A tissue culture plug

and have shallow root systems that are sensitive to drought. They are also susceptible to frost damage. The containers should be irrigated immediately after transplanting. The containers can be placed outdoors for the plants to grow during the first season if danger of frost is past.

Nursery Mature or Dormant Short Canes/Bare Root

Dormant short canes are rooted canes or "handles" with one season of growth that were dug after becoming dormant in the fall. The canes are tipped, or cut, leaving 12 to 18 inches (30 to 46 cm) of cane above the roots. The resulting shape looks like a "handle" and gives rise to the term used. The dormant cuttings are stored until spring shipping. This is the conventional transplant type for raspberries.

The use of dormant short canes may require the use of a larger growing container as the attached root mass may be too large to fit into a 3 gal (13 L) container without becoming damaged. All of the plant's energy is stored in the roots, so it is best to retain as much of the root mass as possible and minimize damage. An advantage of the dormant short canes is that they are not sensitive to frost in the spring, so they can be potted up and set outside in Spring with no worries. It is imperative that the roots are not allowed to dry out prior to transplanting. Soaking the roots in a bucket of water just before and during planting will assist in rehydrating the roots, and give the roots a little head start in moisture absorption. The canes will break bud and grow when outdoor temperatures are typically past the time frame of spring frosts, and any new growth that may be subjected to a spring frost will be hardy to the cold temperatures. A disadvantage of using dormant short canes is that the canes have spent a season in field conditions that may or may not have introduced insect and/or disease pests to the plant. It is impossible to guarantee that the dormant short canes will be 100% pest free, so close observation of the plants should occur to monitor for any indications of pest problems.

Dormant Long Canes

An alternative to using tissue culture plugs for floricane production is field-grown, dormant, dug long canes. These plants have already grown their first year in the field, and since their chilling requirement has been fulfilled, will be ready to fruit on floricanes after transplanting. One advantage of dormant long canes is that there will be fruit to harvest in the current season of transplanting. The long cane will be putting energy into replacing the roots that were lost when it was dug and removed from the growing bed at the nursery. This energy requirement for root replacement will take away some energy resources that would otherwise be available for fruit production. In the second fruiting season, the amount of energy available for fruit production will return to normal and yields will be larger.

It is crucial to slowly warm the greenhouse after transplanting dormant long canes. When they were dug from the field, the dormant long canes lost a great deal of their root system that supported water and nutrient intake, and also served as the cane's energy storage tissue. The cane will need time to re-grow some of the root system to sufficiently support the growth and eventual fruiting that will take place. If the greenhouse is warmed too rapidly, the buds will break and the growth that occurs will be too demanding for the amount of root system present. It is likely that there will be death of the new tissue and if the canes do fruit, the root

system may not be able to continue to support the demands put upon it, resulting in premature death. To avoid this scenario, bring the dormant long canes into the greenhouse and maintain the minimum temperature at 50°F (10°C) both day and night for 3-4 days. Afterwards, gradually warm the greenhouse a couple of degrees every 3-4 days so it will be a couple of weeks before maintaining the temperature at night at 55°F (13°C) and 72°F (21°C) during the day. This gradual warming of the greenhouse will be less shocking to the plant and will allow its root system to re-grow enough to support the new growth and fruiting. Fruiting will be slower compared to pot-grown floricanes.

When using dug canes, it is possible to bring into the greenhouse insects and pathogens in or on the canes or their roots. No matter how clean the plants and roots are, it is impossible to guarantee 100% pest free plants. This possibility of pest introduction requires extra vigilance by the grower to observe the plants for any signs of pest problems. Some growers may choose to apply a soil drench of an approved insecticide or fungicide as a preventative measure. With field dug canes, a consistent stand of plants may not be as likely as with tissue culture plants. Field dug canes can vary in their growth rate, in when they fulfill and break dormancy, and in the time of harvest. If the production site is a great distance from the nursery, the shipping costs for sending a box of dug canes can be a large expense.

Establishing Container Raspberry Plants

When establishing a new planting of container-grown raspberry plants, it is important to use a well-drained potting media rich in organic matter and at the correct pH and with sufficient nutrients. Raspberries grow best in media with a pH between 5.5 and 6.5. Most raspberries will not grow well in media with a pH below 5.5, and iron deficiency may occur in soils with a pH above 7.0. Raspberries must receive adequate moisture during the first few weeks after planting. The containerized plants can be grown outdoors during the first growing season, so it is important to have an available water source near the plants so they will not dry out at any time. Applying a few inches of compost to the pot surface will reduce evaporation and retain moisture. Fungus gnat problems may be reduced as well.

An example of 1, 3, 5, and 7 gallon containers

• Container and Potting Medium Selection
Many options are available for growing potted plants. Some growers use 3, 5 or 7 gallon (13, 22 or 31 L) containers, while some growers may use grow bags and insert the raspberry plants directly into a slit in a bag of peat. A three gallon container is the smallest size recommended as it provides sufficient room for root and primocane growth, and it will also be easier for the grower to move in and out of the greenhouse as the container and its contents will weigh less than the larger containers and contents.

As with other greenhouse crops, the growing media chosen will depend on personal choice as well as research recommendations. What works for one grower, may not be the media of choice for another grower. One recipe that Cornell used was a soil-less mix containing 2 bu (70.5 L) peat, 2 bu (70.5 L) vermiculite, and 1 bu (35.25 L) sand. The sand was included to add weight to keep the containers from tipping over too easily. For the total 4 bu (141 L) media mixture, micronutrients were added including: 411 g of lime, 82 g of triple super phosphate, 82 g of calcium nitrate, and 124 g of Micromax trace elements. Slow release fertilizer also can be added to the mix. All the previously mentioned ingredients are thoroughly mixed and used as the growing medium for the tissue culture plugs. Other commercially available, premixed media such as Metromix and ProMix also have been used successfully. One batch of the media mixture should be sufficient to fill 15-20 3 gal (13 L) containers 2/3 full.

First Season Care and Management

• Location and Spacing

The plants can be potted up and placed outside to grow for the first season. Pest management materials are usually easier to apply outdoors in comparison to a greenhouse. Place the plants in full sun, out of the wind and on a growing bed with a weed barrier and automated drip irrigation. A north-south orientation is preferred for better light interception. If possible, locate the growing bed in a location near the greenhouse to minimize the distance for handling the containers when it comes time to move the plants into the greenhouse. This will minimize damage to the plants as well as the stress on the handler's back. The growing bed should be located away from sources of insect and disease populations as on nearby apple trees, hedgerows, Taxus shrubs and areas containing many weeds that may disperse weed seeds into the containers.

Sufficient spacing between the rows of at least 8 to 10 ft (2.5 to 3.0 m) should be allowed for maximum sun exposure on the lower portions of the canes. If the plants are too close together, the lower buds will not produce fruiting laterals once they are moved into the greenhouse. As the primocanes grow during that first season outdoors, support stakes will be necessary to keep the canes upright in the wind. This upright stability can be achieved through relatively simple measures such as using strategically located bamboo stakes and a series of twine support lines run between the support stakes. Plastic tomato cllps also can be used to attach canes to stakes.

• Pest Control

During the first growing season outdoors (or in high tunnels), insects and diseases should be minimal, but weekly scouting should occur, especially to monitor for Japanese beetles, oriental beetles, and for raspberry sawfly larvae. Oriental beetle pheromone dispensers will disrupt mating and reduce egg-laying. Other pests to watch for include spider mites, aphids, cane borers, tree crickets and root weevils. These and other pests are described in more detail in the insect and disease pest section. Detailed life cycles of insect pests can be found in the *Bramble Production Guide* (Pritts & Handley, 1989). Conventional pest control measures can be utilized when plants are outdoors.

Containers on a gravel bed during the summer

Monitor the containers on a weekly basis and remove any weeds that may have started to grow in the containers. Weeds growing in the containers will be a source of competition for nutrients and moisture with the raspberry plants, as well as possible attractants for insects and disease. Keep the containers away from woody plants, as they may be a source of food for the black vine weevil, a pest that will come into the greenhouse inside the containers.

• Moisture and Fertilization Requirements
The containers should be carefully monitored so they do not completely dry out in the sunny, warm months of summer. Newly potted or transplanted raspberry plants are very sensitive to drying out. During hot, sunny, and/or windy days, the containers may need to be watered more than once a day. The plants should be fertilized with a complete soluble fertilizer solution containing 100 ppm N, either in the irrigation water or at least once a week, while the plants are growing outdoors. This fertilizer solution can be applied via an injector system hooked up to the drip irrigation system or a siphon attachment available through most nursery suppliers.

Late Season Care

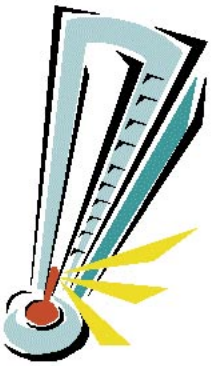
Moving containers in and out of the greenhouse is physically strenuous

As autumn begins, cut back on watering and fertilizing the plants to reduce succulent growth that is more likely to be damaged by cold weather. The containers will not require much watering, but do not allow the containers to completely dry out, as the temperatures begin to decrease in the autumn. In October after leaf drop, move the pots closer together and surround them with bales of straw to protect them from cold temperatures. Root systems are more sensitive to cold temperatures than canes, and temperatures below 20°F (-6°C) for an extended period of time will kill roots, and then some canes, in pots that are setting on top of the ground. In late December, move all of the containers into the greenhouse. Plants may have to be moved earlier if temperatures are forecast to fall below 20°F (-6°C) for several consecutive hours. In this case, move plants into an unheated greenhouse or building until the end of December to allow the plants to fulfill their chilling requirement.

Straw bales insulating containers from cold autumn temperatures

• Chilling Requirements
Tulameen plants require a chilling period of about 800 hours of temperatures between 28°F and 45°F (-2°C and 5°C) in order to break dormancy. If this dormancy requirement is not met, the plants will not break bud, or only the

top few laterals will grow and produce fruit. To ensure that a sufficient number of chilling hours has been achieved, plants can be moved into a cooler (that does ***not*** contain other fruit that can produce ethylene gas) for 8 weeks prior to moving them into a warm greenhouse. If natural chilling is relied upon and autumn temperatures are mild, then chilling may not occur until later than desired. Buds on thicker canes and buds lower on the cane also have a longer chilling requirement (1000 hours) than buds on thin canes or near the top of canes.



If the greenhouse is vacant, the containers can be moved directly into the greenhouse prior to receiving sufficient chilling as long as it is possible to maintain temperatures in the greenhouse below 45°F (5°C). Even on cool sunny days in autumn, the temperatures in a greenhouse can quickly rise well above the 45°F (5°C) mark, and this will be detrimental to the mandatory chilling period for the canes. It may be necessary to closely monitor the temperatures inside the greenhouse at this time and open vents, doors or and use fans to ensure the temperature does not rise above 45°F (5°C) for too long on sunny autumn days.

Alternatively, plants can be moved into a cooler after mid-summer to complete their chilling requirement and begin their fruiting cycle earlier than nature would allow. The plants can be moved into the coolers with their leaves intact as early as August, and after the chilling requirement has been fulfilled, moved into the greenhouse where the plants will break bud, grow their laterals, flower and fruit. Moving potted plants into the coolers and greenhouse is an extremely labor-intensive operation. Consider how this might be accomplished most efficiently. Some growers have built a simple support system on a pallet, and use a forklift to move several plants at a time.

Newly moved in dormant plants

Greenhouse Growing Conditions

After the chilling period has been satisfied, usually by mid to late December in northeastern North America and late January for the Mid-Atlantic region, the plants can be moved into the greenhouse. Initial temperatures in the greenhouse should be maintained at 50°F (10°C) at night and about 65°F (18°C) during the day. Supplemental lighting is not necessary for successful greenhouse raspberry production, but if lights are already installed in the greenhouse, they will accelerate harvest by a couple of weeks and may increase yield by 20-30%. Supplemental lighting is an added expense to the system, and the added expense might exceed income from higher yields. The benefit and cost of supplemental lighting will depend on climatic conditions such as percent of sunshine and average temperatures. It is probably not economical to install lights only for the production of raspberries. Raspberries are a crop that tolerates lower light levels than most greenhouse crops. They also thrive at cooler temperatures than most other greenhouse crops, as the optimal temperature for raspberry photosynthesis is approximately 72°F (22°C).

Once in the greenhouse, canes are spaced with 5.5 to 6.0 ft (1.7 to 1.8 m) (closer for primocane fruiting varieties) between rows, trellised, and watered with a 100 ppm N complete fertilizer solution. Short or broken canes are removed. Three to four canes per container are left to produce fruit. Canes should be supported by an I-trellis, T-trellis, or held upright by some other creative means. It is important to ensure that fruiting laterals are supported and not break.

Rather than staking and tying each individual cane in the container, one grower secures the canes in the upright position by attaching string to the cane, wrapping the string around and up the cane (not too snugly) and tying the other end of the string to an overhead support. Here lies another opportunity for individual expression of ingenuity as to how a grower chooses to manage the canes. Spreading canes into a V-trellis is not an efficient use of greenhouse space although it works well in the field where space is less valuable.

Dormant buds beginning to break

After the canes have been in the greenhouse for one week, an application of a fine horticultural oil before bud break can reduce early outbreaks of spider mites. The use of inexpensive box fans on the greenhouse floor will keep good air circulation around the plants to help reduce pockets of high humidity that encourages disease infections. The relative humidity (RH) should be maintained between 65-75%. Relative humidity below 65% will encourage mite infestations as well as poor pollination, and RH greater than 90% will encourage fruit mold and poor pollination. As the plants fully leaf out, the temperatures can be maintained as low as 55°F (13°C) during the evening and as high as 70°F (21°C) during the day. Injection of CO_2 gas (1000 ppm) in the morning prior to venting may increase yields up to 10%, but it may be difficult to contain the gas in the greenhouse as most greenhouses are not airtight and the gas tends to leak out. The additional yield may not justify the cost of the gas and the measures necessary to maintain an airtight greenhouse.

Trellising and Cane Management

A trellis support system is absolutely required, as the fruiting laterals will become heavily weighed down with the production of the fruit. Pruning and trellising affect plant growth rate, fruit quality, quantity and size, soluble solids (sugars), disease susceptibility, ease of harvest, and spraying efficiency. Brambles respond significantly to pruning and trellising, but these practices are an expensive and time-consuming part of an operation. Growers must use care when choosing pruning and trellising strategies. The actual trellis support system decided upon is an individual choice; several options exist.

Fruiting laterals weighed down with an abundance of ripe and unripe fruit

Option #1:

Monofilament plastic wire is the preferred material for trellis construction. It is as strong as metal wire, but is much lighter and easier to handle. Inexpensive devices hold the monofilament taut at the anchoring posts and can rejoin lines that have been cut accidentally. Trellis posts and anchors should be made from readily available materials. The I-trellis consists of I-shaped wooden or metal posts, approximately 7 ft (2.1 m) long, with 3 ft (1 m) cross arms. The ends of the cross arms have a screw eye or other hardware to hold a length of plastic wire or twine. The wire is strung from pole to pole and pulled tight to keep the canes upright.

Option #2:

As mentioned previously, some growers use a strong string to gently wrap around the cane and tie to an overhead support beam or post to keep the plants securely upright. This method reduces the need to use bamboo posts to secure each individual cane in the upright position. Otherwise, an individual bamboo post or similar product is inserted into the pot for each cane and the cane secured to the trellis in order to maintain upright stability. The use of the individual strings removes the need for

This is one example of a trellis support system with support wires and drip irrigation installed. The white buckets are filled with sand to add weight for stabilizing the trellis frame that will need to support a heavy fruit load during the harvest season

inserting the individual bamboo posts and then remove them when the plants are brought in and out of the greenhouse.

Primocane Management

New emerging primocanes will be growing from the root systems during harvest. These primocanes can grow as much as 15 ft (4.5 m) in the first season, and must be pinched back or the first flush removed so they do not become a major source of competition with the fruiting floricanes or get in the way of harvesting the fruit. Remove primocanes at the soil level leaving only four healthy primocanes for next year's crop or remove the first flush of primocanes and allow the second flush to grow. Eventually, the smallest and the largest primocanes should be removed, leaving only the primocanes about 0.5 in (1.25 cm) in diameter. The smallest canes will be too weak, and the largest, thickest canes will take too long to fulfill and break their dormancy. The four remaining primocanes should be pinched back at their tips when the canes reach a height of approximately 3 ft (1 m) if they are this tall prior to harvest. This will temporarily halt the primocane's growth long enough to harvest the fruit without the primocanes being in the way. The primocanes will break a bud below the pinched area and once again continue to grow later in the season. Under warm, sunny conditions, multiple pinching may be required, perhaps every 3 weeks.

Lateral bud break after cane tip has been pinched off

Pollinator Management

The plants will flower in approximately 5-8 weeks after being moved into the greenhouse. Bumble bees are used for pollination as they tend to function better at cooler temperatures and under cloudy skies than do honey bees. Proper pollination is essential for optimal fruit set and production, and if proper pollination does not occur at the time of flowering, the berries will become very crumbly and, therefore, be unmarketable. Bumble bees are relatively docile and will not sting unless provoked. Even though bumble bees are available year round, vendors should be contacted early enough in the season so hives can arrive in time. Careful scheduling should be followed so the bumble bees are ordered at least one week before they are needed (i.e. 5 - 8 weeks into the season). The vendor can offer a recommendation on which type and how many hives are required for optimum pollination, depending on the size of the greenhouse.

Bumble bee hives are short-lived, 6-8 weeks, so they have to be replaced if a staggered cropping sequence is being implemented. Bumble bees can be obtained from numerous vendors who import them from Holland or Canada. They are flown to a nearby airport for pick-up or can be delivered right to the door via

A commercial bumble bee hive in action

overnight delivery. A list of vendors for biological controls and bumble bees is provided at the end of this guide in the suggested readings and suppliers section.

Water Management

In most areas, water quality should be good enough for irrigation purposes. However, water quality should be evaluated prior to using it for irrigation. Water quality includes its physical, chemical, and biological constituents.

Physical constituents refer to sand, silt, or other suspended materials in water. While physical constituents are generally not damaging to fruit crops, they can create wear on an irrigation system. High sand content, for example, damages pumps and can clog drip systems.

Chemical constituents such as the amount of dissolved material, the proportions of dissolved ions, and any organic-based compounds such as oil should be low in irrigation water. Water with a high concentration of total dissolved solids may affect salt-sensitive fruit crops, such as raspberries, by causing leaf burn and general growth inhibition. Chloride, sodium, and boron are some constituents to which many fruit crops are sensitive. A water sample at your facility should be analyzed to take into account the pH of the water as well as minerals present in the water. The pH and EC (electrical conductivity, or soluble salts in the water) will vary for the water source from one region to another and ultimately will vary depending upon the fertilizer mixture that is used. Some commercial fertilizers will indicate on their packaging the EC levels of the fertilizer mixture according to the ppm and rate. The optimal pH and EC range will vary from crop to crop, with raspberries in the range of 6.0-6.5 for pH and < 30 ppm sodium and < 50 ppm chlorine with an EC < 3 mS/cm. For more detailed explanations on water and nutrient aspects of greenhouse operations, please consult the *Water and Nutrient Management for Greenhouses* publication available from NRAES (Natural Resource, Agriculture, and Engineering Service) listed in the resources section at the end of this publication.

Biological constituents, such as bacteria and algae, are more often present in surface water sources. These constituents are not directly harmful to fruit crops, but they can affect drip and/or trickle irrigation systems. Biological constituents should not be a problem if well or municipal water sources are being used.

Irrigation System

In drip or trickle irrigation systems, emitters are grouped into two categories: (1) line-source and (2) point-source. Line-source emitters are an integral part of a lateral. Point-source emitters can have single or multiple outlets and are generally classified as drippers, bubblers, or misters (foggers), depending on the method of final water application. Compared to sprinkler nozzles, emitters have very small openings, usually pin-hole size. Different emitters have different internal flow characteristics that determine how sensitive they are to pressure changes and particles in the water. Because of the small openings in emitters, water filtration using a 30-200 mesh screen is normally required. However, some emitters are self-cleaning or can be taken apart and cleaned. The use of pressure-compensating emitters will help ensure that each plant receives the same amount of water, and helps prevent overwatering or underwatering.

Low-pressure emitters normally operate at pressures of 2-4 psi, with flow rates of 0.5-1.5 gallons (1.9-5.7 L) per hour. Since the pressure and discharge requirements of emitters are much less than those of sprinklers, drip laterals and mainlines are smaller and the annual operating costs of these systems tend to be lower. A publication entitled *Trickle Irrigation in the Eastern United States* (NRAES-4) provides detailed information on this method of irrigation, including consideration of small fruit crops and many design aspects. Irrigation is adequate when there are no dry spots in the container root zone and water has moved through the entire container. If irrigation continues after water has begun draining from containers, fertilizers will be leached and runoff water will have elevated levels of nutrients. After one year of use, a wetting agent applied to the soil may help plant growth and water regulation.

Drip irrigation tubes installed for efficient delivery of moisture and nutrients

Nutrient Management

The nutrient needs of most crops are provided by granular fertilizers. Because of the small soil volume and frequency of watering in container-grown plants, a different approach is required. Slow release fertilizer added to the potting medium, plus fertigation, is the best approach. Fertigation, or applying fertilizer through the irrigation system, is a practical method of delivering nitrogen and other major nutrients to greenhouse-grown raspberries. The fertilizer solution when applied to the plants should contain approximate 100 ppm N and all of the essential macro and micronutrients. Commercial soluble fertilizers are available that contain a complete set of nutrients. Most of these formulations were developed for flower and foliage crops. In our experience, raspberries grow best with a higher proportion of N relative to the P and K found in commercial formulations. Therefore, it may be necessary to use two stock solutions to obtain the right balance between N and the other nutrients.

A commonly-used soluble fertilizer for greenhouse operations is Peter's Hydrosol (5-11-26). A solution of 100 ppm N from Hydrosol contains too much P and K for raspberries, so two stock solutions can be used to obtain a better balance. Following is an example of how to prepare two stock solutions of 10 gal (38L) each, using a commonly available proportioner to obtain a 100 ppm N solution with lower P and K than would be made with the commercial formulation alone.

Two stock solutions are used: Stock #1 is prepared by dissolving 615g calcium nitrate and 130 g ammonium nitrate in 10 gal (38 L) of water. Stock #2 is prepared by dissolving 1230 g of a soluble, commercial 5-11-26 fertilizer (Hydrosol) in 10 gal (38 L) of water. The fertilizer delivery system contains a proportioner that adds both stock solutions in equal proportions, diluting each to a ratio of 1 part fertilizer to 50 parts water prior to delivery to the plants. Under these conditions, the output from the proportioner contains a solution of 100 ppm nitrogen. A conductivity bridge can be used to determine the electrical conductivity (EC) of this fertilizer solution at 100 ppm nitrogen, and then this EC reading can be used as a standard for maintaining the fertilizer concentration of the irrigation water. The EC of the fertilizer solution should be a maximum of 1.5 mS/cm.

Once the solution is made, use phosphoric acid (if too alkaline) or potassium hydroxide (if too acidic) to maintain the solution pH at 6.5. This application rate of 100 ppm N should be maintained while plants are vegetative; once flowering begins, reduce the overall rate to 50 ppm (change the proportioner to 1:100) to avoid excessively lush canopy growth and soft fruit. When iron deficiency is indicated by leaf analysis, it can be alleviated by the application of an iron chelate fertilizer through the irrigation