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High Tunnel Production: The Basics for Success and Three Case Studies on Profitability

Introduction

This publication summarizes a project that took place in the Mid-Atlantic region, but high tunnels can be successfully used in a wide variety of climates and locations. They are especially profitable when located close to good markets, such as urban and peri-urban areas.

Figure 1. Farmers can use high tunnels to grow a wide array of plants earlier or later in the season. In addition to growing fruits and vegetables, this grower used his high tunnel to store bedding plants in March and April.

The SARE Project in a Nutshell

This three-year SARE-funded study based in the Mid-Atlantic region involved five innovative farmers in building high tunnels to investigate and identify best practices in high tunnel construction, tomato production and factors influencing profitability.

Each farmer cooperator planted three rows of early tomatoes with one row of a standard variety in a 21' x 48' high tunnel. Each farmer selected two additional varieties for the remaining two rows. Farmers followed tomatoes with crops of their choice and collected their own income data.

After analyzing year-one data, it became apparent to project leaders that doing a comparative analysis among five cooperators would not provide accurate results. While each of the cooperators used a similar mix of marketing outlets, each farmer had different harvesting schedules. Project coordinators decided that observing each farmer's experience as a "case study" would provide more accurate production and economic results.

During the summers of years one and two, a technician was hired to visit cooperating farms once per week to assist with production, train growers on collecting data and provide feedback to project coordinators. Project coordinators also

visited cooperators and assisted the technician. The technician's weekly visits helped to timely diagnose and treat problems as they arose in the tunnels.

Numerous field days and presentations aided in outreach of project results. Below are key results of the project.

Best Practices in High-Tunnel Construction and Production

Forty-one high tunnels were built as a result of this project, which led to a wealth of information about best practices for high-tunnel construction and production.

A high tunnel is a simple structure for growing plants, similar to a greenhouse, but less expensive to build and operate. Like greenhouses, high tunnels receive passive solar heat, but they are covered with only one layer of plastic, in contrast to glass-siding or double-layered plastic on greenhouses. And unlike commercial greenhouses, which can cost more than $20 per square foot, high tunnels generally cost only $3 per square foot to build.

High tunnels can be used to grow a wide variety of fruit and vegetable crops, early in the spring and late into the fall, in a more controlled and shielded environment than regular field conditions. High-tunnel production can improve crop quality and increase yields by decreasing pest and disease problems. Economic benefits to growers add up as more produce is sold earlier and later in the season.

In this study, good tunnel management was the key to success for the growers. Good management included spending time daily in the tunnels to identify and quickly resolve any problems, properly balancing tunnel and field work, and carefully monitoring irrigation systems and roll-up sides, which regulate air flow through the tunnel.

The SARE study also found that high-tunnel success hinges on market accessibility. This study focused on farmers who had access to urban markets and/or operated Community Supported Agriculture operations (CSAs), but study coordinators say even rural producers can benefit from high tunnel production, as long as they have dependable market outlets.

The project team found three major factors that promoted profitability in high tunnel production:

- The cooperator's decision to plant supplemental crops in the high tunnel along the sides, thus providing additional income for the season.
- How each cooperator integrated their high tunnel management into overall farming system management, especially labor.
- The amount of time the cooperator spent in the high tunnel during the entire season.

How to Construct a High Tunnel

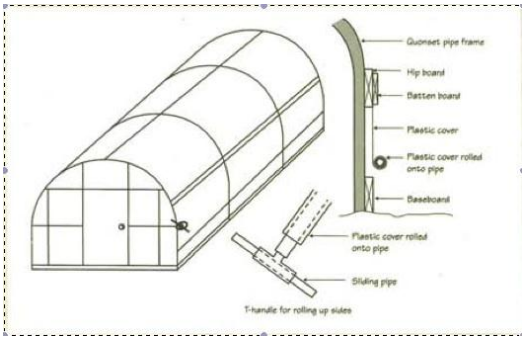

Figure 2. A high tunnel is usually constructed with metal pipes and a wood stud frame. A "T" handle is used to roll up plastic sides.

Correct construction is the first step to successful use of a high tunnel. It is very important to have the soil inside the tunnel four to six inches higher than the outside, to allow for good water drainage away from the tunnels. The roll-up sides will work better in a well-constructed high tunnel, making it easier to ventilate plants for better growth and disease control.

Growers less experienced in construction might consider purchasing a pre-packaged kit, or at least consulting a kit list to know every piece they will need to build the tunnel. Smaller high tunnels do not require a large labor force to put up and take down.

There is no standard size for a high tunnel, but it should be large enough for the grower to plant, monitor and harvest the crop from inside the structure. Tunnels are usually 14 to 28 feet wide, 7 to 12 feet tall at the center (depending on width), and 48 to 96 feet long, or a length in any four-foot interval. It is usually recommended that tunnels should be no wider than 30 feet for cross ventilation and to avoid snow accumulation on the roof.

Growers should invest time laying out corners properly and preparing the site for construction. The structure must be completely square. Orientation of the tunnel will depend on land availability, but an east-west orientation will maximize solar gain. Orienting the long sides to prevailing winds will improve passive ventilation provided by roll-up sides.

Figure 3. The skeleton of this tunnel, built between a driveway and a grove of trees, illustrates that growers need not have a perfect site for the structure. This tunnel was customized to maximize the available space.

Figure 4. SARE project coordinator Bryan Butler helped build this high tunnel, illustrating a useful end wall with a large door, on a University of Maryland research farm.

Make sure the weather is fairly mild when putting up the tunnel, and build it in a timely manner. It is important to have no wind when putting the plastic on. To build the tunnel, drive metal pipes into the ground approximately 2 feet deep and set them every 4 feet of the high tunnel's length, to provide support for the gable framing. The bows fit into the ground pipes and are attached by bolts. The ends of the structure can be plastic or wood on a wood stud frame but should be removable to allow

access for tillage equipment and to increase ventilation in the summer.

The structure is typically covered with a single layer of 6-mil polyethylene with provisions for rolling up the sidewalls. When putting up plastic, it's easier to use warm plastic than cold. The poly is secured onto a hip board on each side of the high tunnel, about 3.5 to 5 feet above the soil line, depending on the tunnel width. A vertical sidewall helps to keep rain out of the tunnel and when rolled up, provides passive ventilation.

A pipe is then attached to the loose bottom end of the plastic along the length of the structure. A "T" handle on the end of the pipe is used to roll the plastic onto the pipe to open the sides.
For more information on tunnel construction, supplies and funding, see Resources at the end of this fact sheet.

Figure 5. Built by growers with an on-farm market store, this large, Quonset-shaped high tunnel featured gutters containing strawberries, raised beds and extra heating. High tunnels offer flexibility and allow growers to customize for their specific needs.

Crop Selection and Management
Tomatoes, peppers, eggplant, greens, radishes, potatoes, raspberries, strawberries, herbs, ginger, cucumbers, kiwis, cut flowers and broccoli are just some of the crops grown successfully in high tunnels. Consider the importance of crop mix and secondary crops – along sides of the tunnel – when making planting plans. Although secondary crops require more work and thought, they can provide significant profits.

Be sure to find a healthy source for transplants. In the SARE study, three farmers had to destroy transplants due to "tomato spotted wilt virus" (TSWV).

Crops are usually planted directly in the soil inside the high tunnel 4-6 weeks before frost-free dates. Planting times for transplants in the SARE studies started as early as March 28 for tomato crops in Maryland. Check with local extension offices and other experts in your region to optimize early and late planting opportunities to maximize profit potential.

Temperature During periods of cold weather, the sides are lowered in the afternoon to hold heat and then raised in the morning to vent before temperatures inside get too high. Closing the sides in the afternoons – from 2 to 4 p.m., depending on the weather and temperature –allows daytime heat to gather overnight. In the morning, however, temperatures can quickly rise to 100+ degrees Fahrenheit in a high tunnel if it is receiving direct morning sunlight. Heat could overwhelm plants as early as 8 or 9 in the morning. If greens were planted in February, direct morning sunlight in late-March or April could stunt growth if sides are not opened to allow heat to escape in the morning. Ventilation not only cools the structure's interior, but also lowers humidity and dries foliage which can help reduce disease.

Keep in mind that in cold weather the high tunnel can only stay 2-3 degrees warmer

than the outside temperature. For extra protection on cold nights use row covers or even space heaters. Unless supplemental heat is provided, the tunnel may not be able to provide adequate protection to the plants after November or December, depending on the region and climate.

Figure 6. This traditional high tunnel stood on the same farm next to the Quonset style in Figure 5. The growers were able to produce these squash and cucumbers almost a month earlier for their on-farm market.

Consider investing in a minimum/maximum thermometer – either a simple one or a computerized model – to monitor and manage temperature in the tunnel. You can then better gauge when sides need to be raised and lowered. Mount a thermometer on the outside of the tunnel as well to learn how temperature extremes outside affect the temperature inside the tunnel.

Fertility

Growers should carefully monitor crop fertility because of the very high yields in high tunnels. As with field crops, test soils and keep current with fertility needs. Two cooperators in the SARE study had such excellent fertility that even with a virus outbreak, plants in their high tunnels yielded well. Both of these cooperators were long-term organic producers who sited their tunnels on former productive fields with good soil.

Figure 7. Bryan Butler demonstrates growth potential of fall bearing raspberries in a high tunnel.

SARE project coordinators highly recommend amending the soil in high tunnels with compost rather than commercial fertilizers, which can cause soluble salt build-up. Lime may be needed every third or fourth year in accordance with your soil tests. They also used no-till to keep worms and microbial soil life active and regular watering to encourage healthy mineral and N uptake.

In addition to using compost and encouraging microbial life and worms, other fertility options can include planting cover crops, and even using “chicken tractors,” in the high tunnel. For example, one SARE cooperator planted an Austrian winter pea in the tunnel in late-November. In February they placed a portable chicken pen inside the tunnel. Over the course of the next two months they moved the chicken pen over the entire tunnel floor so the chickens ate the pea cover crop, worked the soil and distributed manure throughout the tunnel for the benefit of early spring tomatoes. Before considering this cover crop-chicken crop

rotation, confirm that your activity and timing follow U.S. Food and Drug Administration food safety good agricultural practices and regulations.

Long-term fertility can be an issue when high tunnels are used for 6 or 7 years or beyond. SARE coordinators recommend renovation tillage every three to four years. Growers should pull up landscape fabric, perform light tillage, take soil samples, adjust pH and calcium levels and lightly incorporate another three inches of compost. Soil fertility may need to be supplemented every year with some high yielding crops such as tomatoes and cucumbers. Compost, fish fertilizer or other organic fertilizer may need to be added on an annual basis for these crops. Soil as well as tissue testing may be used if there are concerns regarding the amount of growth or yield.

Water Management

Irrigation should be on a schedule, ideally on a timer, and monitored daily with tension meters that indicate the amount of available soil moisture. Consider using trickle irrigation with black plastic mulch. Black mulch will reduce incidence of disease by preventing water from reaching the foliage, which can transport fungal spores or encourage disease development.

Excess moisture will raise humidity in the tunnel and may lead to disease problems. Respiration of the plants will increase humidity at night as air cools. Venting in the morning for 10 to 20 minutes will help dry plants.

Targeted irrigation also keeps the area between beds too dry for weeds to germinate.

Figure 8. These organic farmers wanted more planting flexibility, so they mulched with straw rather than landscape fabric.

It is critical for growers to make daily trips through the tunnel and nip any pest or disease problems in the bud. In a closed environment, these problems can multiply rapidly and destroy crops. Insects will thrive in the high tunnel microclimate created for plants. Integrated Pest Management scouting must begin when the plants are set out. The SARE team found that the sooner an insect problem was addressed, the better the outcome.

Beneficial insects may be the most practical way to deal with some insect and mite problems. However, season extenders can actually be used as physical barriers to keep insects off the plants. For example, screening sides to exclude insects and the use of floating row covers that have the edges secured will also prevent many insects from reaching the crop.

Quick action is also crucial to ward off disease problems. For example, powdery mildew is one disease that may be favored by the high tunnel climate and should be monitored closely.

Pollination for many crops, such as raspberries, strawberries and tomatoes, is

provided to a large extent by the air movement from side to side. However, bumble bees or honeybees may be required to maximize production in the early and later part of the season. More research is needed in this area.

High tunnel floors are generally covered with a layer of 4-6-mil black plastic or permeable woven landscape fabric to help raise the temperature inside the house, control weeds and reduce evaporation of soil moisture.

Due to less weed and pest pressure and a more controlled watering environment, many growers – especially organic and heirloom growers – have found that high tunnels offer an excellent management environment for a wide variety of crops.

The Economics of High Tunnels

It is important to know your markets when introducing high tunnel production into overall farming systems. If you have ensured a marketing outlet for specific crops and/or varieties, you can be creative with your crop choices.

Close proximity to urban areas is an advantage, but this should not discourage growers in more rural areas to try a high tunnel if they have a farmers' market or other dependable outlets for selling their products. It is helpful to have at least one "premier" market that you can count on to bring premium prices for higher quality produce that can be delivered early and later in the season.

When studying markets, consider what will sell best in your area. For example, do you have ethnic markets eager for a certain kind of pepper, or are your area consumers looking for round, red tomatoes before July 4th? While it's important to select appropriate varieties for your specific climate and region, variety selection is also an important consideration on the consumer end.

The SARE team saw a unique opportunity for off-season CSA farms to use high tunnels as a market for early- and late-season fruit and produce, expanding their offerings from 26 to 32 weeks, for example, and having a consistent and early crop available for customers.

The Case Studies

Because harvesting methods and supplemental crops varied, project coordinators employed a case-study approach for the economic analysis of five SARE grower/cooperators' high tunnel enterprises.

The SARE team decided that growers should be able to pay off the high tunnel in their first season. So the economic benchmark for a successful high-tunnel growing season would be total gross sales from the high tunnel to meet the total cost of building a 21' x 48' high tunnel, selected as the standard growing area for data collection. Taking into account all building costs, including lumber, plastic and end wall construction, project coordinators determined the total cost for this size high tunnel was $3,000 during the active years of this project (2005-2007).
The project team found three major factors that promoted profitability in high-tunnel production:

1. The cooperator's decision to plant supplemental crops in the high tunnel along the sides, thus

providing additional income for the season.
2. How each cooperator integrated their high-tunnel management into overall farm-system management, especially labor.
3. The amount of time the cooperator spent in the high tunnel during the entire season.

Case Study 1

In one case study, a farmer/cooperator planted tomatoes in the tunnel, but they were destroyed by 2, 4-D spray drift from an adjacent field where another farmer sprayed for no-till corn production. The cooperator was then too busy to replant with tomatoes so he planted spinach in the high tunnel in late-summer for a fall market mix and for a winter farmers market in Washington, D.C. They harvested 560 lbs. of spinach at $10/lb. for a total income of $5,600 in year one of the project. Due to a mild fall and winter, the spinach yielded well and attendance at the farmers market was high.

In the second year, this farmer planted tomatoes on April 1 and harvested from June 22 until November 25, for 6,532 lbs. at $3/lb. for a total income of $19,596. During this growing season, this cooperator exhibited superb management in the high tunnel – pruning, staking, tying and controlling for pests and disease. The tomato varieties – Moskovich and Prudens – performed very well. Tomatoes were trellised up to a height of 8 feet.
In year three of the SARE project, this grower planted tomatoes on April 3 and harvested June 22 through November 15. A total of 2,276 lbs. of tomatoes were harvested at $3/lb. for a total income of $6,828. This cooperator, who had one of the largest farms in the study, said that because of labor issues less time was spent in the tunnel the third year.

Due to favorable weather and management, outstanding tomato yield and good management, this cooperator far exceeded the $3,000 economic benchmark each year of the study.

Case Study 2

Another cooperator, a long-time certified organic producer selling at local farmer's markets and through a CSA, began in year one of the project by planting tomatoes in the high tunnel on April 15. Although these tomato plants tested positive for TSWV, they continued to grow and produce adequate yields for five weeks. Between July 22 and August 30, this cooperator harvested 425 lbs. at $3/lb. for a total of $1,275. After the tomatoes, the cooperator planted beans in the high tunnel and harvested 300 lbs. at $5/lb. for a total of $1,500, which brought total income for that year from high tunnel production to $2,775.

In year two, the cooperator planted tomatoes April 1 and harvested June 23 to July 28. He only harvested 172 lbs. for a total income of $516 – low yields were due to an uneven watering pattern, insect issues and interference of field work. The cooperator buried a new type of drip tape under the tomato plants and the watering pattern was very uneven, which led to stressed plants. He had to replant a portion of the tunnel on April 12.

The 2006 winter, year two of the project, was mild, and the summer heat began early, with insect issues arising early in the season. Aphids, whiteflies, mites then tomato rust mites became a problem. The cooperator did use beneficial insects, but not in a timely or effective manner, and he

consequently lost the tomato crop. As summer continued to bring hot and dry weather to this area, the high tunnel remained empty since the cooperator had to deal with field production problems. During the coldest part of the winter, the cooperator rolled up the sides of the high tunnel to freeze out any over-wintering insects. In early spring of year two he harvested 200 lbs. of kale at $3/lb. for an income of $600. Combined with tomato income, this brought year two's total to $1,116 for high tunnel production.

The final year of the project brought this cooperator's best season, with no major management or production issues. The cooperator planted tomatoes April 3. June 21 through October 5 he harvested 1,387 lbs. at $3/lb. for a total high tunnel income of $4,161.

This cooperator had the largest field production of all cooperators and best illustrated how balancing management and labor issues between field and high tunnel production can improve profitability in the high tunnel.

Case Study 3

A third cooperator, a certified organic producer selling through a CSA and to restaurants and farmers markets, planted high-tunnel tomatoes on April 1 and harvested June 9 through November 15 for a total of 1,249 lbs. at $3/lb. for a total gross profit of $3,747. This cooperator's tomato plants were diagnosed with TSWV but did not show signs until late in the season. He had good fertility and continued to fertilize the tomatoes throughout the seasons. The tomatoes were excellent quality and yielded three to four weeks earlier than field tomatoes.

In year two of the project, this cooperator planted tomatoes on March 28 and harvested June 29 through August 29. Insect issues were less of a problem for this grower because he was quick to respond and remained diligent in treating problems when they arose throughout the seasons. He shortened the tomato harvest this year because he wanted to grow greens in the tunnel, but still harvested 878 lbs. of tomatoes at $3/lb. for $2,634 income. He also sold $712 of fall greens for a total income in year two of $3,346.

In the final year of the project, this cooperator planted tomatoes on April 23 and the harvest period between June 6 and October 15 yielded 908 lbs. of tomatoes at $3/lb. for $2,724. He also planted both edges of his tunnel in spring chard and harvested 250 lbs. of chard from April 23 to May 9 for $750, bringing the total high-tunnel income for that year to $3,474.

This cooperator found an additional use for tunnels in the spring as they offered an excellent location to store transplants. Project coordinators felt that this cooperator was the most consistent in the study. His management was excellent throughout the project.

Table 1. Summary of gross income from high-tunnel grown produce for the three years of the project. Demonstrates that producers can recoup tunnel costs in first year of use.

SARE Grower/Cooperator Farms	Year 1	Year 2	Year 3	3-Year Income from High Tunnel
Case Study 1	Planted spinach in late-summer; harvested 560 lbs. $10/lb. for **$5,600**	Planted tomatoes April 1; June 22-Nov. 25, harvested 6,532 lbs. at $3/lb. for **$19,596**	Planted tomatoes April 3; June 22-Nov. 15, harvested 2,276 lbs. at $3/lb. for **$6,828**	**$32,024**
Case Study 2	Planted tomatoes April 15; July 22-Aug. 30, harvested 425lbs @ $3/lb. for $1,275; also sold 300 lbs. of beans for $1,500 for a total of **$2,775**	Planted tomatoes April 1; June 23-July 28, harvested 172 lbs. @ $3/lb. for $516; also sold 200lbs of kale for $600 for a total of **$1,116**	Planted tomatoes April 3; June 21-Oct. 5, harvested 1,387 lbs. at $3/lb. for **$4,161**	**$8,052**
Case Study 3	Planted tomatoes April 1; June 9-Nov. 15, harvested 1,249 lbs. @ $3/lb. for **$3,747**	Planted tomatoes March 28; June 29-Aug. 29, harvested 878 lbs. @ $3/lb. for $2,634; also sold $712 in fall greens for total of **$3,346**	Planted tomatoes April 23; June 6-Oct. 15, harvested 908 lb. @ $3/lb. for $2,724; also sold $750 of chard from edges of tunnel for total of **$3,474**	**$10,567**

Figure 9. This high tunnel skeleton illustrates tall, vertical sides and peaked, or gothic, top and simple end walls that are desirable in high tunnel production.

Resources

General Information
Minnesota High Tunnel Production Manual for Commercial Growers. Edited By: Terrance T. Nennich, Sr., University of Minnesota Extension; David Wildung, North Central Research and Outreach Center; and Pat Johnson, North Central Research and Outreach Center. 2012. Go to http://www.extension.umn.edu/distribution/horticulture/M1218.html

Washington State University high tunnel resources list. Go to http://mtvernon.wsu.edu/hightunnels/Content/cropTunnels.html

University of Wisconsin Extension/eOrganic eXtension High Tunnel Webinar, March 2010. Go to http://www.extension.org/pages/26091/high-tunnel-production-and-low-cost-tunnel-construction-webinar

Hightunnels.org website, K-State Research and Extension, University of Missouri Extension and University of Nebraska Cooperative Extension. 2004. Go to http://www.hightunnels.org/

High Tunnel Tomato Production. Lewis W. Jett
Department of Horticulture; David Coltrain, Kansas State University; Jay Chism, James Quinn and Andrew Read. Go to http://extension.missouri.edu/explorepdf/manuals/m00170.pdf

Funding
USDA NRCS EQIP Seasonal High Tunnel Initiative. Go to http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/programs/?&cid=stelprdb1046250

Construction
http://njsustainingfarms.rutgers.edu/hightunnels.html

Rutgers High Tunnel Project, including detailed pictures from building a high tunnel, go to http://aesop.rutgers.edu/~horteng/hightunnels.htm

Budgeting
High Tunnel Production Budget Resources website, including budgets and spreadsheets as well as information on growing a variety of crops. Go to http://extension.unh.edu/counties/grafton/Docs/WinterProd4.pdf

Production
Organic Control of White Mold in High Tunnels, This SARE-funded video presents information on the high tunnel production system most commonly used in Kentucky; the disease cycle of *S. sclerotiorum*; and two control tactics compatible with national organic standards, solarization and biofumigation. http://www.sare.org/Learning-Center/Project-Products/Southern-SARE-Project-Products/Organic-Control-of-White-Mold-in-High-Tunnels

Recommended companies for high tunnel materials or material list:
http://www.ledgewoodfarm.com/home.html

http://www.griffins.com/construction/index.asp

References

Season Extension and Cultivar Evaluations for Increasing Farmer Profitability Using High Tunnels in the Baltimore/Washington Metropolitan Area. Mark Davis, formerly of Future Harvest-CASA and Bryan Butler, Maryland Cooperative Extension. USDA SARE Program Grant LNE 04-206. Reports from 2004 to 2007.

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Small Farm Success: High Tunnels in the Mid-Atlantic Region. Basic Farmer Experiences. By Bryan Butler and Mark Davis. Support from the Small Farm Success Project funding the USDA's Initiative for Future Agriculture and Food Systems (IFAFS) program

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