High Tunnel Raspberries and Blackberries

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Authors: Cathy Heidenreich, Marvin Pritts, Kathy Demchak, Eric Hanson, Courtney Weber, and Mary Jo Kelly
On line at: http://www.fruit.cornell.edu/berry.html

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About this Guide

High Tunnel Raspberries and Blackberries is a work composed of research results generated from ongoing bramble (raspberry and blackberry) high tunnel projects throughout the northeast region. Information in this guide comprises current thought on all aspects of bramble high tunnel production.

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Comments? Email Cathy Heidenreich, Berry Extension Support Specialist, or Craig Cramer, Communication Specialist, Dept. of Horticulture.

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Introduction

Cornell, Michigan State and the Pennsylvania State Universities are conducting research on high tunnel production to help northeastern berry growers capture an increased portion of the market for fresh berries through season extension methods. This publication, along with its counterpart, "Greenhouse Raspberries", (http://www.fruit.cornell.edu/Berries/bramblehtml/ghrasp.html) presents current data and experiences generated by this ongoing research.

Greenhouse production of raspberries and blackberries has helped to bridge one gap in establishing all season bramble production in the Northeast. However, using this method alone to cover bramble production during mid-winter months may not be cost effective for producers, especially in the face of rapidly rising energy costs. Conversely, the same rapidly rising energy costs also provide a unique opportunity for expanding local and regional market shares over those currently held by imports. Production of high quality, locally grown and shipped raspberries and blackberries could potentially shift the market supply from imported to domestic along the Atlantic seaboard.

High tunnel bramble production offers the opportunity to bridge the remaining gaps in availability during late fall and late spring. Because tunnels offer a less expensive form of season extension than greenhouses, they appear to be an ideal production option when temperatures are not too cold.

Furthermore, high tunnels can be utilized to allow less hardy floricane-fruiting raspberries and blackberries to overwinter in climates where they would otherwise be killed.

These technologies, coupled with the continued development of new varieties and field production techniques, bring the goal of all season bramble production closer to fruition (no pun intended!) for northeastern small fruit growers.

What is a High Tunnel, Anyway?

High tunnels are simply large hoop houses covered in plastic (Figure 1), which allow the sides and end walls to be opened to regulate temperature. They provide an intermediate level of environmental protection and control between field production and greenhouse production.

High tunnels are usually not heated, though supplementary heat (such as portable space heaters) may be provided for protection on cold nights. Row covers used within high tunnels provide additional protection from cold temperatures. High tunnels typically have irrigation systems as their protective nature excludes rainfall.

Plants are generally established in ground in a high tunnel, rather than in containers with artificial media - although both types of production are possible.

In-ground high tunnel raspberry plantings are established at a relatively close spacing, frequently prior to tunnel construction.

Installing a tunnel over existing rows as an afterthought is difficult, and the row spacing cannot be changed. There is a possibility that diseases and weeds in tunnels may gain a foothold in the planting prior to covering the tunnel, so close watch of conditions is necessary.

Figure 1. Raspberry high tunnel production in Scotland.

One difference between greenhouses and high tunnels is the plastic covering. Greenhouses are typically covered with double layers of polyethylene plastic that are replaced periodically as needed. High tunnel plastic is usually a single layer greenhouse grade plastic and may be applied and removed seasonally. With some types of high tunnels, seasonal plastic removal is a necessity.

Unlike their greenhouse counterparts, high tunnels typically do not have electric service or automated heating/ventilation systems. The sides of the high tunnel are constructed in such a way that they can be manually rolled up or opened for ventilation (Figure

2). They have no permanent foundation as poles are driven into the ground

Because of these structural differences, high tunnels are usually classified as temporary (removable) structures and/or durable agricultural equipment. This is an important distinction for taxation purposes in most areas; the non-permanent nature of high tunnels may allow them to fall outside certain tax, building, and zoning requirements.

Figure 2. Venting a raspberry high tunnel.

Greenhouses, on the other hand, are classified as permanent structures and as such are subject to various regulations and requirements. Check local zoning ordinances in your area for further details.

The Benefits of High Tunnel Production

Fresh local raspberries are typically available in the Northeast from mid-June to early October (Figure 3) and blackberries in July, August, and September.

Use of high tunnels in berry production can greatly extend the production season, beginning in May for some floricane-fruiting (summer fruiting) raspberry cultivars and extending through November for some primocane-fruiting (fall-fruiting) cultivars. This extended season can assist growers in capturing a larger market share, especially early and late season when premium prices are paid for berries (Figure 4).

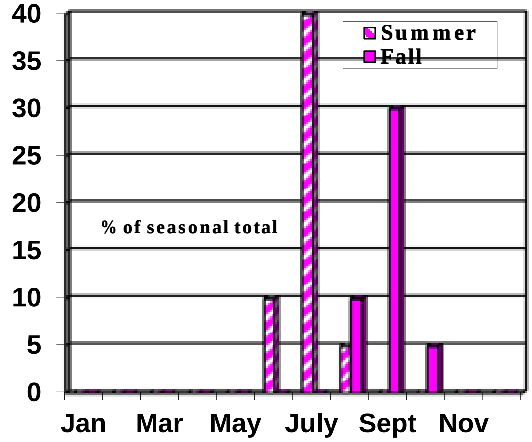


Figure 3. Current availability of fresh local raspberries from the field. (Cornell University data)

Figure 4. Retail raspberry prices often range from $10.00 to $21.00/lb. during early and late season periods.

Primocane-bearing raspberries and blackberries managed for a single fall crop typically yield more than three times as much in tunnels as in the field due to reduced gray mold, larger berries, extended picking seasons, closer row spacings and perhaps other reasons. If managed with a summer crop also, even higher yield is reasonable (Figure 5).

Figure 5. Heritage berries from a tunnel (left) and field (right).

The difference in yield and fruit size between field grown and tunnel grown black raspberries and blackberries (Figure 6) can be significant as well (Figures 7 and 8). Black raspberries, however, are relatively low-yielding and have a short harvest season. Thus, even the yield increases that result from tunnel production may not economically justify tunnel use with this crop.

Figure 6. Thornless blackberries (left) and black raspberries (right) under tunnel production.

Figure 7 Tunnel grown 'Jewel' black raspberries.

For floricane-fruiting blackberries tunnels can make the difference between no crop and the equivalent of 25,000 lb. per acre of marketable fruit if the tunnel remains covered through the winter. The reasons for yield increases from year-round covering have not been sufficiently investigated. Possible reasons could be: 1) a decrease in both stress and possible photosynthesis shutdown from wind, 2) prevention of bud desiccation, 3) adding 3-4 weeks of frost-free growing onto each end of the season increasing growing time, and 4) additional winter protection. There may be other reasons as well.

High tunnel production results in improved fruit quality and shelf life, and harvest of a more consistent crop than in field production. Tunnel production also ensures continuous fruit production when conditions for field harvest are unfavorable.

Soil warming and wind and rain protection are just some of the benefits of high tunnel production compared to field production.

With the exception of mites and powdery mildew, the need for disease, weed, and insect management, compared to field production, is usually less; this minimizes pesticide inputs. Although not our experience in the US, Canadian growers have observed fireblight in tunnels.

While wildlife management issues are reduced compared to the field, we have observed increased rodent activity in tunnels that remain covered through the winter as they seek warm shelter.

Figure 8. Tunnel grown blackberries.

In addition, high tunnel production allows for diversification of farming operations, requires less capital expenditure than greenhouse production, and for relatively low investment, often provides high returns. The above benefits notwithstanding, good planning, cultivar selection and detailed management are essential to successful high tunnel bramble production.

Benefits of High Tunnels

STRATEGY	CAUTIONS
Early harvest of floricane-fruiting raspberries and blackberries	Mite populations can be very high when tunnels are covered beginning in early spring. Primocane growth may be too vigorous.
Overwintering of blackberries and raspberries that are too tender for outdoor production.	Tunnel must be peaked and reinforced to withstand snow load. Also, mites can be a problem with raspberries. Primocane growth can be too vigorous.
Extending harvest of primocane-fruiting raspberries into late fall.	Delay tunnel covering until the start of bloom to reduce mite problems. Vent tunnels daily to release humidity and avoid powdery mildew buildup.
Permit harvesting of primocane-fruiting blackberries in the fall.	Current varieties are very thorny and not overly productive.
Double-cropping primocane-fruiting raspberries for both a summer and fall crop.	Primocanes can grow too tall and spindly, and make harvest from floricanes more difficult. Mites and other pests can easily overwinter since canes are not completely cut and removed each year. Yield and size of the summer berries are usually smaller than that of floricane-only varieties.

Site Selection and Preparation

Plant Requirements

The same criteria for selection of bramble sites for field production apply for in ground raspberry and blackberry high tunnel production but high tunnel sites should be level where each bay will be constructed.

Soil quality is probably the most important factor for success. The top 20 inches of soil will contain about 90% of the raspberry root system. Brambles should be planted on deep, well-drained loamy soils. In addition, these soils should have good water-holding capacity and high organic matter content (>3%). Sandy loam and loamy sand soils are also acceptable since irrigation is essential in tunnels.

Clay and other heavy soils are less desirable. Raspberries and blackberries do not tolerate “wet feet” well. Every effort needs to be made to provide adequate drainage. Heavier soils may be acceptable if drainage improvements are made prior to planting. Raised beds are generally of value in this instance.

Soils should be tested for nutrients and pH prior to site selection and planting. Brambles grow best at a pH between 6.0 and 6.5; pH values above 7.0 may result in iron deficiency. Values below 5.5 may result in poor establishment, growth, and yield.

Soil fertility may be improved by the addition of organic matter. Added organic matter may take several forms: dairy manure, compost, or ‘green manure’ cover crops. Dairy manure incorporated at the rate of 10-20 tons per acre provides N, P, K, and organic matter. It contains fewer weed seeds than horse manure, and is lower in nitrogen and phosphorus content than chicken manures while providing a similar amount of potassium.

A preplant cover crop seeded the year before planting is a second way to increase soil quality through the addition of organic matter. After a season of growth, the cover crop is incorporated into the soil where it decomposes. Legume cover crops provide more nitrogen than other cover crops, along with the added benefit of being turned down in early spring, a month or so before planting.

Other factors to consider in site selection include water quality and availability, previous cropping history, the possibility of significant herbicide carry over, and pest populations.

Irrigation System Selection and Installation

Water quality and quantity are critical to high tunnel production because the water source provides most or all moisture inputs for the tunnel, unlike field production, where irrigation only supplements precipitation.

Water quality testing should be done prior to site selection in all instances, particularly to ensure soluble salts are low (<2.0 ds/m; preferably <1.0 ds/m).

Water high in calcium and magnesium or other elements can cause imbalances in nutrients, soil pH changes, or precipitation of soluble fertilizers. High levels of bicarbonates may act as a buffer, making it difficult to bring the soil pH down if it becomes too high. Treatment options such as acidification, or water softening with a potassium-based softener, should be used if necessary.

Much work has been done on designing and installing drip irrigation (Figure 9), which will not be re-iterated here. See the bibliography for resources on drip irrigation design and installation for more information.

Figure 9. Drip irrigation ingress pipe with in-line water filter and faucet for hose attachment.

Cropping History

Brambles, particularly black raspberries, should not follow solanaceous crops (potatoes, tomatoes, or eggplant) or weeds such as lambsquarters, pigweed, or nightshade or strawberries. These crops are highly susceptible to Verticillium wilt, which also affects raspberries.

Carry-over of triazine herbicides, such as atrazine used in corn production, may also pose a potential danger to new bramble plantings.

Japanese beetle or chafer grubs may be present in soils formerly in sod for several years. These insect pests will feed on bramble roots if present in plantings.

Soil tests are also recommended to detect the presence of nematodes, microscopic soil "worms' which attack the roots of crops, causing crop damage and sometimes vectoring crop diseases.

Sites should also be evaluated for the presence of garden symphylans (sometimes called garden centipedes). Symphylans feed on germinating vegetable and weed seeds, roots and root hairs of plants. Feeding on roots interferes with plant growth and yield, and causes plant stunting.

For more information on these topics see "Site Selection and Preparation", Chapter 2 in the NRAES 'Raspberry and Blackberry Production Guide, 2nd Edition'

Structural Considerations and Orientation

After considering soil suitability, the next step is to examine the potential site in relationship to location of the high tunnel. Tunnel placement is often one of the key factors to success.

Gather information to help make an informed decision when selecting high tunnel sites:

- ❖Direction of the prevailing wind?
- ❖Water drainage on site?
- ❖Air drainage on site?
- ❖Potential snow and ice load?

The site selected should be relatively level and well-drained. Single bay tunnels are best oriented perpendicular to prevailing winds to facilitate cross ventilation. However, multi-bay tunnels are more prone to wind damage, and orientation in the direction of prevailing winds helps reduce the risk of damage.

Light interception also should be considered. During the standard growing season, plants in north-south rows receive the greatest and most even light interception. But very early or very late in the season, the south side of a tunnel will receive the most light. Therefore, it is preferable at high northern latitudes (above 37°) to orient the tunnel in an east-west direction to maximize light interception early and late in the season if the goal is season extension. If plant height differs from row to row due to a predictable factor such as cultivar, the shortest plants should be on the south side to minimize shading of other plants in adjacent rows.

Orient tunnels to facilitate water drainage. Covered tunnels direct large volumes of rain water along the sides and into the leg rows. This water will flow across the tunnel if the orientation is across a slope, potentially eroding soil or flooding plants in the tunnel. Larger tunnels such as multi-bay structures are often best constructed down slopes, so that water can be channeled along the sides and down the leg rows. Small single-bay structures, however, are sometimes oriented across the slope so the sides can be stepped down the slope.

Tunnels should be fully accessible without being in danger of damage from moving equipment. Proximity to other structures should also be reviewed in terms of blocking light exposure or equipment entrance and egress. The same would be true for environmental barriers or obstructions such as wind rows, ditches, bodies of water, large trees, embankments, etc. The distance between adjacent single bay tunnels should be at least as far as the tunnels are tall, to allow for accumulation of shedding snow.

Conversely, proximity to resources such as irrigation water and pump house and postharvest handling and equipment sheds may be beneficial in maximizing labor efficiency. The same environmental barriers or obstacles that may limit equipment accessibility could be beneficial for other reasons, such as serving as wind breaks.

Tunnel Selection

Types of High Tunnels

There are different types of tunnels that can be used for raspberry and blackberry production, and more choices are becoming available over time. One main difference between tunnel types is the number of bays that are needed to provide structural integrity. A tunnel that contains only one bay which can stand on its own may be referred to as a stand-alone or a single bay tunnel. In this publication, the term single-bay will be used.

In other cases, multiple bays need to be connected to each other to provide sufficient structural integrity. These structures are called multi-bay tunnels or gutter-connected tunnels as they sometimes contain gutters between the bays. This type of tunnel also may be referred to as a Spanish tunnel. In this guide, the term multi-bay tunnel will be used.

High tunnels differ in whether they can carry a snow load and thus be covered with plastic over the winter. Tunnels on which the plastic can remain over the winter may be referred to as "four-season" tunnels, whereas tunnels than cannot be kept covered may be called "three-season" tunnels.
Single-bay tunnels are available as either three-season or four-season tunnels. Because the structure itself is quite sturdy, this type of tunnel typically costs more per area than multi-bay tunnels. Single-bay tunnels may have a peaked or Quonset-style frame to help shed snow. Peak-style frames are those whose supporting bows are bent at an angle forming a ridge or peak (Figure 10).

Figure 10. Peak-style high tunnel ribs (bows), Ithaca, NY.

This type of high tunnel construction better supports snow load and facilitates snow shed than either Quonset (Figure 11) or multi-bay tunnels (Figure 12).

Figure 11. Quonset style high tunnel, Ontario, Canada.

Figure 12. Multi-bay style high tunnels, California.

However, under heavy wet snow conditions, even peak-style tunnels maybe subject to collapse if snow is not kept off plastic (Figures 13a and 13b).

Figure 13a. Peak-style high tunnel collapsed under heavy snow load, February 2010, Ithaca, NY.

Figure 13b. View inside collapsed tunnel, February 2010, Ithaca, NY.

Single-bay tunnels are frequently used in colder climates, and are the type needed when producing plants that must be protected over the winter. Single-bay tunnels that can be rolled on tracks to cover different crops at different times of the year are available.

Multi-bay tunnels typically have a Quonset-style frame. Quonset-style frames have smooth rounded bows, which are more susceptible to snow load damage than peaked tunnels. Multi-bay tunnels are generally not designed for snow load and are uncovered in winter. The majority of small fruit production world-wide and in the U.S. is in multi-bay tunnels.

Multi-bay style frames are those that are connected to cover larger acreages. They are more susceptible to high winds than single-bay tunnels due to less structure relative to the amount of area covered. In contrast to single bay tunnels, plastic should be opened and gathered for multi-bay tunnels under high wind conditions (Figure 14). Often they are used primarily as rain shelters. Options exist with at least one manufacturer that allows the tunnel to be lowered for high wind events. As technologies develop, more options are becoming available in tunnel infrastructure and rigging that are improving the tunnels' ability to withstand adverse weather conditions. With brambles, trellising may serve double duty to support the crop and help to stabilize the tunnel if sufficiently robust.

Figure 14. High wind damage to a multi-bay style high tunnel as remnants of Hurricane Ike passed through Upstate New York, fall 2008.

Multi-bay systems concentrate larger amounts of rainwater runoff in the leg rows. Drainage needs to be planned to carry water away from the structure. Buried tile drains in the leg rows may be necessary.

Weed fabric also helps prevent soil erosion (Figure 15). Some manufacturers offer gutters to install in the trough between adjacent tunnels. On sloped sites, tunnels should be oriented to allow water to flow down leg rows and out of the structure.

Figure 15. Weed fabric and gravel-covered tile in the leg row of multi-bay tunnels.

Turf is a manageable alternative to landscape fabric in the leg rows. It prevents erosion, takes up excess water and provides structural support to the soil, which helps keep legs in the ground under high wind/high water situations such as intense thunderstorms.

Determining Tunnel Size

One factor to consider in selecting the proper size high tunnel for raspberry production includes having enough room to plant, monitor, maintain, and harvest the berries from inside the structure. In some instances, this may mean sufficient size to accommodate small tractors for cultivation and spraying.

Tunnel dimensions vary widely with manufacturer or construction plan. Typical single-bay tunnels are 15 to 30 feet wide and 60-96 feet long. Multi-bay tunnels are 20-26 feet wide per bay and can be several hundred feet long. Wider tunnels have the advantage of being easier to manage; overall bay width, however, should not exceed 30 feet. Wider tunnels are usually taller.

Tunnels exceeding 96 feet in length pose some potential problems. Ventilation is more difficult in longer tunnels that cannot be fully vented. Longer tunnels in use year round may be in jeopardy of collapse due to heavier snow loads. Tunnels with long unbroken rows may also pose psychological barriers for pickers.

Peak height may range from 7 to 15 feet. A nine foot minimum peak for raspberry production is recommended. It is also advisable to install 4 to 5 foot side post extensions to increase air circulation, to reduce heat accumulation in the tunnel, and to accommodate the height of raspberry and blackberry plants, especially in outer rows.

Higher tunnels permit more stable temperatures at the level of the plants. Vents installed in the roof and/or end walls below the peaks allow hot air to escape and draw cool air into the structure. The higher the tunnel, the more air flow occurs through the vents. With low tunnels without vents, temperatures inside the tunnel can damage plants on calm, summer days – even when the sides are rolled up.

Sources for Tunnels and Tunnel-related Materials

Regional High Tunnel Suppliers:

Rimol Greenhouse Systems Inc.
Northpoint Industrial Park
40 Londonderry Turnpike
Hooksett, NH 03106
Phone: 877-746-6544
http://www.rimol.com/

Harnois Greenhouse Supply Inc.
12 Acme Road, Suite 212
Brewer, ME 04412
Phone: 800-696-8511
www.harnois.com

Haygrove Multibay Tunnel Systems
Cramer's Posie Patch
116 Trail Road North
Elizabethtown, PA 17022
1-877-CRAMERS
www.haygrove.co.uk

Farm Tek
1440 Field of Dreams Way
Dyersville, IA 52040
1-800-327-6835
http://www.farmtek.com/farm/supplies/home

Growers who also make tunnels:

Ledgewood Farm Greenhouse Frames
Rte 171
Moultonboro, NH 03254
Phone: (603) 476-8829
www.ledgewoodfarm.com

Howard Hoover Family Farm
2849 Swartout Road
Penn Yan NY 14527
315-536-3192

Additional High Tunnel Suppliers

1. M. Leonard (Piqua, Ohio) www.amleo.com
2. Atlas Greenhouse Systems, Inc. (Alapaha, Georgia) www.AtlasGreenhouse.com
3. Conley's Greenhouse Mfg. (Montclair, California) www.conleys.com
4. CropKing, Inc. (Seville, Ohio) www.cropking.com
5. GothicArch Greenhouses (Mobile, Alabama) www.gothicarchgreenhouses.com
6. Hoop House Greenhouse Kits (Mashpee, Massachusetts) www.hoophouse.com

7. Hummert International (Earth City, Missouri) www.hummert.com
8. International Greenhouse Company (Georgetown, Illinois) http://www.igcusa.com/
9. Jaderloon (Irmo, South Carolina) www.jaderloon.com
10. Keeler Glasgow (Hartford, Michigan) http://www.keeler-glasgow.com/
11. Ludy Greenhouses (New Madison, Ohio) www.ludy.com
12. Poly-Tex Inc. (Castlerock, Minnesota) www.poly-tex.com
13. ShelterLogic (Watertown, Connecticut) http://www.shelterlogic.com/
14. Speedling Inc. (Sun City, Florida) www.speedling.com
15. Stuppy Greenhouse Mfg (Kansas City, Missouri) www.stuppy.com
16. Turner Greenhouses (Goldsboro, North Carolina) http://turnergreenhouses.com/
17. XS Smith (Eatontown, New Jersey) www.xssmith.com
18. Zimmerman's Welding (Versailles, Missouri) 573-378-4770

High Tunnel Construction Plans:

Penn State high tunnel plan:
http://njsustainingfarms.rutgers.edu/PDF/Design_construction_Penn_State_high_tunnel.pdf (or use other option as on page 17)

University of Kentucky high tunnel plan:
http://www.uky.edu/Ag/NewCrops/hightunnel.pdf

New Mexico high tunnel plan:
http://cahe.nmsu.edu/pubs/_circulars/CR-606.pdf

Utah State Univ., detailed plans and costs:
http://extension.usu.edu/files/publications/publication/HG_High_Tunnels_2008-01pr.pdf

Rutgers University instructions and plans, including a 61-slide slideshow of the process:
http://njsustainingfarms.rutgers.edu/hightunnels.html

Additional High Tunnel Resources:

High Tunnels web site: http://www.hightunnels.org

Growing for Market web site
http://www.growingformarket.com/
Featuring: *The Hoophouse Handbook*, available in softcover, or as a downloadable e-book and *Growing for Market* newsletter.

Northeast Sustainable Agricultural Research and Education program (NESARE) website:
http://www.uvm.edu/~nesare/FGinfon.html.

Tunnel Construction

Erecting Superstructures

A brief overview of single-bay and multi-bay tunnel construction is provided here by way of introduction. Construction procedures vary with manufacturer and models so follow the manufacturer's instructions provided or do-it-yourself design plans.

For single-bay structures, pay close attention to construction details as this affects how easily the sides roll up to ventilate. Tunnel construction is far easier on level ground.

Most tunnel framing consists of steel pipe or tubing (or PVC tubing). These are bent into bows and form the 'ribs' of the high tunnel (Figure 10). It is important to note peak-style tunnels shed snow loads better than the more gradual curves of Quonset-style tunnels (Figure 11).

After standard soil preparation, metal pipes are driven into the ground along the sides of the tunnel at set intervals, depending on the model of tunnel under construction. The pipes need to be set at approximately 2 feet in depth. The metal bows or ribs are then set into the ground pipes and fastened in place with bolts.

Batten boards are added to stabilize the structure and hold plastic in place (Figures 16 and 17).

Figure 16. Peak-style high tunnel framing - side view showing close up of batten board fastening.

Figure 17. Peak-style high tunnel framing - side view showing batten boards.

Tunnel ends may be plastic or wood, but should be hinged in some fashion to permit ventilation in the summer and entrance and egress of equipment. (Figures 17, 18, 19, and 20).

Figure 17. Peak-style high tunnel framing – front view shows end framing. Doors open outwards at both ends.

Figure 18. Peak-style high tunnel framing - close-up of end door.

Figure 19. End door construction (L to R) door stop, pulley system for door closure, door closure.

Figure 20. Hinged plastic covered tunnel doors.

For multi-bay tunnels, follow manufacturer's instructions carefully. Since these systems usually cover large areas, it is particularly important to accurately measure and mark the leg rows, making sure row spacing is correct and the corners of the tunnel area are square or 90 degrees to one another. Once the ends of each leg row are marked, weed barrier fabric can be laid along each row (Figure 21). The fabric controls weeds and facilitates water drainage while preventing erosion.

Figure 21. For multi-bay tunnels, weed barrier fabric is installed in the leg rows to control erosion and weeds.

Next, mark points in the rows where legs will go, then cut 4-5 inch long slits in the fabric to accommodate installation of the legs.

Legs are manufactured with screw-like ends to auger into the ground (Figure 22). Legs are installed one by one to the desired depth with a skid steer and hydraulic drill or hand-held augers. Watch the legs from the side to make sure they are vertical.

Figure 22. Multi-bay tunnels; leg posts are augered in at pre-marked positions.

Hoops are usually shipped as straight pipe that are bent on site. The bent hoops can be carried to the tunnels where two people lift the ends and insert them over the leg posts (Figure 23).

Figure 23. Multi-bay hoops are installed on leg posts.

Once the hoops are in place, they can be secured to the leg posts with tech screws. Struts, wire and side anchors provide support and strength. Braces are also installed between the first three hoops. Ladders or a hydraulic lift are needed for this step. The braces are positioned diagonally from the first leg down to the second leg. An additional brace is installed at the top of the tunnel between the first and second hoops. Each hoop is then connected to the next at the peak using a wire or nylon strap. Duct tape or specialized anti-friction tape provided by the manufacturer is applied over joints and wire where contact with the plastic is prevalent to reduce the wear on the covering.

End anchors are installed on outside leg rows for added strength. These are placed outside of every second leg on the outside rows only. They are augered into the ground in the same way as the leg posts. The three closest leg posts are wired to each anchor.

A side bracing wire or pipe is run along each leg row and connected to each leg about 4 inches below the fork (Figure 24).

Figure 24. Diagonal pipe and wire braces.

A second wire runs the length of the tunnel and is attached to each hoop a few inches above the bottom. Additional reinforcing wire is installed over adjacent hoops in the middle of the tunnels.

Applying the Plastic

High tunnels are typically covered with a 6-mil layer of polyethylene plastic. The plastic polyethylene film manufactured for use on high tunnels and greenhouse is typically treated with an additive that prevents UV radiation from degrading it. General purpose plastic sheeting as you may obtain at a home improvement store is not treated and will degrade in sunlight faster, only lasting 1 or 2 years on a tunnel at most.

Various features in plastics are available. Light-diffusing plastics transmit similar light levels to standard plastics. These types of plastic can result in less shading and more light getting to the lower leaves, and cooler tunnel temperatures.

Plastic that screens infrared radiation helps to keep tunnel temperatures cooler during the summer. This appears important for raspberries, which thrive in cooler summer temperatures.

Finally, plastic is available that is treated to prevent water that condenses on the plastic from forming into droplets and dripping on the plants, instead causing the water to run down plastic in a thin layer. This ability may diminish over time.

Plastic with these additional features will cost more than standard plastics. Plastic technology continues to advance; consult a plastics specialist before purchasing a cover to get the best plastic available.

Choose a time of day that is relatively calm with little or no wind (i.e. early morning) to apply the plastic. Several workers are needed for plastic installation.

Figure 25a. Applying the plastic over the high tunnel superstructure.

For single bay tunnels, first unroll the plastic over the top of the tunnel. Allow several inches (< 8 inches) of overhang on the end so plastic may be adjusted later if need be and to help in rain runoff.

Figure 25b. Applying the plastic over the high tunnel superstructure.

Beginning there, fasten the plastic from the top down. After one end is secured, pull the plastic tight (not too tight; it will cut during fastening) and fasten the opposite end. (Figures 25a, 24b, 24c).

Figure 25c. Applying the plastic over the high tunnel superstructure.

Fasten the plastic to the side batten boards approximately 5 feet above the soil line on each side of the tunnel. Wiggle wire works well for this purpose (Figure 26a).

Figure 26a. Fastening the plastic to batten boards with wiggle wire. The wire secures the plastic by pinching it in a channel.

Black straps made of batten webbing are then fastened to hook eyes in the batten board and tossed diagonally over the tunnel and fastened on the opposite side to help prevent the sides from flapping and chafing in the wind (Figure 26b).

Figure 26b. Webbing applied over plastic to keep it from blowing in the wind.

Vertical sidewalls below this point are attached to a metal pipe along the length of the structure. A crank or T-handle is then attached to the pipe and is used to roll or unroll the plastic (Figure 2) on the pipe in order to open and close the tunnel sides (Figure 27). This provides protection from rain, ventilation in summer, and heat retention during colder periods. Rolling the plastic so the groove faces toward the inside of the tunnel is better so that water does not accumulate there.

Figure 27. Open vertical side wall.

Optional: Tunnel floors may be covered with a layer of black weed barrier. The purpose of this barrier is 4-fold; 1) it controls weeds, 2) it helps raise the temperature inside the house, 3) it prevents evaporation of soil moisture, and 4) it allows excess water to drain. This barrier should extend across the full length and width of the tunnel and extend slightly under the sides.

Plastic installation on multi-bay tunnels is different. First, pull lengths of plastic down between adjacent tunnels, and cut to provide an extra 6-10 feet on each end. The extra will be used to secure the ends to an inside hoop. (In practice, many growers use extra clamps on the ends rather than the overlapping plastic tail on the end for convenience with good results.)

When conditions are calm and six to eight helpers are available, the plastic bundle is pushed up to the top of the tunnel. It is then unfolded starting at one end and helpers pull the edges to the leg rows on both sides as they work down the tunnel length.

Once the plastic is in place, it is secured to one end as excess material is pulled to the far end. Ropes are then installed over the plastic and secured to the leg posts. These are pulled tight to secure the plastic in place (Figure 28). This is a slow process to begin with, but speeds up as experience is gained. Consult manufacturer's instructions for details.

Figure 28. Bundles of plastic are placed in the troughs between bays then pushed to the peak, unfolded, and secured in place with ropes (left).

Removing the Plastic

Plastic removal is done in reverse order of plastic application. Replacement is length and wear dependent but should occur on approximately a 3 or 4 year interval for tunnels in year round use. Plastic on tunnels used for end of season extension only may be usable for longer periods. Most wear and tear of plastic is caused by fasteners, in some cases reducing plastic life.

Figure 29. When tunnels are not covered, plastic is bundled in black plastic and secured between bays.

Multi-bay tunnel covers are rolled when not in use, and rest in the troughs between bays to keep them off of the ground. These rolls should be covered with black plastic to protect from sun exposure and degradation, and to keep water and ice out of the roll during the winter (Figure 29).

For more information on tunnel construction see the "High Tunnel Production Manual, 2nd Edition". An assortment of publications using various other designs and techniques can be found at http://www.hightunnels.org.

Tunnel Maintenance

Tunnel structures remain relatively maintenance free. Plastic should be inspected regularly for wear and tear; rips should be repaired immediately with clear tape.

If the plastic remains on the tunnel for the winter, periodic removal of snow load may be needed to avoid structural weakening or collapse. This is best done with a non-pointed object such as a long-handled floor broom head or squeegee before a stiff crust or ice forms.

Drip irrigation systems should be inspected for leaks each year before use; drip tapes are particularly attractive to rodents. If the irrigation water is hard (contains high levels of minerals), lines should be flushed with acid before winter. Water treatment may be necessary.

Planting and Plant Selection

Local raspberry production in the Northeast is split for the most part between floricane-fruiting raspberries in the early and mid-seasons, and their primocane-fruiting counterparts mid-to late season (Page 5, Figure 3).Bramble cultivars have not been widely tested under tunnels in the Northeast or Midwest, but varietal differences observed in the field tend to hold under tunnels as well. As a result, those that perform well in the field in one location are likely to do well in tunnels.

Floricane-fruiting raspberries suitable for early season tunnel production include red, purple, and black raspberries (Figure 30). Select early varieties with good cold tolerance for best results.

Primocane raspberries (Figure 31) suitable for high tunnels include both red and yellow raspberries. In this instance, cold tolerance may not be as critical a factor as for floricane-fruiting raspberries.




Figure 30. Top row: Floricane-fruiting raspberries: (L to R) red raspberry, golden raspberry (Rubus idaeus). Bottom row (L to R) black raspberry, (Rubus occidentalis) and purple raspberry (R. idaeus x occidentalis)

Figure 31. Fall-fruiting (primocane-fruiting) raspberry 'Autumn Britten'.

Suggested floricane-fruiting and primocane-fruiting raspberries varieties for high tunnel production are listed in Tables 1 and 2. A more complete description of varieties can be found at the Cornell Fruit Website at www.fruit.cornell.edu/berry/ or in cultivar recommendations for your area.

Four types of plant materials are available for establishing raspberries: tissue culture plug plants, nursery-matured TC plug plants (N-M TC), dormant short canes, and dormant long canes. Table 3 lists advantages and disadvantages for each type of plant material. Nurseries providing raspberry and blackberry propagation material are listed in the Nursery Guide for Berry and Small Fruit Crops found at: http://www.fruit.cornell.edu/berry/nurseries/.

High tunnel brambles can be grown in ground or in containers. In ground production means the tunnel must be dedicated to that purpose alone, unless the tunnel itself is portable. Containerized production may allow multiple crops to be grown in the same tunnel at different points during the growing season - when raspberries are not in the bloom to harvest period.

Containerized Raspberries and Blackberries

Containerized bramble high tunnel production (Figures 32a, 32b, and 32c) allows use of the high tunnel during non-bramble production periods for other crops. It does, however, involve more labor input in terms of transporting containerized plants into and out of the structure.

Figure 32a. Containerized bramble production.

Table 1. Floricane-fruiting raspberries and harvest seasons for high tunnel production.

Raspberry	Summer Season	Description
Red		
Prelude*	Very early season	Berries are small, dark in color, and mildly-flavored. Canes are dense.
Nova*	Early season	Begins fruiting in early July in NY. Productive. Large fruit is flavorful but must be fully ripe to release from receptacle. Canes are stocky and nearly thornless.
Canby	Early season	An old standard that is productive. Fruit is large and flavorful. Susceptible to powdery mildew which can be problematic in tunnels. Canes are smooth.
Titan	Mid-season	Berries are large and have acceptable flavor at best flavor. Susceptible to Phytophthora root rot and crown gall.
Encore	Late season	Large conic berries are flavorful and bright red.
K81-6.	Very late season	Fruit is large and firm with average flavor. Plants are vigorous on well-drained soils. Susceptible to fire blight and Phytophthora root rot.
Black		
Jewel	Mid-season	Mid-season grower standard that is very commonly grown. Berries are large with good flavor.
Mac Black	Late season	Extends the black raspberry harvest season by 7 to 10 days. Produces large berries that can be seedy.
Purple		
Royalty	Late season	Very large conic berries produce excellent processed products.

**Will produce a fall crop that is more substantial in a high tunnel. May be most suitable for double-cropping.*

Table 2. Primocane-fruiting raspberries for high tunnel production.

Raspberry	Fall Season	Description
Red		
Polana	Very early season	Productive in the field with bright red berries that are fair in flavor. Prone to double receptacles which may relate to high temperatures during flowering.
Polka	Early season	Bright, shiny berries sometimes soft and dark but are very flavorful.
Caroline	Early season	Cane growth may be too vigorous in tunnels. Productive and flavorful with medium-sized berries. Produces over a relatively long harvest window.
Autumn Britten	Early season	Cane production is sparse, so close spacing within rows is recommended. Large, uniform flavorful berry, though not as productive as Heritage. Begins fruiting in early Aug. in PA. May form fruit with double receptacles in high temperatures.
Jaclyn	Early season	Large conic berries with excellent flavor that are difficult to pull from receptacle.
Joan J	Mid-season	Has met with grower favor in tunnel production. Good flavor and productivity, fruit may be dark. May not grow as tall in tunnels as Heritage.
Himbo Top	Mid-season	Tends to lack flavor and become soft in hot conditions. Produces long fruiting laterals. Canes need to be heavily trellised.
Heritage	Late season	Very productive and durable. Fruit is small and mildly-flavored. Grows very tall in tunnels.

Raspberry	Fall Season	Description
Josephine	Very late season	Later in PA than Heritage. Large berries with excellent flavor and color.
Crimson Giant	Very late season	Very large conic fruit. Average to good flavor. Begins harvest 30 days after Heritage in NY continuing into November.
Gold		
Goldie	Late season	A sport of Heritage with an apricot color when fully ripe. Other than color, Goldie has similar characteristics to Heritage.
Kiwigold	Late season	A sport of Heritage similar to Goldie.
Anne	Very late season	Large berries with excellent flavor. Cane production is sparse, so close spacing within rows is of value.

Table 3. Plant materials types for establishing raspberries.

Characteristics	Tissue culture plug plants	Dormant short canes/N-M TC plug plants	Dormant long canes
Plant growth and development	Consistent stand of plants, fruiting at approx. same time.	Dormant plants vary in growth rate, dormancy, and time of fruiting first year.	Vary in growth rate, dormancy, and time of fruiting first year.
Plant material	Certified virus-free.	Virus-indexed.	Virus-indexed.
	Small size.	If container grown, needs larger pots.	If container grown, needs larger pots.
	No pre-existing diseases and pests.	Possibility of pre-existing diseases and pests.	Possibility of pre-existing diseases and pests
Climatic restraints	Sensitive to drought.	Sensitive to pre-plant desiccation.	Sensitive to post-plant heat stress.
	Susceptible to frost damage.	Frost tolerant.	Frost tolerant.
Year of first full harvest	Year 2 for primocane-fruiting types	Year 2 for primocane-fruiting types. (Note: Some fruit year 1).	First year
	Years 2-3 for floricane-fruiting types	Year 3 for floricane-fruiting types	

Figure 32b. Containerized bramble production.

The key to successful containerized bramble high tunnel production lies in maintaining plant health when root systems are restricted. Pay careful attention to selection of plant materials, growth medium, and containers. It is also important to provide adequate soil moisture and nutrients during plant establishment and growth.

Establishing Containerized Plants

The growth medium selected for containerized high tunnel brambles should drain readily, contain high levels of organic matter, and have a pH between 5.5 and 6.5. Both custom and commercial mixes have been used with success for containerized bramble growing. It may be advisable to include some sand in the medium to add weight and keep containers from tipping over.

Appropriate containers range in size from 1 (minimum) to 7 gallons. Select the smallest pot size needed to get maximum growth as plants are moved frequently! Experience will tell which size works best for your variety and medium.

One tissue culture plug plant or dormant cane is planted in each container. Plant materials should be watered in after planting and receive adequate water during establishment. A layer of compost applied to the pot surface will help retain moisture and reducing evaporation.

Summer fruiting raspberries and blackberries may be grown outside the first season in or near the uncovered tunnel (Figure 29c). The tunnel floor should be covered with weed barrier fabric or gravel before plants are moved inside for fruiting.

Figure 32c. Containerized brambles grown outside for fruiting under tunnels later in the season.

Potted brambles are then moved into the high tunnel, or plastic is applied to the uncovered tunnel over the plants no later than when they begin to flower, or even earlier when plants are still dormant.

Containerized bramble plants may be used for several successive seasons. After harvest, containers are moved outside until fall allowing the tunnel to be used for other purposes. Summer storage areas should be large enough to space plants apart. Crowded plants will not produce flower buds on lower portions of canes. Pruning should be done before plants are moved to winter storage areas to facilitate plant movement and minimize damage during transit. Plants can be closely spaced in winter storage areas. Winter storage areas should protect plants from sub-freezing temperatures and rodent damage.

Currently, little information is available on variety performance for containerized high tunnel brambles. Varieties which have performed well in containerized greenhouse production may also be suitable for high tunnel production. Some of these include the primocane-fruiting raspberry varieties ‘Autumn Bliss’, ‘Autumn Britten’, Josephine’ and ‘Caroline’, and floricane-fruiting raspberry varieties ‘Cascade Delight’, ‘Chilliwack’, ‘Titan’, ‘Encore’, and ‘Tulameen’.

Plant Spacing

Plants should be arranged in rows with approximately a 2-ft in–row spacing and a minimum of 5.5 to 6-ft between-row spacing for raspberries. Blackberries in containers should be spaced 4 to 5 ft in-row.

Space blackberry rows farther apart (preferably 9 ft minimum) to keep the foliage dry and decrease disease incidence. Primocane-fruiting raspberries can be set at a 7-ft between-row spacing.

Be sure to leave at least a 3-ft space between the tunnel sides and the outside rows. Estimate the total number of containerized raspberries needed for the size tunnel selected.

In-Ground High Tunnel Brambles

In ground production (Figure 33) requires that the high tunnel be dedicated to bramble production alone, unlike containerized production, where other crops may be produced during off-bramble production periods. Soil management issues such as compaction, build-up of soil salinity, and water quality issues can be problematic if left unmanaged.

Figure 33. In-ground bramble production under high tunnel.

Bed Preparation

Work in compost (6 tons/acre) or manure (10-20 tons/acre) or cover crop to increase soil organic matter content. This builds needed water-holding capacity as only irrigation water will be available to plants under the tunnel.

In addition, one may want to work in a slow release fertilizer (100 lb. actual N/acre) at the same time to compensate for lower bioactivity and slower nutrient release under tunnel soil conditions. This fertilizer should be sufficient to feed plants for the first year.

In heavier soils, slightly raised beds may benefit raspberries in high tunnels. Some growers have had success covering beds with black plastic mulch and planting through the plastic. The plastic later is cut or torn so that primocanes are not obstructed, but the plastic provides weed control on the sides of the row.

Plant Spacing

Raspberry rows within the tunnel should be at least 6 ft apart to allow for movement of people and equipment. Blackberries rows should be on an 8-ft spacing. Closer spacing becomes a serious management issue due to vigorous cane growth under tunnel conditions, and is not recommended.

In-row spacing should be closer than the 3 ft recommended for field plantings. Summer raspberries grown for early season production should be spaced approximately 2 ft apart.

Fall-bearing raspberries may be planted at a 2 ft spacing unless a first year harvest is desired. A one foot spacing, coupled with early plastic cover often results in vigorous first year growth yielding a significant harvest for the planting year. Plants should be established as early in the spring as possible in the planting year to further maximize first year harvest.

Thornless blackberries are very vigorous and rows should be 8 ft apart. Plants within rows should be spaced a minimum of 4 ft., possibly wider depending on the trellising system.

Over time, high soil salinity can become an issue in tunnels that are covered year-round, regardless of whether inorganic fertilizers or composts are being used. This has been an issue primarily with salt-intolerant crops such as strawberries, but could negatively impact growth of raspberries and blackberries as well. For this reason, it is recommended that in years when the plastic is being replaced, it should remain off for at least 2-3 months to allow time for rain to leach salts from the soil. Soil salts that build up in three-season tunnels are removed by leaching during the off-season when plastic is not in place.

Some growers report issues with soil compaction from foot traffic in tunnels as well. In these cases, using a subsoiler has been beneficial in breaking up the hardpan before planting a new crop in the tunnel.

Tunnel Management

Moisture and Fertilizer Requirements

Soil moisture should be measured using a tensiometer or other methods (see bibliography) at regular intervals. Drip irrigation may be needed as often as 2 to 3 times per week, depending on readings. It is critical to carefully monitor soil moisture and irrigate as needed; no other moisture source is available for sustaining plant growth and development under the tunnel. However, because wind is reduced in a tunnel, plants may actually use less water than when outside.

Nutrient levels should be sufficient for the establishment year if a slow-release fertilizer was incorporated during bed preparation.
Leaf analysis should be done in early summer of the second year. Nutrients should be amended based on analysis results through use of soluble fertilizers applied through an injection system into the drip irrigation. A ball park estimate might be 100 ppm nitrogen twice a week; remember to adjust this based on analysis results.

In sandier soils, potassium levels may become deficient. If potassium levels become too low, using a soluble fertilizer balanced in nitrogen and potassium may help. Additionally, high calcium and/or magnesium levels in soil or water may contribute to difficulties in the plants obtaining sufficient potassium.

Controlling Environmental Conditions (Tunnel Venting and Covering Times)

With single-bay tunnels, temperatures inside the tunnel are moderated by opening and closing sides, end doors and/or peak vents.

Sides may be rolled up fully, or partially, depending on outside temperatures (Figure 2). During the summer, sides can remain rolled up day and night. In spring and late fall when temperatures are cold at night, sides should be closed overnight.
Sides should be opened each morning to dry leaves on which condensate collected at night, and closed before sunset to keep houses warm during the night. Peak vents (Figure 34) should also be opened in the mornings to create a draft by allowing warm air to escape as it is replaced by cooler air entering from rolled sides, drying foliage more quickly.

Figure 34. Venting the tunnel – peak vents.

Opening end doors is a quick way of reducing heat build-up on warm days. During the winter, tunnels may be kept closed to keep snow out and encourage an early start to the spring season.

Temperature control in multi-bay tunnels is achieved by opening and closing the ends and sides, and by pushing the plastic up along the hoops (Fig. 35).

To retain heat early and late in the season, plastic skirting is installed on the bottom of leg-rows, and ends are enclosed by doors. For maximum venting in the summer, ends are opened, skirting is dropped, and the tunnel plastic is pushed up along the hoops.

Figure 35. Multi-bay tunnels are vented by opening the ends and pushing the plastic up on the sides.

Optimum temperatures for tunnel culture of brambles are not well defined, but raspberry growth is likely best when daily temperatures fluctuate between 65 and 80 °F. Tunnel temperatures in the summer often exceed this, so venting is an important task. Optimum temperatures for blackberries are higher. However, in

July 2011 outdoor temperatures exceeded 100°F for 4 consecutive days in Ithaca, NY. Blackberry yields were lower that season than in previous years, likely due to even higher temperatures in the tunnels.

Multi-bay tunnels can be covered and uncovered when desired. Covering brambles early in the spring hastens harvest, but also may lengthen the internode length of canes, and can result in excessive cane height. Plants covered later in the spring tend to grow to more manageable heights.

Growers may opt to uncover tunnels of floricane-fruiting raspberries after harvest is complete. This may help to control excessive primocane growth in the late summer and fall.

Care and Management of Established Plantings

Pruning/Trellising

The same techniques apply under high tunnel production as they do for field production for both floricane-fruiting and primocane-fruiting raspberries.

Very strong trellising is required to support the fruit load obtained in a tunnel (Figures 36a, 36b, 36c, and 36d).

Figure 36a. T-trellis system.

However, it is highly recommended that the V shape spread should be kept to less than 3 1/2' due to the narrow confines of tunnel, unless the trellis is adjustable. Early season floricane varieties often have shorter canes and need lower or extra middle wires to support the fruiting laterals.

Figure 36b. Common V-trellis constructed with narrow boards tied to a sturdy stake and drilled with holes to accommodate wire.

Figures 36c. Black raspberries grown with standard trellis.

Figure 36d. Black raspberries grown with V-shape trellis.

Trellis Growing Systems has a strong, yet flexible system that allows the canopy to be configured into a V-shape (Figure 37) when access is not needed down the alleyways**.** For more information on this growing system visit: http://www.trellisgrowingsystems.com/

Figures 37. V-shape trellis system using fiberglass poles requires very little space to anchor.

Most primocane-fruiting raspberries require a modest trellis to hold canes erect for harvest. This trellis can be removed each year so canes can be cut to the ground. Because of limited space within the tunnel, the objective of the trellis to is hold canes erect to facilitate harvest – rather than maximizing light interception per plant. Varieties such as 'Caroline' which may produce excess vegetation and 'Himbo Top' which has long fruiting laterals may require more support than other varieties, and may respond to cane thinning.

Primocane-fruiting raspberries can be pruned to ground level after fruiting (for fall crops only), or they can be overwintered and allowed to fruit again in early summer. Some cane thinning will be required then to assure adequate fruit size in the summer.

Weed Management

It is not possible to over- emphasize the importance of using cultural methods such as cover cropping to reduce weeds prior to planting. A spring pre-emergent herbicide maybe applied if needed (i.e. Devrinol) in tunnels if the plastic is not present.

A post-emergent herbicide may also be applied 6 weeks later (i.e. Gramoxone). Rototill between rows to reduce weeds as needed. If the plastic has been in place for a couple weeks, weed emergence between the rows slows due to dry soil conditions. A small mower may be used between the rows at this stage to manage the small amount of weed growth.

Hand weeding is best for in-row weed suppression. Weeds are most likely to be problematic around outside edges of the tunnel. A narrow width of landscape fabric aids greatly.

Pollination

Unlike greenhouse grown brambles which always require introduction of pollinators, there is usually plenty of natural pollinator activity in high tunnels with native bumblebees. Bumblebees are especially fond of high tunnels during late season and may be found waiting to enter as soon as doors open or sides roll up on warm fall days when plants are in bloom (Figure 38).

Figure 38. Native bumblebees fill the tunnel on fall days when raspberries are in bloom.

Some growers have reported crumblier berries in tunnels with summer-fruiting raspberries. This is likely due to poor pollination during the early season when bee activity is less. Growers of early-flowering crops should position hives so bee activity is adequate within the tunnel. Large ranges of multi-bay tunnels may require introduced bumblebees for adequate pollination, but native pollinators are often adequate for an acre or two.

Season Extension and Overwintering

The highest raspberry and blackberry prices are typically received for berries produced earlier or later than usual for the local markets. Certain tender cultivars produce poorly, if at all, in areas with cold winter conditions when they are unprotected in the field. Single-bay tunnels provide needed protection, while also extending the season.

Overwintering

Many caneberries cannot tolerate winters in Zone 5 or lower. Blackberries with excellent flavor exist, but they often are not fruitful after cold winters. However, blackberries and black raspberries grow and fruit exceptionally well under single-bay tunnels that are covered through the winter.

Despite the fact that temperatures fluctuate more inside than outside a tunnel and that temperatures within can be just as cold as those outside, the plants tolerate this quite well. This is likely because plants in tunnels are not exposed to desiccating cold, dry winter winds, though other factors may play a role.

Keeping the sides of the tunnel up about 8 inches during winter will allow for some venting on warm sunny days without causing desiccation. Special care must be used to exclude rodents, especially rabbits, which can girdle canes. A chicken wire barrier along the base of the tunnel provides protection from girdling by rabbits (Figure 39).

Figure 39. Chicken wire fencing used to exclude rabbits from covered tunnels during winter.

Red raspberries overwinter well under tunnels too, but controlling two-spotted spider mite can be very difficult because the mites overwinter very well in the tunnels. This makes the initial mite population in the spring higher, allowing the mites thrive under hot, dry summer conditions. Certain measures taken to remove the mites' overwintering sites (and the mites along with them), such as thorough removal of leaf litter from the tunnel during the winter, are helpful.

Blackberries and black raspberries are much more tolerant of mites and hot temperatures than red raspberries, so they grow exceptionally well under year around covered tunnels.

Yield differences between outdoor and covered blackberries have been dramatic (Table 4).

Very little production is realized from most blackberries grown outdoors, while full crops are consistently achieved inside the tunnels. 'Doyle's Thornless, 'Ouachita', 'Triple Crown' and 'Chester' have performed well.

In the high tunnel environment, black raspberries exhibit higher yields, a longer harvest season, and improved fruit quality as compared to field production, but their relatively short harvest season, low yields, and added management due to their arching growth habit compared to other bramble crops may not economically justify their production in a tunnel.

Table 4. Comparison of blackberry yields, fruit size and quality between open fields and covered tunnels in NY, 2007. Plants are in their first fruiting year.

Variety	Prod. Syst.	Season length (days)	Berry size (g)	Yield[1]	% MF[2]
Doyle's Thornless	Field	12	4.30	146	42
	Tunnel	52	6.13	4,591	85
Ouachita	Field	44	5.33	267	30
	Tunnel	51	7.90	1,092	72
Triple Crown	Field	36	6.31	460	59
	Tunnel	50	9.57	5,046	86

[1] g/plant
[2] marketable fruit

Early Season Extension

Early season raspberry production under high tunnels may be done with both floricane-fruiting and primocane-fruiting raspberries. Raspberries begin growth sooner and develop at a faster rate under the tunnels.

In this instance, raspberries are under plastic for the winter and get a head start in spring as air and soil temperatures in the tunnels rise more quickly than those outside. Light weight floating row cover can be used inside the tunnel on primocane-fruiting raspberries, both to increase earliness of growth and to protect tender new growth on frosty nights. The cover is removed when plants reach approximately 18" in height. Fruiting may occur as much as 2 weeks earlier than in field grown plants of the same variety using this method.

However, research demonstrates fall yield is not increased by early covering and tunneling, whereas plant height is greatly increased (Figures 40a, 40b). These long canes may be overwintered for a subsequent summer crop that produces about 50% as much as the previous fall crop.

Figures 40a, 40b. 'Heritage' red raspberries grown under field (left) and high tunnel conditions (right), NY.

Careful attention to tunnel venting and row cover removal is *essential* in early season raspberry production to prevent overheating on sunny days.

Late Season Extension

Primocane-fruiting raspberries are well-suited for end of season extension under high tunnel production by planting late cultivars or delaying harvest, protecting fruit, and capitalizing on high prices.

In the Northeast, the first heavy frosts occur in late September to early October when fall-bearing raspberries are in the early to middle stages of fruit ripening and harvest. High tunnels allow fruit to continue ripening into November. This, together with tighter row spacings (7 vs. 10 ft), higher percentage marketable fruit, and higher yields per plant has resulted in yields that are often several times higher than those in the field. Multi-bay tunnels also prolong the fall picking season, but since they are not as well sealed as most single bay tunnels, seasons are not prolonged as much.

Several techniques have been tested to delay harvest. Research indicates that June pinching of 'Heritage' primocane-fruiting raspberry can delay peak flowering and fruiting for 3-4 weeks in comparison to unpinched controls. Outside plants succumb to frost in early October, but those within the tunnel continue fruiting for another 4 – 5 weeks, even longer if they have been pinched. Only small differences in yield were observed between pinched and unpinched treatments when pinching occurred during June. To use this technique, use a soft pinch to remove apical meristems and promote branching when canes are approximately 30 inches in height (Figure 41).

Pinching half the planting is a good strategy to harvest over a long period.

Figure 41. Cultural manipulation of 'Heritage' primocane fruiting raspberries – early pinch method.

Season end may be extended further with the use of lightweight floating row covers inside the tunnel. Covers are applied when night temperatures are predicted to fall to 25 °F or lower, and then removed in the morning when temperatures begin to rise inside the tunnel (Figure 42).

Yields from fall-crop-only raspberries have been quite high, between 2,000 – 4,000 half-pints per 30 X 96 ft. tunnel. Canes are mowed to the ground after harvest and the cycle repeats. 'Heritage', 'Caroline', and 'Josephine' have performed well in this system. 'Josephine' is a very high quality fall-fruiting red raspberry that is naturally late to fruit, so requires no pinching.


Figure 42. Light weight floating row cover used inside the tunnel protects fruit and foliage on colder nights.

While fall-fruiting raspberries have been available for 40 years it is only recently that their blackberry counterparts have become available. Recently released from the University of Arkansas breeding program of Dr. John Clark, these thorny primocane-fruiting blackberries can be mowed down after harvest. They emerge the following spring and fruit in fall. The first two commercially available cultivars from this breeding program are 'Prime-Jim' and 'Prime-Jan'. Performance of 'Prime-Jan' primocane-fruiting blackberry is currently under trial with the intention of producing these fruits in September and October. 'Prime-Ark® 45' and other later advance selections from the same breeding program have improved flavor and size compared to 'Prime-Jan' but yields have been very low compared to floricane-fruiting blackberries, producing about 10% as much fruit in comparison.

Research in other states suggests that a soft pinch in spring benefits primocane-fruiting blackberries by synchronizing their flowering and increasing yield (Figure 43).


Figure 43. Cultural manipulation of 'Prime Jan' primocane-fruiting blackberries – early pinch method.

Pest Management Considerations

Bramble pest management needs under high tunnels, as with greenhouses, are greatly reduced compared to field production. That said regular scouting remains the first and foremost line of defense in pest management. Plant health should be monitored frequently (1-2 times/week) and careful records of growth and development kept from week to week, as well as season to season.

Growers frequently ask which pesticides can be applied in high tunnels. EPA's current interpretation of pesticide labeling is relatively non-restrictive (if it's labeled for outdoors and not specifically prohibited from tunnels, it can be used); however, individual states can place greater restrictions on use. Growers are encouraged to check with local authorities, extension personnel, or their state's Department of Agriculture for regulations that pertain to their state.

Arthropod Pests (Insects and Mites)

The most significant and frequent arthropod pest occurring in high tunnel raspberries is two-spotted spider mite (Figures 44a and 44b).

Figure 44a. Adult female two-spotted spider mite.

Stylet oil may be applied as plants are emerging from dormancy to reduce mite pressure. Biological control options are available for two-spotted spider mites and if applied while populations are at or below threshold levels, may be used with good success under high tunnel conditions.

Management of two-spotted spider mites on brambles often requires only two releases of predatory mites during the life of the planting. *Neoseiulus fallacis* is a native species that does well in brambles and can survive without mite prey.

Figure 44b. Two-spotted spider mite damage on raspberries - white stippling (spotting).

Scout for mites and mite damage twice a week with a 10x hand lens. Check the undersides of leaves in several locations throughout the tunnel. Mites are most often seen first in the lower to middle canopy. Be sure to examine the lower sides of leaves for the presence of mite adults and eggs. Introduce mite predators as soon as mites are observed.

Recommended applications rates for predatory mites are usually given per unit area. Predatory mites generally come packaged in a hard plastic breathable container, usually mixed with a bran carrier. They should be applied to leaf surfaces immediately to help ensure good survival and establishment. Follow recommended application instructions and conditions carefully. A *very slight* misting of leaf surfaces may help the bran carrier adhere. Be careful not to over-mist as there is risk of drowning the mites! Sprinkle the mites' carrier gently over leaf surfaces. Predatory mites will move from point of contact to lower leaf surfaces and from leaf to leaf in search of spider mite prey.

If serious outbreaks occur and are not caught early enough for biological control measures to be effective, follow conventional field recommendations for mite reduction and control. Select products based on mode of action and compatibility with predatory mites. For example, hexythiazox is not very hard on beneficial predatory mites, but must be applied early in the infestation (2-3 mites/leaf) in order to be effective since its mode of action affects primarily eggs and immature mite stages.

Mites can be particularly bad when tunnels are covered year round and kept hot during the summer.

Other less serious pests of high tunnel raspberries observed to date include Japanese beetles (Figure 45), potato leaf hoppers (Figures 46a, 46b), aphids (Figure 47), and tarnished plant bugs (Figure 48).

Figure 45. Japanese beetles and damage on high tunnel raspberries.

Japanese beetles present more of a management challenge for both conventional and organic production systems than do two-spotted spider mites. Because adults are highly mobile, new influxes of insects may continue to appear after efforts to control "resident" populations have been implemented. However, Japanese beetles do not prefer plastic covered environments, so populations on tunnel raspberries are often lower than occur on plants in the field. Mechanical collection and destruction of adult beetles is one of the few options for organic management.

Acetamiprid, carbaryl, and malathion are the conventional products labeled for management of Japanese beetles. Conventional products must be applied around harvest periods. Re-entry intervals and days-to-harvest intervals must be taken into account before each application of pesticides.

Although tunnels can help reduce potato leaf hopper (PLH) feeding by physically preventing their entry, injury can still occur. Raspberries differ in their susceptibility to PLH damage. The varieties 'Polka' and 'Jaclyn' have exhibited pronounced leafhopper damage. Look for distorted growth at shoot tips, marginal curling, and yellowing. Proximity to alfalfa may increase PLH problems. When it is mowed adult insects migrate to new food sources in large numbers. Regular mowing of weeds and grass around tunnels and reduction of weeds in field edges and hedge rows can also help reduce PLH populations. When population numbers are high consider applications of conventional products to reduce numbers.

Figure 46a. Potato leaf hopper.

Several species of aphids may be found on raspberries and blackberries. They generally do not pose a problem on brambles as they are often kept in check by natural enemies. If populations build to high levels some degree of damage is possible. One report indicates aphid feeding and the resultant honeydew they secrete caused the growth of sooty mold on ripening fruit, making them unmarketable. Vectoring of viruses from wild brambles in the vicinity by aphids is also a concern.

Figure 46b. Potato leaf hopper damage on high tunnel 'Polana' raspberries.

In terms of biocontrol strategies for aphids, ladybugs are not always as successful under high tunnel conditions as they are in greenhouses. Tunnels are generally open to the air and beetles may move out of tunnel areas in search of more abundant food sources as aphid populations decline. Other biocontrol agents such as lacewings have established well in tunnels, however.

Figure 47. Large raspberry aphid.

Commercial products such as malathion or acetamiprid may be applied to reduce aphid numbers.

Tarnished plant bugs (TPB) have numerous plant hosts; they are attracted first and foremost to flowers and fruit. Their feeding causes deformation of berries (both adults and nymphs). Tarnished plant bugs are often more abundant later in the season when populations numbers can build to high levels.

Commercial products such as malathion or acetamiprid may be applied to reduce TPB numbers.

Figure 48. Tarnished plant bug nymph on green raspberry fruit.

Spotted wing drosophila (*Drosophila suzukii*) is an invasive vinegar (also known as fruit) fly that was first detected in western states in 2008 and in the Northeast in 2011. Spotted wing drosophila (SWD) differs from other vinegar fly species in that the female adult has a large saw-like ovipositor that allows it to pierce and lay eggs in ripening and ripe fruit (as opposed to overripe fruit). Eggs hatch in only 1 to 3 days, and larvae then feed in the fruit for 5 to 11 days. Thus, by the time fruit is ready for harvest tiny white larvae are already present. The highest levels of larval infestation found so far in the mid-Atlantic have been in fall raspberry and late-season blackberry fruit.

Figure 49. First confirmed SWD female (above) and male (below) in New Hampshire, September 2011. Photo courtesy A. Eaton and C. Smith, UNH.

This species is so named because nearly all males have a large black wing spot just forward of the wing tip on each wing (Figure 49). Certain other species of vinegar flies also have spots on their wings, but their spots are either located right at the tip of the wing or are smaller. Females have no distinguishing characteristics other than their ovipositor.

SWD seasonal population patterns in the region are not yet established. However, numbers at the beginning of each growing season probably will be low. Each female can lay between 200 and 600 eggs, and in the mid-Atlantic, 8 to 9 generations are expected to hatch in a typical growing season (Figure 50). The number of generations will vary depending on temperatures. Very high temperatures cause the males to become sterile, and thus populations may drop during periods of hot (greater than 86 F) temperatures.

Since SWD prefers conditions of moderate temperatures and high humidity, it is likely that it will be present in tunnels. However, in different situations, SWD has been reported to either be present in higher numbers in high tunnel raspberries compared to the field, or to be less problematic in tunnels. This could be due to factors such as proximity to other preferred crops and/or cull fruit, harvest intervals utilized, and tunnel temperature. It is not known whether type of plastic covering affects SWD behavior in tunnels.

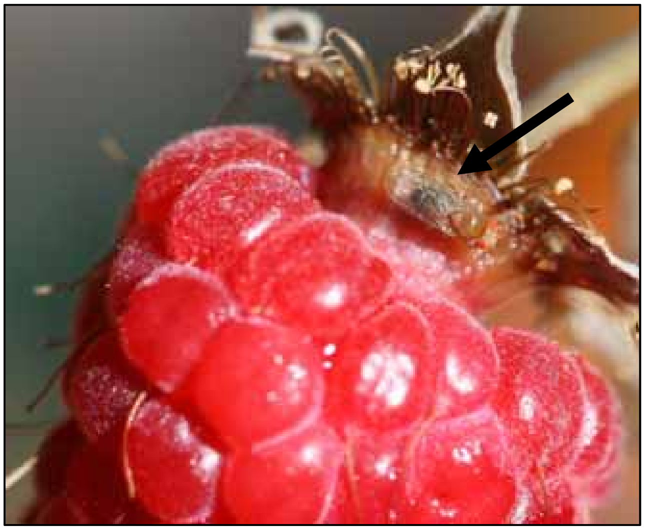


Figure 50. Female SWD sitting on a raspberry fruit, September 2011. Photo courtesy A. Eaton, UNH.

Vinegar traps can be used to detect whether adults are present and thus when management steps should be taken, but will not trap sufficient numbers of flies to make a difference in populations. Important cultural controls are to keep harvest intervals as short as possible, pick very cleanly, and pick fruit as soon as it can be pulled from the plant. Fortunately, these goals are often more attainable in tunnel production compared to the field as the area under production is often smaller and poor weather is not likely to cause missed harvests. Cull fruit should always be removed from the vicinity and destroyed. Composting the fruit only allows SWD to continue to multiply; decomposed fruit also serves as a food source. Fruit, if buried, must be buried very deeply as young flies can emerge after working their way through the soil.

A number of insecticides are effective on adults. Insecticides that contain pyrethroids or pyrethrins (Mustang Max, Brigade, Danitol, and PyGanic) or spinosyns (Delegate, Success, Entrust) as the active ingredient have been effective and also have relatively short pre-harvest intervals. Because this pest has many generations per growing season, development of resistance to pesticides is a very large concern – populations with resistance to PyGanic are suspected to exist on the west coast. Materials from the same chemical class should not be used repeatedly. See publications that discuss SWD identification and management for additional information.

Diseases

Disease pressure under high tunnel production conditions is minimal compared to field production. The tunnel structure helps in minimizing environmental conditions favorable to disease development by excluding precipitation. Careful ventilation to keep relative humidity at low levels and foliage dry will further minimize disease.
The most frequent foliar diseases observed under high tunnel production include powdery mildew and rusts. These diseases are favored more by high relative humidity than actual leaf wetness.

Powdery mildew is caused by the fungus *Sphaerotheca macularis*, and appears as a white powdery patch covering plant surfaces. *S. macularis* is an obligate parasite, meaning it can only grow on its live host. Most powdery mildews are also host specific, infecting only one host. Powdery mildew may occur on all parts of the bramble plant, including leaves, flowers, petioles, and fruit (Figures 51a, 51b, and 51c).

The white patches (fungal mycelium) produce wind-borne spores (conidia) that continue to cause new infections under favorable disease conditions. Care in locating tunnels away from areas where wild brambles grow may help in reducing disease development and spread.

Powdery mildew may be a problem on susceptible cultivars of red, black, and purple raspberries. Blackberries and their hybrids are usually not affected by powdery mildew. Most varieties grown in the Midwest and Northeast today show very good resistance to powdery mildew including the primocane-fruiting varieties ‘Heritage’, ‘Autumn Britten’, ‘Himbo Top’, ‘Polka’, ‘Jaclyn’, ‘Joan J’, ‘Crimson Giant’, and ‘Caroline’, In floricane varieties ‘Prelude’, ‘Killarney’, ‘Moutere’, ‘Titan’, ‘Encore’ and ‘K81-6’ show little to no infection. ‘Canby’ is susceptible and can show extensive infections under conditions favorable to the fungus.

Selection of varieties with known resistance to powdery mildew infection is advisable.

Cultural control methods may also be of some benefit in mildew control. Careful attention to ventilation to keep relative humidity low will help to reduce powdery mildew infection.

While fungicide treatments for powdery mildew are generally not needed in the field, they may be needed under tunnel conditions to prevent widespread disease. Fungicides are labeled for use if needed. Consult the berry pest management guidelines for your area for further details.

Figure 51a. Powdery mildew on raspberry foliage

Figure 51b. Powdery mildew on raspberry buds and blossoms.

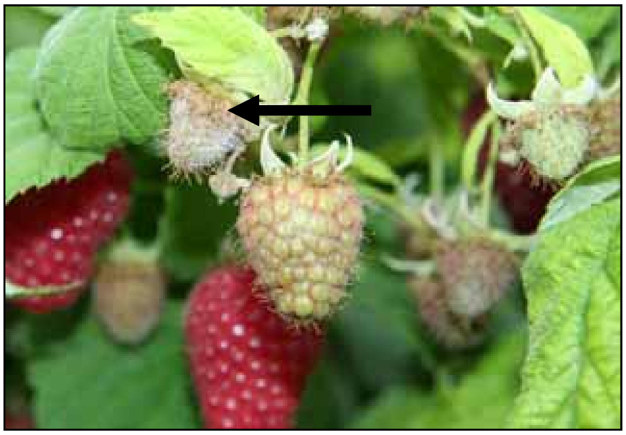


Figure 51c. Powdery mildew on raspberry fruit.

Late leaf rust is a fungal disease of raspberry caused by the fungus *Pucciniastrum americanum* (Figures 52a, 52b, 52c). It does not affect black raspberries or blackberries. This fungus affects many plant parts including canes, leaves, petioles and fruits.

Unlike powdery mildews, rust fungi may require two hosts to complete their life cycle. White spruce (*Picea glauca*) is the alternate host for late leaf rust. Locating tunnels 500 ft. away from spruce plantings or removing white spruce in the immediate vicinity of the tunnel may be beneficial, although the disease has been reported to occur in the absence of the spruce alternate host. Eradication of wild brambles may also help in reducing disease buildup and spread. Very few fungicides are labeled for control of late leaf rust, but unless infections are severe to the point of defoliation, fungicides aren't necessary. Consult your Extension personnel for more information.

Figure 52a. Late leaf rust on the underside of raspberry leaves.

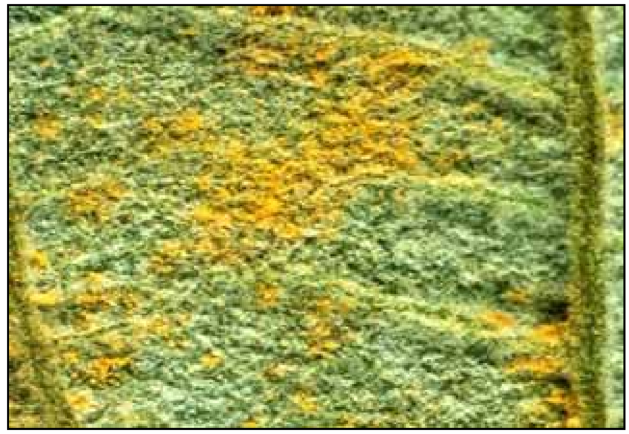


Figure 52b. Late leaf rust on the underside of raspberry leaves; note large light yellow patches between veins.

Figure 52c. Late leaf rust on raspberry fruit.

A different type of rust may occur on purple and black raspberries and blackberries – orange rust (Figures 53a, 53b and 53c). This disease is caused by 2 similar fungi; *Arthuriomyces peckianus* on raspberry and *Gymnoconia nitens* on blackberry. Unlike *P. americanum*, these fungi require only one host to complete their life cycle and are systemic in nature; once plants are infected they remain infected for life. Orange rust does not kill its bramble host; however, infected plants are stunted and weakened, producing little or no fruit. Orange rust develops under conditions of low temperature (43 to 72 °F) and high relative humidity. These conditions are most prevalent early in the season, as opposed to late leaf rust, which develops in late summer early fall.

Remove wild brambles from the vicinity of your tunnel before planting to minimize chances of orange rust spores reaching your plants. Examine new plants one to 2 months after planting for symptoms. Check them again the following season when canes reach 12 to 18 inches in height. Look for plants that are stunted and spindly, often with rust pustules on new leaves.

Figure 53a. Orange rust on newly emerging blackberry canes in spring.

Rogue out and destroy infected plants (including roots) as soon as they appear. A fungicide application prior to infected plant removal may help reduce spread to adjacent non-infected plants. Cover plants with plastic bags before removing.

Figure 53b. Orange rust on lower leaf surface. Note small dark orange spots (pustules) on lower leaf surface.

Figure 53c. Orange rust. Note stunting of canes and foliage.

A fourth fungal disease also occurs under high tunnel conditions. Gray mold, caused by *Botrytis cinerea*, causes disease on bramble fruit and less frequently, on canes (Figures 54a and 54b). While minimal gray mold occurs under high tunnel conditions as compared to field production, it may occur at low levels, particularly on plants near the tunnel ends or sides that may be exposed to rain. Research has demonstrated that some plastics block light wavelengths that cause *B. cinerea* to sporulate.

Cultural practices to reduce gray mold development and spread include:

- Harvesting all ripe fruit promptly.
- Use of trellising practices that promote air circulation around the berries.
- Removal of infected berries.

Figure 54a. Gray mold (Botrytis fruit rot) of raspberry.

Figure 54b. Cane botrytis of raspberry.

Abiotic (Non-biological) disorders and diseases

Careful tracking of nutrient, moisture, and temperature levels should preclude development of most environmentally–based disorders. Routine soil and foliar analysis will aid in preventing development of nutrient deficiencies.

Raspberries and blackberries may however develop white drupelets (Figures 55a and 55b) under hot, sunny weather conditions, particularly in the fall on fruit surfaces exposed to the sun. This is thought to be caused by heat and UV irradiation (sunburn). Varieties differ greatly in their susceptibility, with 'Heritage' and 'Goldie' known to be very susceptible.

Figure 55a. White drupelet disorder on 'Heritage' raspberry.

Figure 55b. Field symptoms of sunscald (white drupelet disorder) on raspberry.

Wildlife

Wildlife damage, in general, is not a major concern under high tunnel production. Birds sometimes like to roost on the supports of open tunnels. Drip tape, however, is often appealing to mice, moles, and voles as winter habitat and nesting materials. In addition, tunnels provide favorable habitats for woodchucks and rabbits (Figure 56).

Black raspberries and thornless blackberries, may incur feeding injury during the winter months (Figures 57a, 57b).Girdled canes should be cut to the ground in spring since they will be unproductive. Red raspberries do not seem to be affected as much by rabbit damage.

Figure 56. Woodchuck burrow opening into raspberry high tunnel, Ithaca, NY.

Figure 57a. Cane girdling and damage of black raspberry caused by rabbits.

Figure 57b. Girdling of thornless blackberry canes by rabbits.

Harvesting Fruit

One advantage of tunnel raspberries and blackberries is that farm workers can continue harvest (and work) in tunnels even when weather outside is inclement.

Raspberries, in general, are highly perishable and have shorter shelf life than other fruits. That said, raspberries produced under high tunnels have improved shelf life over field produced raspberries and may be kept up to a week in cold storage without significant deterioration. Careful attention to harvest and postharvest handling and storage should provide reasonable shelf life for nearly any market situation (Figures 58 and 59).

Figure 58. Harvesting high tunnel raspberries in late October, Ithaca, NY.

Figure 59. Harvesting fruit on cooler fall days.

Production of high quality raspberries requires special attention to a number of preharvest and postharvest factors, as well as the mechanics of harvest itself. Preharvest factors to consider include cultivar selection, growing site, plant health and nutrition, and disease and pest management.

Harvest conditions should also be considered for maximum berry quality. For example, avoid harvesting wet berries whenever possible. Waiting a few hours after sides are rolled up to begin harvesting can significantly reduce postharvest diseases and improve fruit quality. Visible decay can develop in less than 12 hours on warm, wet berries.

Along the same line, temperature can play a significant role in berry quality. Berries harvested early in the morning or in the evening when temperatures tend to be cooler have better shelf life. Harvested raspberries should never be left in the sun; their dark colors readily cause them to absorb heat. Berries also continue to respire after harvest, generating their own internal heat, and causing shrinkage and reduced sweetness. Low temperature is one factor that helps to slow the respiration process, which is much faster in berry fruit than oranges or apples, for example.

Raspberries should be cooled no later than 4 hours after harvest, sooner if possible. A much better return on investment is realized by making several trips to the cooling facility, rather than by making only one or two trips per day.

Raspberries ripen quickly, but not uniformly over the plant or planting. This necessitates harvest on as tight an interval as every other day. For best fruit quality, raspberries should be harvested before they are fully ripe. They should be picked when they are uniformly bright red in color, but before any darker color develops. A good rule of thumb is to pick them as soon as they release easily from the receptacle. Some varieties just won't pull off until they're really ripe and when harvested too early come off in pieces. This is particularly true in cool weather. Because of their highly perishable nature, brambles should always be picked directly into market containers. Half pint containers are preferable; containers should never hold more than 4 layers of berries to prevent crushing of fruit.

Note: Depending on codes and ordinances, the public may not be allowed inside a high tunnel to harvest fruit. Tunnels with public access may be classified as a structure, and be subject to building codes.

Figure 58. Gold at the end of the rainbow…

Rules For Raspberry Pickers

- Keep your hands clean at all times. Wash hands after each visit to the restroom.
- Do not touch berries before they are ready to harvest.
- Harvest fruit that is uniformly bright red in color, but before any darker color develops.
- Put over-ripe berries into cull container and leave immature fruit for the next harvest.
- Berries should be removed with the thumb and forefinger, keeping the hand cupped under the berry to avoid dropping it.
- Don't overfill your hands to avoid bruising or crushing fruit.
- Do not put trash or cull berries into the market container.
- Never allow harvested fruit to remain in the sun. Move harvested berries to the cold room or cooler as soon as possible.

I. Budget for In-Ground Single-bay High Tunnel Fall-Fruiting Raspberry Production, NY

Site Preparation and Tunnel Construction

- 2880 square foot tunnel (30' x 96')
- 4 rows per tunnel, 90 ft length per row
- Labor ranges from $10 to $15 per hour, depending on skill level

Preplant Costs	Input	Unit	Quantity	$/Tunnel
Soil test	lab test	sample	1.0	$ 15
	labor	hour	0.5	$ 10
Tillage, land preparation	machine	total	0.1	$ 15
	labor	hour	4.5	$ 15
Lime, compost, fertilizers,	materials	total	1.0	$ 50
herbicides	labor	hour	2.0	$ 15
Total				**$ 120**

Tunnel Construction Costs	Unit	Quantity	$/Tunnel	Expected Life (yrs.)	Annual cost
Nor'easter greenhouse	package	1.0	$ 6,405	10	$ 641
80 lb. concrete mix	bag	4.6	$ 55	10	$ 6
Lumber		1.0	$ 932	10	$ 93
Exhaust shutters and door hinges		1.0	$ 209	10	$ 21
Storm door		1.0	$ 122	10	$ 12
Misc. Hardware	mixed	1.0	$ 118	10	$ 12
Labor	hour	166.0	$ 1,660	10	$ 166
Tufflifte infrared polyethylene covering	roll	0.4	$ 131	3	$ 44
Total			**$ 9,632**		**$ 995**

Planting and Growing

- Plant establishment - plants per tunnel = 144
- Variety: 'Heritage' primocane-fruiting raspberry.
- Irrigation system: water drawn from municipal supply.
- Trellis construction: Eight ft metal posts, 7 per row. Two 32" metal cross bars per post.

Raspberry plants	Input	Unit	Quantity	$/Tunnel	Expected Life (yrs.)	Annual cost
Plants, bare root	bare root	plant	144.0	**$ 173**	10	**$ 17**

High Tunnel Raspberries and Blackberries

Raspberry planting	Input	Unit	Quantity	$/Tunnel	Expected Life (yrs.)	Annual cost
Plants, bare root	labor	hour	2.5	$ 25	10	$ 3
Fertilizer	Nitrogen	pounds	6.0	$ 1	10	$ 1
	labor	hour	0.6	$ 9	10	$ 1
Straw mulch	mulch	bale	8.0	$ 24	10	$ 2
		hour	2.0	$ 30	10	$ 10
Hand hoe and weed	labor	hour	4.0	$ 60		
Rototill	labor	hour	3.0	$ 45		
Monitoring and ventilation	labor	hour	12.0	$ 180		
Total				**$ 374**		**$ 17**

Irrigation System	Input	Unit	Quantity	$/Tunnel	Expected Life (yrs.)	Annual cost
PVC coupling	material	each	1.0	$ 1	10	$ 0
Disk filter	material	each	1.0	$ 24	10	$ 2
Pressure regulator	material	each	1.0	$ 9	10	$ 1
Poly pipe adapter	material	each	1.0	$ 4	10	$ 0
¾ ” Poly pipe*	material	per 1oo ft	0.3	$ 9	10	$ 1
Poly pipe reducing tee	material	each	4.0	$ 8	10	$ 1
Poly pipe plug (3/4” insert)	material	each	1.0	$ 2	10	$ 0
18 mm drip in pc drip line	material	per 1000 ft	0.4	$ 107	10	$ 11
Netafilm line end	material	each	4.0	$ 1	10	$ 0
Teflon tape (1/2’ x 260”)	material	per roll	1.0	$ 1	10	$ 0
Hose clamp (1/2” x 1 ¼”)	material	each	4.0	$ 7	10	$ 1
Hose clamp (3/4” x 1 ½”)	material	each	10.0	$ 23	10	$ 2
Install irrigation system	labor	hour	1.5	$ 23	10	$ 2
Total				**$ 219**		**$ 21**

High Tunnel Raspberries and Blackberries

Trellis	Input	Unit	Quantity	$/Tunnel	Expected Life (yrs.)	Annual cost
Metal posts, 8 ft	material	each	28	$ 210	10	$ 21
Lumber, pressure treated, (2'x4'x8')	material	each	19	$ 108	10	$ 11
Nuts, bolts, washers	material	each	3 x 56	$ 22	10	$ 2
Wire vise (5058v)	material	each	32	$ 75	10	$ 8
High tensile wire*	material	per 1000 ft	1.6	$ 27	10	$ 3
Post pounding	labor	hour	2	$ 30	10	$ 3
Cut, drill, install cross bars	labor	hour	4	$ 60	10	$ 6
Wire installation	labor	hour	3	$ 45	10	$ 5
Total				**$ 577**		**$ 59**

Summary of Initial Capital Investment for Tunnel

Item	$/Tunnel	Expected Life (yrs.)
Preplant costs	**$ 120**	10
Tunnel construction costs	**$ 9,632**	10
Plants	**$ 173**	10
Raspberry planting	**$ 374**	10
Irrigation	**$ 219**	10
Trellis	**$ 557**	10
Total	**$11,075**	

High Tunnel Raspberries and Blackberries

Year 1 Production and Harvesting

- 2,700 half-pints per tunnel
- $3.00 per half-pint retail price
- Harvest labor per half-pint $0.50.

Production	Input	Unit	Quantity	$/Tunnel	Expected Life (yrs.)	Annual cost
Cover tunnel	labor	hour	6.0	$ 60	1	--
Retighten cover	labor	hour	4.0	$ 40	1	--
Fertilizer	Nitrogen	pounds	4.5	$ 2	1	--
	labor	hour	0.6	$ 9		--
Leaf analysis	lab test	sample	1.0	$ 23	1	--
	labor	hour	0.2	$ 2		--
IPM	yellow sticky cards	each	48.0	$ 14	1	--
	blue sticky cards	each	48.0	$ 28	1	--
Scouting	labor	hour	6.0	$ 60	1	--
	Sevin 80S	application	3.0	$ 2	1	--
	Malathion 57EC	application	3.0	$ 1	1	--
	Savey 50DF	application	3.0	$ 7	1	--
Apply pesticides	labor	hour	3.0	$ 45	1	--
Prune	labor	hour	4.0	$ 40	1	--
Train canes, trellis	labor	hour	4.0	$ 40	1	--
Narrow rows	labor	hour	6.0	$ 60	1	--
Hand hoe and weed	labor	hour	4.0	$ 40	1	--
Monitoring and ventilation	labor	hour	12.0	$ 180	1	--
Total				**$ 621**		**--**

Harvest						
Half pint baskets	container	each	2,700	$ 135	1	--
Half pint shippers	container	each	225	$ 169	1	--
Plastic vented dome lids	container	each	2,700	$ 140	1	--
Picking, packing	labor	half pint	2,700	$ 1,350	1	--
Total				**$ 1,794**		**--**

Yield	Input	Unit	Quantity	$/Tunnel	Expected Life (yrs.)	Annual cost
harvested berries	gross income	half pint	2,700	$ 8,100	1	--
Total				**$ 8,100**	**--**	**--**

Year 2 Production and Harvesting

- 2,700 half-pints per tunnel
- $3.00 per half-pint retail price
- Harvest labor per pint $0.50.
- Replace plastic every 3 years

Production	Input	Unit	Quantity	$/Tunnel	Expected Life (yrs.)	Annual cost
Cover tunnel	labor	hour	6.0	$ 60	1	--
Retighten cover	labor	hour	4.0	$ 40	1	--
Fertilizer	Nitrogen	pounds	6.5	$ 3	1	--
	labor	hour	0.6	$ 9		--
Leaf analysis	lab test	sample	1.0	$ 23	1	--
	labor	hour	0.2	$ 2		--
IPM	yellow sticky cards	each	48.0	$ 14	1	--
	blue sticky cards	each	48.0	$ 28	1	--
Scouting	labor	hour	6.0	$ 60	1	--
	Sevin 80S	application	6.0	$ 4	1	--
	Malathion 57EC	application	6.0	$ 2	1	--
	Savey 50DF	application	6.0	$ 14	1	--
Apply pesticides	labor	hour	6.0	$ 90	1	--
Prune	labor	hour	6.0	$ 60	1	--
Train canes, trellis	labor	hour	4.0	$ 40	1	--
Narrow rows	labor	Hour	6.0	$ 60	1	--
Hand hoe and weed	labor	hour	4.0	$ 40	1	--
Monitoring and ventilation	labor	hour	12.0	$ 180	1	--
Subtotal				$ 697		
Total				**$ 697**		**--**
Harvest						
Half pint baskets	container	each	2,700	$ 135	1	--
Half pint shippers	container	each	225	$ 169	1	--
Plastic vented dome lids	container	each	2,700	$ 140	1	--
Picking, packing	labor	half pint	2,700	$ 1,350	1	--
Total				**$ 1,794**		**--**

Yield	Input	Unit	Quantity	$/Tunnel	Expected Life (yrs.)	Annual cost
harvested berries	gross income	half pint	2,700	$ 8,100	1	--
Total				**$ 8,100**		**--**

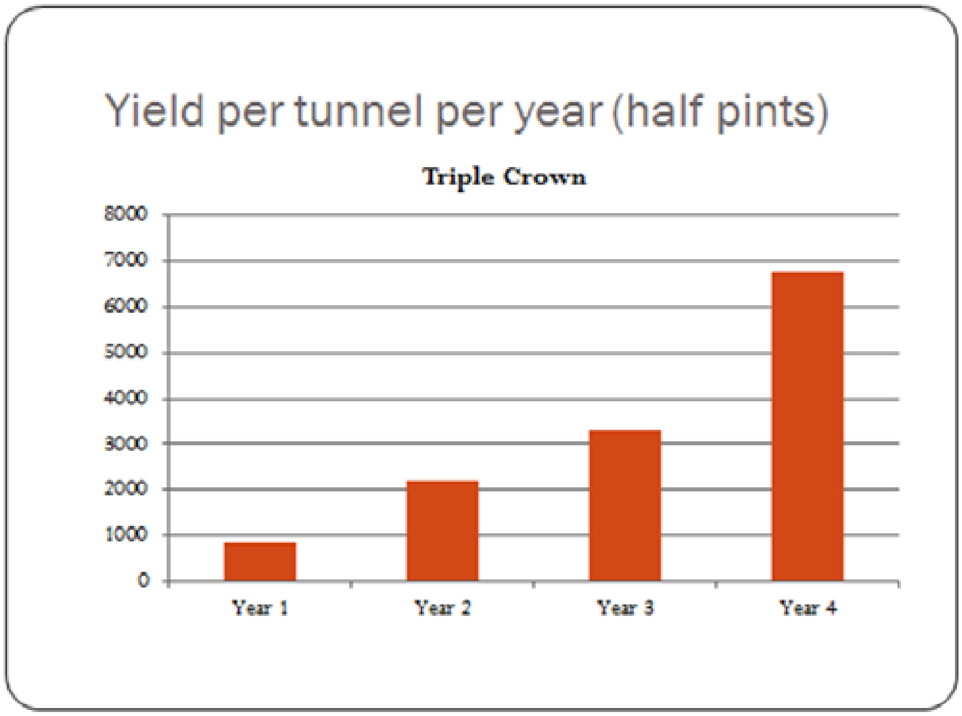
Summary of Annual Cash Expenses (per tunnel)

Year	Expenses	Revenue	Interest (8%)	Cumulative Cash flow*
(establishment) **0**	($ 11,075)	---	($ 886)	($ 11,961)
1	($ 2,415)	$ 8,100	($ 502)	($ 6,778)
2	($ 2,491)	$ 8,100	($ 94)	($ 1,263)
3	($ 2,491)	$ 8,100	($ 0)	$ 4,346
4	($ 2,851)	$ 8,100	($ 0)	$ 9,595
5	($ 2,491)	$ 8,100	($ 0)	$ 15,204
6	($ 2,491)	$ 8,100	($ 0)	$ 20,813
7	($ 2,851)	$ 8,100	($ 0)	$ 26,062
8	($ 2,491)	$ 8,100	($ 0)	$ 31,671
9	($ 2,491)	$ 8,100	($ 0)	$ 37,280
10	($ 2,491)	$ 8,100	($ 0)	$ 42,889

*** Excluding marketing costs**

II. Budget for In-Ground Single-bay High Tunnel Blackberry Production, NY

Assumptions:



- Tunnel construction, packaging and maintenance costs are the same as for raspberries.
- Yield continues at Year 4 average for the subsequent 7 years.
- Price received is $2.25 per half-pint. Harvest cost is 0.50/half pint.
- Replace plastic every 3 years at $360.
- No interest charge.

Year	Expenses	Gross Sales	Cumulative Net Profit*
(establishment) **0**	$11,983	$0	-$11,983
1	$ 621	$0	- $12,604
2	$1,432	$1,967	-$12,069
3	$2,728	$5,111	$-9,686
4	$3,740	$7,567	$-5,859
5	$7,022	$15,525	$2,644
6	$7,022	$15,525	$11,147
7	$7,382	$15,525	$19,290
8	$7,022	$15,525	$27,793
9	$7,022	$15,525	$36,296
10	$7,382	$15,525	$44,439
11	$7,022	$15,525	$52,942

*** Excluding marketing costs**

III. Budget for In-Ground Multi-bay High Tunnel Fall-Fruiting Raspberry Production, MI

Costs were compiled by Michael Von Weihe as part of his graduate program at Michigan State University. They are based on figures from a five-year raspberry trial in southwestern Michigan. Budgets assume a 1 acre tunnel range. Berries were priced lower than those in the single bay tunnel budgets because they were assumed to be marketed wholesale.

Site Preparation and Tunnel Construction

- Nine 200 x 24 ft bays (o.99 acres)
- 3 rows raspberries per tunnel, total row length 5,400 ft
- Labor ranges from $10 to $15 per hour, depending on skill level

Preplant Costs	Input	Unit	Quantity	$/acre
Soil test	lab test	sample	5.0	$ 75
	labor	hour	2.0	$ 40
Tillage, land preparation	machine	total	1.5	$ 125
	labor	hour	10	$ 150
Lime, fertilizers, herbicides	materials	total	15	$ 350
	labor	hour	1	$ 15
Total				**$ 755**

Tunnel Construction Costs	Unit	Quantity	$/acre	Expected Life (yrs.)	Annual cost*
Haygrove tunnels	package	1	$ 32,000	15	$ 3,413
Labor	hour	200	$ 2,000	15	$ 213
Luminence THB polyethylene		1	$ 6,500	3	$ 2,427
Total			**$40,500**		**$ 6,054**

*includes depreciation and interest (8%) on investment

Planting and Growing

- Plant establishment - plants per tunnel = 2,750
- Variety: ‘Heritage’ or ‘Caroline’ primocane raspberries.
- Irrigation system: single trickle line per row, water drawn from an existing well.
- Trellis system: Two 10 ft lengths metal conduit every 20 ft in row. Wood 4 x 4 inch end posts. Six lengths monofilament wire per row.

Raspberry plants	Input	Unit	Quantity	$/acre	Expected Life (yrs.)	Annual cost
Plants, bare root	bare root	plant	2,750	$ 2,041	10	$ 286
	labor	hour	97	$ 970	10	$ 136
Fertilizer	34-0-0	pounds	100	$ 100	10	$ 14
	labor	hour	2	$ 20	10	$ 2
Total				**$ 3,131**		**$ 438**

Irrigation System	Input	Unit	Quantity	$/acre	Expected Life (yrs.)	Annual cost
Netafim trickle system, including couples, filters and pressure regulator	material	1	1	$ 700	10	$ 98
Installation	labor	hour	15	$ 150	10	$ 21
Total				**$ 750**		**$ 119**

Trellis	Input	Unit	Quantity	$/acre	Expected Life (yrs.)	Annual cost
Pressure treated end posts, 2'x4'x8'	material	each	56	$ 216	10	$ 30
Conduit	material	each	500	$ 972	10	$ 136
Monofilament wire 12.5 gauge	material	feet	32,400	$ 1,010	10	$ 141
Bolts, ties, misc.	material	--	--	$ 100	10	$ 14
Installation	labor	hour	70	$ 700	10	$ 97
Total				**$ 2,998**		**$ 418**

Summary of Initial Capital Investment for an Acre of Multi-bay Tunnels

Item	$/Tunnel	Expected Life (yrs.)	Annualized Cost ($)*
Preplant costs	**$ 755**	10	$ 106
Tunnel purchase and construction	**$ 34,000**	15	$ 3,626
Tunnel plastic	**$ 6,500**	3	$ 2,427
Plant purchase and planting	**$ 3,131**	10	$ 438
Irrigation	**$ 750**	10	$ 119
Trellis	**$ 2,998**	10	$ 418
Total	**$ 48,134**		**$ 7,134**

*includes depreciation and interest (8%) on investment.

High Tunnel Raspberries and Blackberries

Year 1 Production and Harvesting

- 5,330 half-pints harvested per acre (2,000 lb.)
- $1.80 per half-pint or $4.80 per lb. This is based on recent wholesale prices.
- Harvest labor per half pint $0.50.
- Container costs: $0.15 per 6 oz. clamshell containers, $0.50 per 12-container flat.

Production activity	Labor Hours	Labor Cost	Fixed and Material Cost	Expected life (yrs.)	Annual cost
Initial capital investments (interest and depreciation)					
Pre-plant and planting				10	$ 1,081
Tunnel purchase/construction				15	$ 3,627
Plastic purchase				3	$ 2,427
Irrigation and trellis installation				10	$ 537
Install plastic	200	$ 2,000			$ 2,000
Purchase bumblebees			$ 250		$ 250
Irrigate	1.8	$ 18	$ 214		$ 232
Fertilize			$ 465		$ 465
Hand hoe/weed	30	$ 300			$ 300
Harvest		$ 2,667	$ 996		$ 3,662
Remove and store plastic	28	$ 280			$ 280
Total		**$ 5,265**	**$ 1,925**		**$ 14,861**

Years 2-10, Production and Harvesting

- 37,330 half-pints harvested per acre (14,000 lb. per acre)
- $1.80 per half-pint or $4.80 per lb. (based on recent wholesale prices).
- Harvest labor per half pint $0.50.
- Container costs: $0.15 per 6 oz. clamshell containers, $0.50 per 12-container flat.

Production activity	Labor Hours	Labor Cost	Fixed and Material Cost	Expected life (yrs.)	Annual cost
Initial capital investments (interest and depreciation)					
Pre-plant and planting				10	$ 1,081
Tunnel purchase/construction				15	$ 3,627
Plastic purchase				3	$ 2,427
Irrigation and trellis installation				10	$ 537
Install plastic	200	$ 2,000			$ 2,000
Prune canes	100	$ 1,000	$ 15		$ 1,015
Purchase bumblebees			$ 250		$ 250
Irrigate	1.8	$ 18	$ 214		$ 232
Fertilize			$ 465		$ 465
Hand hoe/weed	30	$ 300			$ 300
Spider mite spray	9	$ 90	$ 60		$ 150
Harvest		$ 18,667	$6,969		$ 25,636
Remove plastic	28	$ 280			$ 280
Total		**$ 22,355**	**$7,974**		**$38,000**

Summary of Annual Cash Expenses (per acre of multi-bay tunnels)

Year	Annualized costs*	Revenue	Revenue above costs	Cumulative Cash flow
(establishment) **0**	($ 106)	---	(106)	($ 106)
1	($ 14,861)	$ 9,600	(4,861)	($ 4,967)
2	($ 38,000)	$ 67,200	29,200	$ 24,233
3	($ 38,000)	$ 67,200	29,200	$ 53,433
4	($ 38,000)	$ 67,200	29,200	$ 82,633
5	($ 38,000)	$ 67,200	29,200	$ 111,833
6	($ 38,000)	$ 67,200	29,200	$ 141,033
7	($ 38,000)	$ 67,200	29,200	$ 170,233
8	($ 38,000)	$ 67,200	29,200	$ 199,433
9	($ 38,000)	$ 67,200	29,200	$ 228,633
10	($ 38,000)	$ 67,200	29,200	$ 257,833

*** Includes annual expenses and interest and depreciation on capital investments.**
Not included are costs associated with land values, property taxes, insurance, cooling facilities, marketing and shipping, sanitation services, irrigation pump/well, and new buildings.

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