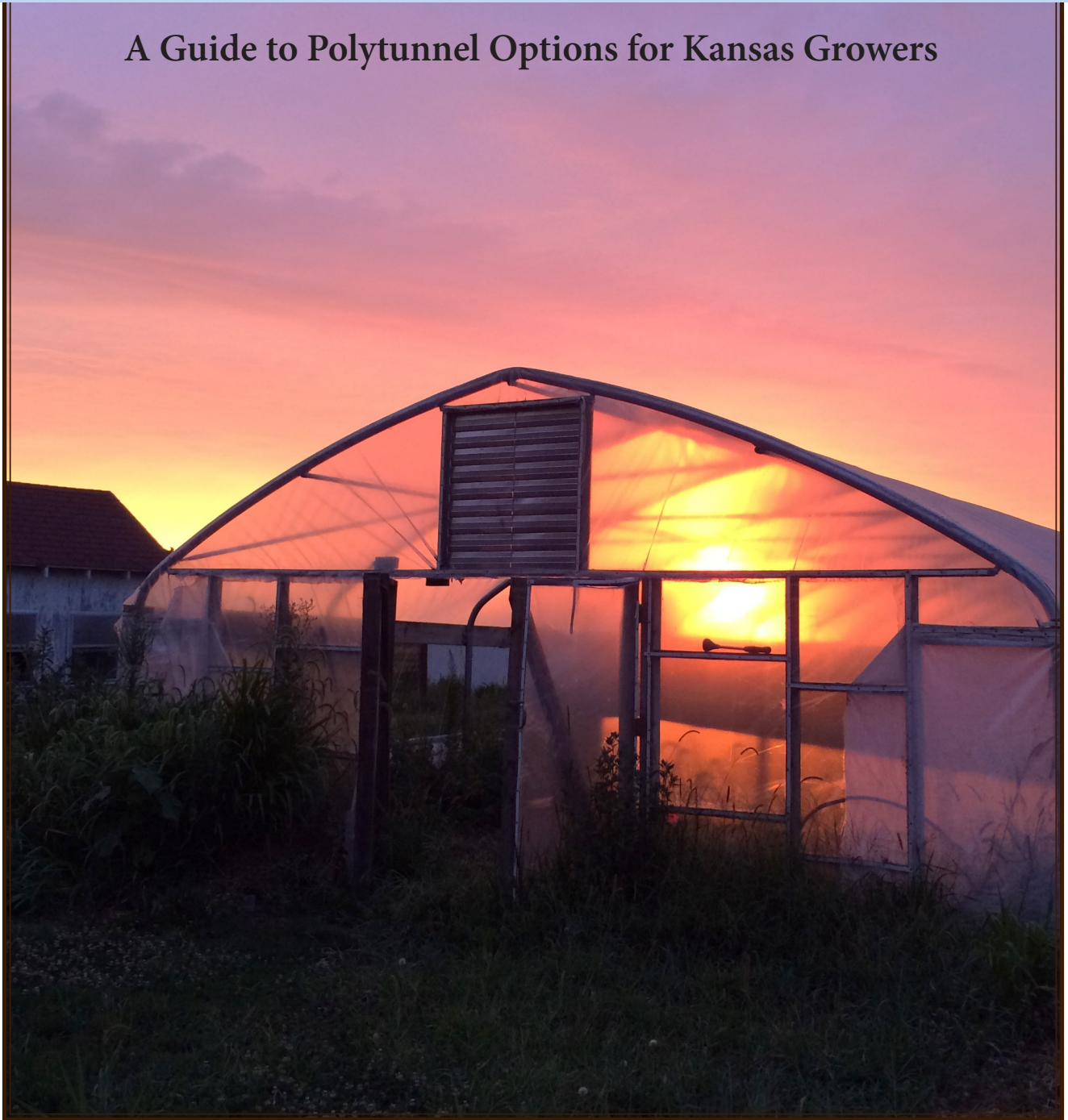


Growing Under Cover

A Guide to Polytunnel Options for Kansas Growers



KRC
KANSAS RURAL CENTER



Growing Under Cover

A Guide to Polyunnel Options for Kansas Growers

A Kansas Rural Center publication
prepared by Dan Phelps

*"I think that the more research one does before investing in a tunnel the better. I feel my investment has not been fully utilized. The tunnel can become a burden when not properly managed. I think scrupulous guidance would be helpful. Asking the difficult questions would have given me a more realistic look at what it means to own and operate a specialty crop operation with a tunnel."**

*All italicized quotes in this guide come from experienced Kansas growers who responded to KRC's 2014 High Tunnel Survey.

Growing Under Cover was produced as part of KRC's Tunnel to Table Program.
Cover photo courtesy of The Red Tractor Farm (www.theredtractorfarm.com).

Funding for *Growing Under Cover* & KRC's Tunnel to Table program was provided by:



KRC Tunnel to Table program team:

Julie Mettenburg, KRC Executive Director – Program Director
Cole Cottin, KRC Program Coordinator – Program Manager
Joanna Voigt, KRC Communications Coordinator – Editor
Dan Phelps, MAD Farm – Lead Researcher and Writer
Kim Scherman – Graphic Designer

Suggested citation: Phelps, Dan, November 2014. *Growing Under Cover: A Guide to Polyunnel Options for Kansas Growers*, a Kansas Rural Center publication, Topeka, KS.
URL: <http://kansasruralcenter.org/growing-under-cover>.

Copyright © 2014

Guide designed by Kim Scherman (kascherman@gmail.com, (785) 218-9488).

Table of Contents

Polyunnel Options: A Comparative Chart - 1

Polyunnel Terminology - 3

Types of Polyunnels 3

Anatomy of a High Tunnel 3

High Tunnel Benefits and Challenges - 4

Benefits of High Tunnel Production 4

Challenges and Potential Solutions 5

Still Interested? 9

High Tunnel Considerations - 10

Purchasing a High Tunnel 10

Constructing a High Tunnel 12

Maintaining a High Tunnel 15

Planting Strategies for High Tunnels 16

Low Tunnel Basics - 17

Polyunnel Resource List - 19

Introduction to *Growing Under Cover*

Polyunnels, such as high or low tunnels, offer growers innovative tools to extend the growing season, help reduce risk, and increase yields, while mitigating extreme and “normal” Kansas weather conditions across all seasons. However, plastic-covered tunnels are no silver-bullet solution. They require significant financial investment, can be labor intensive to manage, and may be damaged or destroyed by extreme weather such as high winds, heavy snow, or hail.

The following guide offers practical information and resources to assist Kansas growers in avoiding common mistakes and tunnel disaster, in order to maximize their return on investment. *Growing Under Cover*, written by Dan Phelps, researcher & educator for KRC’s specialty crop programs, reflects input from more than 60 experienced Kansas high tunnel growers who responded to the Kansas Rural Center’s High Tunnel Survey in 2014.

Polytunnel Options: A Comparative Chart

| | High Tunnel, Kit (stationary) | High Tunnel, Homemade (stationary) | Movable High Tunnel | Multibay High Tunnel | Low Tunnel: plastic cover & metal hoops | Low Tunnel: row cover & wire hoops | Caterpillar Tunnel |
|------------------|---|---|--|---|---|---|--|
| S I Z E | 12'-30' wide X 24'-192' long 30' X 96' is a common commercial size | On smaller side of high tunnel dimensions, typically (12' wide Quick Hoop Benders available at Johnny's Select Seeds) | 30' X 96' max 30' X 48' is a common size Whereas a stationary 30' X 48' structure covers 1,440 square feet, a movable tunnel of the same size (moved three times annually) covers 4,320 square feet – just not all at once. | Half acre minimum purchase (Haygrove) | 4'-6' wide (4' covers one bed, 6' can cover two 2.5' beds with 1' paths) ≤50' length recommended for high wind regions, but length is customizable | 2'-4' wide (width easier to adjust than metal hoops) ≤50' length recommended for high wind regions, but length is customizable | Smaller than high tunnels. Custom built, so size varies. (12' wide Quick Hoop Benders available at Johnny's Select Seeds) |
| C O S T | \$2 to \$3 per square foot for basics / up to \$6 per square foot for a higher quality tunnel | Depends on materials used (~\$1.50 per square foot for materials if using Johnny's Quick Hoops plan costs.) | -\$2.50 to \$4 per square foot for skid system kit -\$3 to \$4.50 per square foot for V-trak system kit (compared to \$2 to \$3 range for stationary high tunnel kits (left)) | \$0.75 to \$1.25 per square foot (not including labor) | \$0.25 to \$0.75 per square foot (not including labor) | ≥\$0.10 per square foot (not including labor) | \$0.50 to \$1.50 per square foot (PVC hoops are much cheaper, but won't last nearly as long as metal) |
| C R O P S | Any crop grown in the field can grow in a high tunnel, although it is important to grow high-value crops & crops that benefit most in protected growing space in order to justify the infrastructure cost. -Warm season crops: The most common is tomatoes. Cucumbers & peppers also common. -Cool season crops include a variety of greens and root crops. Salad mix, baby greens, spinach, and herbs are reported to be the highest value crops. -Small fruits (ex: raspberries, blackberries, & strawberries) and -Cut flowers are also profitable and benefit greatly from high tunnels. | Same as stationary high tunnels, but with these advantages: -No seasonal conflict. -Soil health benefits from occasional exposure to rain -Many crops benefit from being outdoors during certain periods of growth. (Examples: Cool season crops established in tunnels in the late winter/early spring appreciate cooler outdoor temperatures in the early summer. Fall crops benefit from being established in cooler soil outdoors, when the summer temperatures in tunnels may prevent germination.) | Best suited crops include: -Warm season annuals (fruits, vegetables, & flowers) -Perennials tolerant of winter conditions Most common crops grown include: -Tomatoes -Small fruits (rasp-/black-/blue-/straw-berries) -Fruit trees (especially cherries) | Plastic-covered low tunnels are best suited for cool season crops, extending the season into the winter and overwintering some crops. Hardy greens are more successful, such as spinach, kale, collards, & some Asian greens. Can also help establish any warm season crop, protecting them from late frosts & increasing the average temp. Plastic removed once temps. stabilize. | Plastic-covered low tunnels are best suited for cool season crops, extending the season into the winter and overwintering some crops. Hardy greens are more successful, such as spinach, kale, collards, & some Asian greens. Can also help establish any warm season crop, protecting them from late frosts & increasing the average temp. Plastic removed once temps. stabilize. | Row cover is appropriate for any crop. -Offers a temporary way to protect crops from cold temperatures or frost -Effective at increasing plant growth by increasing average temperature | Same as stationary high tunnels. |

Growing Under Cover: A Guide to Polytunnel Options for Kansas Growers

| High Tunnel, Kit | High Tunnel, Homemade | Movable High Tunnel | Multibay High Tunnel | Low Tunnel: plastic cover | Low Tunnel: row cover | Caterpillar Tunnel |
|---|--|--|--|--|---|---|
| <p>B E N E F I T S</p> <ul style="list-style-type: none"> -Season extension -Climate control -Increased yields -Increased income potential -High value / square foot -Pest & disease management <i>(compared to field)</i> | <ul style="list-style-type: none"> -Can be cheaper, depending on materials & longevity -Highly customizable to growers needs <i>(compared to high tunnel kits)</i> | <ul style="list-style-type: none"> -No seasonal conflict -Maximizes space -Increased crop rotation: <ul style="list-style-type: none"> *decrease pest & disease pressure *decrease fertility & salinity issues <i>(compared to stationary high tunnels)</i> | <ul style="list-style-type: none"> -Low cost per square foot -Covers much larger area -Can conform to slopes and contours of site -More mechanization/larger scale production possible because production systems are closer to field production <i>(compared to high tunnels)</i> | <ul style="list-style-type: none"> -Low cost -Easy to construct -Five to 15 degrees frost protection <i>(increased temps. when used with row cover)</i> -Wind, heavy rain, and hail protection for young plants | <ul style="list-style-type: none"> -Low cost -Easy to construct -Two to 6 degrees frost protection <i>(2 layers of 1.5 oz. row cover advised)</i> -Wind, heavy rain, and hail protection for young plants -Ventilation not required | <ul style="list-style-type: none"> -Low cost alternative to high tunnels -Easy to construct -Easy to move -Conform to slopes, curves, & contours -Good entry point to season extension with less financial investment -Can walk inside unlike low tunnels |
| <p>C H A L L E N G E S</p> <ul style="list-style-type: none"> -Climate (heat, cold, wind, snow, hail) -Production (irrigation, crop rotation, fertility, salinity, pest & disease) -Labor requirements -High up-front cost -Learning curve <i>(compared to field)</i> | <ul style="list-style-type: none"> -Can be more vulnerable to wind and snow damage unless engineered properly -Harder to moderate temperature in smaller structures | <ul style="list-style-type: none"> -Increased cost (extra bracing, anchoring, & endwall design) -Learning curve <i>(ex: more planning required)</i> <i>(compared to stationary high tunnels)</i> | <ul style="list-style-type: none"> -Three season structures -Plastic must be removed in winter -Wind damage is a concern, as bracing is minimal -Minimum \$20,000 to purchase, due to 1/2 acre minimum purchase (Haygrove) | <ul style="list-style-type: none"> -Wind is one of the biggest challenges -Ventilation is necessary -Labor intensive <i>(ex: ventilation)</i> -Cannot physically enter the structure (unlike high tunnels) -Crops may be exposed to adverse weather conditions during harvest or other maintenance, when plastic is removed | <ul style="list-style-type: none"> -Wind -Row cover has less light transmission than plastic -Row cover has a shorter lifespan than plastic (lasts ~1-3 seasons) -Cannot physically enter the structure -Crops may be exposed to adverse weather | <ul style="list-style-type: none"> -Difficult to maneuver inside due to low roof -Temperatures harder to moderate than high tunnels (due to size) -Ventilation is more labor intensive than high tunnels -More prone to wind and snow damage than high tunnels |

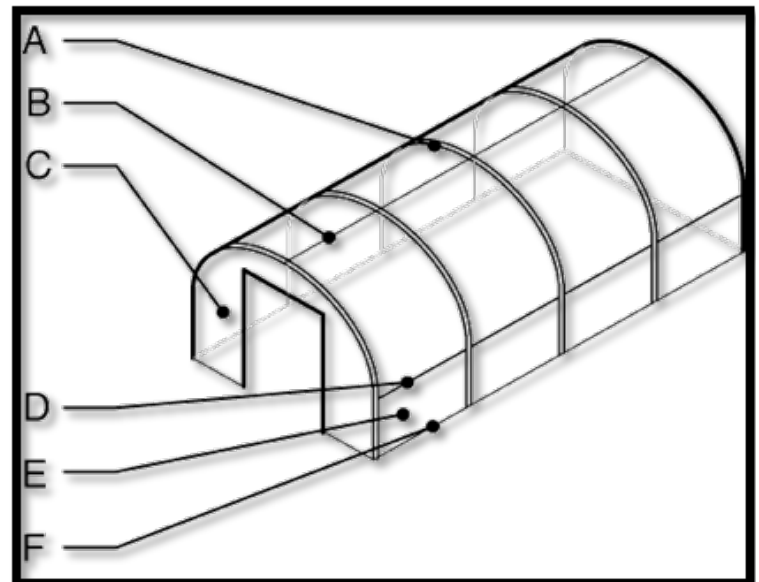
Polytunnel Terminology

Types of Polytunnels

- **High Tunnel** – a strict definition of a high tunnel does not exist, and the terminology may change depending on the structure's use. Page 4 describes high tunnels in detail.
- **Hoophouse** – a term used interchangeably with “High Tunnel”.
- **Single-bay / French Tunnel** – a high tunnel with just one bay (as shown below).
- **Quonset Tunnel** – a high tunnel design whose arc is basically a half circle.
- **Gable Tunnel** – a high tunnel design whose frame rises diagonally from the sidewalls to an A-frame peak.
- **Gothic Tunnel** – a hybrid of Quonset and Gable tunnels, with rounded arcs and a peaked roof.
- **Movable/Mobile Tunnel** – a single-bay high tunnel that can be easily moved (see pages 8 to 9).
- **Multi-bay/ Gutter-connected/ Spanish Tunnel/ Haygrove** – a high tunnel with multiple bays that are gutter connected, these structures can cover many acres. These are three season structures, the plastic is removed in the winter as they cannot withstand snow loads. Vulnerable to high wind.
- **Caterpillar Tunnel** – a hybrid between a high tunnel and low tunnel. They are high enough at the peak to walk through, but they are temporary/ seasonal structures that are easily constructed with materials available at your local hardware store. Unlike high tunnels and similar to low tunnels, the plastic is not attached to the structure. Instead, it is weighted down on the ground and ropes crisscross over the structure. Vulnerable to wind and snow.
- **Hoop Coop** – fixed or movable tunnels used for overwintering/ pasturing animals.
- **Homemade High Tunnel** – discussed briefly on page 10.
- **Low Tunnel** – discussed on pages 17 to 18.
- **Cold Frame** – a box with a transparent top, often glass, built close to the ground. These are smaller structures, commonly used for season extension in home gardens.

Anatomy of a High Tunnel

- A. Rib, Hoop, Arch, Bow
- B. Purlin, Ridgepole
- C. Endwall
- D. Hip Board
- E. Sidewall
- F. Baseboard



Anatomy of a High Tunnel Image and Text provided by hightunnels.org

High Tunnel Benefits and Challenges

What is a High Tunnel?

High tunnel and hoop house are interchangeable terms. A high tunnel is basically a framed structure that is covered with plastic. Frames are typically steel hoops and supports, but PVC can be used (PVC has a short life expectancy and damages plastic film). A single layer of 6-mil. greenhouse grade plastic is common, but many growers utilize a second layer of plastic, inflating the air between the two layers with a small fan. Basic high tunnels don't have electricity or supplemental heat, but are manually vented and passively heated. High tunnels are classified as temporary structures, making them difficult to insure, but exempting them from building codes and taxation. Most tunnels are stationary, but the benefits of a movable tunnel often justify the price increase. Crops are generally planted directly into the soil and irrigated with drip tape. More complex (and expensive) high tunnels utilize greenhouse technologies, such as exhaust and circulation fans, thermostatically controlled ventilation, heaters, and fertigation (fertilizers fed through irrigation) systems.

Benefits of High Tunnel Production

High tunnels are increasingly popular on diversified farms across the country and around the world. And for good reason, they can be an incredible tool to enhance crop protection, quality, and yield. They can dramatically extend the growing season, along with the income generating season, thus increasing the economic viability of specialty crop operations overall.

Season extension: Increased temperature and cold protection are the most significant benefits. A high tunnel with two layers of plastic or high tunnel/low tunnel combination is comparable to moving south two climate zones (Topeka to Dallas), offering an average of 20 degrees of temperature increase. Tunnels don't just provide frost and cold protection at night; daytime temperatures are often 30-50 degrees warmer on a sunny day, rapidly increasing plant growth. For example, tomatoes start producing 4-6 weeks earlier and can keep producing well past first frost. Cold hardy crops can be harvested throughout the winter, although new growth stops between for about a month before and after Winter Solstice. Overwintered crops begin growing again once daylight increases, allowing for early spring harvests, often times before spring crops are even planted in the field.

Climatic control: Protection from extreme weather events, such as high winds, heavy rain, hail, snow, and even drought. Protection from normal weather, such as consistently high winds and harsh heat. The ability to work/harvest on rainy days. The soil is workable, even during wet outdoor conditions common in early spring.

Increased yields: Longer growing season, faster growth, higher productivity, higher quality, and higher marketable yield.

Increased Income: Price premium for "out-of-season" crops; less competition (lower supply=higher demand); ability to gross significantly more per square foot (/ more per acre) due to intensive

management (vertical growth and/or double/triple cropping); year-round income potential; ability to spread labor and income throughout the year; increased capacity to retain employees year-round.

Less pest, disease, and weed pressure: (Exceptions exist. See *Challenges and Potential Solutions* below.) Most diseases are minimized, due to less moisture on foliage; less pest pressure, especially larger pests that are easily excluded; reduction in pesticides and ability to contain biological controls (introduced beneficial insects, such as lady bugs and praying mantises); and less weed seed germination due to precision irrigation; closer crop spacing; use of plastic mulch or landscape fabric; and a decrease in wind-blown seeds.

Challenges and Potential Solutions

“High tunnel production is not as easy, profitable, or beneficial as you think unless you really crunch your financial figures. In Kansas, high tunnels are not the perfect answer. Without the proper preparations, knowledge of construction, and general knowledge of production and marketing, you will more than likely miss your annual projections or miss making a meaningful return off of your investment.”

There’s no point avoiding the reality that, for some, tunnels may be costly, difficult to manage, and vulnerable to extreme weather – they don’t work for everyone. Below is a list of potential challenges, as well as a number of solutions Kansas growers can employ to address those challenges.

Climate: One of the biggest benefits of high tunnel production also presents one of the biggest challenges: controlling the climate.

- **Heat/Ventilation:** Kansas high tunnel growers reported that heat is more challenging than cold to control or moderate. During the fluctuating weather of spring and fall (sunny days, cold nights) sidewalls are rolled up during the day and back down at night. Failure to ventilate on a 60 degree, sunny day can result in indoor temperatures over 100 degrees. During the summer, structures are left fully opened, sidewalls up and doors opened. If the tunnel is not in a high wind area the endwall plastic can be removed (or at least undone at the top). Larger structures make ventilation in the center of the tunnel difficult, leading to issues with disease and poor growth. For this reason, many growers prefer 48’ or 72’ long tunnels over 96’. Where summers are hot (Kansas!), additional measures should be taken to ensure that crops don’t overheat. Shade cloth and rooftop or peak vents are effective tools. White wash (diluted latex paint) is an alternative to shade cloth. Also, fans increase air circulation and misters decrease the temperature.
- **Cold:** Some growers do provide frost sensitive crops (tomatoes) with a portable propane heater to ensure survival on uncommonly cold evenings, but many growers who have done the math have concluded that regularly heating the entire structure isn’t profitable. Some growers provide heat to the root zone by running hot water through buried pipes, rather than heating the whole structure. The latter approach is very effective, as seeds and transplants react to the soil temperature more than the air temperature. When growing cool season crops into the winter, additional protection should be provided.

A second layer of plastic or plastic covered low tunnels can more than double the cold protection of a high tunnel. Row cover also provides additional protection, but should be a thicker mil. and/or double layered. Plastic containing IR (infrared) additives reduce nighttime heat loss by as much as 35%.

- **Hail:** One grower reported losing his plastic three times in his first season. A double layer of plastic decreases hail damage, as does thicker plastic (8-12 mil.) & poly woven greenhouse fabric/cloth. (See “High Tunnel Plastic Lifespan” in *Maintaining a High Tunnel* below.)

Thirty percent of surveyed Kansas tunnel growers reported losing a structure to wind, snow, or ice.

“I lost a brand new tunnel.”

“Losing a tunnel is devastating. Not only do you lose the thousands of dollars invested in the structure, but, if there are crops in the tunnel, you’ll potentially lose thousands more in lost sales, perhaps at a time when the tunnel was your only source of income.”

“We spent hours out there, brushing off 12 inches of snow.”

- **Snow/Ice:** (See the “Wind” sections below in *High Tunnel Benefits and Challenges* and in *Constructing a High Tunnel*, for more structural recommendations.) It is recommended to sweep snow/ice off of the structure as it accumulates. Heating the structure during a snowstorm helps diminish snow accumulation.
- **Wind:** In high wind regions (Kansas!), it is recommended to set at least the end posts (the posts that the endwalls are attached to) in concrete, as these take the brunt of the load. Setting every other post in concrete is common practice. The Noble Foundation suggests putting a bolt through or slightly denting the portion of pipe that will sit in the concrete in order to prevent slippage. Note: setting posts in concrete may change the classification to a permanent structure (check local codes). Where concrete is not an option (as with movable tunnels or where local codes prohibit it), anchors are recommended.

Other recommendations for structural integrity are: To help increase the structure’s ability to withstand high wind and heavy snow loads, try 4’ bow spacing, thicker gauge steel (12 or 14 gauge [smaller number=thicker]), steel framed endwalls and doors, interior bracing/trusses, and additional purlins. A double layer of plastic decreases wind damage, as does poly woven greenhouse fabric/cloth. Windbreaks significantly decrease the likelihood of wind damage, but natural windbreaks take years to establish if not already present.

Learning curve: Growing in a high tunnel simply requires a different set of skills, knowledge, management, tools, and equipment than field production. Fertility, irrigation (drip), pest management, cultivars (parthenocarpic, grafted), and spacing (including trellising) are often different from techniques used in the field. The *Polytunnel Resource List* at the end of this guide offers tools to help.

Labor requirements: Managing a tunnel requires intensive and vigilant attention.

“It’s like adding livestock to your vegetable operation. It’s just a whole ‘nother set of responsibilities that takes you out of the field.” • “I could not use tunnel at all for the first couple years because I was working off farm at the time. It was too hot if I left it closed all day, and too cold if I opened it because I didn’t get home until 9 p.m.” • “Monitor the buildings especially in the spring and early fall. Buildings have to be opened and closed, sometimes in very short notice (storms). I work off farm and have to monitor the weather and ask a helper to get the buildings opened/closed if weather threatens or it warms up enough to vent.” • “Work inside a tunnel is very labor intensive.” • “Avoid being in tunnels in high heat! The early-morning sun hit the tunnel and spiked the temp - I was alone and fainted.”

- **Timeliness:** Timely opening (morning) and closing (night) of the structure is necessary in the spring and fall, making it difficult if you have an off-farm job or leave for the weekend. Structures may need to be closed at a moment’s notice if high winds develop.
- **Time for growing:** Tunnel production often requires more hand labor and general attention to detail. It is estimated that managing a standard size high tunnel takes at least 10 hours a week, significantly more during certain periods (ex: planting), or for inexperienced growers.
- **Time for structural maintenance:** Ongoing structural maintenance requirements include ensuring bolts and screws are tight, patching holes in plastic, replacing plastic, replacing rotten lumber, and repairing doors, endwalls, and sidewalls.
- **Time in the “off season”:** In addition, it may sound appealing to vegetable farmers to have year-round income, but growing and harvesting in the winter can be downright unpleasant if you’re not prepared for it. Typically, farms have wash stations built outdoors or in unheated structures – but washing kale and turnips in near freezing water hurts! Indoor/ heated wash stations can really help. Spinach, the quintessential winter crop, requires hours of crouching to harvest and can be difficult for people with knee or back problems.
- **Time in the heat:** In summer, tunnels get hot! On harvest days many outdoor crops (esp. greens) require early harvest, before it heats up. By the time you get to harvesting tomatoes in the tunnel it might be more than 95 degrees in there. Shade cloth, ventilation, and working during cooler hours reduces risk.

Financial: Polytunnel structures are vulnerable to extreme weather events and are difficult and expensive to insure, making them a risky investment. Although high tunnels generally pay for themselves after a few seasons, the upfront costs may be difficult to finance. NRCS EQIP grant has helped fund many of the high tunnels in Kansas. Check their website for application deadlines.

Pest & Disease Management: Most, but not all, pest and disease pressure is decreased through use of polytunnels. Certain pests (mites, thrips, and aphids) and diseases (powdery mildew) thrive in the high tunnel and can quickly get out of control. Crop rotation decreases the likelihood of outbreaks. Monitoring crops is important. Insect screen along high tunnel sidewalls & doorways can exclude larger insects & mammals from entering. Closing tunnels at night (or using insect screen) can prevent the presence of tomato horn worms because the moths only lay eggs at night, according to the March 2014 issue of *Growing for Market*.

Pollination: Pollinators are able to enter the structure when it is fully opened and planting pollinator habitat, including flowering cover crops, around the tunnel can increase their presence. When insect screen is used pollinators are excluded along with pests. Larger structures can utilize bee hives for pollination. Tomatoes are self-fertile, requiring wind or a good shaking, although the presence of pollinators does increase yields significantly. Some fruiting vegetables, such as cucumbers, are bred for greenhouse production and do not require pollination (this is known as parthenocarpy).

Irrigation: Since no rainfall hits the soil inside a tunnel, all irrigation must be applied. Access to water is essential. Initial installation costs may be significant (getting water to the site), in addition to the irrigation system inside the structure (drip tape, header pipe, and connectors). Irrigation may be difficult in the winter, due to frozen pipes or hoses located outside of the tunnel. Consider placing a water hydrant/spigot inside of the tunnel.

Fertility and Salinity Buildup: Rapid growth, closer spacing, higher yields, and double/triple cropping requires significant nutrient application. It is difficult to break the profitable production cycle to grow cover crops, but the rapid growth inside the tunnel and the numerous benefits of cover cropping should not be overlooked. Compost and manure (and irrigation) can cause mineral accumulation, such as salinity buildup. Removing the plastic temporarily and allowing rain to leach out salinity helps.

“Growers routinely underestimate the fertility requirements of hoop houses. The ability to grow more crops and the expense of building hoop houses causes growers to beat their soil to death. Unless you remove the plastic or move the hoop house, you will have severe problems in 10 years, if not sooner.”

Sacrificing productive crops for next season’s planting: (See “Seasonal Conflict” on page 16.) High tunnel growers aiming for extended season production frequently face the difficult decision of whether or not to remove a crop that is still producing a significant yield and generating income in order to plant a crop that will not be harvestable for several months.

Movable tunnels can be the perfect solution. Growers that utilize movable tunnels are able keep the established crop, while simultaneously establishing the next crop.

For example: In March a tunnel can be in full production with hardy greens and root crops that were either overwintered or established in the late winter. These crops may be the only income generation the grower has at the time, as field crops may not be mature yet, or they have yet to be planted because it’s been a wet spring or a particularly cold winter. The established crops in the high tunnel could continue to be harvested week after week for several more months. Without a movable tunnel these crops would have to be pulled in order to make room for your tomatoes, cucumbers, or other warm season crops. The grower doesn’t want to plant these crops any later, because they want to get an early season price premium. But, if they have a movable tunnel they can simply move the tunnel from the greens and root crop to a new plot where they will establish your summer crops.

Movable tunnels (continued): The cool season crops can be protected with row cover and will continue to yield in the outdoor conditions - even with nights dipping into the high 20's and low 30's. They will actually appreciate the cooler outdoor weather compared to a high tunnel, which will start heating up above 80 degrees, which will damage cool season crops.

And then, in September/October when tomatoes are still producing the grower can establish their cool season crops outdoors with the protection of row cover. When the tomatoes finally succumb to a hard freeze they can move the tunnel over the cool season crops, which will be ready to harvest at that point, and will continue producing into winter months.

Crop rotation is maximized, decreasing potential diseases, and cover crops are much easier to incorporate into this system. The exposed soil gets the benefit of rainfall which helps leach mineral accumulation out of the root zone. Exposure to the winter elements also decreases the ability of pests to overwinter in movable tunnel sites.

Movable tunnels are a more significant investment than fixed tunnels, but this added expense may easily be justified through an increase in production of income-generating yields.

“Take an honest look at your operation! 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. You will just be a poor producer with a high tunnel. I’ve seen far too many tunnels in disrepair or sitting unused or abused when people find out it still takes work to make them succeed. They are not a silver bullet. One other bit of advice would be: plan on spending more than you originally budgeted to get your house totally finished like you want. Lots of incidentals with these things. When we started tunnels were cheap. To put up a quality tunnel now is expensive.”

Still interested?

Great! There are plenty of strategies for success for the driven grower. Check out the *Polytunnel Resource List* below, and continue reading this guide to get Kansas-specific advice on:

- Purchasing a high tunnel
- Constructing a high tunnel
- Maintaining a high tunnel
- Crops you might grow in a high tunnel
- Low tunnels as an alternative or addition to high tunnel production

High Tunnel Considerations

“Build the best house you can afford. Then make it stronger. Eventually catastrophe will come, this is Kansas!”

Purchasing a High Tunnel

Structural Integrity: To view options for enhancing structural integrity, see the “Wind” sections above in *High Tunnel Benefits and Challenges* and below in *Constructing a High Tunnel*.

Structural Options:

Size: The height of a high tunnel is determined by the width of the structure and the height of the sidewalls. Dimensions can vary from 12’-30’ wide and 24’-192’ long. 30’x96’ is a common sized commercial high tunnel. The 96’ length may seem unusual, but the dimensions are adjusted so that the 100’ plastic will be longer by several feet on each end, so that it can be secured to the structure. Larger structures tend to have more stable temperatures due to more thermal mass, storing more heat and releasing it at a slower rate. Taller structures are less likely to overheat, allowing warm air to rise and escape through ridge or peak vents. Smaller structures heat up faster and facilitate better ventilation. One Kansas high tunnel grower recommended keeping the structure less than 50’ long for this reason.

Cost: Prices vary, as does quality. Price tags don’t include the cost of construction (your time and hired labor) or the cost of endwalls and doors, or any upgrades. Larger structures tend to lower the total cost per square foot, as endwalls/ doors cost roughly the same amount despite the size of the structure and a tunnel that is twice as big shouldn’t take twice as long to construct. The price per square foot has risen dramatically over the years, along with the cost of steel and plastic, and will likely continue to increase. Many high tunnel publications say that price per square foot is \$1.50-\$2.50. The current price (2014) is about \$3 per square foot, and as much as \$6 square foot once other expenses and upgrades are factored in.

“Approx. \$6,300 each after final completion of end walls (custom made). The structures themselves cost roughly \$5,400 each.” • “22’ x 96’=\$3000 (\$1.42 sq ft) in 2004, 28’ x 96’=\$5000 (\$1.86 sq ft) in 2009, 30’ x 96’=\$8000 (\$2.78 sq ft) in 2014.” • “Don’t build cheap, lightweight, or flimsy. If possible have some wind protection. Build bigger than you think that you want, they are never big enough!” • “Zimmerman purchased through NRCS program: Out of pocket final ~\$5,000. Re-salvaged trampoline : ~\$100.”

Homemade High Tunnels: There are many variations possible for homemade high tunnels. Some use the same materials and design as manufactured high tunnel, others use cheap or recycled materials like PVC or cattle panels. There are many plans available online for homemade high tunnels. Note that many of these come from regions that don’t experience high winds or heavy snow. Johnny’s Selected Seeds sells a pipe bender that turns 1 3/8” chain link fence top rail into 12’ wide, 7’ tall hoops (taller with ground posts) that is built to withstand wind and snow. A 12’ x 54’ homemade high tunnel (comparable to a manufactured high tunnel) costs less than \$1,000 (\$1.50 per square foot) to construct using Johnny’s plans.

Structural Options (continued): See *Anatomy of a High Tunnel* on page 3 for a visual.

Hoop/bow options: Quonset (round) are cheaper, simpler, and easier to construct, while Gothic and Gable (peaked roof) are structurally stronger (15% more load capacity), shed snow better, tend to have higher sidewalls, and allow more light penetration during low light season. Gothic and Gable tunnels require additional trusses and braces, resulting in a higher cost.

Pipe strength: For larger structures and movable tunnels use thicker gauge steel and larger diameter pipe. 2 3/8" diameter, 14 gauge steel is one of the stronger hoops on the market, but some manufacturers offer 12 gauge. Remember that 14 gauge steel is stronger than 16 gauge.

Hoop spacing: For larger structures or where snow and wind are a concern 4' spacing is recommended over 6'. Where wider hoop spacing is used, trusses may be used to increase the structures strength.

Purlins: Purlins, along with hip boards, provide lengthwise support for the structure. Basic structures usually have one lengthwise purlin at the peak of the structure, but up to three purlins are common and recommended to increase support

Trusses & Bracing: Trusses provide the structure with crosswise support and increase the structure's ability to bear the weight of trellised crops or hanging baskets. Cross braces maintain the structure's vertical alignment. The endwall and second hoop on each side are the most important to secure, as they take the brunt of the force during strong winds and heavy snow loads.

Sidewalls: Options include roll-up or drop-down. Roll-up are simpler and cheaper. Drop-down sides protect young plants from harsh winds, making them much more desirable. A gearbox makes raising and lowering sidewalls much easier than the hand crank method. Programmable thermostats that automatically roll up and drop down sidewalls are available for several thousand dollars. Polypropylene straps help secure sidewalls and prevent damage to the plastic.

Windbreak curtain: Windbreak curtains are recommended for high wind regions. They protect the plastic and prevent wind from blowing through the ends of the sidewalls. A windbreak curtain is located behind the sidewalls and runs from the endwall hoop to the next hoop. They are permanent, remaining in place when the sidewalls are raised or dropped.

Endwalls: Doors and/or tractor access are located on the endwalls. Endwalls brace the structure and should be built strong. Wood is the most common material used for endwalls, as it is cheap and easy to construct. Steel offers the most structural security (Galvanized steel square tubing, C-Purlin, Angle Iron). Endwalls are often covered with the same 6-mil. greenhouse plastic as the rest of the structure. Other options include: woven poly fabric, polycarbonate, twinwall polycarbonate. Twinwall polycarbonate has the best heat retention and transmits the most light, but is by far the most expensive option. North-facing endwalls don't require light penetration and can be built with material such as plywood or rigid foam insulation. Removable endwalls increase accessibility (tractor) and ventilation, but additional support is required.

Doors: Doors should allow for easy access, including tools, carts, wheelbarrows, rototillers, and/or tractors. There are many pre-hung commercial door options available and may be worth the investment. Many growers who design their own doors end up doing so several times before getting a design that functions effectively. Doors that open into the structure are convenient in snowy regions. Track mounted sliding doors are easy to use and maintain. Scissor doors or zipper doors are not recommended for high wind areas.

Baseboards: 1-2"x6"x10' treated lumber is commonly used for baseboard, bolted to the ground post. Organic certification prohibits treated lumber, unless treated with an arsenic-free preservative such as borates (food grade borates, sodium tetraborate, sodium octaborate, Boracare). Alternatives to treated lumber include plastic board, hard woods, or rot resistant woods (Cedar).

Hipboards: The height of the hip board determines the height of the sidewalls. Plastic stretched over hoops is attached to hipboards.

Anchors: Anchors are necessary for movable tunnels and can benefit stationary structures, as an alternative to concrete. Many high tunnel manufacturers offer anchoring options.

Constructing a High Tunnel

*"Build strong enough in the first place.
You cannot do it on the cheap. Trusses are essential."*

Site Selection: Keys to Success

Direction (East-west or North-south): It is recommended that growers well above 40 degrees latitude orient their tunnels east to west and well below 40 degrees latitude orient their tunnel north to south. Growers throughout Kansas can orient their tunnel either E-W or N-S (I-70 [Hays, Salina, Topeka, Kansas City] is roughly 39 degrees N). For spring, fall, and especially winter production an east-west orientation allows for the low angle of the sun to enter the structure better. For summer production, especially with tall (trellised) crops, a north-south orientation allows for maximizes sunlight exposure to the crop's canopy and reduces shading from neighboring crops. A north-south orientation warms up more quickly in the morning, benefitting crops on cold nights, but requires more timely ventilation (also see: "Wind", "Ventilation", and "Shadows" below).

Wind: Tunnels that are oriented perpendicular to prevailing winds often suffer the most damage from strong winds. Orienting your structure so that the endwalls are facing the prevailing wind ensures that smallest surface area is exposed to damaging winds (steel framed endwalls are recommended if orienting parallel to wind in high wind areas). Strong winds can be the biggest challenge for Kansas high tunnel growers. Locating the structure near a windbreak is one of the best ways to protect the tunnel from damaging winds. Windbreaks located too close to the structure will shade the structure in spring, fall, and winter. Windbreaks located too far from the structure may be ineffective.

Ventilation: It is often recommended that the structure is oriented perpendicular to prevailing winds to ensure adequate ventilation, but these structures often suffer the most damage from strong winds. Placing the tunnel on a slight slope (less than 5%) increases ventilation, as heat rises to the peak of the tunnel and a strategically placed peak vent allows the heat to escape.

Shadows: Avoid shadows by ensuring that nearby trees and buildings be located at a distance at least twice their height. If multiple high tunnels are oriented east to west they should be distanced 1 to 2 times the height of the structure (i.e. 10' tall structures should be spaced 10'-20' apart). This is not a concern for north-south tunnels, making north-south the preferred orientation of multi-bay tunnels and larger greenhouses, or if trying to fit multiple high tunnels into a tighter space.

Drainage: This is one of the most important considerations for site selection! Do not place a structure where drainage is a concern. A high tunnel sheds a lot of water and can create drainage and ponding issues where none previously existed (a 30' x 96' structure sheds 1,728 gallons of water for every inch of rain). Build a slightly elevated pad that extends several feet beyond the structure and slopes away from the sides to allow water to flow off of and away from the structure. Create a drainage ditch around the perimeter of the structure with outlets that run away from the structure.

Soil: Amend soil before building the structure. Add ample fertility, adjust pH, and amend soil structure. The high tunnel will likely be on this piece of ground for many years to come and preparing the soil when it is easily accessible is recommended.

Convenient access: Keep in mind that you will need to open and close the high tunnel multiple times a day and locate accordingly. Make sure that you can access the structure with a vehicle or tractor, even in muddy conditions. Locate with convenient access to your tool shed, wash station, pack station, walk-in cooler, or other structures that will be used in conjunction with the high tunnel. Ensure that your building site has access to water. Consider whether or not you need access to electricity, either for construction or management of the structure, such as an inflation fan.

Construction Time

In the 2014 Kansas Rural Center's High Tunnel Survey, the most common answer was more than 80 hours (with paid and volunteer labor factored in) - although more than half of respondents reported construction took them less than 60 hours total.

"The frame takes about 6 hours, but the ends take a lot more time."

"The frame goes up pretty quickly. It's the piles of small hardware (braces, joints, sidewall curtains, purlin braces, doors, etc.) that take forever."

"I started construction on August 22 and finished on November 7. I hired a friend to assist weekly for a total of 60 hours. I might have spent 90 hours of my time."

Construction Logistics

“What is most crucial is to make sure the structure is square/ level/ even when planning it out.”

- **Instructions:** High tunnel kits should come with detailed instructions on construction, although some growers report that the written instructions they have received are confusing or incomplete. There are many construction guides available online or through mail order. The Noble Foundation recently update their High Tunnel Hoop House Construction Manual (available online). Also, The Hoophouse Handbook from Growing for Market – to be updated fall 2014 - offers detailed instructions and advice to help with construction.
- **Trained help:** High tunnel distributors may have recommendations on companies experienced in high tunnel construction. Several Kansas High Tunnel Survey respondents recommended hiring professionals to level/grade the pad and create drainage channels. Hiring a skilled builder (or asking a skilled friend or neighbor) to set the ground posts in was also recommended. It is imperative that the four corner posts are square and level to ensure the rest of the structure comes together. If you don't remember Pythagorean Theorem ($A^2 + B^2 = C^2$) from high school geometry, you may wish to revisit it. Endwall and door construction is customized and also requires some level of building skills (and power tools).
- **Tools that help:** Power tools, such as drills and saws, are essential. Mechanized post drivers make the job go much faster. Extra hands are especially helpful for raising the hoops and pulling over the plastic. And don't attempt to construct a high tunnel without a square and level!

Securing Plastic After the High Tunnel is Constructed

Putting the plastic on the structure is one of the biggest construction challenges Kansas farmers face.

- **Avoid wind:** Finding a windless day in Kansas can be difficult, if not amusing, and coordinating several helpers' schedules around the wind's schedule is a common challenge. Please be assured: attempting to put the plastic on during a windy day is a mistake!
- **Choose a warm day:** Applying plastic on a warm, sunny day is strongly recommended, as the plastic expands when heated. If it is applied on a cold or cloudy day, it will loosen once it heats up. Loose plastic greatly increases the risk of damage.
- **Try these two methods:** 1) Plastic is most commonly attached to the structure with “wobble wire” inserted into “u-channel”. This is reported to be the most effective means of securing plastic, but also the more expensive method. 2) Alternatively, some choose to use two pieces of wood lath to secure the plastic. One is a permanent piece, attached to the top of the hip board before the plastic is on. After the plastic is pulled over, the other piece of wood lath is placed on top of the plastic and is placed just below and screwed in flush to the permanent piece of lath, so that the plastic goes over the top piece and under the bottom piece.

Maintaining a High Tunnel

Ongoing Maintenance Costs

The biggest ongoing maintenance costs is replacing the plastic (see below). Other maintenance costs include repairing sidewalls, endwalls, and doors, replacing rotted lumber (especially baseboards), repairing irrigation parts, and upgrading to more efficient systems or correcting inefficient systems.

“General repairs and maintenance are budgeted at 2% of the original cost of the structure per year (\$126 per structure per year for my structure).”

High Tunnel Plastic Lifespan

- **Expected lifespan of plastic:** Most plastic has a 4 to 6 year lifespan, but in Kansas it is often much shorter due to hail or wind damage. Be aware that many manufacturers offer a 4 year warranty on plastic, which only covers “manufacturer defects”, not damage from wind or hail.
- **Avoid plastic damage:** Plastic damage is most common where friction occurs. Minimize friction by ensuring that plastic is taught and secure from the get go (see “Securing the Plastic” above). Additional securing of the plastic can help reduce friction. Use greenhouse grade batten tape or commercial woven polypropylene restraining straps on sidewalls and over the hoops to keep plastic secured to the structure. Beware that some materials cause degradation to the plastic. Reinforce the plastic with greenhouse tape or other non-degradable tape anywhere it will come into contact with bolts, bows, or corners. Secure the purlin where it meets the endwall, as this is a common place where plastic is damaged.
- **Some plastics are stronger than others:** There are thicker mil. plastics available (6 mil. is the most common, but 8 or 12 mil. plastics exist), or you can look into poly woven greenhouse fabric/cloth or polycarbonate. These are much more expensive, but offer more protection and can have a much longer lifespan. Polycarbonate is a hard plastic that can be used for endwalls.
- **When to replace plastic, even if it’s not damaged:** If you are lucky enough to get the life expectancy out of the plastic, it is still recommended that it be replaced every 4 to 6 years. This is due to decreased light transmission over time, which negatively effects plant growth - especially when light is already minimal (winter, early spring, late fall).

“Due to storms & hail we replaced plastic 3 times in 2013.”

“One of them lasted 8 or 9 years and was shredded by hail last year.”

“They are side by side and the one to the east manages to get hit by straight line winds that removed the plastic, wiggle wire track, and hip boards ... The older plastic on the other one manages to stay on untouched.”

Planting Strategies for High Tunnels

The following reflects highlighted responses from the more than 60 seasoned farmers who responded to the Kansas Rural Center's statewide High Tunnel growers survey.

Most Common Crops Among Surveyed Kansas High Tunnel Growers:

(In order of popularity - not profitability, which varies per farm.)

- | | | |
|-------------|------------------------|--------------------------------------|
| 1. Tomato | 5. Salad Mix | 9. Herbs |
| 2. Spinach | 6. Kale/Collards/Chard | 10. A variety of cold tolerant crops |
| 3. Cucumber | 7. Beet/Carrot/Turnip | |
| 4. Pepper | 8. Head Lettuce | |

Intensive Cropping: 88% of those surveyed reported growing more than one crop per bed in a year, many grow three.

Crop Planning: *"We schedule plantings on each of the tunnels' 5 beds at the beginning of the year to ensure adequate weekly supply to markets. Beds are planted weekly, biweekly, or monthly based on historical yield/production/sales data compiled on farm to ensure the highest profitability and maximum efficiency within each structure."* • *"I try to let weather conditions dictate the crops. I focus on early/late production, so sometimes get 3 successive crops in one bed per season. Planning is necessary."* • *"We use rotational beds, cover crops and detailed records."*

Seasonal Conflict: *"Greens are still producing when tomatoes are ready to go in. Tomatoes take precedence."* • *"Slow process of learning, but crops must be removed to make room for coming season. Summer tomatoes must come out by late August to get winter crops established."* • *"The \$ per square foot potential wins out."* • *"Movable tunnels have really made this easier. Also having multiple tunnels makes this easier. Finally planting multiple plantings of a crop both inside and outside of the tunnel helps."* • *"I look at which crop (established or new) has the most need for the tunnel and the highest amount of revenue (accounting for fixed expenses involved), plus the market demand for each product (i.e. high demand for tomatoes in October, lower demand for fall crops). Based on these factors & use of long-term weather forecasting data, we determine when the best & most economically viable times are to change crops."*

Season Extension: Tunnels help 37% of surveyed tunnel farmers grow year round. Another 36% gain 4-8 weeks extra production on each end of the season. *"Tomatoes are a month earlier & a month later. Spinach can take you right through winter if established well before the darkest coldest days."* *Season extension is part of the benefit, but just general quality & yield is significantly higher for most crops."* • *"Depending on the crop, we can grow year round. Extension of tomatoes is approx. 6 weeks on average, leaf lettuce/greens is approx. 10 weeks but can be longer if marketed correctly. We plan on starting our 2014 high tunnel plantings at the beginning of February (six to eight weeks ahead of our outdoor planting schedule)."*

Tracking Income: Almost half of the respondents said they keep track of income. *"[We track] to learn how quickly the tunnel's cost has been recouped."* • *"A 20' X 54' high tunnel planted only to tomatoes (3-50' rows) produced over 2000 lbs of first quality graded tomatoes from Mother's Day to Thanksgiving. Generally all sold from between \$2-\$2.50 / lb all season (approx. \$4,500)."*

Low Tunnel Basics

What is a Low Tunnel?

Low tunnels are essentially miniature versions of high tunnels, usually two to four feet tall at their peak and four to six feet wide. Length varies, but less than 50 feet is recommended for windy areas. Unlike high tunnels, low tunnels are moved seasonally, lack much of the structural support offered by high tunnels, and have plastic weighted down to the ground or buried (rather than attached to the structure). They may be used within high tunnels (decreasing or negating the issue of wind), or on their own out in the field.

Low tunnels can provide a low-cost, cost-effective investment option for those seeking an entry point to polytunnel production or for those wishing to enhance their current polytunnel production capacity. Low tunnels offer an alternative form of crop protection and season extension that may work even better than a high tunnel for some growers and in certain situations.

As with high tunnels, appropriate crops for winter production in low tunnels include: spinach, kale, collards, chard, leeks, scallions, carrots, parsnips, cabbage, Asian greens, parsley and arugula. Many other crops may not survive the entire winter in a low tunnel, but they can be pushed well beyond the first frost, often all the way to the New Year and their season can begin much earlier than traditional planting.

Potential Benefits and Challenges of Low Tunnels

Low tunnels put to work the same simple technology as high tunnels, at a fraction of the cost. Whereas high tunnels cost two to three dollars per square foot, heavy duty low tunnels with ½” metal pipes and 6 mil. greenhouse-grade plastic cost just 30 to 60 cents per square foot. The cost drops to as little as five cents per square foot if metal wire and row cover (a breathable poly-spun fabric) are used instead.

Unlike high tunnels, these low cost structures can be disassembled, moved throughout the farm, and work with the contours of the land. Similar to high tunnels, plastic covered low tunnels provide crops with several degrees of cold protection at night, but due to their smaller stature low tunnels heat up rapidly on sunny days, even if outdoor temperatures remain low.

Low tunnels have their own unique set of challenges. Because you can't stand-up in low tunnels, you must partially remove the covering to access your crops which can make it difficult to harvest or weed in high wind, rain, snow, or sub-zero temperatures. Low tunnel construction and dismantling must be done annually and is labor intensive. Low tunnels are, of course, lighter, so Kansas farmers must take extra measures to ensure their low tunnel doesn't end up in the neighbor's tree line. According to Johnny's Selected Seeds, a company that sells low tunnel supplies and has done a lot to promote and advance the technology, growers in high wind areas need more than just sand bags to keep their low tunnel structures secure. Burying the edges is effective, but Johnny's also recommends putting in stakes on each side of the tunnel, offset, and crisscrossing rope over the length of the structure.

In Kansas's climate, low tunnels may remain covered from late October or early November through late February or early March. Similar to high tunnels, low tunnels need to be manually ventilated if temperatures reach 60 degrees, as they occasionally do in late fall and early spring.

Low Tunnel Options for Kansans

There are many options for low tunnels configurations. They may be constructed using standard metal hoops, galvanized metal wire (9 gauge wire is most common, but 3/16" round stock is alleged to bounce back after heavy snow loads melt), or PVC (not advisable, due to short lifespan and degradation to plastic covering). Several different cover-options exist, including shade cloth, different thicknesses of row cover, or different types of plastic than the standard greenhouse plastic found on high tunnels. As is explained below, each configuration offers its own unique benefits.

Shade cloth can be used without plastic on low tunnels, to extend the season of cool season crops into the warmer months. This can be especially effective when combined with misters set on timers (used to decrease the temperature through 'evaporative cooling').

Low tunnels covered with poly-spun row cover allow air and water to penetrate while providing several degrees of frost protection. Though row cover does not offer the daytime temperature increase that plastic covered low tunnels can provide, on sunny days it can be beneficial that no ventilation is required. Using thick row cover (1.5 oz.) and/or a double layer of row cover on low tunnels can help give warm season crops a jump start in the spring and can help extend the growing season past the first frost, perhaps as late as winter solstice (but not for overwintering most crops). Thick row cover also protects crops from the wind, though additional measures must be taken in high wind areas to keep the row cover attached. Note: The thicker the row cover or the more layers of row cover, the less light penetration. To offset this effect, growers can remove row cover on warm, sunny days to allow maximum light penetration.

Thinner row covers (0.5 oz.) offer little cold protection, but instead serve as physical barriers to insects - preventing pests like squash bugs and cucumber beetles from reaching the crop. However, many tunnel crops require pollination. In these cases, the row cover is removed for pollination once the plants start flowering, at which time the plants are established enough to deal with some pest pressure.

Perforated plastic provides about as much frost protection as row cover, but also provides much higher daytime temperatures - similar to those of greenhouse plastic. However, unlike greenhouse plastic, perforated plastic self-ventilates when temperatures reach a certain point and the slits in the plastic walls contract, allowing heat to escape.

Further Reading

One of the best resource for low tunnel production, and season extension in general, is Eliot Coleman's *The Winter Harvest Handbook*, as well as Coleman's other books. He has decades of experience and is largely responsible for the progression of this technology. Johnny's Selected Seeds sells many of the supplies required for low tunnels, including the Eliot Coleman designed pipe bender. For detailed information on the construction process and the necessary materials Johnny's Low Tunnel Bender Instruction Manual is available online at: http://www.johnnyseeds.com/assets/information/9377_9520_quickhoops-low-tunnel_benders_instruction-manual.pdf

Polytunnel Resource List

Recommended Educational Resources

Books:

- Hoophouse Handbook (Growing For Market)
- Winter Harvest Handbook & Four Season Harvest (Eliot Coleman)
- Walking to Spring (Paul and Alison Wiediger)
- How to Grow Food in Your Polytunnel All Year Round (Mark Gatter and Andy McKee)
- The Polytunnel Handbook (Mark Gatter and Andy McKee)

Publications:

- Growing for Market is a national magazine for market farmers. <http://www.growingformarket.com> / (800) 307-8949 / PO Box 3747, Lawrence KS 66046.

Online Manuals:

- Iowa High Tunnel Fruit and Vegetable Production Manual <http://www.leopold.iastate.edu/sites/default/files/pubs-and-papers/2010-01-iowa-high-tunnel-fruit-and-vegetable-production-manual.pdf>
- High Tunnels: Using Low Cost Technology to Increase Yields, Improve Quality and Extend the Season <http://www.uvm.edu/~susagctr/Documents/HighTunnels.pdf>
- Minnesota High Tunnel Production Manual For Commercial Growers <http://hightunnels.cfans.umn.edu/minnesota-high-tunnel-production-manual/>
- High Tunnel Hoop House Construction Manual <http://www.noble.org/Global/ag/horticulture/hoop-house-construction-guide/nf-ho-14-01.pdf>
- High Tunnel Production Manual, 2nd Edition. 2003. W. Lamont. Pennsylvania State University. <http://extension.psu.edu/plants/plasticulture/technologies/high-tunnels/high-tunnel-manual> (Mail order only \$25).
- Missouri High Tunnel Manual: A Guide to Making Produce Profitable and Accessible. <http://extension.missouri.edu/p/M200> (Mail order only \$30)

University and Extension Resources:

- Cornell <http://www.hort.cornell.edu/hightunnel/index.html>
- Michigan State <http://www.hoophouse.msu.edu/index.php?q=home>
- Penn State Center for Plasticulture <http://extension.psu.edu/plants/plasticulture/technologies/high-tunnels>
- Iowa State http://www.iowaproduce.org/pages/production/files/high_tunnel/iowa_tunnel_guide.pdf
- Kansas State <http://connect.ksre.ksu.edu/p92357183/?launcher=false&fcsContent=true&pbMode=normal>
- U. of Kentucky <http://www.uky.edu/Ag/CCD/introsheets/hightunneloverview.pdf>
- U. of Missouri - <http://extension.missouri.edu/p/M200>
- U. of Minnesota - <http://hightunnels.cfans.umn.edu/>
- U. of Maine - <http://umaine.edu/publications/1022e/>
- U. of Vermont - <http://www.uvm.edu/sustainableagriculture/Documents/HighTunnels.pdf>
- Washington State - <http://mtvernon.wsu.edu/hightunnels/Content/cropTunnels.html#lowtunnels>
- Rutgers - <http://njsustainingfarms.rutgers.edu/hightunnels.html>

Websites:

- Hightunnels.org (link to national high tunnel listserv)
- Extension.org:
http://www.extension.org/pages/18358/introduction-to-high-tunnels#.Uzx16_lDwTw
http://www.extension.org/pages/18369/construction-of-high-tunnels:-resources-for-organic-farmers#.Uzx0_PldWtw
- SARE: High Tunnel and Other Season Extension Techniques: <http://www.sare.org/Learning-Center/Topic-Rooms/High-Tunnels-and-Other-Season-Extension-Techniques>

Presentations:

- Jay Sleichter, Kansas High Tunnel Farmer: <http://highfarming.blogspot.com/p/conference-presentations.html>
- Dr. Cary Rivard, K-State Extension Vegetable & Fruit Crop Specialist: <http://old.kansasruralcenter.org/publications/OOOHoophousesRivard.pdf>

Videos:

- Kansas Center for Sustainable Agriculture and Alternative Crops series: <http://kansassustainableag.org/news>
- Five part series from Nebraska:
 - <http://www.youtube.com/watch?v=Q1w6G6Vaxs4>
 - http://www.youtube.com/watch?v=_J6OnAXfNlc
 - http://www.youtube.com/watch?v=8_KqUO_RCBs
 - <http://www.youtube.com/watch?v=lJE0Dd-ZEN0>
 - <http://www.youtube.com/watch?v=lJE0Dd-ZEN0>

Conferences:

- Kansas Rural Center Food and Farm Conference (Location varies)
- Great Plains Growers Conference (St. Joseph, MO)
- Many others across the U.S. – see list in KRC's *Finding Your Niche: A Marketing Guide for Kansas Farms* <http://kansasruralcenter.org/marketing-guide>

Polytunnel Supply Sources**Regional High Tunnel Sources**

- Four Season Tools - <http://www.smallfarmtools.com/>
9615 Grandview Road; Kansas City, MO 64137
(816) 444-7330 - info@smallfarmtools.com
- Zimmerman's High Tunnels and Greenhouses - <http://zimmermanshightunnels.com/>
16645 Ridgewood Rd; Versailles, Mo. 65084
(573) 378-4770 - Dan Healy, greenhousedan7@gmail.com
- Morgan County Seed - <http://www.morgancountyseeds.com/>
18761 Kelsay Road; Barnett, MO 65011-3009
(573) 378-2655 - Errol Ahlers, errolahlers@juno.com
- Hummert International - <http://www.hummert.com/>
1415 N.W. Moundview Drive; Topeka, KS 66618
(800) 798-2799 - email through website
- Stuppy Greenhouse - www.stuppy.com
North Kansas City, MO
(800) 733-5025 - greenhouse@stuppy.com

Examples of High Tunnel Construction Support

- Local Contractors/ Engineers (especially for endwalls and site lay-out)
- Contact L & M Roofing & Construction (Tipton, MO) - <http://landmroofingconstruction.com/>
573-378-8678 / 660-337-6879

Low Tunnel Sources

- Your local hardware store! (Should have access to get most parts, except pipe bender.)
- Johnny's Selected Seeds - <http://www.johnnyseeds.com/>
- Four Season Tools - <http://www.smallfarmtools.com/>
- Agriculture Solutions - <http://www.agriculturesolutions.com/>

Funding Opportunities

- NRCS EQIP Seasonal High Tunnel Initiative – National Resource Conservation Service (NRCS) provides financial and technical assistance to agricultural producers. The goal of the Environmental Quality Incentives Program (EQIP) High Tunnel Initiative is to assist producers to extend the growing season for high value crops in an environmentally safe manner. For more information visit: <http://www.nrcs.usda.gov/wps/portal/nrcs/main/ks/programs/financial/eqip/> or contact the Kansas' NRCS office at 785-823-4500. Every county has their own USDA Service Center with a District Conservationist that serves as a NRCS representative. For a list of Service Centers by county go to: <http://offices.sc.egov.usda.gov/locator/app?state=KS>
- Sustainable Agriculture Research and Education Program (SARE) offers an array of competitive grants for researchers, agricultural educators, students, farmers and ranchers throughout the United States. Grants are regionally administered. For more information, visit the North Central SARE website (<http://www.northcentralsare.org/>) or contact the Kansas State Coordinator, Kerri Ebert (Phone: 785.532.2976, Email: kebert@ksu.edu).



Growing Under Cover: A Guide to Polyunnel Options for Kansas Growers
was prepared for the Kansas Rural Center by: Dan Phelps of MAD Farm (KS).
Available electronically at <http://www.kansasruralcenter.org/growing-under-cover>.

The Kansas Rural Center is a non-profit that, since 1979, has worked to advance a sustainable farm and food system in Kansas that is ecologically sound, economically viable, and socially just. KRC conducts community-based research, education, and advocacy activities to benefit Kansans. We collaborate with Kansas farmers, communities, and leaders to learn from and understand their needs, co-design strategic responses, and connect and empower them with the information and resources they need to continue to advance Kansas's healthy farm and food future.

For more information or to make a donation, please visit kansasruralcenter.org,
or contact KRC directly at: info@kansasruralcenter.org / (866) 579-5469 /
4021 SW 10th Street #337, Topeka, KS 66044.