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Center for Crop Diversification System Profile
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High Tunnel Overview

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Introduction

High tunnels, also known as hoop houses, are relatively simple polyethylene-covered greenhouse-like structures built over ground beds. High tunnels can be used to extend the production season and marketing window of a wide variety of crops. They have been used in Kentucky to produce early season vegetables, cut flowers, brambles and strawberries. High tunnels can also make it possible to produce leafy greens and herbs during the winter. Shaded, well-vented high tunnels can be used to grow some cool-season crops later into early summer.

In addition to the potential for season extension and off-season production, high tunnels afford a number of other advantages.They provide protection from unfavorable weather conditions, including wind, hail, frost, and excessive rainfall. This can help improve the survival rate of perennial crops, as well as result in faster plant growth, higher yields, improved produce quality, fewer culls, and more marketable produce for many crops. Insect and disease problems are often less severe in a high tunnel; fewer pests can mean improved organic production potential. High tunnels also provide a sheltered environment for laborers during planting, production, and harvest operations.

Marketing and Market Outlook

High tunnels can allow producers to extend the time period over which cash flows are generated from produce crops. Maximum returns will be realized for exceptional quality crops harvested when the traditional open field production season has not yet begun or has ended. This extended harvest season, along with higher yields of quality produce, should provide high tunnel growers with a marketing advantage. Early crops attract consumers to a farm operation and may help retain those customers throughout the season. Demand can vary greatly according to a local area, so producers should identify what other high tunnel production is nearby. Simple marketing plans can help producers identify the nuances of their local markets and adjust planning and production accordingly.

Single-bay quonset high tunnel

High tunnel production is more expensive than open field production due to the costs involved in constructing and maintaining the structure. For high tunnels to be economically viable, growers need to be able to recoup this investment. One way to defray this cost is to demand premium prices for these out-of-season tunnel crops, especially if high quality and steady supply are maintained. High tunnels may make it possible for some growers to produce crops they would not otherwise be able to grow in open, unprotected field situations, thus providing additional revenue. Organic production within the tunnel is another means of adding further value to these crops and recouping the high tunnel investment.

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Direct markets such as on-farm retail markets, roadside stands, farmers markets, and community supported agriculture (CSA) may provide the greatest premiums to producers of early crops. High tunnels can also be a good fit for producers selling to local restaurants, especially restaurants willing to pay premium prices for early and late season, locally grown crops. Early and late season crops could also be marketed wholesale to groceries and through produce auctions.

Farmers market producers who extend their season into fall and winter, when many farmers markets are not open or have limited hours, could generate a subscription list and establish a pickup location or delivery service for those high tunnel crops. An e-mail distribution list and/or social media are great ways to notify customers of product availability, as well as the order deadline for the week. Orders can then be received via return e-mail or by phone.

Tunnel Construction

Types of Tunnels

Tunnel design, dimensions, and construction materials all have an impact on the structure's use and performance. Before building or purchasing any tunnel, it is important to plan ahead to make sure the selected design and size will meet the grower's future (as well as immediate) needs for the life of the tunnel. Well-constructed, properly maintained tunnels can last for 20 years.

Tunnels are often categorized by the shape of their roofs. The two main types are quonset and gothic.

Quonset tunnels have a rounded roof that generally extends from "ground to ground," giving the structure a semi-circular shape. Quonsets are among the simplest and least expensive tunnels to construct. The low tunnel height along the sidewalls, however, limits the types of crops that can be grown in that space. Alternately, the hooped roof may be set on straight sidewalls to increase the vertical growing space along the outer walls. The rounded roof of the quonset tunnel does not shed snow readily, making them more likely to suffer damage from a heavy snow load. Spacing the hoops at closer intervals and/or bracing the bows with cross braces are ways to strengthen the structure. Another alternative is to remove the plastic covering during the winter, at least when significant snowfall is expected. Tunnels constructed from PVC pipe are particularly vulnerable to collapse from snow. Quonset style tunnels may be either single bay or multi-bay. The Haygrove tunnel is an example of a multi-bay, three-season tunnel that can be used to cover larger acreages.

Multi-bay quonset (Haygrove) tunnel

Gothic style tunnels have a peaked roof and straight sidewalls. The steeper roof sheds snow and ice more readily than the rounded roof of a quonset tunnel. Additionally, condensing moisture within the tunnel tends to run down the sloping roof to the sides, rather than dripping on the plants below. The straight sides provide more usable growing space along the outer walls than the typical rounded quonset. In addition, the greater height of the gothic tunnel permits the production of taller crops. This height also helps increase air circulation, especially when vents are installed at the gable-ends. Gothic style tunnels are built only as single bay structures.

Gothic style high tunnel

Endwalls

Endwalls can vary considerably in their design. They may be framed with wood or metal, or they may simply have an unframed plastic curtain that can be rolled up or pulled back. Framed endwalls, which add strength and stability to the high tunnel, are constructed after the tunnel itself is assembled. Fixed endwalls may have just a single or double storm door/screen door built into one or both ends for worker access. Some framed endwalls have a large rectangular section hinged at the top so that the endwall can be opened. These may completely swing open or fold up accordion style. Others have sliding doors or removable panels. Tunnels in which a large portion of the endwall can be opened or removed not only have better ventilation, but also afford easier access for equipment. Gable end vents installed near the peak of gothic style tunnels offer additional air exchange. The choice of endwall design will depend largely on tunnel size, grower needs, construction costs, and personal preference.

Tunnel size

There are a number of factors that should be considered when deciding on the size of the high tunnel. Obviously, the tunnel should be tall enough for workers to walk into

comfortably. The amount of maximum vertical space required for the various crops that will be grown in the tunnel is another determining factor for tunnel height. Adequate square footage should be available for planting, producing, and harvesting the various crops, as well as for maneuvering small tractors or any other equipment that will be used in the tunnel. Typical tunnels are 9 to 15 feet tall, 15 to 30 feet wide, and 60 to 96 feet long.

Size will also affect the environment within the tunnel, especially heat retention and air movement. For example, while narrow tunnels are easier to ventilate than wider ones, narrow tunnels also experience more heat loss on cold nights. Long tunnels are more difficult to ventilate, especially if they are wide. Tall, wide houses typically retain heat in winter better than short, narrow tunnels.

Movable vs. Permanent

The high tunnel concept seems to suggest mobility; however, tunnels are often built in such a way that they are difficult to move without considerable effort. As a result, they often remain on the same site for a number of years before being moved to another location (semi-permanent) while others are never moved (permanent).

A LOW-COST MOVABLE TUNNEL

Typically, permanent/semi-permanent structures have in-ground posts, galvanized steel bows, and rot resistant wood baseboards. Endwalls can be constructed of steel or wood. When tunnels are not moved each year, the grower will need to implement a good crop rotation program. Tunnels that remain in the same location year after year, where either no rotation or a short rotation is practiced, can have high levels of soil pathogens and insect pests, leading to serious crop losses. Fertilizer salt build-up will become a problem unless the plastic covering is removed to allow precipitation to flush salts from the soil. Once in place, soil preparation in these tunnels each year can present a challenge. Hinged endwalls permit easier access for small equipment. When the endwalls are fixed, soil preparation will need to be accomplished by hand or with a small power tiller.

Movable tunnels may be built with PVC bows, which not only makes them lighter, but cheaper to construct. Only quonset style tunnels can be built from PVC. Tunnels built with steel bows but without in-ground posts are easier to move; however, tunnels that sit on top of the ground will be more vulnerable to wind damage unless they are well-anchored. Another way to make the tunnel more mobile is to build it on skids or runners. An important advantage to movable high tunnels is the ability to relocate them to a new site each growing season to facilitate crop rotation. The soil in movable tunnels is worked prior to erecting the structure.

University of Kentucky researchers are experimenting with a low-cost movable tunnel design that can be quickly disassembled and moved to a new site. The PVC bows are fitted over pieces of steel pipe that have been driven into the ground. Tunnels are constructed over already formed beds, making it possible to use traditional tractors and transplanters prior to constructing the tunnel.

Covering

One or two layers of greenhouse-grade polyethylene (4 to 6 mil) are used as the covering. Those covered with two sheets have an air layer in between, thus offering better insulation, and consequently, more cold protection. Two layers will require an inflation fan, which in turn requires access to electricity or installation of a solar system for power.Occasionally growers will insert Styrofoam blocks between the layers of plastic if they do not have electricity to their tunnels. While the second layer of plastic does offer greater heat retention, it also reduces light penetration into the tunnel. When using a single layer of plastic, low tunnels or floating row covers can be used within the high tunnel for additional cold protection.

The plastic film used to cover a high tunnel can be treated to reduce condensation dripping on plants. Additionally, an infrared re-radiate material (infrared blocker) added to the film reduces overnight heat loss. As the plastic ages, the amount of light transmitted through it will be reduced. The plastic covering should be replaced approximately every four to five years.

When a high tunnel is used for the summer production of cool-season crops, the frame is covered with shade cloth. The shade cloth, which is used either alone or on top of the polyethylene, reduces light intensity and air temperature within the tunnel. The combination of shade and irrigation keeps soils cooler, as well.

Trellising

Some crops grown in a high tunnel may require trellising. Unless the frame has been reinforced to support the

heavy load of fruit-laden plants, trellising to the tunnel roof is not advisable. An overhead bracing system can be used to suspend lines for plant support, or a separate trellis system can be constructed inside the high tunnel if needed.

Site selection and orientation

Tunnel location and orientation, in addition to the site soil conditions, are essential to production success. Site selection is more critical when the high tunnel is built to be a permanent structure; however, it is an important consideration even when constructing semi-permanent or movable tunnels.

Select a naturally fertile, well-drained site in full sun that is near a reliable water supply for irrigation. A relatively level surface is generally needed for the high tunnel frame. An exception is the multi-bay Haygrove tunnel, which does not require a level site. Avoid hilltops or other areas subject to high wind. Providing a windbreak can help reduce the threat of wind damage to the tunnel. On the other hand, the site should have good air flow for ventilation. Stay away from low sites that are poorly drained or likely to serve as frost pockets, as well as sites too close to wooded areas. Orienting the house perpendicular to the prevailing wind on the farm will help facilitate cross ventilation in the tunnel. For maximum sun exposure during the fall and winter, the tunnel should be oriented in an east-west direction. When constructing multiple tunnels, make sure that they do not shade one another.

Placing the tunnel on ground that is slightly higher than the surrounding area helps prevent water from flowing into the tunnel during heavy rains. Alternately, a shallow trench along the outside perimeter can keep water from entering the tunnel.

Tunnel Management

Temperature and ventilation

High tunnels are passively solar-heated, and nighttime low temperatures within a high tunnel can be a few degrees warmer than outside temperatures. Row covers used in conjunction with the high tunnel will provide additional cold and frost protection. Because row covers also block sunlight, they should not be left on for prolonged periods during the winter. Placing the row covers over hoops will help to keep tender leaves from freezing to the fabric. As an alternative, a heater can be used when unexpected drops in temperature occur. However, due to rising energy costs, the use of heaters should generally be limited to short durations. A grower who has received NRCS EQIP funds to purchase a high tunnel should check his/her state's NRCS High Tunnel System Conservation Practice Standard to make sure heaters are allowed. NRCS allows the permanent installation of heaters in Kentucky. Such additions should be included in the manufacturer's design and recommendations.

High tunnel temperatures and ventilation are manipulated by rolling up or down the sidewalls as needed. The sidewalls can be left down in early spring, but may need to be rolled up as daytime temperatures rise. However, once the warmer weather of summer arrives, the sidewalls should be left rolled up day and night. This is generally done manually; however, automatic systems are also available. Removing or opening the endwalls is another way to increase ventilation. During sunny days, temperatures in the tunnels can reach 30° F to 40° F higher than outside temperatures, necessitating that tunnels be adequately vented. Improperly ventilated tunnels will overheat quickly.

High tunnel with plastic rolled up

Because tunnels prevent natural rainfall from reaching plants, drip irrigation is essential. The irrigation system can also be used to provide fertilization during the season. Iowa State University has developed a system for catching, storing and reusing rainwater run-off for irrigation in a high tunnel. Although this system is best installed at the time of high tunnel construction, it can be added to an existing tunnel. To learn more, refer to the publication in Selected Resources below.

Pollination within the tunnel

Pollination may present a challenge for some plants grown in a high tunnel. Honeybees do not effectively pollinate crops in this production system since they require UV light to navigate and often become disoriented under the plastic covering. High tunnel growers may need supplemental bumblebee hives if they do not observe sufficient natural pollinator activity within the tunnel. Reportedly, mason bees and alfalfa leaf cutter bees may be used as a supplemental source of pollination.

Pollination of tunnel-produced tomatoes is not adversely affected as long as there is good air movement through the structure. If the tunnel sidewalls need to be kept down for extended periods of time, it may be necessary

to promote pollination by vibrating plants, by tapping the crop support system (i.e. stakes or cages), or by using a leaf blower.

Pest management
Diseases that plague field-grown crops are often less of a threat in high tunnels. However, because of the unique environment within tunnels, growers may encounter different diseases than in the field. Because the tunnel excludes rainfall, the foliage tends to stay dry, resulting in fewer disease problems due to those pathogens spread by rain splash or requiring leaf-wetness for infection. In contrast, powdery mildew and rust diseases, which require high humidity for infection but not leaf wetness, could become a problem in a tunnel environment.

Insect pests in tunnels differ as well. While the high tunnel presents a barrier to some insects, it is an ideal environment for others, particularly whiteflies and aphids. Mite infestations often become a more serious problem in a tunnel than in the open field due to the drier tunnel environment. Grasshopper feeding has been known to occur throughout the winter on crops such as greens since the ground within the tunnel does not freeze. Without natural predators, such as birds, to help keep insects in check, serious pest infestations may develop very quickly.

Due to the relatively high density of plants in tunnels, insects and diseases tend to spread rapidly. Frequent scouting to monitor populations is essential for keeping ahead of potential problems. Pesticides registered for open field production may not be registered for use in the enclosed space of the high tunnel.

Weed management prior to tunnel construction is important. When possible, avoid constructing the tunnel on sites with high noxious perennial weed populations. Other pre-plant strategies include tillage, crop rotations designed to reduce weed pressure, and weed suppression via cover or smother crops. Once the tunnel is built, plastic or organic mulch can be used to suppress weeds within rows and along tunnel edges. Rototillers and/or hand weeding is used for managing weeds within the tunnel.

Tunnels with covers left in place throughout the winter will experience increased rodent activity when these animals discover the warm, sheltering environment that the tunnel provides. Traps can help control rodent populations in the tunnel and bait stations outside the tunnel will also help. Occasionally rabbits and deer will also find their way inside a tunnel to feed on the crops when the sides or ends are left open.

Harvest
The protection offered by the tunnel means that crops can be harvested regardless of the weather. Not only are harvesters protected from the elements, but they also do not have to contend with muddy fields or wet produce.

Labor requirements
Labor requirements for establishing high tunnels vary considerably by high tunnel type and system, operator experience, and the useful life of the plastic covering. Average construction times for unheated quonset-style high tunnels of 2,000 to 2,500 square feet range from 65 to 100 hours. Labor times for erecting heated or larger tunnels can move toward 150 hours. Time needed for site preparation, and the amount of time needed for replacing shorter-lived coverings, can greatly impact labor requirements.

Economic Considerations
High tunnels are a relatively inexpensive way to extend the growing season. Excluding labor, the approximate cost of a less permanent high tunnel is $1.30 to $1.50 per square foot. More permanent structures are likely to fall in the $2.50 per square foot range, and high tunnels constructed from kits may cost even more per square foot. Because of their simple design, high tunnel structures are not difficult to construct. Compared to the cost of a traditional production-ready greenhouse ($8 to $30 per square foot) the high tunnel requires little capital investment. High tunnel production, however, does represent a much greater investment than growing produce in the field.

EQIP Seasonal High Tunnel Initiative
The USDA-NRCS Environmental Quality Incentives Program (EQIP) High Tunnel System Initiative offers financial and technical assistance to agricultural producers interested in pursuing high tunnel crop production. Refer to their website, listed under Selected Resources, for further details of the program, including eligibility requirements and application deadlines.

Selected Resources
- University of Kentucky High Tunnel Research Facility http://ukhtrf.webs.com/
- Building the KSU High Tunnel (Kentucky State University, 2007) http://organic.kysu.edu/Tunnel.html

- How to Build a High Tunnel (University of Kentucky, 2005) http://www.uky.edu/hort/sites/www.uky.edu.hort/files/documents/hightunnel.pdf
- Low Cost High Tunnel Construction (University of Kentucky and eXtension, 2012) http://www.extension.org/pages/18356/low-cost-high-tunnel-construction
- High Tunnels in New Jersey (Rutgers, 2011) http://njsustainingfarms.rutgers.edu/hightunnels.html
- Cornell High Tunnels (Cornell University) http://blogs.cornell.edu/hightunnels/
- Economics of High Tunnel Vegetable and Strawberry Production in the Central Midwest (Purdue University, 2007) 1.2 MB file https://ag.purdue.edu/hla/fruitveg/Presentations/econ_summer_crop6.pdf
- EQIP High Tunnel System Initiative http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/programs/?&cid=stelprdb1046250
- High Tunnels (Kansas State University, University of Missouri, and University of Nebraska Extension Services) http://hightunnels.org/
- High Tunnels (University of Vermont, 2007) 2.4 MB file http://www.uvm.edu/~susagctr/Documents/HighTunnels.pdf
- Minnesota High Tunnel Production Manual for Commercial Growers (University of Minnesota, 2012) http://www.extension.umn.edu/garden/fruit-vegetable/docs/high-tunnel-manual-2012.pdf
- Introduction to High Tunnels (eXtension, 2010) http://www.extension.org/pages/18358/introduction-to-high-tunnels
- High Tunnel Agriculture (Mielkes Farm, Wisconsin) http://www.mielkesfarm.net/hightunnels.htm
- High Tunnel Resources (Pennsylvania State University) https://extension.psu.edu/catalogsearch/result/?q=high+tunnels
- Natural Ventilation in High Tunnels (eXtension, 2012) http://www.extension.org/pages/27782/natural-ventilation-in-high-tunnels
- Portable Poly Pipe High Tunnel Hoop House Construction Plans (Noble Foundation, Oklahoma, 2012) http://www.noble.org/ag/horticulture/poly-pipe-hh-plans/
- Rainwater Catchment from a High Tunnel for Irrigation Use (Iowa State University, 2012) https://store.extension.iastate.edu/product/Rainwater-Catchment-from-a-High-Tunnel-for-Irrigation-Use

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Photos: Mark Williams (multi-bay tunnel, pg. 2) and Tim Coolong (movable tunnel, pg. 3), University of Kentucky; USDA-NRCS (quonset tunnel, pg. 1; gothic tunnel, pg. 2; and tunnel with rolled-up walls, pg. 4).

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