	2	\$ 10.85	\$ 21.70		\$ 14.34	\$ -	\$ 58.70	\$ 0.03
	IPM (Scouting/Application)	Insecticide	1	\$ 119.00	\$ 119.00	12	\$ 10.85	\$ 130.20		\$ 14.34	\$ -	\$ 249.20	\$ 0.12
Harvesting	Harvesting (12 weeks)				\$ -	48	\$ 10.85	\$ 520.80		\$ 14.34	\$ -	\$ 520.80	\$ 0.26
Post Harvest	Washing/Grading/Packing (12 weeks)				\$ -	48	\$ 10.85	\$ 520.80		\$ 14.34	\$ -	\$ 520.80	\$ 0.26
	Boxes and Other Supplies				\$ -	4	\$ 10.85	\$ 43.40		\$ 14.34	\$ -	\$ 43.40	\$ 0.02
	Utilities/Storage				\$ -		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ -	\$ -
Marketing	See Fixed Costs Spreadsheet		4	\$ 123.33	\$ 493.33							\$ 493.33	\$ 0.25
Total Variable Costs											\$ 2,521.34	\$ 0.88	
Monthly Fixed Costs (4 months)											\$ 420.04	\$ 0.15	

Revenue	Unit	Qty	Price	Unit	Total	\$/sq ft.
Marketing Channels: farmers market, retail (Yield 6lbs per plant)	lbs	3072	\$ 1.50	lbs	\$ 4,608.00	\$ 2.30

Net Income \$ 1,666.62 \$ 0.83

LEAFY GREENS

Greens can be harvested at two stages of growth and have different production methods. Greens can be densely sown and harvested at baby leaf stage, including baby leaf lettuce, or they can be spaced more widely and used to produce full grown bunching greens. Both are suited to production in high tunnels during cool weather and promote diversity at late and early season market stands. Baby leaf salad mix is a relatively fast, short season crop, and at times of optimal temperature, only 4-5 weeks from sowing to initial harvest. These hardy crops are well suited to late fall or early spring production in Kansas. Greens are frequently harvested at baby stage and sold by the pound but they can also be grown to maturity and bunched.

SUGGESTED VARIETIES

Baby Leaf Varieties

Lettuces: Red Saladbowl, Green Saladbowl, Parris Island

Brassicas: Arugula, Red Russian Kale, Mizuna, Tatsoi, Red Giant Mustard

Other: Sorrel, Claytonia, Bull's Blood beets

Pre-Mixed: All-star- Johnny's Selected Seeds

Bunching Leafy Greens

Swiss Chard: Bright Lights, Celebration

Kale: Red Russian, Toscano, And Winterbor

Collard Greens: Flash

Heading Crops

Chinese Cabbage: Rubicon, Bilko

Other Asian Greens: Tatsoi, Komatsuna, Mei Qing Choi



Leafy greens, C and C High Tunnels

MANAGEMENT

The optimum temperature range to promote growth for these crops is between 60-65°F. The seeds can germinate at soil temperatures as low as 45°F, but not above 75°F. If managed well, mixes can be planted (seeded heavily) in the fall for winter production of baby greens, and then later thinned and allowed to grow into larger greens for bunching greens in the late winter and spring. Greens can also be transplanted, although the increased production costs limit the already somewhat limited profit potential. Baby leaf production usually is densely planted, and plants for mature greens production are typically spaced eight to ten inches apart in the row, with rows spaced at the same interval.

Greens can be grown to harvest in the fall, or started in the fall in time for overwintering. To overwinter, greens should be grown to near marketable size prior to mid-November. The high tunnel acts as a refrigerator

for winter harvest and growth resumes in February as temperatures slowly begin to rise. Add an internal layer of row cover and suspend it over the plants. Even with this protection, heading greens and more mature leaves are more susceptible to frost damage than the smaller ones.

This can be challenging as some greens can grow quite tall when mature and it is important to not let row cover touch the plants. These crops are prone to white fly and aphid invasion. IPM monitoring should be in place weekly, if not every few days.

ECONOMICS

While yield depends on the varieties grown, baby leaf green production is generally expected to yield somewhere between 1/10-1/3 lb. per square foot. The market price also varies widely, from \$4.00/lb. on some wholesale markets to \$12/lb. in some direct retail settings. Water management and harvesting accounts for most of the labor required to grow the crop. The quick season minimizes the need for other labor and management. The budget below for baby leaf salad is based upon labor and management times from Kansas growers and yield information from Johnnys Selected Seeds.

Economic data on fully mature greens is somewhat limited but market demand for these kinds of products appears to be growing as consumers become more interested in their nutritional advantages. Larger scale producers have caught on to the demand for many of these crops, pushing market prices down. Kale, in particular, can be available at grocery stores for low prices, but some greens such as chard and collards, can sell for \$2.50 to \$3.00 a bunch at retail markets.

CROP ENTERPRISE BUDGET FOR LEAFY GREENS (SALAD MIXES)

Category	Task	Materials				Hired Labor			Owner Labor			Total Cost	\$/sq ft.
		Unit	Qty	Price	Total	Hours	Rate	Total	Hours	Rate	Total		
Preparation	Fertilizer	Yards	6	\$ 5.00	\$ 30.00	3	\$ 10.85	\$ 32.55		\$ 14.34	\$ -	\$ 62.55	\$ 0.03
	Row Cover	Sq Foot	2000	\$ 0.03	\$ 60.00		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 60.00	\$ 0.03
	Hoops	each	75	\$ 0.40	\$ 30.00		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 30.00	\$ 0.02
	Tilling				\$ -		\$ 10.85	\$ -	1	\$ 14.34	\$ 14.34	\$ 14.34	\$ 0.01
	Lay Beds				\$ -	1	\$ 10.85	\$ 10.85		\$ 14.34	\$ -	\$ 10.85	\$ 0.01
	Seeds	lb	1	\$ 141.00	\$ 141.00		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 141.00	\$ 0.07
	Drip Irrigation	feet	1300	\$ 0.03	\$ 34.97	2	\$ 10.85	\$ 21.70		\$ 14.34	\$ -	\$ 56.67	\$ 0.03
Production	Planting				\$ -	1	\$ 10.85	\$ 10.85		\$ 14.34	\$ -	\$ 10.85	\$ 0.01
	Weeding				\$ -	3	\$ 10.85	\$ 32.55		\$ 14.34	\$ -	\$ 32.55	\$ 0.02
	IPM	Insecticide	1	\$ 25.00	\$ 25.00	4	\$ 10.85	\$ 43.40		\$ 14.34	\$ -	\$ 68.40	\$ 0.03
	Venting				\$ -	5	\$ 10.85	\$ 54.25		\$ 14.34	\$ -	\$ 54.25	\$ 0.03
	Other- Ladybugs		1	\$ 37.50	\$ 37.50		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 37.50	\$ 0.02
Harvesting	Harvesting and washing				\$ -	40	\$ 10.85	\$ 434.00		\$ 14.34	\$ -	\$ 434.00	\$ 0.22
	End of season clean up				\$ -	2	\$ 10.85	\$ 21.70		\$ 14.34	\$ -	\$ 21.70	\$ 0.01
Marketing	See Fixed Costs Spreadsheet		2	\$ 123.33	\$ 246.67							\$ 246.67	\$ 0.12
Total Variable Costs											\$ 1,281.33	\$ 0.64	
Monthly Fixed Costs (2 months)											\$ 210.02	\$ 0.11	

Revenue	Unit	Qty	Price	Total	\$/sq ft.
Marketing Channels: retail, farmer's market	lbs	600	\$ 8.00	\$ 4,800.00	\$ 2.40

Net Income \$ 3,308.65 \$ 1.65

ROOTS - BEET/CARROT/TURNIP/RADISH

Roots crops can be successfully grown in high tunnels, and many growers use them to add diversity to their production. Beets, turnips and radishes are frost tolerant and add flavor to late and early production. Carrots are somewhat different than the other crops in that the roots are less susceptible to cold damage because they are underground. They may be grown to maturity and essentially stored through the winter, available whenever the grower chooses to dig them. Other root crops might suffer damage and become spongy during exceptionally cold spells.

SUGGESTED VARIETIES

Radishes: Rover, Easter Egg, D'avignon

Beets: Red Ace, Boldor, Chioggia

Salad Turnips: Hakurei, Scarlett Queen

Carrots: Napoli, Sugar Snax

MANAGEMENT

Most root crops do best in light textured, deep, loose soil. Raised beds are well suited for root vegetables. They are usually direct seeded, using an Earthway seeder or another similar type of planter. They can be transplanted, but this is not common.

Close row spacing is important to ensure maximum yield out of a tunnel and minimize weeding time. For most root crops, this is usually in rows six to twelve inches apart. Radishes can be planted on the narrow end of that range, and beets and turnips generally require the wider part of that range. Carrots can be planted even more densely and Eliot Coleman recommends twelve rows for a 30" wide growing bed. Carrots require a relatively long period to germinate and need consistent soil moisture during that time.

One major pest concern regarding root crops in high tunnels is damage by rodents. Trapping is the only recommended solution.



Carrots, along with spinach, lettuce and other cool crops grown at Spoon Creek Organic Farm, Gardner, Kansas

ECONOMICS

While there has not been much research on the profitability of root crops in high tunnels, it is probably safe to say that they are decidedly less profitable on a per square foot basis than many other options. There is still a place for growing such crops to fill market niches, and market tables early in the spring or late in the fall. Prices vary depending on the type of crop. Turnips and radishes are usually at the bottom end, \$1.00 to \$2.00 a bunch and beets and carrots are at the higher end, roughly \$2.00 to 3.00 a bunch. Radishes are a particularly quick crop, and can be well suited to short intervals in the tunnel. If market demand is high, they can be profitable. The pricing and management numbers in the following crop enterprise budget are derived from Kansas growers, and the yield potential of beets is derived from trials at the University of Minnesota.

CROP ENTERPRISE BUDGET FOR BEETS

Category	Task	Materials			Hired Labor			Owner Labor			Total Cost	\$/sq ft.		
		Unit	Qty	Price	Total	Hours	Rate	Total	Hours	Rate			Total	
Preparation	Fertilizer	Yards	6	\$ 5.00	\$ 30.00	3	\$ 10.85	\$ 32.55		\$ 14.34	\$ -	\$ 62.55	\$ 0.03	
	Tilling				\$ -		\$ 10.85	\$ -	1	\$ 14.34	\$ 14.34	\$ 14.34	\$ 0.01	
	Lay Beds				\$ -		\$ 10.85	\$ -	1	\$ 14.34	\$ 14.34	\$ 14.34	\$ 0.01	
	Seeds		20,000	1	\$ 61.00	\$ 61.00		\$ 10.85	\$ -		\$ 14.34	\$ -	\$ 61.00	\$ 0.03
	Drip Irrigation	feet	400	\$ 0.03	\$ 10.76	2	\$ 10.85	\$ 21.70		\$ 14.34	\$ -	\$ 32.46	\$ 0.02	
Production	Planting				\$ -	1	\$ 10.85	\$ 10.85		\$ 14.34	\$ -	\$ 10.85	\$ 0.01	
	Weeding				\$ -	6	\$ 10.85	\$ 65.10		\$ 14.34	\$ -	\$ 65.10	\$ 0.03	
	IPM	Insecticide	1	\$ 25.00	\$ 25.00	4	\$ 10.85	\$ 43.40		\$ 14.34	\$ -	\$ 68.40	\$ 0.03	
Harvesting	Harvesting and washing				\$ -	30	\$ 10.85	\$ 325.50		\$ 14.34	\$ -	\$ 325.50	\$ 0.16	
	End of season clean up				\$ -	2	\$ 10.85	\$ 21.70		\$ 14.34	\$ -	\$ 21.70	\$ 0.01	
Marketing	See Fixed Costs Spreadsheet		2	\$123.33	\$ 246.67							\$ 246.67	\$ 0.12	
Total Variable Costs											\$ 922.91	\$ 0.46		
Monthly Fixed Costs (2 months)											\$ 210.02	\$ 0.11		

Revenue	Unit	Qty	Price	Total	\$/sq ft.
Marketing Channels: farmers market, retail	lbs	1920	\$ 2.00	\$ 3,840.00	\$ 1.92

Yield Based upon University of Minnesota High Tunnel Trials

Net Income \$ 2,707.07 \$ 1.35



Photo taken at Gieringer's Orchard, Edgerton Kansas

APPENDIX

GENERAL HIGH TUNNEL INFORMATION

- *Growing Under Cover, A Guide to Polyunnel Options for Kansas Growers:* Kansas Rural Center, kansasruralcenter.org/our-publications/
- Management Practices of Growers Using High Tunnels in the Central Great Plains of the United States. Sharon J.B. Knewtson, Edward E. Cary, M.B. Kirkham, Hort Technology, June 2010 20(3).
- HighTunnel.org website: hightunnels.org
- Midwest Vegetable Production Guide for Commercial Growers: ag.purdue.edu/btny/midwest-vegetable-guide/Pages/default.aspx
- Institute of Agriculture and Trade Policy Manual: iatp.org/files/2015_04_02_SeasonExtension_PH_0.pdf
- SARE Information: sare.org/Learning-Center/Topic-Rooms/Topic-Briefs/High-Tunnels-and-Other-Season-Extension-Techniques
- University of Minnesota High Tunnel Manual: hightunnels.cfans.umn.edu/minnesota-high-tunnel-production-manual/
- University of Vermont Manual: uvm.edu/~susagctr/Documents/HighTunnels.pdf
- University of Missouri Manual: extension.missouri.edu/p/M200

HIGH TUNNEL ECONOMICS

- Growing Organic Heirloom Tomatoes in the Field and High Tunnels in North Carolina: Comparative Economic Analysis. Olha Sydorovych, Cary L. Rivard, Suzanne O'Connell, Chris D. Harlow, Mary M. Peet, and Frank J. Louws. HortTechnology, April 2013, 23 (2).
- Iowa State Crop Enterprise Budgets: store.extension.iastate.edu/Product/Vegetable-Production-Budgets-for-a-High-Tunnel
- Iowa State Ag Decisionmaker Tool: Tool for projecting high tunnel enterprise budgets. extension.iastate.edu/agdm/crops/xls/a1-23hightunnelbudget.xlsx
- University of Kentucky Fruit and Vegetable Enterprise Budgets: uky.edu/Ag/CCD/vegbudgets13.html
- University of Vermont Economic Analysis: hort.vt.edu/ghvegetables/documents/Economics/Reference%20Other/HoopHouseHighTunnelProfitability_HT22_215-223.full.pdf

HIGH TUNNEL ECONOMICS (CON'T)

- A recordkeeping guide from North Carolina: carolinafarmstewards.org/record-keeping

MANAGEMENT HELP

- Winter Production: Eliot Coleman. *Winter Harvest Handbook*. Chelsea Green, 2009.
- IPM Resources:
 - uvm.edu/~entlab/Greenhouse%20IPM/GreenhouseGuide.html
 - sare.org/Learning-Center/Fact-Sheets/Sustainable-Pest-Management-in-Greenhouses-and-High-Tunnels?utm_source=New+Research+on+Biological+Pest+Control+in+Unheated+High+Tunnels&utm_campaign=Season+Extension+Factsheet&utm_medium=email
 - ca.uky.edu/agcomm/pubs/ID/ID235/ID235.pdf
- Aphid Control: http://rvpadmin.cce.cornell.edu/uploads/doc_197.pdf
- Pruning: Mefferd, Andrew. 2014. *Pruning Crops for Health and Yield*, Growing for Market. 23:5, 1.
- Grafting
 - HighTunnels.org resource website: hightunnels.org/resources-tomato-grafting
 - Vegetable grafting informational website: vegetablegrafting.org.

CROP INFORMATION

- Tomatoes
 - hightunnels.cfans.umn.edu/files/2012/11/21-Econ-Marketing.pdf
 - cru.cahe.wsu.edu/CEPublications/FS090E/FS090E.pdf
 - hightunnels.cals.cornell.edu/economics/sample-budgets-spreadsheets/
- Lettuce
 - Summer Production of Lettuce, and Microclimate in High Tunnel and Open Field Plots in Kansas. Zhao Xin and Edward Carey. HortTechnology, January-March 2009, 19(1).
 - High Tunnel Lettuce in Utah. extension.usu.edu/htm/publications/file=12499
 - 2011 Cost of Producing Head Lettuce in High Tunnels in Western Washington. cru.cahe.wsu.edu/CEPublications/FS092E/FS092E.pdf
- Cucumbers
 - Cornell Cucumber Best Management Practices rvpadmin.cce.cornell.edu/uploads/doc_342.pdf
- Peppers
 - K-State Variety Trials: hightunnels.org/wp-content/uploads/2015-KSU-Bell-Pepper-Variety-Trial-Report.pdf
 - Utah State High Tunnel Pepper Guide: extension.usu.edu/files/publications/publication/Horticulture_HighTunnels_2012-01pr.pdf
 - Pruning Peppers: Mefferd, Andrew. 2015. Pruning Greenhouse Peppers. Growing for Market. 24:3, 11.



Since 1979, the Kansas Rural Center has worked to strengthen small and family farms and their rural communities. We have provided a vision and a voice for those who see alternatives for our agricultural future, and help and resources for those who want to implement them.

We envision a future of thriving family farms, revitalized communities, a clean environment, a healthy local and regional food system, and viable livelihoods for farmers, including opportunities for the next generation who will grow our food.

OUR MISSION:

To promote the long-term health of the land and its people through research, education and advocacy that advance an economically viable, ecologically sound, and socially just food and farming system.

FOR MORE INFORMATION:

For more information or make a donation, please visit kansasruralcenter.org, or contact KRC directly at: info@kansasruralcenter.org | 866.579.5469
4021 SW 10th Street #337, Topeka, Kansas 66604

Guide designed by Kimberly Oxley, Research Extension Associate, Kansas State University