Organic High Tunnel Raspberry Production

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Raspberries are a high value and high demand crop in Minnesota. In-state raspberry production has trended down in the last several years while demand remains high, opening opportunities for growers interested in this crop.

In cold climate areas such as Minnesota, cold winters and a short growing season limit open-field fruit production and overwintering potential of some raspberry varieties. High tunnel production is an opportunity to solve this problem (*Image 1*).

The primary advantage of growing high tunnel raspberries in Minnesota is the extended harvest season. However, many growers are also drawn to its additional benefits like increased fruit quality, higher yields, reduced disease incidence due to exclusion of rainfall, and protection from wind, hail, and birds. As climate change brings wetter seasons and more intense rain events, high tunnels protect high value crops from the elements.

Types of raspberries - floricane vs. primocane

Raspberry varieties are classified based on whether fruit is produced on the current season's canes (primocanes) or second season's canes (floricanes).

Primocane raspberry recommendations:

Primocane-fruiting raspberries bear fruit on the current season's growth. Harvest begins in late summer and lasts until the first hard fall frost.

Image 1: High tunnel raspberry production at Untiedt's Vegetable Farm, Montrose, MN on June 5, 2019.

High tunnels extend this harvest period by protecting the plants from the first hard frost.

Studies conducted by several universities found higher yields with primocane-fruiting varieties than floricane-fruiting varieties when grown in high tunnels.

Primocane-fruiting varieties are also easier to maintain. They require little to no training during vegetative growth (before harvest) and can quickly be removed in the fall by mowing. This saves on labor both during and after harvest.

Plant spacing: Typical in-row spacing is 2 to 3 feet (ft), but some varieties can be heavier cropped with 1.5 ft spacing. Row centers should be at least 6.5 ft apart to allow cane spread, with recommendations up to 8 ft. Between-row spacing can be influenced by the style of high tunnel. A standard quonset-style tunnel with a curved ceiling may only allow for three rows, while a gothic-style tunnel would be more capable of four rows due to the straight sidewalls.

Training: Primocane plant growth increases in tunnels. When covered in the spring, canes can reach 8 ft in height. A simple trellis system, with removable wires or twine at 3 ft and 6 ft heights provides fruiting canes adequate support. Keeping canes erect ensures easy accessibility at the time of harvest. Trellising canes also enhances light penetration and air circulation, thus reducing potential disease and pest pressure.

Maintenance: One of the biggest advantages of planting primocane-fruiting raspberries over floricane-fruiting varieties is that they can be cut to the ground each year after harvest and new canes will emerge the next spring (*Image 2*). A sharp lopper, hedge trimmer, or mower can provide a fast clean up. Remove low-hanging trellis wire/twine, drip irrigation, and soil moisture sensors prior to cane removal.

Variety selection: Breeding programs have focused more on primocane-fruiting varieties than floricane. A host of red, golden, and purple primocane raspberry varieties are available, with different ripening times. However, not all varieties are suitable for high tunnel production, nor are they fully hardy to Minnesota. Refer to Table 1 for more information.

Pinching: Some primocane varieties can be tipped or "pinched" once canes reach 3 or 4 ft. This extends the harvest season by forcing the plants to create more lateral branching. This method works best if growers pinch some canes and leave others un-pinched to promote the longest possible harvest period.

Image 2: Primocane-raspberry canes emerging after winter in a high tunnel on May 1, 2020.

Double-cropping: Primocane-fruiting varieties also provide growers the opportunity to 'double crop'. If desired, primocanes can be tipped and overwintered after fruiting, forcing basal nodes to send out flowering shoots on second year canes (floricanes) the following summer. Those floricanes will produce a small crop in the summer before senescing. The fruiting-cycle can then be repeated on primocanes the following fall. This does not necessarily provide a yield advantage; the main objective is to spread out the harvest season which may or may not be desirable depending on the farm.

Floricane raspberry recommendations:

Floricane-fruiting raspberries are also called summer-bearers because their fruit ripens in the summer months. Fruiting-laterals only develop on second-year canes (floricanes). This means no fruit is produced in the planting year, and only a small fruit load is

produced in year two. Full yield potential is achieved starting in the third year.

Plant spacing: Space plants 2 to 3 ft apart in-row. Some varieties need to be more densely planted due to sparse cane spread.

Image 3: Raspberries planted at 2-foot spacing, 7 weeks after planting, in Northfield, MN.

Variety selection: Depending upon variety, floricane-fruiting raspberries can either bear red, purple, or black fruit. A renewed interest in fruits possessing high anthocyanin levels has also led to black raspberry breeding, though variety selection is limited to floricane-fruiting types only. It is recommended to separate black raspberries from other raspberry varieties as they are more susceptible to viral diseases from increased aphid pressure. See Table 2 for more information.

Training: Floricane-fruiting varieties require a robust trellis system for adequate support. Additional wires located lower than 3 ft, and between 3 ft and 6 ft, are often needed as floricane-fruiting varieties tend to position fruiting-laterals lower on the cane.

Separating fruiting canes from vegetative primocanes aids in harvest accessibility. Growers can achieve this by training all floricanes to the left side of the trellis and all primocanes trained to the right side. Modular trellising systems with adjustable arms such as “rotating cross arm trellises” offer a more sophisticated way of achieving the same result, while reducing labor. They also allow growers to minimize row widths when floricanes are not in production.

Cropping potential: Floricane-fruiting raspberries grown in a high tunnel typically ripen 2 to 3 weeks earlier than field plantings, or around mid- to late-June in Minnesota depending upon variety selection. However, hot air- and soil-temperatures during the fruiting period can adversely affect floricane-fruiting yield in high tunnels. Research at Iowa State University found reduced ‘Tulameen’ yields and a shortened harvest season due to intense heating of the tunnel environment in June, July and August, whereas the primocane fruiting ‘Autumn Bliss’ saw no change in yield.

Left: ‘Polana’ raspberries ripening in a high tunnel on Oct. 12, 2020 in Northfield, MN

Right: Sunscald on a raspberry, resulting from insufficient watering and heat damage in a high tunnel. *Leah Worth*.

Table 1: Recommended primocane-fruiting raspberry varieties for high tunnel production.

VARIETY	BERRY COLOR	RIPENING TIME	DESCRIPTION
Polana	Red	Early	Medium/large round berries with good flavor. Hardy to zone 4. Vigorous grower. Ripens mid-June, producing a heavy flush of berries. Also produces a second smaller-flush of berries in the fall.
Polka	Red	Early	Large, firm, conical-shaped berries full in flavor. Hardy to zone 4. Upright growth habit and vigorous cane spread. Wider in-row spacing recommended.
Caroline	Red	Early-mid	Large berry packed with flavor. Hardy to zone 4. Not tolerant of heat or drought. Less susceptible to phytophthora root rot than 'Heritage' and 'Autumn Bliss' parents.
Joan J	Red	Early fall	Large, firm fruit with relatively low moisture for increased shelf-life. Hardy to zone 4 and more heat tolerant than some varieties. High yielding. Can be double-cropped for first season fall production, and mid-summer and fall harvests thereafter.
Himbo Top™	Red	Early-mid	Large fruit with good flavor. Hardy to zone 4. Not heat tolerant. High tolerance to phytophthora root rot. Heavier cane cropping at the time of planting is beneficial with low cane spread. Fruiting laterals are long, and canes are tall, requiring a good trellis system.
Heritage	Red	Late fall	Medium-sized fruit with moderate sweet flavor. Widely planted and known cultivar. Hardy to zone 4. Resistant to most diseases. Upright canes with medium vigor and robust thorns. Ripens late-August to first tunnel frost.
Autumn Bliss	Red	Late fall	Larger fruit than 'Heritage' with sweet flavor. Hardy to zone 4. Berries darken after harvest with a shortened shelf-life. Resistant to most diseases. Tall canes with medium vigor and numerous medium-sized thorns. Ripens a few weeks earlier than 'Heritage', with a concentrated flush of berries after two weeks.
Autumn Britten	Red	Late fall	Shape, firmness, and post-harvest characteristics similar to 'Autumn Bliss', with slightly better fruit quality. Fruit darkens in storage. Hardy to zone 3. Tall canes need more trellis support. Very high yielding if densely planted, since cane spread is somewhat sparse. Harvest falls on the heels of floricane-fruiting varieties and lasts through October.

Anne	Golden	Late fall	Medium sized berries with a pink blush. Hardy to zone 5, so it requires supplemental mulching and/or row cover to overwinter. Can be double-cropped for first season fall production, and summer and fall harvests thereafter.
Double Gold	Golden	Late fall	Medium sized berries with a pink blush. Hardy to zone 5, so it requires supplemental mulching and/or row cover to overwinter. Can be double-cropped for first season fall production, and summer and fall harvests thereafter.

Table 2: Recommended floricane-fruiting raspberry varieties for high tunnel production

VARIETY	BERRY COLOR	RIPENING TIME	DESCRIPTION
Prelude	Red	Early summer	Medium-round berries with good flavor. Hardy to zone 4. Vigorous grower. Ripens mid-June, producing a heavy flush of berries. Also produces a second moderate flush of berries in the fall, benefiting from double-cropping. Resistant to phytophthora root rot.
Nova	Red	Early summer	Medium-sized firm berries that are slightly acidic. Ripening begins late June to early July in MN, which can extend into early August. Extremely cold tolerant, hardy to zone 3. Also heat tolerant, making it a great choice for MN high tunnel growers. Vigorous, upright canes have fewer spines. Also produces a second smaller flush of berries in the fall.
Encore	Red	Late summer	Large conical berries. Hardy to zone 4. Vigorous and upright canes need a sturdy trellis system. Relatively spineless. Do not plant if soil has trouble draining since it is more susceptible to phytophthora root rot.
Jewel	Black	Mid-summer	Large flavorful berries. A prolific producer if given extra winter protection. Hardy to zone 5. Not as seedy as other black varieties. More disease resistance than other black varieties, including anthracnose.

Royalty	Purple	Late summer	Large and very sweet berry. Most popular purple variety that is best known for jams and jellies. Hardy to zone 4. Canes are vigorous, long, and thorny. Can benefit from double-cropping. Fruit can be separated from the receptacle when still firm and red.

*Tables adapted from a USDA multi-state collaborative project and Cornell University Extension [16, 1]. Additional resource for home raspberry varieties: **Growing raspberries in the home garden**.

Insect pests in high tunnel raspberries

Spotted wing drosophila (SWD) is the most significant insect pest for raspberries. In Minnesota, it is active from around late June to September (FruitEdge).

Research at UMN has evaluated whether high tunnels can be used to protect raspberries against SWD, and results were mixed. While some high tunnels in the study had higher infestations than raspberries outside the tunnel, other tunnels had decreased infestations. In order for high tunnels to successfully exclude SWD, the sides should be fitted with fine mesh exclusion netting. However, the grower would need to ensure that the flies can never enter or colonize the tunnel, which is challenging when ventilation is considered. Pollination needs must also be considered.

Numerous research-based resources have been published on SWD, including organic and integrated pest management (IPM) practices. Recommendations are updated as new research develops.

Management Recommendations for Spotted Wing Drosophila in Organic Berry Crops

Spotted Wing Drosophila | FruitEdge

Spotted wing drosophila | UMN Extension

Managing SWD in organic high tunnel raspberries

Since SWD is the most economically damaging pest of raspberries in Minnesota, modern raspberry IPM programs are largely based around managing SWD.

Before reaching for organic insecticides, first implement cultural management practices to discourage this pest:

- Harvest every 1-2 days during harvest season. Research has found that harvesting every 1-2 days instead of every 3 days can significantly reduce egg and larval infestation.
- Refrigerate the berries as soon as possible after harvest.
- Maintain good airflow through the tunnel by opening the sides and using fans. Follow established pruning recommendations to avoid overcrowding. SWD are poor fliers, and they take refuge in still, shaded areas during the day.
- Remove all infested or damaged fruit from the tunnel. Use brooms and leaf blowers to clean up dropped fruit. This is easiest with landscape fabric in the aisles.

Image 4: Spotted wing Drosophila on a raspberry. *Charlie Rohwer.*

Organic insecticides for SWD

Most organic raspberry growers surveyed in Minnesota reported using insecticides for SWD in addition to cultural practices. The broad-spectrum organic insecticides applied for SWD will also help control other raspberry insect pests but are toxic to beneficial insects.

Organic insecticides for SWD include spinosad (i.e. Entrust), Grandevo (*Chromobacterium subtsugae*), and Pyganic. Spinosad is the most consistently effective active ingredient, while Grandevo and Pyganic are not consistently effective. Use these products in rotation, making applications about every 7 days during the harvest season when SWD is present based on trap monitoring. To help prevent insecticide resistance, follow all label directions and do not repeat the same product more than 1-2 times in a row.

Entrust (active ingredients Spinosin A and spinosin D) is an organic-approved broad spectrum insecticide. It is the most effective organic option for SWD according to trials, but also kills a wide range of pest and beneficial insects including bees. SWD resistance to Entrust has been reported outside of Minnesota and could occur in our area. It is critically important that all growers manage for insecticide resistance by not overusing this product, so that it remains an effective option. Always follow label instructions.

- Rate: 1.25-2 oz/acre per application.
- Maximum: 9 oz/acre per year, and no more than 6 applications per year.
- 1-day pre-harvest interval and 4-hour re-entry interval.
- Provides 5 days of residual control; wait a minimum of 5-7 days between applications.
- Do not apply more than twice in a row.

Grandevo (active ingredient *Chromobacterium subtsugae)* is moderately effective on SWD but less effective than Entrust. It works best if applied when pest populations are low. Grandevo repels honeybees for 4-6 days after spraying, so it may not work very well in raspberries if relying on honeybees. Apply at 1-3 lb/acre in 10 gallons of water. It has a 0-day pre-harvest interval (PHI).

Pyganic is an OMRI listed broad spectrum insecticide, moderately effective on SWD. Like Entrust, Pyganic is also toxic to bees. It provides 2 days of residual control, and has a 0-day PHI and 12-hour re-entry interval (REI). Follow label rates.

Planning a spray program: Plan ahead to decide what rotation of insecticides to use based on major pests and the length of the harvest season, while following label restrictions like maximum oz/acre/year. Spray weekly during the harvest season if SWD persists, alternating between Entrust and either Pyganic or Grandevo. Cultural management tactics may allow for extended intervals between sprays by decreasing SWD pressure.

Essential oil-based repellents

University of Minnesota is currently researching how to use essential oils to repel SWD. Results have so far been promising for raspberries. Field trials found that Ecotrol repelled SWD from raspberries when sprayed every 7 days, reducing infestation to 6%, compared to 17% infestation in non-treated

plots. However, no effect was found in blueberry field trials. Future research will determine best management practices such as how often to spray, and how weather impacts efficacy. For now, growers may try essential oils experimentally.

Image 5: Japanese beetle adult on a leaf. *Jeff Hahn.*

Japanese beetles

Japanese beetles are another major insect pest of raspberries (*Image 5*). They are not as economically damaging as SWD because they primarily target leaves rather than fruit. They are only occasionally found feeding on berries.

Timing of Japanese beetle infestation overlaps with SWD, with both insects causing the most damage in the months of July and August in Minnesota. Therefore, organic insecticide applications for SWD may also provide some control of Japanese beetles. Do not use Japanese beetle pheromone traps, as they have consistently been found to attract more beetles than they control.

Visit the Japanese beetle trapping network, FruitEdge and the UMN Fruit and Vegetable News for more information on Japanese beetle management and phenology.

Insect pests of lower economic importance for Minnesota raspberries include Multicolored Asian lady beetle, leafhoppers, leafrollers, and picnic beetles. Find information on all of these insects on the UMN Extension website or by contacting your local agriculture Extension Educator.

Weed management

The need for proper weed management is heightened in high tunnel production. While the enhanced microclimate of high tunnels benefits plant growth and development of many high-value crops such as raspberries, plant vigor is also advanced in weed species. Growers often have a more difficult time combating nutrient and pest management issues in high tunnel berry production without proper weed management strategies in place.

Research has shown that annual and perennial weed species such as foxtail (*Setaria* species) and bindweed (*Convolvulus arvensis*) can produce up to 2,500 and 300 seeds per plant, respectively [13, 18]. Additionally, it can take 1 to 12 years for some common agricultural weeds to be broken down by environmental or mechanical processes [11]. A high weed seed bank combined with increased seed longevity of many annual and perennial weed species signifies the importance of weed management in tunnel production, especially before bramble establishment.

Organic growers often have to apply a variety of preventative, cultural, and physical approaches to their weed management strategy due to the restricted use of herbicides.

Prevention

Planting cover crops the year prior to bramble establishment can help reduce weed pressure and increase soil organic matter. Grasses and grains usually make the best

cover crops for transition into berry production [3].

The use of reusable plastic tarps in tandem with cover crops has been shown to be 96% effective in suppressing weeds in organic production prior to planting [15]. Tarps are often impermeable, depriving weeds of light and moisture needed for germination. Tarps and plastic sheeting also increase root-zone temperatures which can dry out weed seeds and hasten the breakdown of cover crop residue. Applying tarps and/or removable plastic sheeting for three weeks prior to raspberry planting can provide growers the additional support needed for a successful weed prevention plan.

Production years

Consider different weed management strategies for in-row, between-row, and the tunnel perimeter.

In-row: Hand-weeding is the main option in the rows. Mulching for weed management in-row is only recommended during the establishment years. Leaving mulch around canes in subsequent years may encourage root rot, due to increased soil moisture and decreased soil temperatures. The cooler soil environment also slows cane emergence in the spring. Keeping a 3-5 feet wide strip of bare-soil, and periodically hand weeding it is the best practice for weed management once canes are established, despite the high labor requirement of hand weeding. Once the stands become established, the canopies will decrease weed density on their own simply through shading the ground.

If permanent mulch is left in the rows, the grower must manage irrigation carefully to prevent overly wet soil. Constant wetness leads to phytophthora root rot, described later.

Between-row: Growers can choose one or a combination of the four between-row weed management methods for their high tunnel raspberries. Once again, it is critical to consider the timing of these methods with raspberry cane growth.

Cultivation

Cultivation is a common practice used for between-row weed management in field and high tunnel bramble production. In the planting year, repeated cultivation every 10-14 days can significantly reduce weed pressure [3]. If aisles are bare soil in subsequent years, only shallow cultivation is recommended as potential damage to the shallow raspberry shoots increases. Maintain bare-soil aisles with periodic mowing, hand pruning of canes, and hand-weeding.

Mulch

Growers use non-living, plant-based mulches for a variety of reasons in tunnel culture. As a physical barrier of weed seed and soil contact, mulch impedes weed seed germination within tunnel aisles. A mulch layer at least one inch thick is sufficient to impede light penetration required for germination of many annual weed species [16]. Mulch also retains soil moisture by reducing evaporation.

Warm-season grasses, such as switchgrass (*Panicum virgatum)*, and cereal straw are two non-living, plant-based mulch options for tunnel growers. Switchgrass mulch decomposes at a slower rate than cereal straws and blocks light from the soil surface more effectively. As a result, a lower portion of weed seeds germinate with warm season grass mulch compared to cereal straw. Cereal straw mulch is much more widely available, thus repeated applications from faster decomposition are not as costly or challenging as switchgrass mulch.

Image 6: Autumn Britten raspberries growing with switchgrass mulch. *Leah Worth.*

Heat gained during the day from solar radiation is often lost at night in tunnel culture, thus causing extreme fluctuations of day and night-time temperatures. In tunnels, mulch helps reduce nighttime heat loss while also cooling soil temperature during peak daytime solar heating. Reducing the fluctuation of night and day-time soil temperatures has been shown to improve raspberry growth, yield, and cane spread the following year [14, 16]. However, it can also slow spring growth due to reduced soil temperatures in the spring [3].

Mulching can occasionally increase the risk of disease and raspberry pests. Just as obtaining disease free planting-stock is important for disease prevention, so is obtaining plant-based mulches free of diseases. Cereal straw has been found as a more favorable host for fusarium than warm-season grasses [16]. When mulch is applied at greater than 6-in depths, it can increase relative humidity in the tunnel, promoting foliar diseases such as powdery mildew (*Sphaerotheca macularis*) and rust [12].

We recommend that high tunnel raspberry growers pile mulch in narrow rows in the spring, allowing for maximum soil solar radiation and reduced incidence of prolonged soil moisture. Aisles should again be covered for soil temperature and moisture retention once raspberry canes initiate buds. Non-living mulches may require application every year, but the annual cost of material and labor is usually low.

Landscape fabric

Landscape fabric, also called weed barrier, is commonly used to suppress weed growth between tunnel rows. Increased soil temperature in the spring, higher nighttime temperatures, and a low annual input are the biggest reasons why high tunnel growers choose landscape fabrics over non-living organic mulches. Though polyethylene plastics are common with high tunnel vegetable production, they typically only last one season. Landscape fabrics can be in place for multiple years before breakdown.

Landscape fabrics are generally opaque, limiting light transmission to the soil surface, thus suppressing the germination of existing weed seeds located between rows.

Research has shown high soil moisture retention and increased solar heating within the tunnel with the use of landscape fabric [12]. However, increased air- and soil-temperatures as a result of increased summer solar heating can create negative effects to raspberry growth, fruit quality, and overall yield in temperate raspberries [14, 3]. High tunnel growers often apply a thin layer of plant-based mulch on top of landscape fabric to mitigate its thermal and reflective radiation properties. Though the initial cost of landscape fabric can be high, the cost is easily recovered in the first year of

production with the increase in yield and reduced hand-weeding labor [7].

Cover crops

The advantages of planting cover crops between rows in the open field are not the same when planted in high tunnels. While annual cover crops can reduce potential weed seed germination, increase soil organic matter, and reduce the need for cultivation, potential drawbacks generally outweigh the benefits when used in tunnels. As irrigation and fertigation requirements of both crops increase, so does the competition for nitrogen and soil moisture. Berry yield is reduced if nitrogen availability is limited. Cover crops can also be potential host plants to common bramble pests like spotted wing drosophila. Thus, growers should transition to non-living organic mulches or landscape fabric between rows once raspberry canes are established.

Tunnel perimeter: It is equally important to include a weed management plan for the tunnel perimeter. Wind seeds can be dispersed from the outer edges of the tunnel, causing problems inside. Eliminating any perimeter flowering weeds will help keep your weed management plan inside the tunnel on track, in addition to reducing potential host plants for berry pests and diseases. Some growers use landscape fabric along tunnel perimeters to eliminate the need for hand-weeding.

Disease management in high tunnel raspberries

Disease incidence in high tunnel raspberries should be significantly lower than open-field raspberries due to the exclusion of rainfall. When you suspect a disease, contact your local or state Extension fruit specialist, who may suggest submitting a sample to a Plant Disease Clinic for diagnosis.

Most diseases can largely be prevented in tunnels via good cultural management practices. Prevent physical cane injury, use clean tools and clothing to minimize transmission of infected soil, and keep the soil appropriately irrigated (i.e. not overly wet).

Botrytis fruit rot (Gray mold)

Botrytis (*Botrytis cinerea)* is one of the most common and serious diseases of raspberries worldwide.

It is less common in tunnels with drip irrigation, because it spreads with rainfall or overhead irrigation and is favored in cool, moist environments. However, it can potentially occur in very humid tunnels if the spores blow in from outside.

Botrytis infects plants during bloom and then develops gray mold on ripe fruit either before harvest or during storage.

Since the spores infect weeds and can be spread by wind, keep the area around the tunnel free of weeds.

Maintain ventilation in the tunnel to prevent excessively high humidity.

Cane blight

Cane blight infection only enters through wounds in primocanes. It then spreads through cane vascular tissue, causing vascular damage, cane dieback, and lateral shoot wilt on floricanes the following year.

While infected wounds are hard to identify on primocanes, cane dieback may begin within a month of infection in mid-summer.

Avoid overhead irrigation and encourage ventilation, sunlight penetration and air flow through the plant canopy. On summer-

bearing raspberries, training the floricanes to one side of the trellis and the primocanes to the other has been found to reduce disease incidence.

Identify potential causes of cane injury such as hoeing, and canes rubbing against trellis wires and each other. Take appropriate action to prevent this when possible.

'Latham' has some resistance to wound infection.

Other types of cane blights include anthracnose, ascospore dieback, cane botrytis, purple blotch, and midge blight. More information is available in the Compendium of Raspberry and Blackberry Diseases and Pests [9].

Phytophthora root and crown rot

The pathogens that cause this disease are common in the soil. They require wet, heavy soil or standing water to become pathogenic. Phytophthora infects the crown (base) and roots of raspberry plants.

Image 7: Phytophthora root and crown rot infection at the base of primocanes of Autumn Britten, June 2020.

Symptoms: Base of cane has dark, water-soaked lesions. Roots are reddish-brown after peeling back the outer layer, instead of white. Leaves desiccate and canes collapse because the infection girdles the canes, damaging vascular tissue.

Phytophthora may already be present in the soil or introduced from infected plants, soil (on boots, tools, etc.), and irrigation water.

Use soil moisture sensors to avoid over-irrigation. Reduce irrigation frequency if soil is continually wet.

When placing and building a high tunnel, make it slightly elevated above the surrounding area to prevent standing water.

Do not rely on organic fungicides for phytophthora control.

'Latham', 'Killarney', 'Boyne', and 'Prelude' have significant resistance while 'Heritage' is somewhat susceptible.

Powdery mildew (*Podosphaera aphanis*)

This disease is more common in high tunnels than other diseases because it favors warm, dry weather with high relative humidity.

It overwinters in buds on shoot tips in Minnesota, and spreads by wind.

Symptoms: Leaves and fruit have white fungal growth with a "powdery" appearance; heavily infected leaves may curl, and canes may be stunted.

Organic fungicides: Sulfur and *Bacillus subtilis* (i.e. Serenade) are preventative and must be sprayed before infection occurs. Horticultural oils (e.g. neem oil, jojoba oil) help treat existing infections. To avoid plant injury, do not apply oil and sulfur within 2 weeks of each other and do not apply sulfur when temperatures exceed 85°F. Read labels for pre-harvest and re-entry intervals.

Spur blight

Spur blight is more common in overgrown, weedy, or extremely vigorous plantings, or where excess nitrogen has been applied.

Infection is less common in high tunnels, because the spores spread by splashing rain drops.

Symptoms: It infects leaf blades in June and July, and spreads to the petioles and nodes on the cane, creating dark brown lesions. The leaves wilt and die. Infection is more common on lower nodes.

Prune to prevent overgrowth and promote air flow. Studies in Scotland and Poland have found that thinning to reduce the number of primocanes reduces spur blight.

Irrigation and Nutrient Management

Running drip irrigation during the fruiting period is essential to obtaining high quality fruit. Unmarketable, crumbly berries are a common sign of water stress.

Establish a water source and test the water quality prior to high tunnel site selection and before raspberries are planted in your high tunnel. Water that is high in certain macronutrients can limit the availability of some micronutrients, in addition to altering the soil pH. Testing the water and keeping the soil pH in the 6.0-6.5 range will minimize nutrient and soil buffering challenges.

High tunnels produce taller canes with overall greater plant canopies compared to those found in the field. This increase in growth corresponds with greater water needs. Water management varies throughout the growing season. Evapotranspiration peaks between the summer months of June, July, and August in most of the United States, transpiring up to a quarter of an inch of water each day [3]. The Raspberry and Blackberry Production Guide from the Natural Resource, Agriculture, And Engineering Service (NRAES) estimates roughly 0.2 inches of water is lost from the field via evapotranspiration per day in the months of July and August in Minnesota. The demand for water is even higher with the increased temperature environment of high tunnels.

Irrigation

Drip, also called trickle, irrigation systems deliver water uniformly and only to the raspberry plants. The slower release and the lack of unnecessary watering between rows reduces water lost via evapotranspiration. Soil type, soil water-holding capacity, and maturity of the raspberry crop determine what the irrigation schedule may look like in a given year.

A new planting in sandy loam soil requires 18 gal/day per 100 feet of row. A mature planting in the same soil type requires 27 gal/day per 100 feet of row [3]. Growers should irrigate frequently and in smaller amounts to keep up with increased water demand in the peak evapotranspiration months of July and August. Increasing weekly water application in peak summer heating may also be needed.

In drip irrigation systems, water is delivered down the raspberry rows via two tubes per row (*Image 8*). Evenly spacing the two tubes down the row width ensures all adventitious root buds and fruiting canes have access to moisture as they spread. A more permanent line system is generally more favorable with high tunnel raspberries than disposable ones as they tend to be less susceptible to rodent and insect damage.

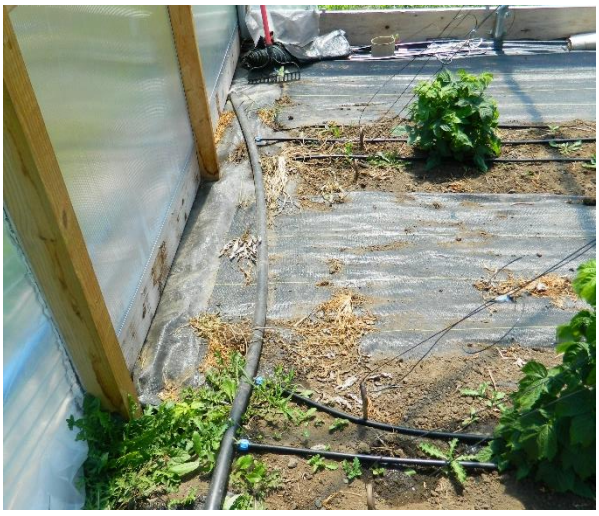

Image 8: Drip tape system including 2 tubes per row.

Overhead irrigation is strongly discouraged in tunnel production because it can increase risk of foliar disease due to leaf wetness and high relative humidity.

Nutrient management

Fertilizer needs will likely differ between farms, as well as the age of the planting and the bloom period. A good fertilization program should remove potential soil factors that may hinder quality yields.

Determine nutrient requirements through soil nutrient and foliar tissue analysis. To determine fertilizer needs, conduct a plant tissue analysis once raspberries reach the second year of production, and on alternate years thereafter. A soil nutrient test should be conducted before planting, and every three years thereafter.

Soil nutrient testing:

Soil nutrient tests are widely used to measure the level of nutrients present in the soil. Fertilizer recommendations are generated based on research-based optimal nutrient ranges for the crop being grown. The UMN Nutrient Management Guide for Fruit and Vegetable Crops lists the optimal ranges for each macro- and micronutrient for major specialty crops including raspberries.

Sandier soils found in some parts of Minnesota may have potassium deficiency and increased nutrient leaching.

The ideal pH range for raspberries is 5.5-7.0. More acidic soils may require amending with lime to raise the soil pH. Compost with a high pH can also be used to increase soil pH and the organic matter content of the soil. Soils with a pH above 7.0 should be amended with sulfur prior to planting. Testing the soil 6-12 months before raspberry planting allows enough time to adjust nutrient levels and soil pH if needed. Recommendations are described in the nutrient management guide.

For more information on soil testing, visit Soil Testing Laboratory | Department of Soil, Water, and Climate.

Foliar analysis:

Plant tissue (foliar) analysis measures the actual nutrient concentrations in the plants and compares them to optimal ranges, thus providing a more accurate depiction of nutrient availability for raspberry production. For example, the micronutrient boron, which is critical for bud break and fruit set, is better predicted with foliar tests than soil tests.

Use foliar analysis in raspberry production in two ways: to diagnose current season nutrient issues, and to optimize annual fertilizer programs. For routine monitoring, sample young, fully expanded leaves at the same time every year. If nutrient deficiencies are suspected, you may collect samples at any time. Submit a second sample from healthy plants to aid in diagnosis.

Normal foliar analysis is done midsummer, when nutrient concentrations are the most

stable. Collect at least 50 newly expanded primocane leaves, selecting only one leaf per primocane. The leaves should be free of disease or insect damage. Contact your local soil analysis laboratory and follow their plant tissue collection and preparation guidelines.

Fertilization:

Fertilizer can be delivered by granular broadcast or through drip irrigation. Many growers choose to couple their fertilization schedule with their irrigation schedule (this is called fertigation) to save time and ensure even fertilization rates to their plants.

Fertigation may include a mix of macro- and micro-nutrients. See Table 3 for nitrogen recommendations. Soils with higher sand content typically require higher levels of potassium (K).

It is possible to over-fertigate. This means that excess nutrients are applied that offer little to no benefit, or when levels of certain nutrients become toxic to plant growth. Excess nitrogen, for example, leads to increased vegetative growth and a reduction of fruiting laterals due to longer internode spacing. While we occasionally see claims about the benefits of routine calcium application to berries throughout the season, peer-reviewed research with field trials generally have not supported routine calcium application.

Fertilizer programs are most cost-effective, sustainable, and efficient when based on soil and foliar tests and objective research.

Table 3: Nitrogen recommendations based on maturity of raspberry planting.

	Primocane	Floricane	Broadcast Timing	Fertigation Timing
Planting Year	2.5 ounces N per 10 feet of row (70 lbs/A)	2 ounces N per 10 feet of row (50 lbs/A); black raspberries with 0.5 ounces N per plant (45 lbs/A)	Divide required N into 3 equal applications; 1) 2 weeks after planting, 2) 1 month later, 3) 2 months after planting.	Divide required N into equal weekly, or bi-weekly waterings from 2 weeks after planting through July.

Established Planting	3 ounces N per 10 feet of row (80 lbs/A). *An additional 1 ounce per 10 feet of row (20 lbs/A) may be needed in late fruiting varieties.	2-3 ounces N per 10 feet of row (50-80 lbs/A)	Divide required N into 3 equal portions for primocanes; 1) just as new primocanes start to grow, 2) late May early June, and 3) during flowering in September/October. Divide required N into 2 equal applications for floricanes; 1) just as new primocanes start to grow, 2) late May early June.	Divide required N into equal amounts, adding to weekly or bi-weekly waterings from April through July for floricanes, and through September for primocanes. Adding 1 ounce of N per 10 feet of row may be needed during fall bloom.

*Table adapted from Oregon State University Extension Service [2].

Summary:

Raspberries are a high-value crop worthy of prized high tunnel space. They can reward growers with higher marketable yields, better fruit quality, and a longer season than open-field raspberry production. High tunnels reduce disease incidence by excluding rainfall, but do not typically exclude insect pests unless careful exclusion netting is used. This guide focuses on recommendations specific to raspberries; refer to general high tunnel publications for information on ventilation, construction, and annual tunnel maintenance. Like other crops in high tunnels, raspberries require proper ventilation to maintain moderate temperatures.

Key points:

- Both primocane- and floricane-bearing raspberries can be grown successfully in high tunnels in Minnesota. Use the tables in this guide for variety recommendations.
- After the establishment years, weed management in the rows relies most often on hand-weeding, as in-row mulch increases the risk of root rot. If mulch is used, carefully monitor soil moisture. Growers can choose between several between-row weed management strategies. Controlling perennial weeds before planting eases labor in subsequent years.
- Insect pest management is a critical part of raspberry management, inside or outside of high tunnels. Spotted wing drosophila (SWD) and Japanese beetles are the highest frequency pests.

- Growing raspberries in high tunnels should reduce the need for fungicides by excluding rainfall and thereby reducing pathogen infection. However, continue to monitor for diseases and understand your management options in case infections occur.
- Irrigate using drip tape, which also allows for fertigation. Do not use overhead irrigation.

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