2019

High Tunnel Production Guide for Raspberries & Blackberries

TunnelBerries

Sponsored by USDA-SCRI

About this Guide

This High Tunnel Raspberries and Blackberries production guide is based on research results generated from ongoing bramble (raspberry and blackberry) high tunnel projects throughout the northeast region of the United States. An important funding source is USDA-SCRI but other state funding sources contributed to the project: NIFA, New York Farm Viability Institute, and USDA Hatch and Smith-Lever Funds.

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Introduction

Much of the world's raspberry and blackberry supply is now produced in simple controlled environment structures such as high tunnels. These systems, along with smaller field tunnels and pest exclusion netting, as well as greenhouses, are sometimes referred to as 'protected culture.' High tunnels protect the crops from the vagaries of the outdoor weather and the very fragile fruits are also protected from moisture (rain, dew, fog) which greatly extends their shelf life after harvest. In addition, high tunnels reduce the incidence of crop diseases and reduce wind damage. Yields can be much higher in tunnels compared to open field production, in part because the growing season is greatly extended by high tunnels and growth is enhanced under reduced wind speeds and with warmer temperatures. Blackberries also can overwinter more successfully in high tunnels so they can be productive in areas once thought too cold for them. Finally, harvesting and other field operations can take place even when it is raining or cold because workers are under cover as well.

Figure 1: Examples of high tunnels with berry crops inside. Top, a single bay tunnel; above, a multi-bay tunnel.

Consumer interest in obtaining produce from local producers provides an opportunity for expanding local and regional market shares relative to those currently held by domestic and foreign imports. Production of high quality, locally grown raspberries and blackberries could potentially shift the market supply from imported to locally-grown along the Atlantic seaboard for much of the year. Although high tunnels are used throughout the world, each region has different options and specific requirements to optimize production under high tunnel systems. This publication presents current data and experiences generated by more than a decade of research with high tunnels in several states in the Northeast and Midwest.

What is a High Tunnel?

High tunnels differ from greenhouses in that they are considered non-permanent structures (i.e., they typically don't have a foundation that involves poured concrete) and they don't have a heating system (i.e., they cannot be used to produce berry crops during the middle of winter).

Growers interested in winter production using greenhouses should consult the publication "Greenhouse Raspberries". https://cpb-us-e1.wpmucdn.com/blogs.cornell.edu/dist/0/7265/files/2016/12/ghrasp-128la1g.pdf

Figure 2: Venting a high tunnel with a manually operated roll-up system.

High tunnels are simple hoop houses covered with a plastic film and side and end walls that can be opened to regulate temperature (Fig. 1). They provide an intermediate level of environmental protection and control be- tween field production and greenhouse production. High tunnels are typically not heated, although some amount of supplementary heat (e.g., from portable space heaters) can be provided for protection on cold nights. Row covers used within high tunnels may provide additional protection from cold temperatures, though this benefit becomes less marked with increasing height.

High tunnel production requires irrigation (e.g., drip irrigation) because the plastic cover excludes rainfall. Plants are generally grown in the ground inside a high tunnel, rather than in containers with soilless media, although both types of production systems are possible. Installing a tunnel over existing rows after planting is more challenging, since at that point the row spacing is fixed and may not be ideal. It is recommended to plant in a way that optimizes the growing space inside high tunnels, even if they will not be installed until after the plants are in the ground.

One difference between greenhouses and high tunnels is the plastic covering. Greenhouses are typically covered with glass, rigid plastic panels, or a double layer of polyethylene film (typically 6 mils thick). High tunnel covers may consist of a single layer of greenhouse grade film that either stays in place for the duration of the film life (single-bay tunnels), or is bundled up and tied to the structure during the winter season (gutter-connected or multi-bay tunnels). High tunnels also have double layers of poly film similar to greenhouses. In some cases, primarily in the ornamental nursery industry, high tunnels are used as overwintering structures and covered with an inexpensive plastic film that lasts for one season.

Unlike their greenhouse counterparts, high tunnels have no permanent foundation since poles are driven into the ground and no permanent floor that prevents planting in the ground. High tunnels often do not have electric service or automated heating/ ventilation systems; the sides of the high tunnel are constructed so that they can be manually rolled up (opened) for ventilation (Fig. 2). Some growers are using motorized gearboxes that can be controlled by thermostats or timers affixed to other climate monitors and that can be battery or solar-powered. The cost is relatively low for this type of 'insurance' (Fig. 3).

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 regulations. Greenhouses, on the other hand, are usually 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

- Higher quality fruit (Figure 4)
- Higher yields per unit area
- Opportunity to capture high prices
- Extended harvest season
- Larger fruit size
- Fewer diseases
- Lower numbers of certain insects
- Extended life of plantings
- Can harvest in the rain
- Fewer weeds
- Less wildlife damage
- Less expensive than greenhouses
- Do-It-Yourself kits are available

Figure 3: Example of a connected tunnel with a motorized side adjustment to improve ventilation.

Figure 4: Heritage berries from a tunnel (left) and field (right). Notice the size and quality difference.

The Disadvantages of High Tunnel Production

- Cost to purchase and construct high tunnels
- Requires attention to detail (e.g., frequent adjustments to the ventilation system)
- Longer harvest season that increases labor demand, requires a reliable and well developed market.
- The plastic film cover requires regular replacement. The interval for replacement depends on the quality of cover.
- Potential for wind damage exists. Proper siting and a high quality frame will reduce the likelihood of damage, but not eliminate it.
- Heavy snow loads can cause structural issues – again, the quality of the steel and the appropriate design and installation will help reduce this challenge.

Site Selection, Preparation, Water Quality, and Tunnel Orientation

Soil Requirements

Good soil quality is an important factor for success, even in tunnels. 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 (>2%). Sandy loam and loamy sand soils are also acceptable since irrigation will be present in tunnels. Clay and other heavy soils are less desirable.

Even though high tunnels keep rain off of the planting, water can still collect around the tunnel and seep under the sides, causing wet areas within the tunnel. Raspberries and blackberries do not tolerate ‘wet feet’. 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 can be useful in heavy soil situations, particularly for ‘three- season’ tunnels where the plastic is removed for winter.

Soils should be tested for nutrients and pH prior to site selection and planting, and recommendations followed for amendments. Brambles grow best at a pH between 5.5 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 in the form of dairy manure, compost, ‘green manure’ cover crops or other materials. 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. Compost (6 tons/acre) will increase soil organic matter content. Compost water-holding capacity is important since only irrigation water will be available to plants grown in the tunnel. Animal manures remain an important source of nutrients for crops, but farmers should refer to the guidelines for produce food safety prior to incorporating manure in a berry crop production system.

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

Note: A standard 30 X 96 ft. tunnel is 1/15th of an acre.

A pre-plant cover crop seeded the year before planting is another 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 over in early spring, a month or so before planting, but there are many cover crop options and growers should consider their specific situation when choosing the appropriate cover crop strategy.

Additional Considerations

Other factors to consider are water quality and availability, especially in tunnels where the plastic cover is kept on the structure all year long. Also consider previous cropping history, the possibility of harmful herbicide carry over, pest populations, and the availability of electricity if needed for any equipment (e.g., motorized roll-up sides, back-up electric heaters, environmental monitoring system).

Soil and Nutrient Management Guidelines

A soil and nutrient management guide for berry production, along with 12 associated webinars, are available for free download at: [https://blogs.cornell.edu/berries/productions/berry- soil-and-nutrient-management-a-guide-for-educators- and-growers/](https://blogs.cornell.edu/berries/productions/berry-soil-and-nutrient-management-a-guide-for-educators-and-growers/)

Cropping History

Brambles, particularly black raspberries and blackberries, should not follow solanaceous crops (such as potatoes, tomatoes, or eggplant) as these crops are highly susceptible to Verticillium wilt, a very destructive soil borne fungus. Because tomatoes are one of the most popular crops grown in tunnels, this may be a challenge if the tunnel was previously used. Weeds such as lambsquarters, pigweed, or nightshades or wild strawberries are susceptible, so if these weeds are present in the prospective planting site, it is possible that soil borne disease levels could be high.

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

Japanese beetle or chafer grubs may be present in soils, especially when formerly in sod for several years. These insect pests are known to feed on bramble roots.

Soil tests are recommended to detect the presence of nematodes, microscopic soil ‘worms’ that 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. These can easily been seen with the naked eye. They are unlikely to be present if the site has been fallow for a length of time.

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). This is particularly important for crop production in high tunnels because rainfall will not occur to leach accumulated salts out of the soil.

Figure 5: Water supply (vertical standpipe) to the inside of a tunnel showing (left) a faucet used for drip irrigation (with an irrigation timer directly attached to the faucet), and (right) an unused faucet for attaching an irrigation hose (not shown).

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. Please consult with your local Extension Agent about water management strategies, and see the Bibliography for resources on drip irrigation design and installation (Fig. 5).

Structural Considerations and Tunnel Orientation

After considering soil suitability, the next step is to examine the potential site for proper 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:

- Overall site conditions
- Sunlight availability and obstructions
- Water drainage
- Ease of movement around tunnel exterior
- In windy areas, windbreaks

The site selected should be relatively level and well- drained. (Fig. 6) Consider the potential for air flow obstruction from surrounding vegetation and/or neighboring structures. Consider the direction of the prevailing wind.

Figure 6: High tunnel placed on excellent site.

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 (i.e., with the end-walls facing the prevailing wind direction) can help reduce the risk of damage.

Tunnels should be located away from tall trees or buildings that cast shade on the proposed site as light can be a limiting factor at certain times of the year. During the standard growing season, plants in north-south rows receive the greatest and most even light distribution.

Very early or very late in the season, the south side of a tunnel will receive the most light. Therefore, it may be preferable at high northern latitudes (above 40^{o}) 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. For three-season production systems (i.e., without overwintering), the light penetration is minimally affected by tunnel orientation.

Orient tunnels to facilitate water drainage. Covered tunnels shed large volumes of rain water along the sides and into the leg rows. Depending on the topography of the site, this water could flow across the tunnel, 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 (free-standing) structures are sometimes oriented across the slope so the sides can be stepped down following the slope.

Tunnels should be fully accessible without being in danger of damage from moving equipment. Proximity to other structures in terms of blocking light exposure or equipment entrance and egress should be considered. The same is 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 wide as the tunnels are tall, to allow enough room for 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 acting as wind breaks.

Tunnel Selection and Sizing

There are different types of tunnels that can be used for raspberry and blackberry production, and more choices are becoming available each year.

Single vs. Multiple Bay

A main difference between types of tunnels is the number of bays needed to provide structural integrity. A single bay tunnel refers to that structure that can stand alone. Multiple-bay tunnels are connected to each other to provide sufficient structural integrity. These structures are also called 'gutter-connected' as they sometimes contain gutters between the bays.

Figure 7: Peak-style (gothic arch) high tunnel during construction and prior to the installation of the plastic film cover, Ithaca, NY.

Figure 8: Multi-bay style high tunnel with plastic cover wrapped between Quonset-shaped tunnels.

Three-season vs. four-season

High tunnel frames differ in snow- and ice-carrying capacities which determine if plastic can be left on over the winter. Tunnels on which the plastic can remain over the winter are 'four-season' tunnels, whereas tunnels that cannot be kept covered are 'three-season' tunnels. Single-bay tunnels are available as either three-season or four-season tunnels. A single-bay tunnel typically costs more per area than multi-bay tunnels because the frame is sturdier, but farmers should be sure to evaluate different brands as all single bay tunnels are not alike. Single-bay tunnels may have a peaked, (Gothic arch) or Quonset-style frame to help shed snow. Gothic arch, or peak-style (Fig. 7) of high tunnel construction better supports snow load and facilitates snow shed better than either Quonset (Fig. 8) or multi-bay tunnels (Fig. 9).

Figure 9: Multi-bay style high tunnels with plastic cover in place, California (left) and Michigan (right).

Figure 10: Peak-style high tunnel collapsed under heavy snow load, February 2010, Ithaca, NY.

Under heavy, wet snow conditions, even peak-style tunnels may be subject to collapse if snow is not removed from the plastic film (Fig. 10). Snow can be (gently) removed from tunnels by tapping the inside of the film with a broom or building a device to pull snow from the top of the tunnel. In worst case scenarios, and similar for high wind conditions, it may be better to cut the film (and likely lose the crop) than to lose the structure due to collapse. When designing a trellis system, keep in mind that in shorter tunnels, trellising posts may be able to provide additional support for the structure during the winter, especially if rows are centered on some of the purlins.

Single-bay tunnels are frequently used in colder climates when farmers are producing plants that must be protected during the winter. Single-bay tunnels that can be rolled on tracks to cover different crops at different times of the year are also 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 usually uncovered during the winter. The majority of small fruit production world-wide and in the U.S. is in multi-bay tunnels.

Multi-bay style frames can be thought of as multiple single-bay sections that are connected along a common sidewall. They are used to cover larger acreages. They are more susceptible to high winds than single-bay tunnels because they typically have less support structure relative to the amount of growing area covered, though heavy rope rigging is used to minimize damage. In contrast to single bay tunnels, the plastic roof cover of multi-bay tunnels should be opened and gathered (at the gutter area) under high wind conditions to prevent damage (Fig. 11). Often multi-bay tunnels are primarily used as rain shelters (Fig. 12). Options exist with at least one manufacturer that allows the tunnel to be lowered for high wind events. As technologies develop, more options will become available for tunnel construction and rigging that can improve the tunnels' ability to withstand adverse weather conditions.

Multi-bay systems can accumulate larger amounts of rainwater runoff in the leg rows. Proper drainage is needed to carry water away from the structure. Buried tile drains in the leg rows may be necessary. A gravel apron around the exterior perimeter will move water and have the added benefit of discouraging weeds.

Landscape fabric also can help prevent soil erosion (Fig. 13). Some manufacturers offer gutters that can be installed in the 'valley' between adjacent bays. On sloped sites, tunnels without gutters should be oriented to allow rainwater to flow down leg rows and out of the structure.

Grass strips are an 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 the legs (posts) secured in the ground under high wind/high water situations such as intense thunderstorms.

Determining Tunnel Size

One consideration for selecting the proper size high tunnel is having enough room to plant, monitor, maintain, and harvest the berries from inside the structure. Some growers want tunnels big enough to accommodate the passage of small tractors for cultivation and spraying.

Tunnel dimensions vary widely with type and manufacturer. 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, but individual bay width should not exceed 30 feet. Wider tunnels are usually taller, but provide more structural support (Fig. 14).

Tunnels exceeding 96 feet in length pose some potential problems. Ventilation of multi-bay high tunnels can be more challenging. Longer tunnels in production use year round may have a higher risk of collapse due to snow loads and may be difficult to ventilate properly. Very long tunnels may 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 advisable to install 4 to 5 foot 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 plant level. Vents installed in the roof and/or end walls allow hot air to escape and draw cool air into the structure. The higher the tunnel, the more air flow occurs through the vents. Even when the sides are fully opened, high temperatures occur in shorter tunnels that don't have additional vents, which can result in plant damage.

Figure 11: High wind damage to a multi-bay style tunnel.

Figure 12: Potted raspberries under rain shelters.

Figure 13: Landscape fabric and a buried gravel trench.

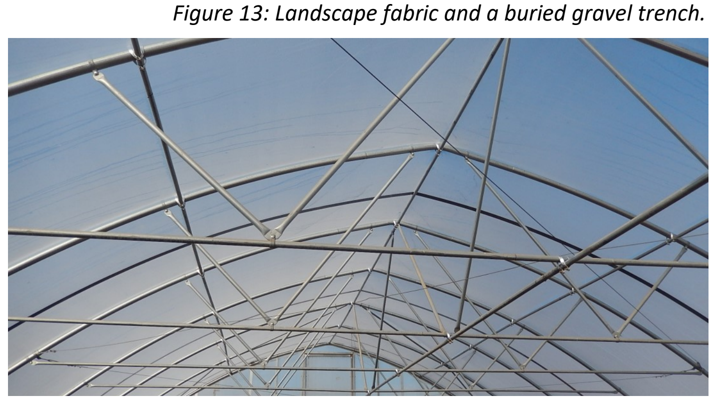

Figure 14: Wider tunnel with more structural support.

Sources for Tunnels and Tunnel-Related Materials*

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
116 Trail Road North, Elizabethtown, PA 17022
Phone: 717-945-8711 http://www.haygrove.com/us/

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

High Tunnel Construction Plans:

- Penn State high tunnel plan: https://sustainable-farming.rutgers.edu/wp-content/uploads/2014/09/ Design_construction_Penn_State_high_tunnel.pdf
- University of Kentucky high tunnel plan: https://www.uky.edu/Ag/CCD/hightunnel.pdf
- New Mexico high tunnel plan: http://aces.nmsu.edu/pubs/_circulars/CR606/
- Utah State Univ, detailed plans and costs: http://digitalcommons.usu.edu/cgi/viewcontent.cgi? article=1296&context=extension_curall
- Rutgers University instructions and plans, including a 61-slide slideshow of the process: http://sustainable-farming.rutgers.edu/high-tunnel-construction-demonstration/

Additional High Tunnel Resources:

- Tunnel Berries: https://www.tunnelberries.org/
- 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.sare.org/Learning-Center/SARE-Project-Products/Northeast-SARE-Project-Products/High-Tunnels
- Cornell High Tunnels: http://blogs.cornell.edu/hightunnels/
- Penn State Extension – search for High Tunnels: https://extension.psu.edu/

** Additional sources may be found at the TunnelBerries website: https://www.tunnelberries.org*

Tunnel Construction

Erecting Superstructures

A brief introduction to single-bay and multi-bay tunnel construction is provided in this section. Construction procedures vary with manufacturer and models so it is recommended to follow the manufacturer's instructions.

For single-bay structures, pay close attention to construction details as this affects how the tunnels operates, especially how easily the sides roll up to ventilate. Remember that tunnel construction is far easier (and safer) when standing on level ground, compared to working on ladders or elevated platforms.

Most tunnel frames are made of steel pipe or tubing. PVC tubing is appropriate only for seasonal, short term tunnels. The steel pipe is bent to form the 'ribs' or 'bows' of the high tunnel. When choosing your rib design, remember that peak- style tunnels (Fig. 7) shed snow loads better than the more gradual roof curves of Quonset-style tunnels (Fig. 8 and 9).

It is important to make sure the tunnel footprint is 'squared', as tunnel components will not fit together properly otherwise. After standard soil preparation, metal ground posts are driven into the ground along the sides of the tunnel at set intervals, depending on the model of tunnel under construction (4 feet is a common interval). The ground posts need to extend to below the frost line (typical depths are 2-3 feet). The metal bows or ribs are then attached to the ground posts and fastened in place with bolts.

A ridge pole or pipe at the peak of the tunnel and horizontal purlins that run the length of the tunnel are next added to tie the bows together. Depending on the width and shape of the tunnel, cross bracing may be used to add strength and prevent tunnel collapse, and will be a necessity with wider tunnels. Diagonal bracing will also typically be attached to the bows to prevent the tunnel from shifting and leaning lengthwise over time. Hip boards or metal track are added to stabilize the structure and hold plastic in place (Fig. 16) at the point where the vertical sidewalls curve to form the roof. Wooden treated baseboards (e.g., 2 by 12 inches) are installed at the soil line to prevent wind entry and provide additional stabilization.

The frames of the tunnel end walls are typically made of wood and then covered with plastic film, and may be hinged in some fashion to permit additional ventilation during the summer and allow for easy passage of equipment (Fig. 17, 18, 19, and 20). On windy sites, keep in mind that every moveable joint is a point where flexing will occur, and it is easy to underestimate how much wear-and-tear will occur over time.

For multi-bay tunnels, follow manufacturer's instructions carefully. It's important to measure and mark the leg rows accurately, making sure row spacing is correct and the corners of the tunnel area are square. Once the ends of each leg row are marked, weed barrier fabric can be laid down (Fig. 21). The fabric controls weeds and facilitates water drainage while preventing erosion.

Figure 16: Fastening batten board to frame.

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

Depending on how you wish to attach the plastic, either wooden hip boards or metal track are added to stabilize the structure and hold plastic in place (Fig. 16) at the point where the vertical sidewalls curve to form the roof. Wooden treated baseboards (e.g., 2 by 12 inches) are installed at the soil line to prevent wind entry and provide additional stabilization.

Figure 17: Peak-style (gothic arch) high tunnel framing (above)—side view showing base and hip boards and end door construction of (L to R below) door stop, pulley system for door closure, door closure.

Some posts are manufactured with screw-like ends that auger into the ground

(Fig. 22). Legs are installed one by one to the desired depth with a skid steer and hydraulic drill or with a hand-held auger. Use a level to make sure the posts are installed vertically.

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 posts (Fig. 23).

Figure 18: Peak-style (gothic arch) high tunnel framing—front view showing end wall framing. Large doors open outwards at both end.

Once the hoops are in place, they can be secured to the posts with tech screws. Struts, wire and side anchors (options provided by the manufacturer) provide support and strength. Cross 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 plastic film.

Side wall anchors are installed on the outside of the outer most row of posts, typically at every second or third post. They are augered into the ground in the same way as the posts. The two or three closest posts are connected (usually with wire) to each anchor.

A bracing wire or pipe is run along each post row and connected to each post approximately 4 inches below the fork (Fig. 24).

A second horizontal wire is installed along the length of the tunnel and is attached to each hoop a few inches above the fork. Additional reinforcing wire may be installed over adjacent hoops in the middle of the tunnels.

Selecting the Plastic Covering

High tunnels are usually covered with a 6-mil layer of polyethylene greenhouse film. The plastic film formulated for use on high tunnels and greenhouse contains additive(s) that slow breakdown from sunlight. General purpose plastic sheeting that can be purchased at a home improvement store <u>is not</u> treated and will degrade in sunlight much faster, lasting 1 or 2 years on a tunnel at most.

Various film characteristics are advertised and discussed in product literature; these vary with manufacturer and individual film type.

Light transmission: High tunnel (and greenhouse) films are designed to transmit a high percentage of visible light, which includes the range of wavelengths that plants use for photosynthesis. The majority will transmit 90% or more of visible light when new; however, over the life of the plastic, dust and grime will accumulate and the percentage of full sunlight entering the tunnel will be reduced.

Figure 19: Door covered in plastic.

Light diffusion: High tunnel films diffuse light to varying degrees. Most are easy to see through at close range, but diffusing films are more difficult to see through from a distance. On bright days, the shadow of the tunnel structure and plants will be clearly visible with non-diffusing films, but will become less discernable as diffusion increases. Because light-diffusing plastics scatter sunlight throughout the structure, there is the potential for more light to reach the lower leaves, depending on foliage density and trellising configuration. Diffusing plastics also scatter wavelengths that result in heat buildup, and thus foliage temperature is lower on bright days under a diffusing film than a non-diffusing one, and sunscald is reduced.

Figure 20: Hinged plastic covered tunnel doors.

Infrared (IR) transmission: "IR"-films are formulated to reduce the amount of infrared radiation entering or leaving the tunnel. Most are sold for use on tunnels or greenhouses that are covered with a double-layer of film; here the objective is to prevent heat loss at night. Some plastics also block IR wavelengths (and some of the visible) light from entering the tunnel during the day, with the intent of reducing daytime temperatures. This helps keep tunnel temperatures cooler during the summer, an important effect especially for raspberries grown in hotter climates. In cooler regions of the country and in tunnels where plastic is kept on all year, the heating that takes place in fall and spring is also reduced, thus potentially cancelling out the benefits of any improved growth during the summer.

UV light transmission: While all films block some UV, the amount and type of UV reduced varies widely among plastics depending on the additives used to prevent breakdown (blockers vs. stabilizers). Some plastics block only the wavelengths of UV which insects,

Figure 21: For multi-bay tunnels, week barrier fabric can be installed in the leg rows to control drainage, soil erosion and weed growth.

including bees, use to navigate, and thus may be sold as being 'bee-friendly'. Growers are likely to notice little to no difference in bee behavior. In tunnels covered in these plastics, what growers may notice is a greater reduction in Japanese beetle numbers. In tunnels covered with increased UV blocking plastics, and also a decreased incidence of sunburn.

Anti-condensate or anti-drip characteristics: Plastic greenhouse film may be treated to affect how water droplets form. Some films may be treated to cause water droplets to remain small and thus remain on the plastic. Other films may be treated so the water droplets run down the film. In either case, large droplets are prevented from coalescing and dripping onto the plants and workers. With some films, the anti-condensate feature may diminish as the film ages.

Various types and sizes of greenhouse films are available from

Figure 22: Multi-bay tunnels; ground posts (legs) are augered in at pre-marked positions.

Figure 23: Multi-bay hoops are installed on ground posts (legs).

Figure 24: Diagonal pipes provide support. Buckwheat is growing as a cover crop.

distributors, both brick and mortar, and the internet. The ideal plastic for raspberry production will vary with latitude and light conditions. Regardless of which plastic is used, growth can be improved greatly by choosing plastics carefully in northern locations, high visible light transmission is the characteristic that is most important to obtaining the highest yields. Plastic technology continues to advance; always consult a plastics specialist before purchasing a film to cover your tunnel. From a cost standpoint, paying for a film doesn't necessarily translate into higher yields – costs have been found to vary more between suppliers of the same plastic film than it does between different plastics from a given supplier, and shipping charges may influence the final cost to the grower more than anything else.

Applying the Plastic

Single-Bay Tunnels

Choose a time of day that is relatively calm with little or no wind to apply the film. Several workers are needed for plastic installation. Measure and cut the plastic to size prior to installation, allowing at least a 12-inch margin for error on all sides.

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

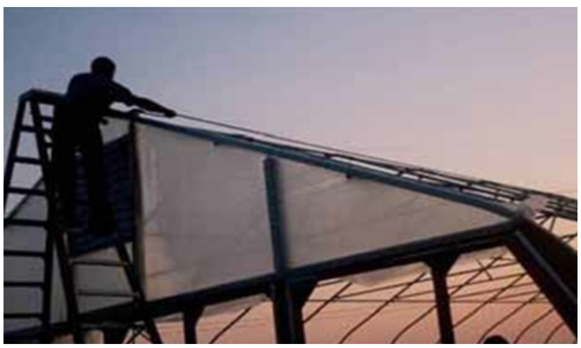

Figure 26: Installing the plastic film to the end wall of a high tunnel.

A common question is whether there is a 'right side' or 'wrong side' to the plastic. If there is a side that must be facing in, information will be stamped on the plastic indicating the correct orientation. If no words are stamped on the plastic indicating this is the case, it is probably safe to assume that there is not an 'in' or 'out' side. However, any literature that accompanies the plastic should be consulted just in case.

Plastic may be applied and attached in different ways.

If attaching sides and top (roof) separately, attach the film to the sides and end walls first, and to the top (roof) of the tunnel last. Therefore the plastic on the roof should be "on top" of the other plastics (e.g., when installing multiple layers of plastic in a single aluminum extrusion track with zig-zag wires); this will assist in keeping the track area cleaner. In other words, start with the sides first and apply the top last.

Figure 27: Fastening plastic to hipboards.

For single-bay (freestanding) tunnels, when installing the film on the roof, some manufacturers may recommend the plastic over the length of the tunnel (Fig. 25).

Next, fasten the film at one end wall. After one end is secured, pull the plastic very taut but not too tight as it might cut during fastening. Then fasten along the opposite end. (Fig. 26).

Finally, fasten the plastic to the hip boards approximately 5-6 feet above grade along each side of the tunnel (Fig. 27).

Nylon ropes or polypropylene straps can be used to keep the film and the roll-up sides securely in place during high-wind conditions. (Fig. 28).

Alternatively, the plastic can be rolled out the length of the tunnel on the ground, cut to length, spread out and regathered close to the tunnel (similar to a curtain), and then tied to weights (rubber mallets, rolls of duct tape) every 15 to 20 feet using a sufficient length of twine that will reach over the tunnel. Weights are either thrown over the tunnel, or passed across the tunnel top, and then the plastic can be pulled over the entire tunnel from the opposite side.

Another option for covering narrower tunnels is to leave the plastic that will cover the roof and sides in one piece. This works best when double track is used to attach the plastic to the hipboard area, as the plastic can be cut after attachment should new plastic for the roof or sidewalls be needed.

Figure 28: Webbing applied over plastic to keep it from blowing in the wind.

Figure 29: Open vertical side wall.

Vertical sidewalls that can be rolled up for ventilation 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 on the pipe in order to open and close the tunnel sides (Fig. 2, 3 and 29). The roll-up sides allow for ventilation and when closed provide protection from rain and heat retention when the outdoor temperature gets colder.

Rolling the plastic so that the pipe stays on the inside is preferred. Otherwise water may get trapped during the rolling process (Figure 30).

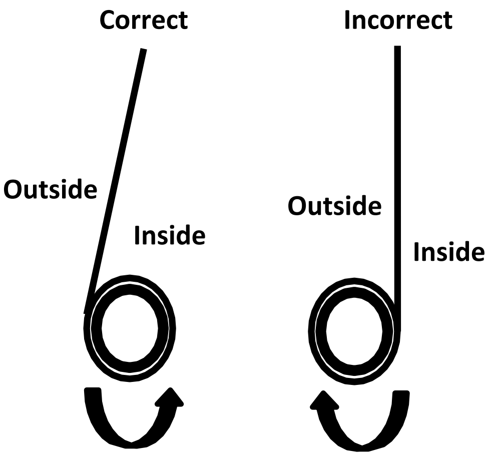

Figure 30: Direction of plastic rolled on pipe.

The final step is to use zig-zag or wiggle wire to attach plastic securely to channels on end walls (Fig. 31). Note that if double-track for wiggle wire is used, wooden hipboards will not be needed.

Optional floor installation: The ground inside a tunnel may be covered with a layer of black weed barrier (landscape fabric). The purpose of this barrier is 4- fold; 1) it controls weeds, 2) it helps raise the temperature inside the house, 3) it reduces 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. It may be applied just between the rows if raspberries will be grown in the soil, or across the entire width if they will be grown in containers.

Multiple-bay tunnels

Plastic installation on multi-bay tunnels is different. First, pull lengths of plastic over the hoops of a single bay, 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 toward the posts on both sides as they work down the tunnel length.

Once the plastic is in place, it is secured to one end and excess material is pulled to the far end. Ropes are then installed over the plastic and secured to the posts. These

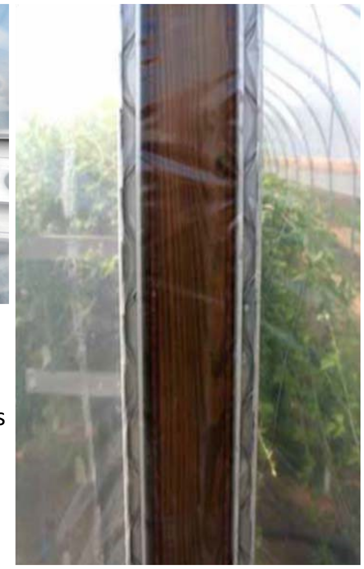

Figure 31: Plastic film attached to the end wall of a tunnel with aluminum extrusions (attached to the wooden frame) and zig-zag wire (wiggle wire). The zig-zag wire secures the film by holding it in place inside the aluminum (U- shaped) extrusion. The zig-zag wire can be easily removed when the plastic needs to be replaced. While the zig-zag wire can be used multiple times, it is often replaced when new plastic is installed.

ropes are pulled tight to secure the plastic in place. This is a slow process in the beginning, but speeds up as experience is gained. Consult manufacturer's instructions for details.

Removing the Plastic

Plastic removal is done in reverse order of plastic application. The replacement interval depends on the duration of use and wear, but should occur in approximately 4 or 5 year intervals for tunnels used year-round. Plastic on tunnels used for end of season extension only may be usable for longer periods. Most wear and tear of plastic will occur at attachment points or where rubbing occurs, which can reduce plastic life. Multi-bay tunnel covers are rolled up when not in use, and secured (bundled) between bays to keep them off the ground. These rolls should be covered with black plastic to protect them from sun exposure and degradation, and to keep water and ice out of the roll during the winter (Fig. 32).

Venting

Installing a vent at the peak of the end wall (Fig. 33) is a good way to reduce the heat load and allow drier air to circulate through the

Figure 32: To apply plastic, the bundles are placed in the troughs between bays then pushed to the peak, unfolded, and secured in place with ropes (left). At the end of the growing season, plastic covers on multi-bay high tunnels are bundled and secured between the bays as shown (right). This method prevents damage to the film during the winter months when no crops are grown inside.

tunnel. These vents are often louvered and can be operated manually or with a small motor. These can be very helpful when venting for temperature and humidity.

Wind damage

Single-bay or multi-bay high tunnels are susceptible to wind damage, especially when opened sidewalls or end walls allow the wind to get underneath the plastic film covering the structures. These wind forces can be so strong that the resulting forces are strong enough to lift the posts out of the ground. When this happens, the structural components (posts and bows) are often damaged beyond repair. Growers are encouraged to be extra vigilant when high wind conditions occur. In some cases it might be preferable to cut the plastic in an attempt to save the structure. However, this strategy could result in the loss of the crop and/or the cost of replacing the plastic. For three-season tunnels, make sure the plastic is securely bundled and tied down so it is not unraveled by winter wind.

Routine Tunnel Maintenance

Tunnel structures remain relatively maintenance free. Plastic should be inspected regularly for wear and tear; rips should be repaired immediately with greenhouse tape made specifically for this purpose. Snow and ice removal is part of the normal maintenance routine.

Figure 33: Vent at the peak of a gothic-style high tunnel.

Drip irrigation systems should be inspected for leaks each year before use; drip tape and tubing are attractive to rodents. If irrigation water has a high mineral level, lines should be flushed with acid before winter.

Routine examination of perimeter to monitor for animal intrusion, especially woodchucks and rabbits, will reduce crop and structure damage.

Production Systems

Diverse bramble and high tunnel types and management strategies offer many options for bramble production in tunnels. The primary goals for growing brambles under tunnels are to increase yields and fruit quality, and to alter the harvest seasons.

Primocane fruiting raspberries

Primocane-fruiting raspberries bear fruit in the late summer and fall on current season canes. When grown in the ground, plants are spaced 2 to 3 feet apart in the row with row centers spaced at least 7 feet. A small crop can be harvested in the fall of the planting year, and full crops picked each fall thereafter.

Primocane-fruiting raspberries in a tunnel may be covered in early spring or as late as mid-summer. Early covering, or growing them under a four-season tunnel, will give plants a head start on producing a fall crop as air and soil temperatures in the tunnels rise more quickly than those outside. Light weight floating row cover also can be used inside the tunnel in early spring to accelerate growth and protect tender new growth on frosty nights. The cover is removed when primocanes reach approximately 18” in height. Using this method can push fruiting as much as 2 weeks earlier than in field grown plants of the same variety. Careful attention to tunnel venting and row cover removal is essential in early season raspberry production to prevent overheating on sunny days.

Delaying covering plants until mid-summer (just prior to bloom) has the advantage of extending the harvest season into the fall. Rather than accelerating flowering and fruiting, covering later in the spring will allow harvest of some cultivars to be extended into November since plants will be protected under the cover. Tight row spacing, higher percentage marketable fruit, and higher yield per plant have resulted in total yield/area that is often several times higher than in the open field.

Multi-bay tunnels also prolong the fall picking season but not for as long since they are not sealed as well as single bay tunnels.

To ensure late harvest, a portion of the primocanes (e.g. 50%) may be pinched when they reach a height of 3 – 4 feet (Fig. 34). This will cause branching and some delay of flowering, pushing the harvest later. This is undesirable in the open field where plants are susceptible to fall frosts, but is advantageous under a tunnel. The later the pinching, the greater the delay in harvest. Shifting the harvest earlier or later has only a small effect on total yield. By pinching half the planting, a very long harvest season can be achieved from the combination of unpinched and pinched rows. ‘Josephine’ is a very high quality fall-fruiting red raspberry that is naturally late to fruit, so requires no pinching. Newer late varieties released in recent years would be managed in a similar fashion.

Figure 34: Cultural manipulation of ‘Heritage’ Primocane fruiting raspberries—early pinch.

Primocanes may be cut to the ground after harvest. They will grow back in spring and produce another crop in fall. This pattern can continue for more than 10 years. Cutting canes to the ground after harvest saves pruning labor.

Primocane height is increased the longer the plants are covered (Fig. 35). Plantings covered in early spring can produce primocanes that are 8 feet tall. Rather than mow these canes to the ground after the fall harvest, one can remove just the expended tops and the remainder of the cane can be overwintered and fruited the following summer. Fruiting on primocanes and floricanes is termed ‘double cropping’. The subsequent summer crop yields can be as much as the fall crop. Floricanes should be removed as soon as harvest is done, and the new primocanes will begin fruiting a few weeks later. Double-cropping can be the most economical way to manage primocane-fruiting raspberries. Although pruning and trellising takes more time, double cropping greatly increases yields and prolongs the marketing season.

Figure 35: Uncovered ‘Heritage’ (left) and tunneled ‘Heritage’ (right) at the same location.

The fall season can 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 (Fig. 36).

Most primocane-fruiting raspberries require a modest trellis to hold canes erect for fall harvest. This trellis can be removed each year if canes are to be cut to the ground. Because of limited space within the tunnel, the objective of the trellis for primocane-fruiting types is

Figure 36: Lightweight floating row cover used inside the tunnel protects fruit and foliage on colder nights.

to hold canes erect to facilitate harvest – rather than maximizing light interception per plant. 'Caroline' which may produce excess vegetation, and 'Himbo Top', which has long fruiting laterals, may require more support than other fall-fruiting varieties. A sturdier trellis is required if these varieties will be overwintered for summer fruiting.

Primocane fruiting blackberries

While fall-fruiting raspberries have been available for 40 years, their blackberry counterparts have become available only recently. Several cultivars have been released from the University of Arkansas breeding program of Dr. John Clark. These primocane-fruiting blackberries can be mowed down after the fall harvest. They emerge the following spring and fruit in fall. The first cultivars from this breeding program, 'Prime-Jim', 'Prime-Jan', and 'Prime-Ark® 45', have not performed well in northern climates because the primocanes begin fruiting too late to yield well. Primocane yields have only been a fraction of typical yields from floricane blackberries. Newer releases from the same breeding program appear to have higher yield potential as well as thornless canes. These types are being evaluated. New earlier-fruiting blackberry cultivars will have improved flavor and size compared to 'Prime-Jan' but yields have still been low compared to floricane-fruiting blackberries, producing about 10 – 30 % as much fruit in comparison, due to their late fruiting.

Research in other states suggests that a soft pinch in spring benefits

Figure 37: Cultural manipulation of 'Prime Jan' Primocane-fruiting blackberries—early pinch method.

primocane-fruiting blackberries by synchronizing their flowering and increasing yield (Fig 37). However, in colder climates, the season is too short to take advantage of this technique.

Summer-fruiting raspberries

Summer-fruiting raspberries may be overwintered in tunnels and fruited the following summer. The fruit ripens about two weeks earlier than it would in field plantings if the tunnel was covered with plastic early in the spring. Cultural practices are similar to those used for field plantings.

Raspberries are spaced 2.5 - 3 feet apart in row with row centers 7 or 8 feet apart. Expect a small crop of fruit the year after planting, and full yields in the third year.

Some growers are using 'long cane' raspberries for field production. Long canes are planted directly into the soil at a very close spacing and fruited the same year. Often, these are fruited and then removed from the tunnel, rather than carry them over for additional years of fruiting. Strategies for managing long canes can be found in Section 5 describing containerized raspberry production. The long cane system is predominately a container system.

A substantial trellis is required for summer- fruiting raspberries. A trellis that can convert from a V-shape to a closed shape works well. When not harvesting, the V-shaped trellis can be spread to less than 3 ½ feet due to the narrow confines of tunnel. Early season floricane varieties often have shorter canes and need lower or extra middle wires to support the fruiting laterals.

Figure 38: Adjustable trellis system.

Figure 39: Black raspberries in open (left) and closed (right) positions.

Trellis Growing Systems has a strong, yet flexible system that allows the canopy to be configured into a V-shape (Figures 38 and 39) when access is not needed down the alleyways. It is also rotatable.

Figure 40: Blackberries producing in a high tunnel in Ithaca, NY.

For more information on this growing system visit: www.trellisgrowingsystems.com.

Red raspberries respond well to tunnels and produce higher yields and larger fruit than field grown plants. Black raspberries do not respond as well as red raspberries to a tunnel environment, but they still benefit from a tunnel.

Summer-fruiting blackberries

Blackberries respond exceptionally well to the high tunnel environment. It is not unusual for primocanes to grow 20 feet during the season and yields to exceed 20,000 pounds per acre. Blackberries are planted 4 – 8 feet apart in the row and require a minimum of 7.5 feet between row centers. Full crops are not realized until the 4th or 5th year after planting. Heavy-duty trellises are required to hold up to heavy fruiting.

As with raspberries, expended floricanes must be removed from the planting after harvest and the primocanes thinned (to about 6 canes per hill) to prepare for fruiting the following year.

Overwintering

Two unique challenges must be managed for a grower producing blackberries in colder climates.

Blackberries survive well under single-bay four-season 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 (Fig. 40).

Keeping the sides of the tunnel up about 8 inches during winter will allow for some venting on warm sunny days without causing desiccation. It is very important to exclude rodents, especially rabbits, which will girdle canes. A chicken wire or hardware cloth barrier along the base of the tunnel provides protection from girdling by rabbits.

Exceptionally cold winters can damage blackberry canes in covered tunnels, with significant die-back of canes occurring. In more typical years, damage is minimal. It may be possible to cover the tunnel with a second sheet of protective cover to aid in overwintering during such severe winters.

Growing blackberries in a three-season tunnel will require that primocanes are trained to a rotatable cross-arm trellis www.trellisgrowingsystems.com so they can be laid horizontal and covered with row cover for the winter (Fig. 41 a, b, c). With this system primocanes are bent and trained horizontally along a low wire. Weekly training is required to keep the primocanes horizontal. When the tip of the primocane reaches the adjacent plant, it is tipped to promote lateral growth. Laterals are trellised vertically on additional wires. Before winter, the entire trellis is rotated horizontally onto the ground and the canes are covered. In the spring, the trellis is uncovered and the trellis is moved to the erect position for flowering and fruiting. The tunnel is recovered at this time to protect the flowers and fruit.

Managing primocanes

Excessive primocane growth can be controlled by pruning off any excessive growth throughout the growing season. This results in a very thick mass of both primocanes and floricanes growing together, making harvest difficult. Floricanes have to be removed from the planting after harvest, and the tangle of canes makes this task difficult.

Another option is to allow only 4 or so primocanes to grow from each hill. Remove any canes that emerge later to control the amount of vegetative growth.

Figure 41 a, b, c: Blackberries laid on the ground using a rotatable cross-arm trellis and then covered to minimize winter injury.

Figure 42: Blackberries trained to one side of a V-trellis to facilitate harvesting.

Another option is to space blackberry plants farther apart within the rows (e.g. 8 feet) and train them as one would for a rotatable cross-arm trellis (described above). The difference is that the trellis does not have to rotate and a permanent V-trellis can be used. Primocanes are bent and trained horizontally along a low wire on just one side of the V trellis. When the tip of the primocane reaches the adjacent plant, it is tipped to promote lateral growth. Laterals are caught and trellised vertically on a second or third wire, but only on one side. The following year, that side will fruit while primocanes are trained horizontally to the opposite side. No more than four primocanes should be trained to the horizontal wire – the rest can be removed when they emerge from the crown (Fig. 42).

This system has the advantage of separating primocanes from floricanes, making harvesting and pruning much easier. In years without winter injury, yields are mostly equivalent to the higher density system. However, during those cold winters, tip die back can damage the horizontally-trained blackberries much more than the vertically-trained (conventional) blackberries, so using the rotating cross-arm trellis to winter berries under a row cover will help those plants survive (Fig. 41 a, b, c).

Growing brambles in containers

Raspberries and blackberries are increasingly grown in containers under tunnels. Container plants allow production where soil pathogens or other conditions limit production. This also allows growers to manipulate harvest times if plants can be held over winter in cold storage rooms. Plants can be returned to the tunnel on a staggered schedule to extend harvest. Another advantage is that in situations were the irrigation system needs to be shut down to avoid line freezing, the plants can be kept in storage until the irrigation system is operational.

There are numerous approaches to container production, but container plants typically cost more to maintain and require more oversight. Irrigation needs to be reliable and precise. The plant root system is limited so drought stress can occur in just a few hours during warm days. Growers should consider the additional labor necessary to manage potted plants and whether the market return will make this production method pay (Fig. 43).

Establishing Containerized Plants

The growth medium for containerized high tunnel brambles should drain readily, and have a pH between 5.5 and 6.5. Both custom and commercial mixes have been used with success for containerized bramble growing. Mixtures of ground pine bark and peat (70:30) have worked well in Michigan. In Pennsylvania, a 2:1 mixture of horticultural grade peat and coarse perlite was found to have a good combination of drainage and water-holding capacity. Coconut coir material is a standard media for container brambles around the world.

Containers range in size from 1 (minimum) to 7 gallons. Smaller pots require very precise water and nutrient management, but they are easy to move and media and pots costs are low. Large pots are hard to move and costly, but water and nutrient management is easier. Containers can be molded hard plastic or even plastic bag pots. Hard plastic pots may provide the best drainage, particularly those with legs to keep the bottom of the pot off the ground. Plants may survive for more years in larger pots. Experience will tell which size works best for your variety and medium.

Plant in the spring with tissue culture plug plants or dormant 'long cane' plants. Plug plants may be started in a greenhouse in March before placing outside in late May. The goal is to achieve two long-fruiting canes per pot in the first year, either by planting them directly (with long canes purchased from a nursery—these will fruit the year they are planted) or grown from young plants (these will fruit the year after planting if they are floricane-fruiting). Additional primocanes should be removed so energy goes into the two selected canes—unless they are primocane-fruiting varieties. Growers can retain several primocanes per pot in primocane-fruiting varieties if the goal is a fall crop only. These canes are cut to the ground after fruiting and the cycle will repeat the following year.

Plant materials should be watered thoroughly after planting and receive adequate water during establishment. Plants are usually arranged in rose that are 6-7 feet apart. Spacing in the row is usually 1 to 3 feet, depending on the pot size and plant vigor. The goal is to space plants so that there are no spaces in the canopy later in the season. Pots are usually arranged on top of weed barrier fabric to prevent weeds from growing in the tunnel.

Summer fruiting raspberries and blackberries started from plugs may be grown without tunnel cover during the first season since they do not produce fruit that benefit from the high tunnel protection. When growing plants outside for the summer (e.g. the first year of establishment), areas should be large enough to space plants apart. Crowded plants will not produce flower buds on lower portions of canes where light is limiting. Any pruning should be done before plants are moved to winter storage areas to facilitate plant movement and minimize damage during transit. Ensure that plants are dormant before moving them into winter storage.

Plants overwinter well if stacked either inside or outside of a tunnel and covered with a heavy row cover fabric or felt. A limitation of this system is that plants under cover become active very early in the spring and can be injured by late spring freezes. An alternative is a pot-in-pot system where plants are set into holes lined with an identically-sized plastic pot. Placing the potted plant into the other buried pot helps keep plants erect and aids in overwintering in place. Cold storage rooms are ideal overwintering sites, too. Temperatures can be controlled so that there is no cold damage but plants remain dormant. A below-ground area of an unheated barn may suffice if a cooler is not available. Plants can be closely spaced in winter storage areas. Winter storage areas should protect plants from sub-freezing temperatures and rodent damage. Containerized bramble plants may be used for several successive seasons if overwintered properly.

After overwintering with floricanes intact, these plants are moved under the protection of a high tunnel early in the second season to

Figure 43: Potted raspberry plants fruiting in a tunnel (left) and growing vegetatively outdoors (right).

protect ripening fruit. Plants can be moved from cold storage to a high tunnel at different times in spring (e.g. from May through July) to create a very long harvest period. A light-weight trellis is needed to hold the canes erect. Plants typically require considerable labor to regularly remove excessive primocanes and tie up the two desired fruiting canes.

Long cane plants are typically grown for fruit production in a high tunnel and then discarded after harvest. However, at the end of the season, canes can be pruned to the ground and pots overwintered for additional fruiting years. To facilitate additional fruiting, pots with canes removed are set outside after overwintering so primocanes regrow during the second year. All but two primocanes are selected per pot. These primocanes are fruited again the following year after overwintering again. Essentially these plants are fruiting in alternate years (fruiting year 1, vegetative year 2, fruiting year 3). Growers keep two sets of plants, half of which fruit in one year and the other half in the following year. This system reduces the costs of purchasing long cane plants, but requires that plants be maintained in a vegetative state for an additional year.

Such 'long cane' plants are expensive but very productive. Nursery sources in the U.S. are experimenting with production of long cane plants, but they are only available to growers by contract at this time.

Varieties that have performed well in containerized greenhouse production may also be suitable for high tunnel production. Some of these include the floricane- fruiting varieties 'Cascade Delight', 'Chilliwack', 'Titan', 'Encore', and 'Tulameen" (Figure 44). Primocane fruiting varieties also can be grown in containers for fall cropping or double cropping (summer plus fall).

Figure 44: Red (left) and black (right) floricane-fruiting raspberries.

Planting and Plant Selection

Suggested floricane-fruiting and primocane-fruiting raspberries varieties for high tunnel production are listed in Tables 1 and 2.

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: https://blogs.cornell.edu/berrynurseries/.

Typically, brambles of any type are planted in the early spring in colder climates. Applying a light mulch (e.g. straw) around the plants helps them establish and allows the new primocanes to grow through the mulch.

Table 1. Floricane-fruiting Raspberries and Harvest Seasons for High Tunnel Production

Cultivar	Summer Season	Description
Red Raspberries		
Prelude	Very Early	Berries are small, dark in color and mildly-flavored. Canes are dense and very hardy. Fruit is borne on floricanes (summer) and some on primocanes (fall).
Nova	Early	Begins fruiting in early July in NY. Productive. Large fruit is mild-flavored but must be fully ripe to release from receptacle. Canes are stocky, nearly thornless, and very hardy. Shelf-life of berries is good.
Encore	Late	Large conic berries are flavorful and bright red. Canes are vigorous and hardy. Susceptible to Phytophthora root rot.
K81-6	Late	Fruit is large and firm with average flavor. Plants are vigorous on well- drained soils. Susceptible to fire blight and Phytophthora root rot. Vigorous, hardy canes.
Black Raspberries		
Bristol	Early	Best early season black raspberry. The fruit is well formed but relatively small. Very good flavor.
Jewel	Middle	Mid-season grower standard that is very commonly grown. Berries are large with good flavor.
Mac Black	Late	Extends the black raspberry harvest season by 7 to 10 days. Produces large berries that can be seedy.
Purple Raspberries		
Royalty	Late	Very large conic berries produce excellent processed products.

Table 2. Primocane-fruiting Raspberries for High Tunnel Production		
Cultivar	**Fall Season**	**Description**
Red Raspberries		
Polana	Very Early	Shorter canes but 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	Productive with bright, shiny, flavorful berries (sometimes soft or dark). Plants attractive to leafhoppers (symptoms can resemble virus infection and rosetting of tips) and especially susceptible to two-spotted spider mites. Plants tend to branch making canopy dense.
Caroline	Early-mid	Cane growth may be too vigorous in tunnels. Productive and flavorful with medium- sized berries. Produces over a relatively long harvest window.
Joan J	Early	Has met with grower favor in tunnel production. Productive with excellent flavor and firmness, but dark color. May not grow as tall in tunnels as Heritage.
Himbo Top	Early-mid	Very productive with large berries, but flavor is only average and berries can become soft in hot conditions. Produces long canes and fruiting laterals; needs to be heavily trellised.
Crimson Treasure	Late-mid	Very productive variety with uniform, medium red berries with good flavor. Berries hold well when picked light red. Openly displayed at the top of upright canes plant for easy harvest. High yield in double cropping system.
Heritage	Late	Very productive and durable with tall canes. Fruit is small, which increases picking labor needed for harvest, and mildly-flavored.
Imara	Late	Very productive with very large, firm, flavorful berries. Season similar to Heritage. Vigorous canes that may not be hardy enough for some locations.
Josephine	Late	Slightly later than ‘Heritage’. Large, firm berries with excellent flavor, darker color. Plants are very vigorous and have tall upright canes.
Kweli	Late	Very productive with very large, firm, flavorful berries. Season similar to Heritage. Vigorous canes that appear hardy.
Crimson Night	Late	Deep burgundy berries with excellent flavor. Upright canes need little trellising.
Crimson Giant	Late	Very large conic fruit. Average to good flavor. In NY harvest begins 30 days after Heritage continuing into November.
Golden Raspberries		
Double Gold	Late	Deeply blushed variety with superior flavor. Relatively soft fruit. Color intensifies with cooler weather. Tall canes can be double cropped.
Anne	Late	Large, pale yellow berries with excellent flavor. Cane production is sparse, so close spacing within rows is of value.
Purple Raspberries		
Royalty	Late	Very large conic berries produce excellent processed products.

Table 3. Plant Material 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 approximately same time.	Dormant plants vary in growth rate, dormancy, and time of fruiting in first year.	Vary in growth rate, dormancy, and time of fruiting in 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.	

Tunnel Management

Controlling Environmental Conditions (Tunnel Venting and Covering Times)

Temperatures inside single bay tunnels are moderated by opening and closing sides, end doors and/or peak vents, if installed.

Sides may be rolled up fully, or partially, depending on outside temperatures. During the summer, sides can remain rolled up day and night. During spring and late fall when temperatures are cold at night, sides should be closed overnight.

It will periodically be necessary to ventilate for humidity control in addition to managing temperature. During high humidity conditions, condensation can form on leaf tissue. This should be avoided since it can cause crop diseases (e.g., mold or mildew). High humidity and temperatures below the dew point will result in condensation. Ventilation removes the moist air and replaces it with drier outside air. Ventilation for moisture control is accomplished with roll-up sides and/or with peak vents. Venting or moisture control is commonly needed early in the morning before the need for ventilation for temperature control. Manual ventilation for humidity control can increase the labor effort.

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. 45).

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.

Optimum temperatures for tunnel culture of brambles are not well defined, but raspberry growth is likely best when daily temperatures fluctuate between 65^{o} and 80^{o}F. Tunnel temperatures during the summer often exceed this, so venting is important. Optimum temperatures for blackberries are higher. However, temperatures above 100^{o}F for consecutive days will reduce yields.

Some growers have opted to cover the entire single bay tunnel during late fall with a second layer of plastic film to better hold in heat and help overwinter tender varieties. This system works best if air is blown between the two layers. A small squirrel cage fan can be used for this, but it will require electricity to operate. If a double layer inflation system is used on the roll-up sides, the system needs to be deflated before it can be rolled up or down.

Figure 45: Multi-bay tunnels are vented by opening the plastic film covering the ends of the hoops above the side wall.

Multi-bay tunnels can be covered and uncovered with plastic film when desired. Covering brambles early in the spring hastens harvest and tends to increase the internode length of canes, resulting in taller canes. 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 control excessive primocane growth during the late summer and fall.

Moisture and Fertilizer

Soil moisture can be measured using a soil tensiometer or other sensors (see bibliography). Multiple sensors will provide a better idea of the moisture conditions throughout the tunnel. Drip (trickle) irrigation will likely be needed as often as 2 to 3 times per week, when plants are grown in the ground. 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 compared to plants grown outside, but this does not compensate for the low moisture levels in tunnel soil, especially if the tunnel is covered throughout the winter and water field capacity is never achieved during the production cycle.

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 leaf analysis results. Some growers have found that foliar testing on a monthly basis through the season provides them assurance that the plants are receiving the appropriate nutrients.

Figure 46: Combined symptoms of Potassium deficiency (left) as well as other nutritional problems (right).

In sandier soils, potassium levels may become deficient, which may complicate other nutritional challenges (Fig. 46). 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 regardless of soil type.

Soil Salinity

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 more 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 or melting snow 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, a subsoiler has been beneficial in breaking up the hardpan before planting.

Weed growth

It is not possible to over-emphasize the importance of using cultural methods such as cover cropping to reduce weeds prior to planting. Make sure perennial weeds such as quackgrass are eliminated from the tunnel before planting.

Most commonly, landscape fabric is used to prevent weed growth in the tunnel between rows, with only enough space kept uncovered for the raspberry rows. If no landscape fabric is used and the tunnel is uncovered, a spring pre-emergent herbicide maybe applied if needed (i.e. Devrinol).

Rototill between rows as needed to reduce weeds. 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 around the perimeter helps greatly reduce weeds.

Pollination

Unlike greenhouse grown brambles which always require the 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 (Fig. 47).

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. Growers should monitor pollinator activity and make annual determinations about hive needs.

Figure 47: Both bumble bees and honey bees pollinate raspberries in tunnels.

Pest Management Considerations

Bramble pest management under high tunnels, is greatly reduced compared to field production, but 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)

Spotted wing drosophila (*Drosophila suzukii*) is an invasive vinegar or 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 and fruit quality is ruined. The highest levels of larval infestation found in berry crops have been in fall raspberry and late-season blackberry fruit.

Figure 48: First confirmed SWD female (above) and male (below) in New Hampshire, September 2011.

This species is so named because nearly all males have a large black wing spot just forward of the wing tip on each wing (Fig. 48). 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

Figure 49: Tunnel with exclusion netting. Note the end wall which may need additional ventilation.

smaller. Females have no distinguishing characteristics other than their ovipositor.

SWD seasonal population patterns based on monitoring show that numbers at the beginning of each growing season are very low. Each female, however, can lay between 200 and 600 eggs, and there are many generations during each growing season. 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^{o} F) temperatures.

SWD prefers conditions of moderate temperatures and high humidity, and so is present in tunnels. However, reports vary in different situations, SWD populations have been reported to be higher in high tunnel raspberries compared to the field, and also to be less problematic in tunnels. This variation is due to a number of factors including density and management of foliage especially at ground level, trellising configuration and training methods, volume of fruit present, and raspberry variety.   Population differences may also be due to factors such as proximity to other preferred crops and/or cull fruit, harvest intervals, and tunnel temperature. Plastic covering type has had some effects on SWD populations; but the pest is still present and numbers can quickly increase regardless of plastic type used.

Traps using SWD baits or various attractive drowning solutions 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 include keeping harvest intervals as short as possible (daily if possible, and avoid any harvest intervals of 3 days or longer), harvest very thoroughly, and pick fruit as soon as it can be pulled from the plant. Removing unneeded primocanes and leaves from the bottom foot of canes helps with opening the lower canopy; some research has shown that SWD numbers can be reduced with management techniques that lessen cool moist "hiding" areas for SWD. 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 unlikely to cause missed harvests. Cull fruit should always be removed from the tunnel 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 more than twice in a row. See publications that discuss SWD identification and management for additional information.

Using Exclusion Netting in High Tunnels

Insect exclusion netting has been used in many specialty crop production systems when growers are trying to minimize or eliminate pesticide applications. Netting is particularly useful when managing small insects like Spotted Wing Drosophila or thrips. The netting most frequently used is either a 50 gram mesh or an 80 gram mesh. Some exclusion netting is actually just shade cloth, which may not have the same longevity as the warp knit industrial fabric that constitutes true exclusion netting. 80 Gram mesh excludes any insect over .6mm plus provides protection from heavy rain, winds, and hail as well as bird damage when used as a field cover. Netting causes minimum shade due to the white color. It is estimated to have a 7-10 year field life. Netting has obvious attributes for field production, and anecdotally appears very promising as a modified covering for raspberries in tunnels though this use is still being analyzed (Fig. 49). The primary problem is that the insect excluding tight weave also excludes air movement. Covering the side wall and peak vents with this material can cause heat build up in the tunnel. Active ventilation with fans would be needed to keep the heat moderated. For more information on exclusion netting, see Appendix 1.

Here is a video showing the application of exclusion netting: https://www.youtube.com/watch?v=sscb-M9Grws&t=80s

Figure 50: Two-spotted spider mite damage on raspberries—white stippling (spotting).

Additional Arthropods of Concern

A significant and frequent arthropod pest occurring in high tunnel raspberries is two-spotted spider mite (Fig. 50). Economic action thresholds are quite low, if 25% of leaves are infected with 1 or more mites, control action must be taken.

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 can require multiple releases of predatory mites during a season. *Phytoseiulus persimilis* is a large, active predator that specializes on two spotted spider mite. *P. persimilis* prefers higher temperatures with RH over 75% making it the perfect predator in a tunnel. *Neoseiulus fallacis* is a native species that does well in brambles and can survive without mite prey. It also prefers cooler temperatures than *P. persimilus*. Additionally, *Neoseiulus californicus* prefer spider mites but can tolerate hot and dry conditions better than either of the other species.

There could be benefits to combining several species, a fast feeder that is very active and specializes in eating spider mites (e.g. *Phytoseiulus persimilus*) with a species that can persist better at low prey densities than the specialist (e.g. *Neoseiulus fallacis* or *N. californicus*).

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 or prophylactically when mites are suspected.

Recommended applications rates for predatory mites are usually given per unit area. To prevent TSSM, a rough rule of thumb is 1 to 10 predatory mites per square foot of crop with the lower density at the very first sign of spider mites. If there are obviously abundant spider mites plus plant damage, a corrective pesticide compatible with predatory mites should be used before the predators are released.

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.

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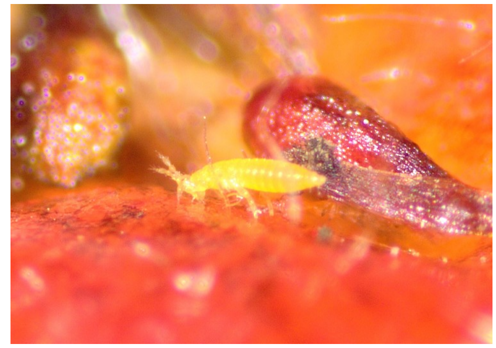


Figure 51: Thrips cause bronzing on berries and are occasional serious problems in greenhouses and tunnels.

Figure 52: Japanese beetles and damage on high tunnel raspberries.

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 (Savey) 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.

Flower thrips, particularly Western flower thrips are an infrequent pest of brambles in the field but often become quite abundant in greenhouse and high tunnels (Fig. 51). Thrips (immature stages and adults) will feed on young leaf tissue but their primary impact is on fruit. Densities can become quite high in flowers and the feeding damage to reproductive tissue causes fruit to be bronzed, hard and seedy. Thresholds have not been well established for NY conditions, but over 5 per flower is reason for concern. Some take-home messages for thrips management include:

- Monitor for adult and immature thrips in open flowers. Prior to flowering, monitor with sticky traps.
- Weeds around or inside the tunnel can increase problems with thrips.

Figure 53: Potato leaf hopper.

Figure 54: Potato leaf hopper damage on high tunnel 'Polana' raspberries.

Figure 55: Large raspberry aphid.

Figure 56: Tarnished plant bug nymph on green raspberry fruit.

Figure 57: Raspberry cane borer punctures.

- Release of predatory mites (*Neoseiulus cucumeris*), if applied early in the infestation, may provide control.
- Chemical control options are limited.

Other less serious pests of high tunnel raspberries observed to date include Japanese beetles (Fig. 52), potato leaf hoppers (Fig. 53 and 54), aphids (Fig. 55), tarnished plant bugs (Fig. 56) and occasionally raspberry cane borer (Fig. 57).

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. Japanese beetles do not prefer plastic covered environments for reasons related to light quality, so populations on tunnel raspberries are often lower than occur on plants in the field, especially if the plastic used is one that reduces UV light. 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.

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.

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.

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 58: Powdery mildew on raspberry foliage.

Figure 59: Powdery mildew on raspberry buds and blossoms.

Figure 59: Late leaf rust on raspberry leaf.

Figure 60: Orange rust on lower leaf surface.

One additional pest that has sporadically caused puzzling symptoms on blackberries, especially primocane-fruiters, has been the broad mite (*Polyphagotarsonemus latus*). Symptoms have included leaf distortion similar to that which would be expected with a growth-regulator type of herbicide, blackened curved terminals that could be mistaken for fire blight, abnormally compact flower clusters, and flowers that dry up and fail to form fruit. Prompt removal of plants that show these symptoms can prevent spread to additional plants.

Diseases

Disease pressure under high tunnel conditions is minimal compared to field production. The tunnel structure helps reduce 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. . Powdery mildew may occur on all parts of the bramble plant, including leaves, flowers, petioles, and fruit (Fig. 58 and 59).

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’, and in floricane varieties: ‘Prelude’, ‘Killarney’, ‘Moutere’, ‘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.

Late leaf rust is a fungal disease of raspberry caused by the fungus *Pucciniastrum americanum* (Fig. 59). 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.

A different type of rust may occur on purple and black raspberries and blackberries – orange rust (Fig. 60). 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.

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 61: Cane botrytis of raspberry.

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 (Fig. 61). 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.

Gray mold also can infect canes (Fig. 61) under moist conditions, so venting the tunnel is an essential part of managing these diseases. Do not confuse sunscald (Fig. 62) with gray mold on fruit.

Spray Application Technology for Tunnels

Fixed sprayer systems have been used for years in high density apple orchards and even in grapes – any crops that have a fixed trellis could adopt the technology and that was the thought behind the adaptation to a high tunnel (Fig. 63). Labor reduction and applicator safety are primary reasons for adoption of this system. More on the fixed spray system can be found at: http://nyshs.org/wp-content/uploads/2014/09/Agnello-Pages-19-23-NYFQ-Fall-2014-Book-5.pdf

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.


Figure 62: Grey mold (Botrytis fruit rot) of raspberry (top) and sunscald (bottom).

Raspberries and blackberries may develop sunscald or sunburn (Fig. 62) under hot, sunny weather conditions. The symptoms are white drupelets particularly on the side of the berry exposed to the sun. This is thought to be caused by heat and UV irradiation. Varieties differ greatly in their susceptibility, with 'Heritage' and 'Goldie' known to be very susceptible.


Figure 63: Drop fix-sprayer nozzles applying pesticide in a high tunnel.

Wildlife

Wildlife damage, in general, is not a major concern under high tunnel berry 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 (Fig. 64).

Figure 64: Woodchuck burrow opening into raspberry high tunnel, Ithaca, NY.

Figure 65: Girdling of thornless blackberry canes by rabbits.

Black raspberries and thornless blackberries, may incur feeding injury during the winter months (Fig. 65). 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.

For more information about managing all pests, consult your local Extension personnel and the berry pest management guidelines for your area for further details.

Harvesting Fruit

Raspberries are highly perishable and have a 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 post-harvest handling and storage should provide reasonable shelf life for nearly any market situation.

Figure 66: Harvesting raspberries in late October.

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

Production of high quality raspberries requires special attention to a number of pre-harvest and post-harvest factors, as well as the mechanics of harvest itself. Pre-harvest 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 post-harvest diseases and improve fruit quality since berries can be wet even in tunnels. Visible decay can develop in less than 12 hours on warm, wet berries. Temperature plays a significant role in berry quality.

Figure 67: Aluminum flat stand designed to keep market containers off the ground.

Berries harvested early in the morning or in the evening when temperatures tend to be cooler have better shelf life (Fig. 67). 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. This is particularly important with the arrival of SWD in the area. 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 col- or 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. Even if larvae from SWD are in

Figure 68: Air is drawn through the wrapped pallet with a fan to create a homemade, but effective, forced air cooling system helping to improve shelf life.

Figure 69: Modified Atmosphere Packaging (MAP) offers an alternative for small growers.

the fruit, cooling the fruit for two days at 35°F will either kill or mostly inactivate the larvae.

There have been some technological advancements in the area of post-harvest – even for the small growers. Forced air cooling systems can be easily made for almost any scale of production (Fig. 68).

In addition, Modified atmosphere Packaging (MAP) offers another option for berry growers that want to extend the shelf life of their product even for a few days (Fig. 69). These commercially available bags come in several sizes and help reduce the respiration of the berry to slow degradation and increase shelf life.

Rules For Berry 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 cooler as soon as possible. Field heat should be removed immediately to improve shelf life.

CONSTRUCTING BUDGETS

Budgets vary considerably based on the many types of tunnels available (3-season vs. 4 season; single vs. multi-bay, etc.) and the many assumptions that go in to the calculations (e.g. price received, yield per tunnel, etc.). There are fall-fruiting raspberries and blackberries, summer-fruiting only types, and the option exists to manage fall-fruiting types for a double-crop. It is not possible to provide budgets for each possible combination. In general, we attempt to provide realistic numbers for a few selected types of tunnels based on results from our research and prices that we pay, including interest on investment.

These budgets show that tunnel production of berries is a long-term investment like most other agricultural operations. While yields per tunnel are generally much higher than in the field, the cost of the tunnel itself has to be paid off. For single bay tunnels the pay off period is about 7 years as reflected in the following budgets. However, another way to think about budgets to is take the cost of the tunnel and divide by the life span of the tunnel, say 20 years. For example, the cost of a single bay four-season tunnel with top-of-the-line plastic is $17,575. This number is then divided by 20 years for an annual pro-rated expense of $879. With annual variable expenses of $2,500 and annual tunnel depreciation of $879, one has to have income exceeding ($2,500 + $879) or $3,379 per tunnel to be profitable over the long term. Projected revenues from raspberries are $6,000 per tunnel, indicating that the enterprise is profitable.

The first budget considers fall-crop only raspberries. Allowing the planting to produce an additional summer crop along with the fall crop can increase profitability. In general, a summer fruiting crop will produce 50% additional fruit, or in our example, an additional 1,000 half-pints per tunnel. The expense of harvesting and packaging an additional 1,000 fall-fruiting raspberries and blackberries, plus summer-fruiting half-pints is $765 and there would be some additional pruning costs. But the revenue generated would be $3,000. Subtracting the approximately $1,000 in additional expense from the $3,000 revenue, one gains an additional $2,000 in profit each year.

Our budget includes $240 a year to monitor temperatures and adjust ventilation if needed. This process can be automated and could save expenses over the life of the tunnel and improve the quality of the growers life by removing the need for adjustments several times a day. Growers should consider the cost of automation vs. the cost of manual monitoring.

The second budget considers an in-ground single-bay tunnel for blackberries in New York state, while the third budget is for a multi-bay high tunnel planting of fall fruiting raspberries in Michigan.

Growers should attempt to construct their own budgets with their own unique set of assumptions and projections. These budgets are only intended as guidelines for construction to ensure that most costs are included, and do not reflect actual profits. Be aware that the labor costs are estimated at $12-$20/hour for all of the budgets, depending upon the skill needed for the task indicated. These hourly wages are rapidly becoming outdated growers should reflect on the true cost of labor when putting their estimates together.

All growers are encouraged to consider depreciation, which is not included in these estimates. Interest on investment is included at the rates of 4% or 6%. Farmers may want to adjust these rates depending on their own situation.

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

Site Preparation and Tunnel Construction

2880 square foot tunnel (30' x96')

- 4 rows per tunnel, each row is 90 ft long
- Labor is assumed at $15—$20 per hour, depending on skill requirement

Preplant Costs	Input	Unit	Quantity	$/Tunnel
Soil test, tillage, land preparation, soil amendments, fertilizer and herbicide		total	1.0	$135
	labor	hour	7.0	$140
Total				**$275**

Tunnel Construction Costs	Unit	Quantity	$/Tunnel	Expected Life (yrs.)	Annual cost
Nor'easter greenhouse (Rimol)	package	1.0	$9,000	10	$900
Misc. construction supplies, exhaust shutters, storm door			$2,010	10	$201
Labor	hour	166.0	$3,320	10	$332
Infrared/condensate polyethylene film	roll	0.16/sq ft	$1,024	3	$341
Total			**$15,354**		**$1,774**

Planting and Growing

- Plant establishment - plants per tunnel = 144 plants per tunnel, 36 plants per row and 2.5 ft between plants
- 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 Planting	Input	Unit	Quantity	$/Tunnel	Expected Life (yrs)	Annual Cost
Plants				320	10	$32
Fertilizer, Straw Mulch				65	10	$7
Planting Labor	Labor	Hour	4.5	$90	10	$9
First season care: Weed, Rototill, Ventilation monitoring	Labor	Hour	33.0	$660		$660
Total				**$1,135**		**$708**

Irrigation System	Input	Unit	Quantity	$/Tunnel	Expected Life (yrs)	Annual Cost
Irrigation equipment	Material	Each	1.0	$200	10	$20
Install Irrigation System	Labor	Hour	1.5	$23	10	$2
Total				**$222**		**$22**

Trellis	Input	Unit	Quantity	$/Tunnel	Expected Life (yrs.)	Annual cost
Trellis posts, wire and supplies	material	each	28	$454	10	$45
Post pounding, trellis and wire installation	labor	hour	9	$135	10	$14
Total				**$589**		**$59**

COSTS DO NOT INCLUDE SHIPPING, COOLING OR TRANSPORTATION OF MATERIALS TO THE SITE NOR THE COST OF SUPERVISING THE CONSTRUCTION, GROWING, HARVESTING AND MARKETING OF THE CROP.

SUMMARY OF INITIAL CAPITAL INVESTMENT FOR TUNNEL

Item	$/Tunnel	Expected Life (yrs)
Preplant Costs	$275	10
Tunnel Construction Costs	$15,354	10
Raspberry Planting	$1,135	10
Irrigation	$222	10
Trellis	$589	10
Total	**$17,575**	

Year 1 Production and Harvesting

- 1,500 Half-pints per tunnel
- $3.50 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	$120	1	—
Retighten Cover	Labor	Hour	4.0	$60	1	—
Fertilizer	Nitrogen	Pounds	4.5	$9	1	—
	Labor	Hour	0.5	$10	1	—
Leaf Analysis	Lab Test	Sample	1.0	$25	1	—
IPM	Labor	Hour	0.2	$4	1	—
	Yellow Sticky Cards	Each	48.0	$14	1	—
	Blue Sticky Cards	Each	48.0	$28	1	—
Scouting	Labor	Hour	6.0	$90	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	$60	1	—
Prune	Labor	Hour	4.0	$60	1	—
Train Canes, Trellis	Labor	Hour	4.0	$60	1	—
Narrow Rows	Labor	Hour	6.0	$90	1	—
Hand Hoe and Weed	Labor	Hour	4.0	$60	1	—
Monitoring and Ventilation	Labor	Hour	12.0	$240	1	—
Total				**$940**		

Harvest						
Half-pint baskets	container	Each	1,500	$120	1	—
Half-pint shippers	container	Each	225	$125	1	—
Plastic vented dome lids	container	Each	1,500	$150	1	—
Picking, packing	Labor	Half-pint	1,500	$750	1	—
Total				**$1,145**		

Yield						
Harvested berries	Gross income	Half-pint	1,500	$4,500	1	—
Total				**$4,500**		

Year 2 Production and Harvesting

- 2.000 Half-pints per tunnel
- $3.00 per half-pint retail price
- Harvest labor per half-pint: $0.50
- Replace plastic every 3 years

Production	Input	Unit	Quantity	$/Tunnel	Expected Life (yrs)	Annual Cost
Cover Tunnel	Labor	Hour	6.0	$120	1	—
Retighten Cover	Labor	Hour	4.0	$40	1	—
Fertilizer	Nitrogen	Pounds	6.5	$13	1	—
	Labor	Hour	0.6	$9	1	—
Leaf Analysis	Lab Test	Sample	1.0	$25	1	—
IPM	Labor	Hour	0.2	$3	1	—
	Yellow Sticky Cards	Each	48.0	$14	1	—
	Blue Sticky Cards	Each	48.0	$28	1	—
Scouting	Labor	Hour	6.0	$90	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	$120	1	—
Prune	Labor	Hour	6.0	$90	1	—
Train Canes, Trellis	Labor	Hour	4.0	$60	1	—
Narrow Rows	Labor	Hour	2.0	$40	1	—
Hand Hoe and Weed	Labor	Hour	4.0	$60	1	—
Monitoring and Ventilation	Labor	Hour	12.0	$240	1	—
Total				**$972**		

Harvest						
Half-pint baskets	container	Each	2,000	$160	1	—
Half-pint shippers	container	Each	167	$169	1	—
Plastic vented dome lids	container	Each	2,000	$200	1	—
Picking, packing	Labor	Half-pint	2,000	$1,000	1	—
Total				**$1,529**		

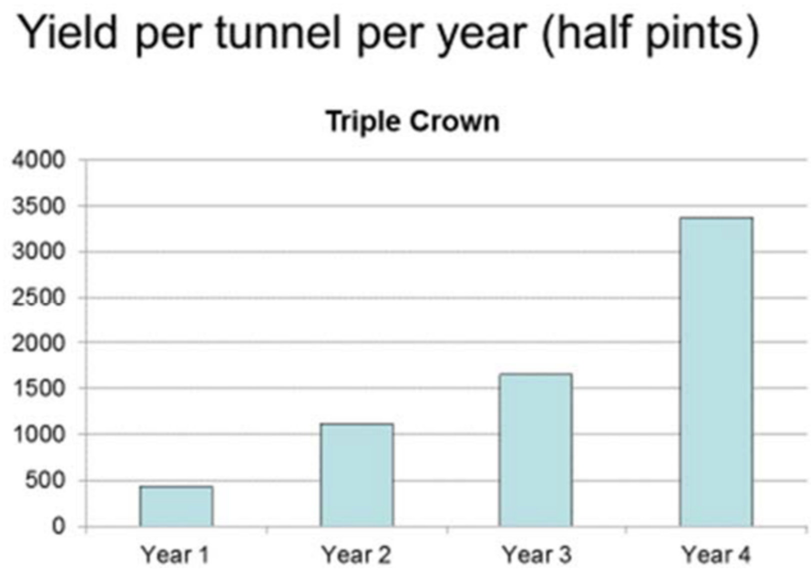
Yield						
Harvested berries	Gross income	Half-pint	2,000	$6,000	1	—
Total				**$6,000**		

Summary of Annual Cash Expenses (per tunnel)

Year	Expenses*	Revenue	Interest (4%)	Cumulative Cash flow*
(establishment) **0**	($ 17,575)	---	($703)	($18,278)
1	($ 2,085)	$ 4,500	($635)	($16,498)
2	($ 2,501)	$ 6,000	($520)	($13,519)
3	($ 2,501)	$ 6,000	($401)	($10,421)
4**	($ 3 ,221)	$ 6,000	($306)	($7,948)
5	($ 2 ,501)	$ 6,000	($178)	($4,627)
6	($ 2,501)	$ 6,000	($45)	($1,173)
7**	($ 3 ,221)	$ 6,000	($0)	$1,606
8	($ 2,501)	$ 6,000	($0)	$5,105
9	($ 2,501)	$ 6,000	($0)	$8,604
10	($ 2,501)	$ 6,000	($0)	$12,103

*excluding marketing costs
**replace plastic covering

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 $3.00 per half-pint. Harvest cost is $0.50/half-pint.
- Replace plastic every 3 years at $720.
- Marketing, transportation, and supervisory costs are not included.

Year	Expenses	Gross Sales	Cumulative Net Profit*
(establishment) **0**	$17,789	$0	-$18,501
1	$940	$0	-$20,218
2	$1,307	$1,440	-$20,889
3	$1,858	$3,600	$-19,913
4	$2,884	$4,800	$-18,717
5	$3,465	$9,900	$-12,773
6	$3,465	$9,900	$-6,592
7	$4,185	$9,900	$-912
8	$3,465	$9,900	$5,523
9	$3,465	$9,900	$11,958
10	$4,185	$9,900	$17,673
11	$3,465	$9,900	$24,108

*excluding marketing costs

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

These costs were estimated from observations during raspberry research trials in Michigan. Budgets assume a 1 acre tunnel range. Primocane-fruiting raspberries are grown and pruned for only primocane (fall) fruit production. When depreciation costs are calculated, assume the tunnels, raspberry plants and plastic will last 15, 8, and 3 years, respectively. Depreciation is not considered in this budget.

Site Preparation and Tunnel Construction

- Nine 200 x 24 ft bays (0.99 acres)
- 3 rows raspberries per tunnel, total row length, 5,400 ft
- Labor estimated at $15 per hour for all jobs

Pre-plant Costs	Unit	Quantity	$/acre	Expected life (yrs)	Annual Cost
Soil tests, land prep	—	—	$400	8	$50
Lime, fertilizer, herbicide	—	—	$280	8	$35
Total			**$680**		**$85**

Tunnel Construction Costs	Unit	Quantity	$/acre	Expected life (yrs)	Annual Cost
Haygrove Tunnels	Package	1	$36,000	15	$2,400
Labor	Hour	200	$3,000	15	$200
Luminence THB polyetheline		1	$8,000	3	$2,666
Total			**$47,000**		**$5,266**

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. Treated wood 4" x 4" x 8' end posts. Six lengths 12.5 gauge 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	8	$255
	Labor	Hour	97	$1455	8	$182
Fertilizer	35-0-0	Pounds	100	100	8	$13
	labor	Hour	2	$30	8	$4
Total				**$3,626**		**$454**

Irrigation System	Input	Unit	Quantity	$/acre	Expected Life (yrs)	Annual Cost
Trickle tube, couples, filters, pressure regulator	Materials	1	1	$1,200	8	$150
Installation	Labor	Hour	20	$300	8	$38
Total				**$1,500**		**$188**

Trellis	Input	Unit	Quantity	$/acre	Expected Life (yrs)	Annual Cost
Materials				$1,120	10	$112
Installation	Labor	Hour	70	$1050	10	$105
Total				**$2170**		**$217**

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

Tunnel Expense item	$ per acre	Expected Life (yrs)	Annual Cost*
Pre-plant preparation	$680	8	$85
Tunnel purchase, construction	$39,000	15	$2,600
Tunnel plastic purchase	$8,000	3	$2,666
Plant purchase and planting	$3,626	8	$453
Irrigation	$1,500	8	$188
Trellis	$2,170	10	$217
Total	$54,976		$6,209

* These figures do not take into consideration depreciation or interest income that could have been earned on your tunnel investment.

Year 1 Production and Harvesting

- 5,330 half-pints harvested per acre (2,000lb.)
- $2.50 per half-pint or about $6.70 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 labor valued at $12/hour

				Overall Cost
Production Activity	**Labor (hrs)**	**Labor (Cost)**	**Fixed and Material Cost**	**Annual Cost**
Install plastic	60	$720		$720
Purchase bumblebees			$350	$350
Irrigate	20	$240	$214	$454
Fertilize			$465	$465
Hand hoe/weed	30	$360		$360
Harvest		$3,200	$996	$4,196
Remove plastic	28	$336		$336
Annual Variable Expense Total		**$4,856**	**$2,025**	**$6,881**
Initial annual capital investment (without interest and depreciation)				**$6,040**

Years 2-10, Production and Harvesting

- 26,670 half-pints harvested per acre (10,000 lb. per acre)
- $2.50 per half-pint or $6.70 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 labor valued at $12/hour

Capital Investment				**Overall Cost**
Initial capital investments (interest and depreciation)				$7,665
Production Activity	**Labor (hours)**	**Labor (cost)**	**Fixed and Material Cost**	**Annual Cost**
Install plastic	60	$720		$720
Prune canes	100	$1,200	$15	$1,215
Purchase bumblebees			$350	$350
Irrigate	20	$240	$214	$454
Fertilize			$465	$465
Hand hoe/weed	30	$360		$360
Pesticide sprays	20	$240	$400	$640
Harvest		$16,000	$4,978	$20,978
Remove plastic	28	$336		$336
Total	**258**	**$19,096**	**$6,422**	**$25,518**

SUMMARY OF ANNUAL CASH EXPENSES (PER ACRE OF MULTI-BAY TUNNELS)

Year	Expenses*	Revenue	Interest (6%)	Cumulative Cash Flow
(establishment) **0**	($54,976)	—	($3,299)	($58,275)
1	($6,881)	$13,400	($413)	($52,169)
2	($25,518)	$67,000	($641)	($40,841)
3	($25,518)	$67,000	($0)	$641
4	($25,518)	$67,000	($0)	$42,123
5	($25,518)	$67,000	($0)	$83,605
6	($25,518)	$67,000	($0)	$125,087
7	($25,518)	$67,000	($0)	$166,569
8	($25,518)	$67,000	($0)	$208,051
9	($25,518)	$67,000	($0)	$249,533
10	($25,518)	$67,000	($0)	$291,015

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

Tunnel Berry Videos: Bramble Production in Tunnels

Blackberry production in tunnels: *Current research by Dr. Marvin Pritts from Cornell University in Ithaca, New York focusing on testing trellising techniques along with an overview of the economics of blackberry tunnel production.*

https://youtu.be/I9JYK44Ebzw

Constructing Multi-Bay Tunnels for Organic Fruit Production: *Shows the construction of multi-bay high-tunnel hoophouses from Haygrove Tunnels Ltd. at Michigan State University's Student Organic Farm.*
https://youtu.be/xWnI6iIZeVQ

Double Cropping Primocane Fruiting Raspberries: *Describes the growth cycle of primocane fruiting raspberries and how to manage them for a double crop by fruiting the floricanes.*
https://youtu.be/Nc4oy7C6WpY

Grower Observations and Adoption of Tunnel Technology: *Discusses the rewards and challenges of growing berries in both high and low tunnels in New York state and will be especially useful for extension educators.*
https://youtu.be/geyJJhDujpY

Growing Containerized Raspberries Under High Tunnels: *Procedures for growing raspberries in containers under tunnels including irrigation, trellising and overwintering.*

https://youtu.be/gxHWgFT2uR0

Growing Raspberries in High Tunnels: *Eric Hanson, Michigan State University Professor, discusses how high tunnels are less expensive, greenhouse-like structures that provide several important benefits. Learn how tunnels can be chosen and managed for profitable bramble crop production.*
https://mediaspace.msu.edu/media/Growing+raspberries+in+high+tunnels++%20/1_7a1hfr0e

High Tunnel Ventilation: *A detailed presentation on venting high tunnels: physical properties, selecting the type of ventilation and the ventilation configurations currently being evaluated as part of the TunnelBerries research project.*
https://youtu.be/mP8YndXz7r8

Low and High Tunnels for Protected Culture for Berries: *Marvin Pritts, Cornell University Professor, discusses the production of berries in protected structures to extend the sales season.*
https://youtu.be/5ErlnTZNuxM

Managing High Tunnel Blackberries on Swing Arm Trellises: *Describes overwintering and training tender blackberry varieties in central Michigan, a region with cold winters.*
https://youtu.be/0EJmtyKEMnw

Managing High Tunnel Raspberries with a V trellis system: *Raspberries grown under high tunnels can be grown on a V-trellis systems to improve double cropping and ease of harvest.*
https://youtu.be/aXGNBhZTSFo

Organic Raspberry High Tunnel Pest Management: *Organic management techniques are describes for a variety of pests found in high tunnels.*
https://youtu.be/Ex2dTcn_Ehc

Parts of a High Tunnel: *Information on all parts of a single-bay gothic peak high tunnel along with the terminology is commonly used for various high tunnel types.*
https://youtu.be/WVJEhw7TdjQ

Primocane Fruiting Raspberries: Growth Cycle and Management: *Follows primocane fruiting raspberry plants through two growing seasons, explaining production on primocanes and floricanes.*
https://youtu.be/It9ntjftM6U

Raspberry Cultivars for High Tunnels: *Seven raspberry cultivars are featured: Joan J, Polka, Imara, Kweli, Kwanza, Crimson Night and Double Gold.*
https://youtu.be/x7ysAAr5S0U

Site Selection for High Tunnels: *Provides information on important factors to consider when deciding on a location for a high tunnel.*

https://youtu.be/2dmS-8c6WyA

Types of High Tunnels: *Provides information on the types of high tunnels (single and multi-bay) that are commercially available and important features of each to consider.*

https://youtu.be/dPRuKE-QdnE

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Appendix 1: Screening and Netting Resources

Screen houses:

https://projects.sare.org/project-reports/ow15-019/

https://gms.ctahr.hawaii.edu/gs/handler/getmedia.ashx?moid=2972&dt=3&g=12

https://gms.ctahr.hawaii.edu/gs/handler/getmedia.ashx?moid=2572&dt=3&g=12

http://hightunnels.org/wp-content/uploads/Net_House_Technology.pdf

Exclusion Netting Suppliers:

Berry Protection Solutions—https://www.berryprotectionsolutions.com/

DuBois Agrinovation—https://www.duboisag.com/

Shade netting:

https://extension.usu.edu/productionhort/files-ou/UsingShadeforFruitandVegetableProduction.pdf

Netting designers:

https://www.nettingbuilder.com/hail-netting/

https://yamko.co.il/greenhouse-division/net-house-model/

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Maughan, T., D. Drost, B. Black, and S. Day. 2017. Using Shade for Fruit and Vegetable Production. Published by Utah State University Extension.