Commercial Greenhouse Tomato Production in Alberta

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AGRICULTURE, FOOD AND RURAL DEVELOPMENT

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NOTE:

The depiction of certain brands or products in the images in this publication does not constitute an endorsement of any brand or manufacturer. The images were chosen to illustrate certain aspects of commercial greenhouse production only, and the author does not wish to suggest that the brands or products shown are in any way superior to others. Growers should note that there are many products on the market, and buyers should research these products carefully before purchasing them.

Introduction

This tomato production guide is intended to provide basic production information for commercial greenhouse tomato growers. This guide is not a substitute for hands-on tomato production experience, but does provide a framework for production decisions.

The guide presents information on the growing of beefsteak and cluster tomatoes and will make specific references to either type of tomato where production differences exist. In most cases, the production of beefsteak and cluster tomatoes is very similar.

Commercial greenhouse tomato production in Alberta includes both cluster and beefsteak tomatoes. Cluster tomatoes are also referred to as "truss tomatoes" or "tomatoes on the vine," as they are harvested and sold as complete clusters of three to five tomatoes still attached to the flowering truss or vine. Beefsteak tomatoes are harvested and sold as individual tomatoes (Figure 1). There is commercial cherry tomato production in Alberta; however, the production area is quite small (Figure 2).

Figure1. Beefsteak tomatoes ready for market.

Figure 2. Cherry tomatoes.

New growers can reach target yields for beefsteak and cluster tomatoes of between 50 and 55 kg/m^2 of production area. Top Alberta producers have attained over 60 kg/m^2 while the Crop Diversification Centre South at Brooks has achieved over 70 kg/m^2 in the research production greenhouses.

Increased yield comes with increased grower experience and expertise, but the largest incremental yield increases attained by experienced growers come through the adoption and use of new technology. The skilled use of computerized environmental control systems, newer, taller greenhouses and efficient cooling systems all help to increase yield. The use of carbon dioxide (CO_2) supplementation has the potential to increase the yields of a skilled grower who now attains between 55 to 60 kg/m^2, up to 70 kg/m^2.

But technology costs. Even though higher yields are always generally better than lower yields, yield potential is constrained by a grower's ability to control the greenhouse environment. But a top-of-the-line greenhouse with all the bells and whistles that maximizes control and results in a 70 kg/m^2 crop costs considerably more than a greenhouse with a few less bells. A 50 kg/m^2 greenhouse can be as profitable as a 70 kg/m^2 greenhouse when capital and operating costs are factored in.

Technical improvements should be planned to complement the skill of the grower and the financial means of the business. It is of no use to focus on a new CO_2 supplementation system if growers are not optimizing the rest of their operation. For the CO_2 system to pay dividends, a grower must be running a finely tuned, top yielding crop with the current greenhouse.

For some greenhouse businesses, the biggest bang for the technical improvement buck might actually be a newer, taller structure. Growers must analyze where they are with their business, where they want to be and the most logical way to get there. An analogy might be that a driver would not expect to win a car race simply by buying an Indy car. The driver has to be completely skilled in driving the high performance vehicle in the first place.

Tomatoes: A Brief History

The tomato (*Lycopersicon esculentum* Mill.) originated in South America, and due to its value as a crop, it has come to be distributed throughout the world. Tomato selection and breeding to improve the adaptation of this tropical plant to different environments as well as general improved quality and disease resistance characteristics have been ongoing for approximately 200 years. Domestication of the tomato is generally believed to have started in Mexico.

The cherry tomato (*L. esculentum*. var. *cerasiforme*) originates in Central America and is the direct ancestor of the modern cultivated tomato. Cherry tomatoes are the only wild tomatoes found outside South America, and domestication has included considerable selection for larger fruit.

Tomatoes do not tolerate chilling injury. Commercial cultivars are sensitive to temperatures below 15°C throughout all stages of plant development. Temperatures in the original South and Central American environment produce an average minimum day temperature of 19°C, with an average minimum night temperature of 15°C.

The soils in the native range of the tomato are relatively dry. Although tomatoes now thrive in temperatures between 10°C and 30°C, they are not frost tolerant and are generally not tolerant of waterlogged soil conditions. However, the cherry tomato is better adapted to wet tropical conditions than any other of the *Lycopersicon* species and is frequently found in areas of high rainfall in Mexico.

Commercial Greenhouse Cultivars

Commercial tomato cultivars can be classed as determinate or indeterminate based on their growth habit. Determinate cultivars produce a branching system that has limited growth into a final form of a bush. Indeterminate cultivars produce branching systems that have the capacity to grow indefinitely, which produces a prostrate growth habit. Greenhouse tomato cultivars are indeterminate and require constant maintenance and physical support of the plants to allow for long term fruit production.

Cultivar selection is based on several factors:

- the type of tomato to be grown – cluster or beefsteak
- high yield potential under Alberta growing conditions
- disease resistance

Fruit quality characteristics such as size, colour, taste, shelf life and resistance to shrink cracking are also important. A short calyx is also desirable since a long calyx on the fruit can damage adjacent fruit during packing.

The market is the ultimate authority on whether a cultivar meets the requirements of the consumer, and growers are well advised to grow the market-proven cultivars. The "best" cultivars are subject to change as seed companies are constantly working to develop greenhouse tomato cultivars with improved quality characteristics.

Commercial Cropping Cycle

The greenhouse tomato production cycle is based on using the same set of plants for a full year. The plants are seeded in mid-November, with harvest beginning at the end of March to early April and continuing through to the following November. An approximate yield target for introductory growers would be 50 kg/m^2 for beefsteak or cluster tomatoes.

Fertilizer Feed

The feed program is designed in such a way as to deliver adequate nutrition throughout the productive life of the plant. Arguments are made for changing the feed program as the nutritional requirements of plants change as they grow to maturity and fruit production, and these arguments are valid.

However, the feed targets presented in this manual (Table 1) are designed to provide adequate nutrition throughout all stages of the crop and will make it possible for growers to obtain maximum yields. These feed targets have been used to reach yields in excess of 60 kg/m^2 of tomatoes.

Table 1. Nutrient feed targets (ppm) for greenhouse tomatoes in sawdust

Nutrient	Target (ppm)
Nitrogen	200
Phosphorus	55
Potassium	300
Calcium	200
Magnesium	55
Iron	3.00
Manganese	0.50
Copper	0.12
Molybdenum	0.12
Zinc	0.20
Boron	0.90
Target E.C.	2.5 mmho
Target pH	5.8

Tomato Plant Propagation

Seeding

The propagation area or seedling nursery area must be cleaned and disinfested before use. Planting fresh seed is also important because seed older than one year can have reduced germination rate and vigour.

The crop is seeded around November 15. Seed is placed directly into rockwool plugs that have been soaked with a seedling feed solution with an electrical conductivity (E.C.). of 0.5 mmho, a pH of 5.8 and a temperature of 25 to 26°C. Always use quality rockwool rooting media.

The feed solution is prepared by diluting a standard tomato feed solution (approximately 2.5 mmho E.C.). A typical standard feed solution for tomatoes is presented in Table 1. The rockwool plugs must not be allowed to dry out, or the seedlings can be severely damaged.

The seedling feed solution, at an E.C. of 0.5 mmho and a temperature of 25 to 26°C, is used to wet the plugs as required. The goal is to maintain moisture levels in the plugs without waterlogging them. As long as the feed solution is able to drain away from the bottom of the plugs, waterlogging should not occur.

A general rule is to apply feed solution to the point where it just begins to run off from the bottom of the plugs. The seedlings will require almost daily watering at this stage. Use light applications of the 0.5 mmho E.C. feed solution.

The temperature at the root zone should be maintained at a constant 25 to 26°C for the first two weeks, while the seeds are germinating and the young seedlings begin to establish. Air temperatures should also be maintained at 25°C.

The relative humidity in the nursery should be maintained at 75 to 80 per cent (vapour pressure deficit (VPD) of 3 to 5 g/cm^3) until the seedlings have emerged. The rockwool plugs are often covered by a plastic tunnel to help maintain optimum humidity. Seedling emergence is usually complete within 10 days after seeding.

Once all the seedlings have emerged, the plastic tunnel is removed. The plants must be conditioned to the greenhouse environment before removing the tunnel completely, which is done by opening up the tunnel slightly. This method allows air to circulate around the plants for a few days before complete tunnel removal.

Supplemental light is applied to the emerging seedlings at 160 watts/m^2 for 16 to 18 hours per day. This level can be achieved by using 400 W (high pressure sodium) lights placed in rows 2 metres (6 feet) above the seedlings, with 3 metre (9 feet) spacings between the lights in the row. Adjacent rows of lights are spaced 3.5 metres (12 feet) apart.

Once the seedlings have emerged, the root zone temperature is reduced to 23°C, and the air temperature is maintained at 25°C. The relative humidity is reduced to 70 to 75 per cent (VPD of 5 to 6 g/cm^3). Supplemental CO_2 is delivered to ensure a target of 800 to 1,000 ppm. Liquid CO_2 is the preferred source because of its purity.

The seedlings can also be misted once a day for the first four days after emergence. Apply the mist around mid-day, since it is important for the leaves to dry as the night approaches, to avoid disease development. Continue to water with the 0.5 E.C. feed solution to ensure the plugs are always moist.

Root zone temperatures are maintained by using bottom heating systems, located close to the rockwool plugs. It is important to maintain optimal root zone temperatures throughout the entire cropping cycle; seedling tomatoes are particularly sensitive to cold temperature injury.

Experience has shown that when bottom heating systems fail and even if temperatures fall only a few degrees Celsius for a few hours, seedling development will be set back over a week. Even after the apparent recovery of the seedlings, the plants remain developmentally delayed, with weaker root systems when compared to seedlings maintained at optimal conditions. Tomatoes are sensitive to chilling injury throughout all stages of plant development. Exposure to temperatures below 15°C will delay plant development, flower and fruit set.

First Transplanting

The young seedlings are transplanted into rockwool blocks when the cotyledons (seed leaves) begin to touch or when the first true leaves appear. The rockwool blocks are completely soaked with full strength feed solution E.C. 2.5 mmho at approximately 23°C, just before transplanting.

As with sweet pepper seedlings, the young tomato seedling is rotated 90 degrees as the seedling is seated into the depression on the top of the rockwool cube. This operation layers the young seedling stem between the rockwool plug and the rockwool cube. Once the stem has been placed in a "root" environment, the stem reacts by developing roots along the layered portion of the stem. Just after transplanting, the root zone temperatures should be dropped to 21°C.

The blocks need to be watered daily (E.C. 2.5 mmho, 21°C) to ensure they remain wet, but growers should avoid overwatering. It should always be possible to squeeze some water out of the blocks. Root zone temperatures of 21°C are targeted for the next two weeks, and then, the root zone temperature is lowered to 20°C. Air temperatures are maintained at 24°C during the day and 22°C at night, for a 24-hour average temperature of 23°C.

Supplemental lighting should be maintained at 160 watts/m^2 for 16 to 18 hours per day. Carbon dioxide supplementation should also continue, maintaining a target of 800 to 1,000 ppm. Combining CO_2 enrichment with supplemental lighting in seedling tomatoes has be shown to increase seedling weight and to generally improve early yields.

One week before the second transplanting into the production greenhouse, growers should cut the supplementary lighting to 12 hours per day to condition the plants to the lack of supplementary lighting in the main production greenhouse. Plants not receiving this slight reduction in supplementary lighting tend to suffer from "light shock" when they are transplanted into the production greenhouse. This shock can set their development back approximately one week.

Once the seedlings have established in the rockwool cubes, growers need to monitor the E.C. of the cube two to three times a week. The E.C. will rise and can reach a maximum of 5.0 mmho. It is not advisable to allow the E.C. to rise beyond this point. Once the E.C. reaches 5.0 mmho, the feed solution should be reduced to 2.0 mmho, and the E.C. in the block should be then brought down to 3.5 mmho in advance of the second transplanting of the seedlings into the production greenhouse.

As the seedlings establish in the rockwool blocks, they have to be adequately spaced. Crowded plants will stretch, becoming tall and spindly, resulting in poor quality transplants. The ideal transplant has a stocky appearance, with a stem diameter of about 1 centimeter at the surface level of the rockwool block. The young plants should be spaced on the table when it looks like the leaves of each plant are about ready to touch those of another.

Plant Density

Determining the plant density is a very important component of the greenhouse preparation and determines the number of seedling plants required for the production greenhouse. Plant density is directly linked with final yield and quality.

Too many or too few plants per unit area of production space will have a negative effect on yield and quality. Dense plantings tend to result in lower yields and smaller tomatoes, as can sparse plantings. The point growers need to remember is that there are optimum planting density targets, and these targets can vary depending on cultivar, climate and available light.

Plant density targets for tomatoes actually change throughout the growing season in response to the differences in available light over the year. There is less available light at the beginning and end of the crop cycle, corresponding to the shorter days and less intense light. A more open plant density is required at both the beginning and the end of the season. A denser planting is targeted during the high light summer months, in direct response to the changes in the available light. If a crop is initially planted at the optimum density for the summer months, the planting will be too dense for both the early and late season.

A density that is too tight during the early stage of the crop will result in insufficient light falling on each of the plants; each plant will receive insufficient light to develop the flowering trusses. The lack of light is a factor "limiting" plant growth (Figure 3).

Figure 3. When spring light levels in the canopy become limiting for truss development, trusses will abort. This condition can occur in Alberta tomato greenhouses as a result of high spring planting density.

Under conditions of limiting light early in the season, tomato plants will not develop flowers. The plant will continue to grow vegetatively, producing leaves and stems until light levels increase enough to support flower development and fruit set.

Later in the season, when light is limiting again, plantings that are too dense will limit how well the fruit is filled, resulting in smaller fruit, reduced quality and yields.

In contrast, a more open canopy during the intense light of the summer will result in too much light falling on each plant, stressing the plant and resulting in smaller, shorter leaves as the plant moves out of balance. The plant will then have become too generative, and there will be significant reduction in quality and yield.

Under the intense Alberta summers, more tomato plants are required to maintain a crop canopy able to produce enough leaves to intercept the light and shade the fruit to protect it from sunscald. The greater density is also needed to maintain the humidity required for the plants to preserve the optimum balance for production.

A change in plant density is accomplished by "twinning" selected tomato plants in the greenhouse. This action is done by allowing a lateral stem to develop to a producing "main stem," to take advantage of the high summer light levels. As the season progresses towards fall, the twinned stem is removed to reduce crop competition for light. The process of twinning will be discussed in greater detail later in the manual under the section "Twinning to Increase Crop Density."

Growers should plan for an early plant density target of 2.3 plants/m^2, which will be increased later in the season to 3.5 to 3.7 plants/m^2. It is important for growers to always be aware of what other growers in the area are doing with respect to planting density and to recognize that different cultivars may have different density requirements.

For example, some cultivars are particularly sensitive to low light levels early in the season and require a less dense, more open canopy in the early months. Caution should be exercised with regard to following recommendations from distant areas that have significantly different growing conditions as the information may not apply directly to Alberta production greenhouses.

Setting up the Greenhouse

Once the greenhouse has been thoroughly cleaned, the next stage is to lay down the growing media in rows to receive the plants. The sawdust bags or rockwool slabs are laid down in double or single rows to meet the requirements of the planting density target.

Example: Grower who is growing in sawdust bags

The total number of plants required for the production greenhouse is determined by multiplying the production area (in square metres) by the planting density. An initial planting density target of 2.3 plants/m^2 is reasonable for most beefsteak and cluster tomato cultivars.

Next, to determine the number of sawdust bags required, divide the total number of plants by the number of plants that can be grown in each bag. A standard greenhouse sawdust bag will hold approximately 20 litres of sawdust and will have dimensions of 23 cm (10 inches) wide, 86 cm (34 inches) long and 15 cm (6 inches) tall when full. Two tomato plants are grown in each bag.

Now that the number of sawdust bags is known, the number of rows can be determined. There needs to be a walkway between each of the rows; the walkway is also where the pipe and rail heating pipes are located. Using the example for double rows, the walkway is the distance between bags from adjacent double rows; this distance is approximately 76 centimetres (30 inches). The distance between bags in the two adjacent single rows of the double row is approximately 20 centimetres (8 inches), with a total width of 70 centimetres (28 inches) for the full double row. This information allows the grower to determine the number of double rows that can be placed in the greenhouse.

Knowing the number of bags required and dividing this number by the number of rows (double rows preferred), the grower will arrive at the number of bags required per row to reach the target plant density (Figure 4). The number of bags in a row are spaced out evenly along the length of the row.

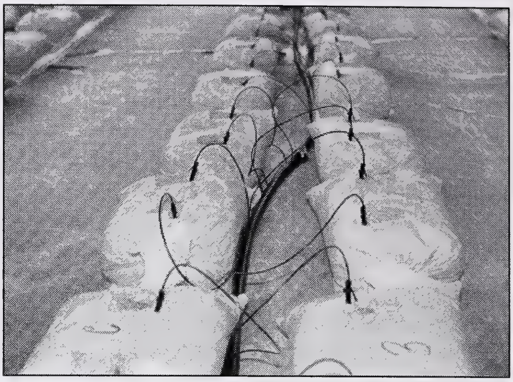

Figure 4. Sawdust bags set out in a double row.

Some growers prefer to grow in single rather than double rows. Deciding on the number of rows required is accomplished in the same way as with double rows. Adjustments are made in the number of bags per row (increased) and with the walkway width (decreased) as required to meet the planting density target.

The decision to grow in single versus double rows has an effect on how the plants are trained during the growing season. Individual tomato plants can grow up to 12 metres (40 feet) long over the course of the year, so the plants can grow longer than any average greenhouse is tall. To accommodate this growth, much of the tomato stems are laid down along the length of the row beside the sawdust bags or rockwool slabs. The plants at the end of the row are trained around the end of the row to grow along the other side of the row.

The single row system is often referred to as the V-training system (Figure 5). In the V-training system, the first plant in the bag is leaned over and trained along one side of the row, in one direction while the second plant is trained along the other side of the row and in the opposite direction. This pattern of plants being alternately trained to either the right or left side of the row continues along the entire length of the row.

In the double row system, all the plants in one side of the double row are leaned over and trained in the same direction along the row, with all the plants in the other side of the double row being trained in the opposite direction along the row (Figure 6).

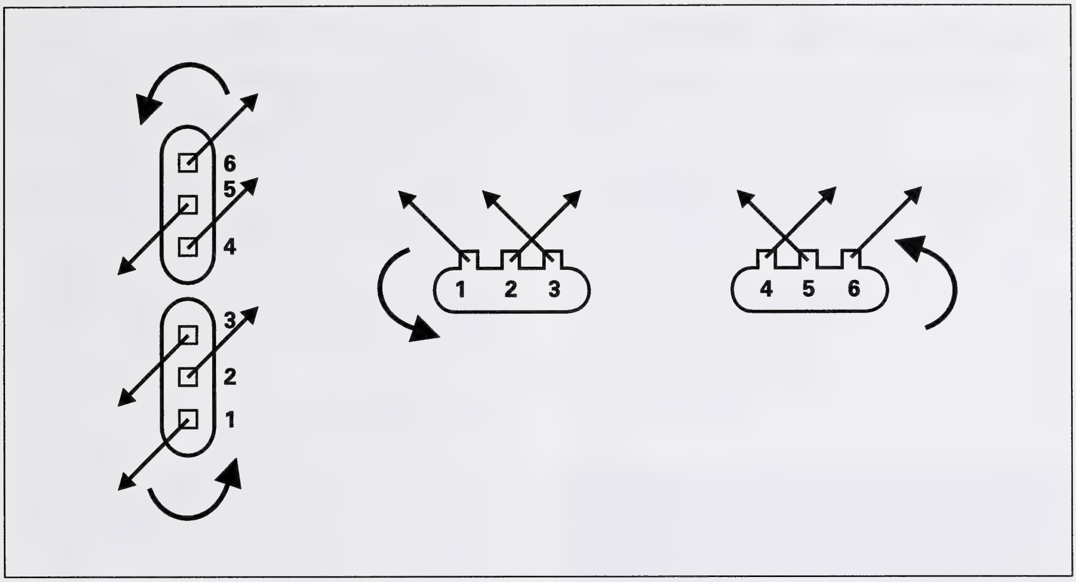

Figure 5. Overhead and side views of the V-training system for tomato plants grown in single rows. Every second plant is trained in the same direction on the same side of the row. Adjacent plants are trained in opposite directions on opposite sides of the rows.

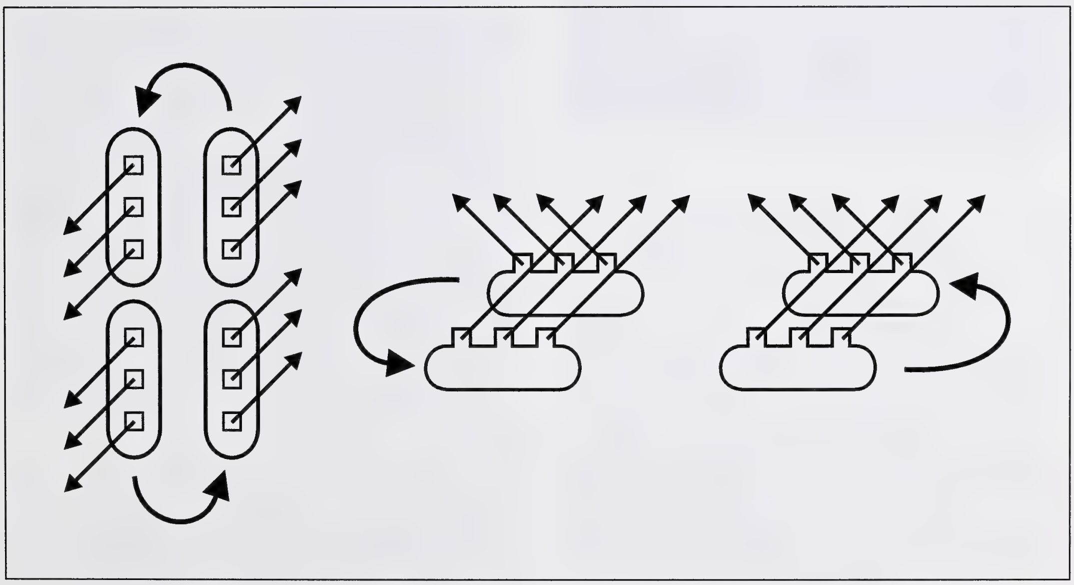

Figure 6. Overhead and side views of the double row system for tomato plants. Every plant in each side of the double row is trained in the same direction along the length of the row. Once plants reach the end of the row, they are trained around and down the other side of the row.

Hanging Trough System

The hanging trough system is a variation of the single row system. The major difference is that the growing media is placed on troughs that are approximately four feet off the ground. The troughs are suspended from the roof, which places additional structural demands on the greenhouse. There is also additional expense associated with capital costs of the troughs.

The troughs are designed to catch the overdrain and channel it to the end of the rows. The plants are trained down to the floor level before being trained to the overhead wire above the level of the trough (Figure 7).

Figure 7. The hanging trough system.

The major advantage of this system is that it can allow for the starting of a second crop before the old crop is completely finished, which will shorten the period the greenhouse is out of production.

New plants can be introduced into the greenhouse and, due to the height of the growing media, these young plants are not shaded by the established crop whose canopy is mostly below the trough level. The young plants then establish themselves while the established plants are still producing. When the new crop begins to produce, the old plants are removed. How the new plants are introduced and the old plants are removed varies; however, the introduction and removal are usually done in stages throughout the entire greenhouse.

The use of the hanging trough system is not widespread in Alberta at this time. New growers are advised to study the local situation with respect to any advantages before adopting the hanging trough system. It may be best to construct a greenhouse that can accommodate a hanging trough system, but growers need to develop their crop production skills with the growing media on the floor. This focused approach will allow for a relatively easy transition into the hanging trough system at a later date.

Transplanting

The seedlings will be ready to transplant into the greenhouse at five to six weeks of age (Figure 8). The plants will have seven to eight true leaves at this point. Some growers place the plants on the plastic of the sawdust bags or rockwool slabs in the production greenhouse for the last week, usually because of a lack of space in the nursery as the plants require increased spacing.

Figure 8. Five-week-old tomato seedlings on the plastic and ready to be transplanted directly onto the sawdust.

The plants are placed in direct contact with the growing media when a number of roots are developing through the bottom of the rockwool blocks. It is important to place the seedlings in direct contact with the sawdust or rockwool slabs before the roots begin to grow horizontally along the plastic of the seedling table/sawdust bag/rockwool slab.

The goal is to ensure the roots go directly into the sawdust or rockwool to ensure firm rooting. Seedlings allowed to develop a horizontal root mass at the bottom of the rockwool cube before transplanting do not establish as well into the final growing media.

Before the young plants are placed on the final growing media, the sawdust bags or rockwool slabs have to be saturated with feed solution so that the E.C. in the final growing media is the same as is in the rockwool block of the seedling. This method ensures a continuity of environment between the block the roots are growing out of and the media they are growing into. The target rootzone E.C. at this time is about 3.5 mmho. The temperature of the rooting media should be 20°C at transplanting.

If sawdust bags are used for the final growing media, the bags should be filled with feed solution for one week before transplanting. This preparation allows for the complete wetting of all the sawdust. Failure to wet the sawdust properly will result in the bulk of the sawdust bag remaining dry throughout the season, which means a reduction in the volume the roots are able to occupy. Transplanting onto dry sawdust has demonstrated that only "cones" of wet sawdust develop directly beneath the irrigation drippers, which are located at the top of the bag.

The sawdust bags are slit for drainage immediately after the young tomato plants are placed onto the sawdust media. Failing to slit the bags results in a very unfavourable waterlogged, anaerobic environment that will severely stall the plants.

The slits are approximately 4 cm (1.5 inches) long and are made on the sides of the bags facing the drainage channel. One slit is made between every two plants. The slits run to the bottom of the bag to ensure complete drainage of the bags and to avoid any pooling of the feed solution at the bottom of the bag.

Once the plants are placed on the final growing media, the air temperatures are maintained at 20°C day and night, with a relative humidity of 75 per cent (VPD of 3.5 to 5 g/m^3) and liquid CO_2 supplementation to 800 to 1,000 ppm. One week after transplanting, growers need to drop the night temperature to reach a minimum 18°C and maintain the 24-hour average temperature at 19.5°C. The root zone temperature must stay at a stable 20°C.

At this time, the goal is to establish a strong, vegetative tomato plant on the growing media, with specific emphasis on the root system. Ideally, the tomato plants will establish deep into the sawdust bags within two weeks.

Once the plants establish on the rooting media, they tend to become overly vegetative or "bullish." The leaves at the tops of the plants tend to curl back on themselves towards the stem (Figure 9). Raising the 24-hour average temperature by 1°C to 20.5°C will direct the plant back into balance and set the stage for fruit production. The 24-hour temperature average should be returned to 19.5°C once the plants have come out of their "bullish" growth habit.

Figure 9. Overly vegetative, "bullish" young tomato plants.

A precise irrigation schedule is an important component in the system of ensuring plant establishment and root system development. Feed should be delivered at an E.C. of 2.5 mmho, with a target 10 to 15 per cent overdrain while delivering about 200 mls per plant per day. Growers should schedule seven irrigation events per day, of about 30 ml per event, starting at 9:00 a.m. and ending at 3:00 p.m. The strategy is to apply adequate water throughout the day, but to time the water delivery so that the roots grow to actively search for water between watering events.

If water were to be applied almost continuously to the young plants, there would be no signal to the plant of a possible moisture deficit, so there would be no incentive for the plant to develop any more roots than it already has. If the plant is meeting its water requirements, there is no need for it to expend more resources developing a more extensive root system. Within nature, this lack of further development is a practical response to the environment; however, greenhouse growers have other plans for their crop. These plans require the plants to put more resources into their root systems.

The more frequent the watering events, the less chance the plants will undergo any water stress. Some water stress is beneficial for growers because the condition directs the plants to search for water by developing a more extensive root system. Young plants may not require a more extensive root system at this early stage of their development. But as the crop matures and fruit production begins, the extensive root system becomes a necessity. Maintaining intensive fruit production demands considerable mobilization and distribution of plant resources. The plant draws on the bulk of these resources through the root system.

The onset of fruit production is designed to coincide with the increasing light levels, with the first harvest beginning in mid to late March. June is usually the month in which Alberta sees a rapid increase in the amount and intensity of light received by the crop.

With an increase in light comes an increase in the demand on the root system. The demand on the root system is proportional to the light received. If the root system is not ready to meet the demand caused by a heavy emphasis on fruit production under conditions of intense light, then wilting can occur.

Experience in Alberta has demonstrated that unless the young tomato plants are managed with a small amount of water stress to promote early root development, they will not have an adequate root system when the high light period begins. The resulting stress typically causes wilting due to a undersized root system.

Increasing the amount of water delivered does not remedy the problem since the volume of water delivered is not the problem. In fact, increasing the water volume delivered increases the problem by creating a situation of waterlogging, which promotes the development of anaerobic conditions and disease. This problem can be avoided completely by careful early management of the young plants' irrigation schedule.

As plant growth continues, growers should increase the amount of water delivered to maintain the 5 to 15 per cent overdrain target by increasing the duration of each watering event, rather than by increasing the number of watering events. As day length increases while the season progresses towards summer, increase the number of watering events to ensure the first watering is about 1/2 hour after sunrise and the last watering is about 1/2 to 1 hour before sunset.

Plant Balance

The goal of greenhouse tomato production is to maintain the maximum sustainable yield of high value tomatoes for profit. The way to maintain yield is to maintain plant balance. Plant balance is defined as the partitioning of the plant resources towards vegetative growth (the production of stems and leaves) and generative growth (the production of fruit). Optimum plant balance is the balance between vegetative and generative growth required to attain maximum sustainable yield.

Skilled growers learn to recognize the signals that indicate a plant is out of balance, with too much emphasis on either generative growth or vegetative growth. Thick stems and large long leaves with associated slow fruit development are symptoms of a plant that is too vegetative. The development of leaflets at the end of a flowering truss is very symptomatic of overly vegetative plants. Thin stems, short leaves and small fruit that ripen quickly are symptoms of overly generative plants. An overly generative plant will eventually stall, with insufficient leaf development to fill the fruit and an accompanying focus on setting more fruit that will not size properly.

The general approach to directing an overly vegetative plant back into balance is to increase the stress on the plant. Plants that are stressed tend towards more fruit production. This stress condition is usually accomplished by raising the 24-hour average temperature by 1°C for a time or by modifying the watering schedule to increase the time between watering events. When adjusting the watering schedule, it is important to maintain the optimum overdrain targets. The strategy is to adjust the timing of the watering events, not the amount of water delivered to the plants. Once the plants have been brought back into balance, the temperature settings and watering schedules are returned to "normal."

To direct overly generative plants back to a more vegetative focus, the approach is reversed. The 24-hour average temperature is reduced by 1 or 1.5°C, and the watering schedule is adjusted to provide more frequent waterings. The idea is to reduce the stress on the plants.

It is important to remember that once a plant begins to produce fruit, the tendency is to continue to produce more fruit. Also, as light levels increase, so does the stress on the plants, and the generative focus also increases. For most of the producing season, the tomato plants will be tending more to a generative focus, so more correction will have to be applied to direct the plant to be more vegetative. The greenhouse should be shaded with whitewash as the high light season begins in June, or it can be very difficult to maintain adequately vegetative plants.

Plant Training and Pruning

Plant training

Tomato plants are trained to one stem that is physically supported by twine hanging from an overhead wire (Figure 10). The wires are located above the rows and run the length of the greenhouse, and they are usually placed one foot beneath the gutter height.

Figure 10. Plants supported by twine to an overhead wire.

At about one week after tomato plant transplanting, the twines are attached to the young tomato stems using plastic "tomato clips." It is important that the young tomato plant be firmly rooted in the sawdust bag before it is clipped to the twine (Figure 11).

Figure 11. Plastic support clip being placed around a tomato stem.

The first plant training procedure after clipping the plants to the twine is to lean the plants in the direction that they will eventually be trained in along the row. It is important to have the plant leaning before the first fruit sets and begins to fill, as this training allows for the all fruit to develop beneath the leaned stem.

By contrast, if the plants are allowed to set fruit while still vertical, the fruit will start to develop on the same side of the stem where the truss originates. As the plant grows in height and has to be leaned, the trusses could completely twist off under the weight of the fruit shifting to the low side of the leaned stem.

Greenhouse tomato plants have tremendous growth potential, with vines reaching up to 12 metres (40 feet) in length during the growing season. Because of this potential, the plants have to be properly pruned and trained to maintain an optimum plant balance. Pruning and training will also avoid unruly, "wild" plants that will develop if the laterals are not pruned, resulting in excessive vegetative growth and the development of multiple stems.

Tomato plants are fast-growing under optimum conditions. Pruning and plant training are critical to proper plant management if an optimum plant balance is to be maintained that will result in high yield.

Plant training and pruning are ongoing tasks that must be scheduled to keep pace with plant growth. There is really no catching-up with plants that have been allowed to grow too long without pruning. The plants can be brought back into balance, but not without some associated yield loss due to the plant resources that were directed into lateral stems, which should have been pruned earlier.

Pruning

The standards for how to prune and manage the plants are set by the head grower, and the pruning standards are implemented by the workers according to a schedule. In larger greenhouses where there are a number of workers, efficiency of the plant pruning and handling tasks can vary by worker. The efficiency of workers improves when they are motivated; work organization can have a significant effect on motivating workers.

Assigning each worker an area of the greenhouse for which they are personally responsible to do all the pruning and plant handling can help workers establish a sense of pride in their work. This system can help ensure that the plants are maintained to the highest standards set by the head grower.

This assignment system also establishes an atmosphere of friendly competition as workers strive for peer recognition for their personal high standards, demonstrated by the performance of their section of the crop. This atmosphere of competition can be managed to help solidify a strong team of workers, especially when workers are paid bonuses based on crop performance.

When the pruning and crop management standards have been established by the head grower, it is also important to recognize that there will be variation in individual plants within the crop. In general, management standards are usually based on the crop as a whole. The standards that will be discussed are examples of this principle, such as truss pruning to four fruit per truss after the first truss or maintaining a specific fruit-to-leaf ratio.

Automatically implementing these standards for all plants in the greenhouse does not allow for weaker plants that can require individual modifications to the plant handling standard. Modifications may be need to shift the vegetative/generative balance to manage the weaker plants, so they can be strengthened.

Primary pruning and plant training tasks:

- removal of lateral shoots
- twisting the support twine around the lengthening stem
- truss pruning
- harvesting
- plant lowering
- removal of the older lower leaves

Plant twinning is another plant training technique used to increase the effective plant density. Increased density is achieved by allowing a second lateral stem on selected plants to develop to produce fruit.

Pruning out the laterals and twisting the support twine is usually done twice a week. The lateral stems are pruned out as soon as they can be easily distinguished from the primary stem. Great care has to be taken to ensure the plants are not “blinded” by removing the primary growing point. If this point is removed and if all lateral sems have already been removed, the productive life of the plant is terminated because the plant will no longer grow without the primary stem.

Starting a new plant as a replacement transplant is generally not effective. The new plant will be too small to obtain the light it needs to develop properly in a canopy of larger plants. In addition, the young plant will be receiving the same amount of water as the larger plants, which will be more than it needs and will likely result in waterlogging and root disease development.

Truss pruning is also done as required during the twisting and pruning events. Truss pruning involves removing the young fruit from the truss as a technique to maintain optimum plant balance. This procedure ensures that the plant does not try to fill too many fruit and also that the fruit left on the plant can reach their maximum size potential.

Premium prices are paid for beefsteak tomatoes that reach the large and extra large grade categories and that have optimum colour and are free of blemishes. The grade size categories are based on the tomato fruit diameter (reduced size translates to reduced grade and reduced price). The greater the number of tomato fruit that are allowed to set on any given truss, the smaller the fruit size.

There are also optimum characteristics for cluster tomatoes. Generally, the market requires clusters of four to six tomatoes, with all tomatoes showing a touch of mature colour. The weight of the clusters should be between 454 to 680 grams.

In addition, truss pruning is also important for maintaining plant balance. If too many fruit are left to be filled, the plant will shift its resource allocation to fill fruit rather than developing leaves and stem. If this pattern is left to continue, the plants will eventually "stall," with very little growth occurring. The result will be a plant with numerous small fruit and short, small leaves. The plant with the greatest yield potential is the plant that allocates resources appropriately to developing new leaves and stems, which are the prerequisite to continuous top grade fruit production.

Normally, a good balance for tomato plants would be approximately 20 to 25 fruit to 20 leaves; however, this balance can vary among cultivars. Growers should prune the trusses to allow three fruit to set on the first truss and four fruit per truss on the following trusses. As the plant continues to grow to the wire, the optimum fruit-to-leaf balance outlined above will be attained.

It takes about six weeks from flowering to fruit pick under optimum light conditions. The first trusses can take seven weeks to develop to harvest due to the lower spring light conditions. As the lower fruit are harvested, new trusses flower and set, and more fruit begins to develop. The balance of 20 to 25 fruit to 20 leaves is maintained with both the fruit harvesting and the removal of leaves.

Leaf pruning, the removal of the lower leaves, is a distinct operation from the pruning of lateral stems. As the fruit develops on the stem, its relative position moves further down the stem in the sense that the subsequent truss develops from the growing point of the plant. The tomato plant canopy is usually maintained at 2 to 2.5 metres (7 or 8 feet) in height. As the plant continues to grow and lower fruit and leaves are removed, the plant is also lowered to maintain the canopy height. The lowering is consistent with the training process outlined in Figures 5 and 6.

As growers develop more skill in assessing the productive potential of the plant, truss pruning can be based on the individual plant. For example, if the overall fruit size on a particular plant is smaller than the crop average, then it may be better to allow only three fruit to ripen on one or two trusses, to direct more resources to the stem and leaves. Plants that have too many fruit will not fill that fruit to optimum size; in addition, the average leaf size will also shorten, which, in turn, leads to even smaller fruit size.

Truss pruning works to balance a weak plant, to allow it to strengthen vegetatively, which allows for the fruit size to begin to increase. This technique allows growers to adjust the vegetative/generative plant balance of individual plants within the entire canopy. Even when the greenhouse environment has been set to optimize the plant balance of the entire crop, individual plant status can vary. Managing the number of fruit allowed to fill on individual plants is a technique that allows for fine tuning the entire crop to ensure optimum individual plant balance.

Canopy height

In the taller greenhouse structures, the overhead support wires can be as high as 3.5 metres (12 feet) above the floor. The height of the support wire defines the practical limit of the tomato crop canopy height. Under the low light conditions of the early spring in Alberta, some growers will allow the tomato canopy to reach the 3.5 metre (12 foot) level to ensure the developing fruit can size up and be ready for harvest without coming into contact with the floor.

Maintaining a tall canopy height is only practical when there are systems in place which allow for working in such a tall crop. The most common approach for working tall crops is to use electric carts with adjustable platforms that allow workers to ride the carts along the row, using the heating pipes as the rails. The pipe and rail system is discussed in more detail in a companion Alberta Agriculture publication *Commercial Greenhouse Production in Alberta*.

Although it is possible to maintain a tall tomato crop canopy throughout the entire growing season, it is not recommended. As the summer approaches with its high light levels, it is recommended that crops be lowered to maintain a maximum canopy height of about 2.5 metres (8 feet).

The greenhouse environment can stratify under the hot, light intense Alberta summers. The higher you go in the canopy, the hotter it gets. Tomatoes are particularly sensitive to high temperatures; if plants are allowed to grow too tall, the temperature signals to the top portion of the plant are not the same as those to the lower.

Depending on the growers ability to control the greenhouse environment, it may not be possible to provide a uniform temperature regime to the entire plant in a tall canopy. Setting the computer sensor at the top of the plants may allow for maintaining temperatures for the optimum plant balance at that height, but could result in temperatures in the lower canopy being too cool. As a result, the lower canopy may become too vegetative, and the tomatoes would size up more slowly although they would reach a larger size before ripening. In addition, placing the sensors in the canopy of the tall crop means the tops of the plants will then generally be exposed to higher temperatures than desired, thus becoming overly generative.

A canopy height of 2.5 metres (8 feet) will allow for more uniform temperature signals to the entire plant, which, in turn, makes it easier to maintain an optimum plant balance throughout the crop.

If the crop canopy is allowed to develop beyond the 8 foot level, it should gradually be lowered to the 2.5 metre (8 foot) level in late May or early June. Canopy lowering is accomplished as the lower fruit are harvested and the lower leaves removed. A lower plant canopy is quite workable under high light conditions because the fruit develops faster and is harvested sooner than under low light conditions.

All factors considered, the determining factor with canopy lowering is to maintain a canopy height such that the lowest, most advanced fruit do not touch the floor.

Twinning to Increase Crop Density

As the crop moves into the summer season, the increased light intensities and associated increase in temperature serve to put more stress on the plants. Increased stress directs the plants to become more generative. The increased generative focus results in shorter, smaller leaves and less growth to the stems. Over time and without correction, the crop canopy would become sparse. As well, the fruit would not fill properly and would be exposed to the direct sunlight, resulting in further quality problems associated with overheating, shrink cracking and blossom end rot.

As the light levels begin to increase with the progression from spring to summer, twinning allows growers two advantages:

- increase the crop density to take advantage of the higher light levels to increase production
- allow for more leaves to shade the fruit and maintain fruit quality

Twinning should take place about 10 weeks after seeding. Certain plants are selected for twinning to ensure the increase in plant density is uniform throughout the crop. For the twinning to be successful, strong plants have to be selected to carry the extra stem. If weak plants are selected, the plant will not be able to support the second stem, and yield will be compromised. In addition, weak twins will not be able to properly fill in the canopy required for the crop to reach maximum yield and collectively resist the stress of the intense sunlight. The result of weak twins will be plants that are that are out of balance and too generative.

The selection of plants suitable for twinning is based on an assessment of vegetative vigour. Strong plants will have relatively bigger leaves and thicker stems near the top of the plant. A good rule of thumb in selecting a plant is to measure the first fully expanded leaf near the head (growing point) or top of the plant. This leaf should be at least 45 cm long for the plant to be considered suitable for twinning.

One more note on selecting the lateral stem to develop on twinned plants. The lateral stem should be selected from the "top side" of the main stem; otherwise, there is a risk of the lateral stem breaking under the weight of the main stem when the stems are lowered to the floor.

Flowering

Flowering is a prerequisite to fruit development, and delays in flowering generally result in delayed fruit production. It is important for growers to understand the process of flower development and how maintaining optimum growing conditions ensures flower development for maximum, sustainable yield (Figure 12).

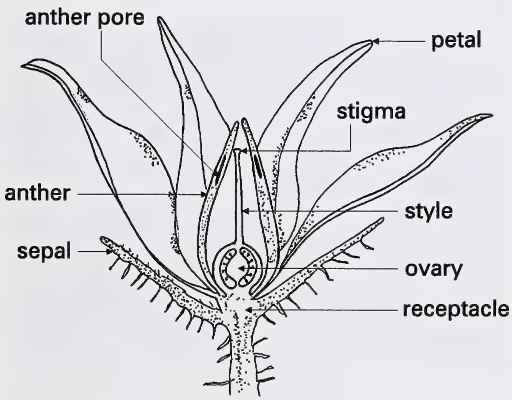

Figure 12. Diagram of a tomato flower

Flower initiation in tomato begins within three weeks of the expansion of the cotyledons, specifically coinciding with the third oldest true leaf reaching one centimeter in length. In the very early stages of flower development, the flower is very small, a barely noticeable bump on the stem length.

Flowering in seedlings is inhibited by low light levels. Reducing light levels from 10,000 to 2,500 lux (approximately 100 to 25 W/m^2) has been shown to delay flower initiation by up to 29 days, allowing up to 7 more leaves to be produced before the first flower was initiated. This example is another strong argument for the use of supplemental lighting during the seedling production stage.

Plant shoot environment can have a significant effect on the number of flowers initiated on an inflorescence. The 24-hour average temperature is the primary temperature factor important for controlling flowering, which suggests that higher day temperatures can compensate for cooler night temperatures. However, branching of the inflorescence or "double trusses" occurs at temperatures below 13°C (Figure 13). Lower night temperatures also have an effect on flower form, increasing the number of petals and stamens.

Figure 13. A double truss.

High temperatures or low light conditions can promote the elongation of the style out of the anther cone, resulting in a reduction of pollination and an increase in flower abortion due to failure to pollinate. Improved cultivars and the high fertility regimes of greenhouse production, including CO_2 enrichment, have largely overcome the detrimental effect of low light on pollination. However, a major cause of poor fruit set is reduced pollen viability driven by high temperatures.

After the flowers on a truss have been initiated, the rate of flower development is primarily determined by temperature, with more rapid development at 20°C (24-hour average temperature). High incidences of flower abortion have been observed when temperatures reach 21°C (24-hour average temperature).

Elongated trusses tend to develop under the low spring light levels in Alberta. Under very low light levels, trusses can even fail to develop, a condition that can depend on the light requirements of the variety and is influenced by heavy canopies associated with planting densities that are too high. Growers should always consult their seed supplier regarding the specific requirements and cultural recommendations for the cultivar they are growing.

Under favourable light conditions, tomato plants that are water stressed or stressed by excessive E.C. levels in the root zone can exhibit reduced rates of flower development. In contrast, under low light conditions, slight water stress can act to promote flower development.

Flower initiation begins very early in the seedling stage of the tomato plant. Poor temperature management and low light levels can have a significantly negative effect on flower development and the subsequent crop yield.

The rate of flower initiation and development are strongly influenced by the environment of the stem. It is important to maintain the optimum 24-hour temperature average for tomatoes in the greenhouse environment to optimize the development of the plant and crop as a whole. This optimum temperature is also ideal for flower development. It is also clear that low temperatures at the growing point can have a negative effect on flower development, which indicates a need to ensure optimum temperatures are maintained at the tops of the plants.

In the early months of the production cycle, it is possible to have cold spots in the greenhouse or temperature fluctuations at the tops of the plants even when the sensors indicate that optimum temperatures are being maintained. Oversized flowers, flowers with too many petals and other morphological abnormalities and dual trusses are all indicators of cooler than desired temperatures at the flowers during early stages of their development. Low temperatures during flowering and pollination can also result in fruit deformities. The use of heating pipes at the tops of the plants can ensure that optimum temperatures for flowering and flower development are maintained.

Carbon dioxide supplementation up to 1,200 ppm does not have an influence on the number of flowers formed. However, carbon dioxide supplementation under the low light conditions commonly experienced in the winter and early spring have been shown to accelerate flower growth in the first inflorescence and reduce flower abortion.

A word of caution when using carbon dioxide generated by combustion, growers need to watch for potential negative effects of pollution. Ethylene can be a by-product of combustion, especially in situations where there is incomplete fuel combustion. Tomato flowers between the bud stage and anthesis are very sensitive to ethylene. Ethylene levels at 0.5 ppm during these stages are sufficient to cause flower abortion.

Pollination

Pollination is the critical event where receptive flowers begin to develop fruit. The tomato flower has both male and female structures. The male structures are associated with pollen development and include the anthers, which hold the pollen. The female structures include the stigma, the structure that receives the pollen, and the ovary that eventually develops into a fruit if pollination takes place.

In the development of the tomato flower, the stigma becomes receptive to pollen one to two days before the anthers actually start to shed pollen, and the stigma remains receptive for a total of six to eight days. The stigma is receptive to its own pollen (self-pollination) or to other pollen (cross-pollination).

Pollen grains must also adhere to the stigma, so the pollen can fertilize the ovary. The adherence of the pollen to the style may be reduced if relative humidity falls below 70 per cent or if temperatures are outside the range of 17 to 24°C. Pollen release can also be reduced under high humidity. Experience in Alberta greenhouses has demonstrated that tomato pollen release is reduced when the relative humidity approaches 85 per cent.

Although modern greenhouse tomato cultivars are self pollinating, tomatoes require some form of mechanical pollination for the crop to attain optimum yield. Any mechanical disturbance of the tomato flower will cause some release of pollen and improve the overall pollination levels in the crop.

Battery powered electric "bees" have been a popular form of mechanical pollination (Figure 14). These devices are used to vibrate the flowering trusses to release the pollen. Tomato pollen is more readily released under bright sunny days and when the temperatures are above 20°C. Conversely, cool cloudy weather reduces the release of pollen. When electric vibrator pollination is used, the plants must be pollinated every second day throughout the cropping season.

Figure 14. An electric "bee" pollinator.

The use of bumblebees, both the western bumblebee (*Bombus occidentalis*) and the eastern bumblebee (*Bombus impatiens*), as pollinators in tomato greenhouses has almost completely replaced the use of the electric bees. Bumblebee hives can be purchased from commercial suppliers (Figure 15). Usually, seven hives per hectare (three hives per acre) are sufficient to ensure complete pollination throughout the tomato crop.

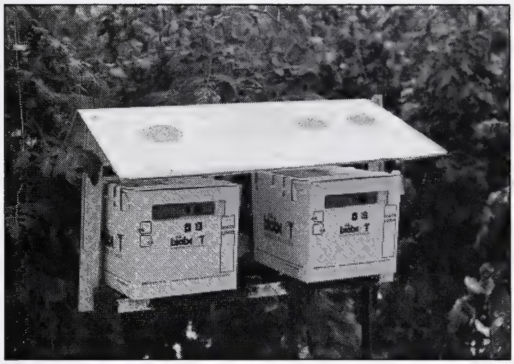

Figure 15. Bumble bee hives for pollination can be purchased from commercial sources.

The association between bees and flowers is long, going back 100 million years to the middle of the Cretaceous period. In short, bees know flowers. Based on observations in Alberta tomato greenhouses, the use of bumble bees as pollinators can result in an approximate 10 per cent increase in yield over using electric bees for pollination. Bees are in the business of collecting pollen and nectar, and they visit tomato flowers when the flowers are most ready to release the pollen.

Bumblebees are not normally aggressive and will not sting unless the hive is disturbed or if individual bees are squeezed, which can occur if bees get caught up in the clothing of workers. The eastern bumblebee is relatively more aggressive than the western bumblebee and tends to be more sensitive to people standing close to the hive. It is important to know whether any staff working in the greenhouse are allergic to bee stings and to consult with medical authorities to ensure that all necessary precautions are taken to be able to respond to a bee sting incident appropriately.

Growers need to know the requirements of bumblebees and how to manage the hive for maximum pollination. Detailed instructions on hive placement and installation, as well as care and maintenance of the colonies, can be obtained by the supplier. Specific recommendations can vary with bee species, but there are some general considerations for care and management.

Using bumblebees as pollinators in greenhouse tomato crops is more easily accomplished when used in conjunction with biological pest control programs. Bumblebees are extremely sensitive to insecticides and can be adversely affected by fungicides. If growers have to use a pesticide, they should always consult with their bee supplier or an extension specialist to determine how to minimize the negative effects to the bees. With many pesticides, there will always be a negative effect on the bee pollinators, and sometimes, these effects can be long term.

As tomato flowers don't produce nectar, the bees require a feed solution as a nectar substitute. The feed solution comes with the hive and usually is of sufficient size to last the productive life of the hive.

Growers need to ensure the hives are placed about 1.5 metres off the ground and are placed in the canopy to shade them from direct sunlight. Warning signs must be posted at the entrances to the greenhouse to inform visitors that bumblebees are used as pollinators in the tomato crop. Growers should also monitor pollination levels two to three times a week to assess the performance of the hive.

When bumblebees visit and pollinate a tomato flower, they leave bruises on the anther cone of the flower. This bruise can be used as proof of pollination (Figure 16). To assess the level of pollination, a grower can collect at least 20 withered flowers from 4 to 5 areas within the greenhouse and determine the percentage of pollinated flowers. Pollination levels should be 80 per cent or better; high yields depend on high pollination levels. Growers should contact their supplier when pollination levels fall below 80 per cent as this level is an indicator that the hives are not performing adequately and may be in decline.

Figure 16. Tomato flower with a bruise on the anther cone indicating the flower has been visited by a bumblebee.

Fruit Set and Development

Consistent high fruit set is a prerequisite to high yield, and pollination is the prerequisite to fruit set. Pollen germination is temperature dependent and takes about 1 hour at 25°C. Pollen must adhere to the stigma to allow germination to take place. As mentioned earlier, if the relative humidity is below 70 per cent or the temperature is outside the range of 17 to 24°C, the adherence of pollen on the style may be reduced. The rate of fruit development depends on temperature. Optimum day temperatures range between 18 to 20°C, with night temperatures dipping to 15 to 16°C to meet the optimum 24-hour average temperature of 19.5 to 20°C. The optimum night temperature for fruit set is in the range of 15 to 16°C.

With reasonable temperature control, neither pollination nor fruit set are limiting for fruit production under greenhouse conditions, provided that light levels are adequate. With the development of tomato cultivars that perform well under conditions of high fertility and CO_2 enrichment, the detrimental effect of poor light on pollination in winter has largely been overcome.

Poor fruit set on apparently healthy plants depends on the climatic conditions before and at the time of pollination. Flower abscission (blossom drop) shortly after anthesis is the most common symptom of the flower's failure to pollinate and set fruit. Low light intensities, short photoperiods and high night temperatures are important limiting factors to fruit set. The temperature three days before anthesis has been shown to have the biggest effect on flower set. Even without style elongation, fruit set at high temperatures is often very low, which suggests that pollen germination and growth of the pollen tube may be disrupted at high temperatures.

High temperatures, low humidity and low moisture all increase blossom drop. During periods of high temperature and low humidity, the flower style elongates before the pollen is released and can result in the flower failing to pollinate if the stigma extends beyond the stamen cone. In addition, the resulting damage to the surface of the elongated stigma makes the stigma unreceptive to pollen.

Fruit size is reduced by water stress, mainly as a result of a decreased fruit growing period. Fruit size can be similarly reduced by excessive electric conductivity (E.C.) in the root zone. Both the sugar concentration and acidity of the fruit are increased by high conductivity of the feed solution.

The fruiting truss is supplied mainly by the subtended leaves, the leaves immediately below the truss. In the tomato plant, the movement of nutrients from a particular leaf and the sources of supply for a truss change as the plant continues to develop. The relationship between leaves as organs that supply nutrients for growth of the fruit and plant, and the established leaves as the sources of these nutrients is termed the source/sink relationship. These relationships define the nutrient supply and demand for the plant and can be quite complex.

When the supply of nutrients is limiting, there is competition between trusses. In fact, the growth of a fruiting truss can suppress the flowering of later trusses. In general, successive trusses flower at six to seven day intervals, but delays of up to one month in the development of later trusses can occur under conditions of limiting nutrients. There is, however, an accelerated growth rate of the fruit under CO_2 enrichment.

Maximum profit depends on more than just yield. It is a function of yield and quality. Tomato quality can be defined as those characteristics of the fruit demanded by the market. Quality characteristics include:

- size
- shape
- colour
- firmness
- taste
- texture
- solids content

Beyond ensuring the plants are managed to produce the maximum number of fruit that meet the required grade for optimum quality, maximum profit is a function of supply and demand.

The profit picture for a greenhouse tomato grower depends on the overall supply of tomatoes from both greenhouse and field production. Prices are usually at their lowest for greenhouse tomatoes during the summer months, when the field tomato crop is in production. Regardless of the supply of tomatoes on the market, the higher prices generally go to the fruit with the highest quality.

Harvest

The fruit of beefsteak tomatoes is preferably harvested at colour break, where a yellow-orange colouration is evident at the blossom end of the fruit (Figure 17). At the very minimum, the tomato fruit must be at least at the mature green stage before harvesting.

Figure 17. Colour break occurs when the fruit begins to take on a hint of mature colour.

As with all quality characteristics, the market is the ultimate authority in determining when to harvest. Growers will adjust the harvest colour standard based on the market they are serving. The further the distance to the market, the more likely the tomato fruit will be harvested with less colour showing. The nearer the market, the more colour showing at harvest. Individual growers with a specific niche at specialty markets may leave the fruit on the vine to ripen almost completely.

It is quite common for the first fruit that reach mature size on the plant to be slow to ripen. These first fruit also show a tendency to continue to increase in size with no indication of colour break. In this situation, a strategy to coax the fruit to ripen is to remove the leaves below the truss and one or two leaves above the truss, exposing the fruit to the direct sunlight.

Cluster tomatoes are harvested when all the tomatoes on the cluster have reached colour break, which then implies that some of the tomatoes will be more advanced in ripening. There are also requirements for the number of tomatoes on the cluster, usually not less than four and no more than six. These requirements for number of tomatoes also have implications for how much the clusters or trusses can be pruned early in the cluster development. This pruning is done as a management strategy to ensure optimum plant balance.

The individual clusters of four to six tomatoes are bagged before they are sent to market. Bagging allows for ease of handling by the consumer and ensures that fruit are not lost from the cluster as the tomatoes are transported home. This bagging also requires extra effort at the greenhouse or packing shed over and above what is required for the tray packing of beefsteak tomatoes.

How the tomatoes are handled at harvest also affects the presentation of the tomatoes at the market. Careful handling will increase the shelf life of the tomato, primarily by avoiding physical damage to the fruit, which increases the probability of spoiling.

Important handling precautions include minimizing the height from which the tomatoes are dropped into the harvest basket and picking early in the morning when the fruit temperatures are cooler than during the heat of the day. It is also important to avoid overfilling the harvest baskets as fruit can be damaged when the baskets are stacked on the pallets for transport to the packing shed.

Table 2. Ranges of vitamin and mineral components of ripe tomato fruit constituents per 100 g of fresh tissue

Constituent	Normal Range	Unit
Dry matter	4.71 - 8.3	grams
Vitamin A	192 - 1,667	IU
Vitamin B1	16 - 80	μg
Vitamin B2	20 - 78	μg
Vitamin B3	280 - 340	μg
Vitamin B6	50 - 150	μg
Niacin	0.3 - 0.85	mg
Folic Acid	7.4 - 8.6	mg
Vitamin C	8.4 - 59	mg
Potassium	92 - 376	mg
Phosphorus	7.7 - 53	mg
Calcium	4.0 - 21	mg
Magnesium	5.2 - 20.4	mg
Sodium	1.2 - 32.7	mg
Iron	0.2 - 0.95	mg
Aluminum	0.5 - 2.95	mg
Boron	0.04 - 0.13	mg
Copper	0.05 - 0.2	mg
Lead	0.02 - 0.05	mg
Manganese	0.04 - 0.05	mg
Zinc	0 - 0.25	mg
Chlorine	24 - 69	mg
Nitrate	1.3 - 30	mg
Ash	0.51 - 0.7	grams

From Redenbaugh et al, 1992

In deciding when to harvest, the grower's main goal is to present the highest quality tomato in colour, size, shape, smell and freedom from blemishes at the point of contact with the consumer. When consumers buy tomatoes, they use their senses of sight and smell to judge the quality and taste of the tomato, and after some consideration of price, a selection is made.

Beat-up, ugly tomatoes don't sell as well as near perfect-looking tomatoes, no matter how well they might taste. However, it also true that consumers do have a memory for how well the last tomato tasted, so the best looking tomatoes still have to perform well on the table.

Table 3. Nutritional value of ripe tomato fruit per 100 grams of fresh tissue (Recommended Daily Allowances – RDAs)

Nutrient	Per cent contribution to the total nutrient supply from tomato
Protein	0.8
Vitamin B	63.5
Vitamin A	9.5
Vitamin C	60
Thiamin	3.2
Riboflavin	1.3
Niacin	3.1
Ascorbic acid	12.2
Magnesium	2.6
Calcium	0.9
Iron	15

From Redenbaugh et al, 1992

When tomatoes are harvested, they are destined for someone's table The act of the harvest should be considered as one of the very early stages in the preparation of a meal. Growers must be aware of the food safety requirements of their market. There is more and more emphasis on ensuring the safety of the food supply, which includes accountability for how the produce was grown and handled in the greenhouse.

Food safety requirements include certain design specifications of the fruit handling areas to ensure the fruit do not come into contact with soiled surfaces. The picking baskets have to be washed regularly, and greenhouses must ensure that workers handing the produce have ready access to washing facilities that make it easier to maintain clean hands while fruit is being handled.

Table 4. Variation in amounts of carotenoid pigments in ripe fruit per 100 grams of fresh tissue

Constituent	Range among six tomato cultivars
Phytoene	9.8 - 29
Phytofluene	2.1 - 15.5
ß-carotene	1.4 - 11.9
Lycopene	43.6 - 181.2
Values in μg/g fresh tissue	

From Redenbaugh et al, 1992

Pest and Disease Management

Successful crop production means crop pests and diseases must be managed, so their effects on the plants are minimized. Crop disease management is directed at preventing the establishment of diseases and minimizing the development and spread of any diseases that become established in the crop. Managing pest problems is directed at preventing pest populations from becoming too large and uncontrollable. Pests and diseases are facts of crop production, and growers must use all available options and strategies to avoid serious pest and disease problems.

Integrated pest management (IPM) is a term used to describe an evolving process where cultural, biological, and chemical controls are included in a holistic approach to pest and disease control. Key components of effective pest and disease control programs include:

- sanitation
- crop monitoring
- cultural control
- resistant cultivars
- biological control
- chemical control

Sanitation – Greenhouse Cleanup

Greenhouses are completely cleaned and disinfested at the end of each production year. This operation sets the stage for the new crop by ensuring no pest and disease problems carry over from the previous year. The old crop is completely removed from the greenhouse along with the growing media.

The interior greenhouse structure is pressure washed with a detergent solution and then rinsed. A wash with a 10 per cent bleach solution followed by another rinsing can also be used to ensure that any disease organisms or pests are disinfested from the structure. Growers should not combine the detergent with the bleach in a one-wash operation; otherwise, there could be a chemical reaction between the detergent and bleach. Protective gear, including a respirator, must be worn when pressure washing the greenhouse to avoid prolonged, direct exposure to the bleach solution.

All dripper stakes, clips and truss supports should be soaked overnight in a 10 per cent bleach solution and then rinsed. Irrigation lines should be flushed with nitric or phosphoric acid at a pH of 1.6 to 1.7 (1 part acid to 50 parts water). The pH or E.C. sensors should not be touched by the bleach or acid as these sensitive instruments can be damaged. The acid solution should be held in the irrigation lines for 24 hours before the lines are rinsed thoroughly with water.

CAUTION: To avoid the build-up of fumes, growers should always provide good ventilation throughout the greenhouse when flushing the lines with acid. The pH of the flushed water must be tested to ensure the flushed water does not have a pH of below 5 or else dangerous chlorine gas may form.

New sawdust bags should be used for every crop while rockwool slabs can be reused for two or three years. Slabs that have lost more than 10 per cent of their original height should not be reused because their structure will have changed substantially. This change will result in yield reduction of the crop.

Steam sterilization of rockwool slabs is a prerequisite to reuse. The slabs should be heated to 100°C and held at this temperature for 10 minutes, or held at 75°C for 20 minutes. Rockwool slabs that have been stacked on palettes and wrapped in heavy plastic require 5 hours of heating to reach 100°C.

Crop Monitoring

Crop monitoring is the continual surveillance to detect the presence of a pest or disease at the very early stages of development of the disease or pest population, before economic damage has occurred. Everyone involved in working the crop should be made aware of the common pest and disease problems and should know what to look for to detect the presence of crop problems. In addition to this general crop surveillance, dedicated crop monitoring should be included in the weekly work schedule.

Blue sticky cards placed throughout the crop are a useful monitoring tool to help trap and detect pests before they become a significant problem. Yellow sticky cards are known to attract and catch some biological control agents such as *Aphidius sp.* Biological control agents can be released well before any pest population explosion, thus allowing for the establishment of the control agents and the prevention of a serious pest problem.

Crop monitoring should begin when the crop is still on the seedling table or at the transplant stage (especially when transplants are obtained by another greenhouse, that is, purchased from a propagator). If transplants are being purchased from a propagator, the greenhouse grower should be in contact with the propagator regarding any pest problems occuring during the production of the transplants.

It is also important to know what pest control measures were used, if any. Growers should establish in advance what control measures they are willing to have applied to the transplants at the propagator's before the plants are received into the production greenhouse. The concern is that any pesticides that were applied must be compatible with the grower's pest control programs, such as biological control programs, that will be used for the duration of the crop. Some growers may insist that only biological controls be used during the production of transplants and/or that biological control agents be introduced to the transplants as a preventive measure before the growers take the transplants into their greenhouses.

Cultural Control

Cultural pest and disease control methods involve providing the conditions that favour the growth, development and health of the crop, and wherever possible, providing conditions that work against pest and disease development.

Free water or condensation on the plants can provide ideal conditions for many disease-causing fungi and bacteria. High relative humidity promotes the development of disease, so maintaining the environment below 85 per cent relative humidity will help escape or avoid disease problems. Ensuring proper ventilation and air movement within the crop canopy, as well as maintaining optimum plant spacing and a relatively open canopy, will ensure good air circulation and will minimize the establishment of micro-climates that favour disease development. Proper contouring of the greenhouse floor will avoid water pooling, which contributes to localized high relative humidity.

Optimizing the greenhouse environment to favour plant development will ensure a strong, healthy plant. Such an environment is not only a prerequisite for high yields, but also results in plants that are better able to resist diseases and insect pests.

Just as greenhouse sanitation is a vital component of crop management, good crop sanitation is another important aspect of successful cultural control. The plants must be pruned and maintained on schedule, and all crop debris should be removed promptly from the greenhouse area. Any weeds that happen to gain a foothold through gaps in the floor plastic should be removed immediately upon discovery and the floor repaired. Personal plants or "pet" plants should not be grown in the greenhouse. Both weeds and "pet" plants can be a source and haven for pest and disease problems.

Pruning tools and other equipment should be cleaned and disinfected on a regular basis. Aprons or other clothing worn by the workers should be washed frequently. When a disease or pest problem area exists in the greenhouse, that area of the greenhouse should be worked last, to avoid the workers spreading the disease or pests. In this situation, special care must be taken to disinfect tools and to clean clothing.

Growers need to maintain a 6 to 10 metre wide buffer zone around the outside of the greenhouse by regularly mowing any weeds in this zone. Plants close to the greenhouse can serve as a reservoirs for the continual introduction of pests and diseases. Screening the air intake vents can also play an important role in excluding pests from the greenhouse. It is not enough to just screen-off the intake vents because the screening restricts the air flow into the greenhouse. It is important to ensure that the surface area of the screening is large enough so that it does not restrict the air flow into the intake vents. Ensuring adequate air flow may require that a screen chamber be constructed over the vent.

Resistant Cultivars

Plant breeders have had considerable success in developing cultivars that contain genetic resistance or tolerance to diseases. When selecting the cultivars to be grown, it is important for growers to consider the genetic resistance of the cultivars to the prevalent disease problems in the region.

The development of cultivars possessing genetic resistance to pests has been relatively unsuccessful; however, the techniques of genetic engineering have made inroads in conferring pest resistance in plants. Genetically modified, pest resistant plants may become available to greenhouse growers in future.

The development and use of genetically modified plants or genetically modified organisms (GMOs) is currently a contentious issue, and cultivars such as these may not be accepted by consumers.

Biological Control

Biological control (or biocontrol) uses beneficial organisms, primarily predators and parasites, to control pest populations below economically significant levels. The goal is to establish a balance between the pest population and its parasites and predators to keep the pest population under control. Complete eradication of the pest population is not the goal of biological control programs, as some pest organisms are needed, so the parasites and predators can reproduce.

The greenhouse industry has a well established reputation for using biological pest control agents, more so than any other crop production industry. The reason for this practice is, in part, due to the ability of greenhouse growers to manage the environment to favour the biological control agents. Another factor is the relatively limited number of pest species in greenhouses, as well as a general tolerance of greenhouse crops to leaf damage caused by these pests.

The high value of greenhouse produce is another reason why the use of biological controls is economical in greenhouse crops. The increased use of biological controls has led to a reduction in pesticide applications, giving the industry the lead in environmentally responsible, intensive crop production.

The effective biological control of diseases is a more difficult goal to reach and to date, has rarely been achieved. However, research in developing biological controls for greenhouse crop diseases is ongoing, and it is likely that biological control products for greenhouse diseases will be available in Canada in the near future.

The primary biological control strategy for greenhouse plant diseases is to introduce fungal parasites to control populations of disease-causing fungi in the greenhouse environment. The fungal parasites either reduce the fungi's ability to infect the plants, or they prevent the infection altogether. Some of the promising biological control agents, for example fungi in the Genus *Trichoderma*, are strong competitors of the disease-causing fungi such as *Botrytis cinerea*, and these agents can be used to protect wound sites to stop *Botrytis* from colonizing the wounds.

Chemical Control

Pesticides can be valuable tools when used as a component of an integrated pest management program. Insecticides should be applied only in support of biological control programs, dealing with localized pest outbreaks in the crop that have escaped the biological control agents. When insecticides are used, care must be taken to ensure they are compatible with biological control agents and that there will be minimal long term adverse residual effects on biological control programs. Fungicides are used only when a disease problem is detected.

Pesticides are often regarded as the controls of last resort because their misuse creates high profile environmental and food safety problems. Also, the application of some pesticides to a crop can cause stresses that reduce the productive life of the crop and can make the plants susceptible to other pests and diseases. Biological control agents are used to obtain a balance between pests and predators that does not threaten the productive yield of the crop, while the indiscriminate use of pesticides creates imbalance and uncertainty in the crop.

Common Physiological Disorders

Blossom end rot

Blossom end rot is the most common physiological disorder of greenhouse tomato in Alberta (Figure 18). The disorder is due to a calcium deficiency in the fruit and can occur even when there are acceptable calcium levels in the fertilizer feed solution.

Figure 18. Blossom end rot.

Calcium is an immobile nutrient, and once the calcium has been placed at a specific site within the plant, it cannot be redirected to another site that may be lacking.

The transpiration process is the mechanism by which nutrients, including calcium, are brought up from the roots and distributed to the developing organs of the plant, including the fruit. As water is lost from the leaves during transpiration, there is a natural pull from the leaves to draw more water and nutrients to them. Fruit, on the other hand, either does not transpire or transpires at very low levels due to the lack of stomata. This lack requires that calcium and the other nutrients necessary for proper fruit development be directed to the fruit.

Any condition that stresses the plant and interrupts the flow of calcium to the fruit can result in localized calcium deficiencies in the fruit. These deficiencies will result in the subsequent development of blossom end rot.

The most obvious symptom of blossom end rot is the development of a dry, sunken, dark brown or black area at the blossom end of the tomato. The symptoms of blossom end rot can also be completely contained within the fruit, in which case they are recognized by the blackening of internal tissues, usually within the bottom quarter of the tomato fruit.

Conditions that can result in blossom end rot include fluctuating levels of fertilizer feed to the plants or other factors that induce water stress on the plant, such as inadequate water/fertilizer feed. Fluctuating light levels are also associated with the development of blossom end rot, primarily through the resulting fluctuation in water and nutrient uptake from the fertilizer feed.

High levels of competing cation (positively charged ions) nutrients in the feed solution, specifically potassium and to a lesser extent magnesium, can interfere with and restrict calcium uptake. Potassium is the nutrient most often involved in restricting calcium uptake because increasing potassium levels in the fertilizer feed is used as a strategy to correct blotchy ripening, another physiological disorder that affects tomato.

Prevention is the best approach to controlling blossom end rot. Growers need to ensure there are always adequate levels of calcium in the feed and that the plants are receiving adequate fertilizer feed. Overdrain targets should be maintained at 25 to 30 per cent during the high light periods, and particular attention needs to be given to the water delivery during periods of fluctuating light levels. In such situations, care must be taken to ensure the plants are not overwatered during instances of low light and not stressed by periods of underwatering when light levels rapidly increase. Optimum vapour pressure targets (VPD) must be met (a discussion of VPD is included in the Alberta Agriculture publication *Commercial Greenhouse Production in Alberta*).

Growers must always be aware of the natural cycle of light levels during the year and need to anticipate the plants' increased water requirements. For example, the light levels in Alberta increase dramatically in late May and June. Failure to increase the volume of the fertilizer feed delivered at this time will result in water stress, which, in turn, can bring on blossom end rot.

Growers need to pay close attention to the daily per cent of overdrain as this figure will be the first indicator of the need for increased fertilizer feed as the per cent overdrain drops below the optimum 25 to 30 per cent. Daily monitoring of the E.C. also gives clues to the relative water stress on the plants.

High E.C., above 3.5 mmho, can place a salt-induced water stress on the plants and result in the onset of blossom end rot. The feed E.C. needs to be maintained at a level that will ensure the resulting root zone E.C. is within acceptable limits for the cultivar being grown. The acceptable level for most cultivars under high light conditions is usually around 3.5 mmho. When growers consider dropping the feed E.C., they should always ensure that the volume of water delivered to the plants is optimized first. Any adjustments to the E.C. of the feed solution should be made gradually, in 0.1 mmho increments per day.

The plants on the outside rows of the greenhouse will require more water than the plants in the interior of the crop, because the outside plants receive more light. This situation is especially true of the plants on the east, south and west sides of the greenhouse. These plants may require additional drippers to maintain adequate overdrain.

The strategy of increasing the drippers from 1 to 1.5 or 2 drippers per plant (2, 3 or 4 drippers per bag) allows for more water to go to these plants without increasing the volume of water delivered to the majority of the plants beyond the 25 to 30 per cent overdrain target.

Blotchy ripening

Uneven colouration of the ripening fruit is symptomatic of blotchy ripening. This disorder (Figure 19) is primarily considered to be a physiological disorder, but can also be a result of virus infection. A number of conditions can bring about blotchy ripening of the fruit:

- inadequate fertilizer levels
- high fruit temperatures
- infection by tomato mosaic virus

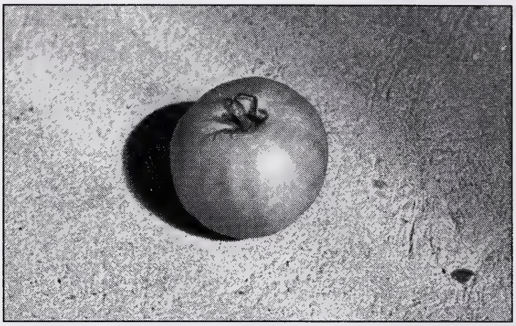

Figure 19. Mature tomato fruit exhibiting blotchy ripening.

When fruit temperatures exceed 39°C, the red pigments of the fruit can be destroyed, and the less heat-sensitive yellow pigments remain. The overall effect is blotchy yellow and red fruit. If the blotchy ripening occurrs primarily on fruit that is exposed to the direct sunlight, the cause of the problem is probably high fruit temperature. Be aware that air temperature is not a good indication of fruit temperatures, which can rise to over 10°C above air temperatures. Infrared thermometers can be used to measure the temperature of an object and will give an accurate reading of fruit temperature.

Plants in the outside rows are the first to be affected by temperature-induced blotchy ripening since they have the greatest exposure to direct sunlight. Applying shading to the greenhouse is standard practice in commercial enterprises in Alberta, particularly in the south, and will help reduce the occurrence of blotchy ripening. Adjusting pruning practices to leave more leaf cover to reduce fruit exposure to direct sunlight will also have a dramatic effect in reducing the incidence of blotchy ripening.

Growers also need to remember that plants that are out of balance can exhibit blotchy ripening. Overly generative plants will have smaller leaves and may not be able to provide the required canopy to protect the fruit. Plants that are overly generative during the high light season will simply continue this tendancy over time, and yield can be severely reduced. Plants need to be twinned well before the high light season to ensure the summer planting density targets are met, which will, in turn, provide an adequate crop canopy.

Plants that are overly vegetative can also exhibit blotchy ripening because they will direct too many resources towards the production of leaves and stems, at the expense of the developing fruit. Fruit-to-leaf ratios of 20 to 23 fruit to 14 to 15 leaves represent optimum targets and will result in the reduced likelihood of blotchy ripening.

Inadequate nutrition to the plant can also result in blotchy ripening. Daily monitoring of the feed and leachate E.C. will ensure the overall level of fertilizers has not fallen off drastically because of an equipment malfunction. In situations where the fertilizer feed and the leachate E.C.s are optimum and blotchy ripening is occurring, attention should then be focused on the fertilizer feed targets, and a nutrient analysis would be conducted.

Excessive nitrogen can also play a role in the occurrence of blotchy ripening. Nitrogen favours vegetative growth, and an overly vegetative plant results in inadequate resources being directed to the fruit. Inadequate levels of potassium can also result in blotchy ripening. A feed analysis will confirm the levels of nutrients in the fertilizer feed. Fertilizer feed targets must be met before any other adjustments to the feed are considered.

In the situation where the nutrient feed targets are being met and all other reasons for blotchy ripening have been ruled out, attention turns to the potassium levels in the feed. In most situations where increasing the potassium levels is considered, the actual potassium levels in the feed have not fallen below the levels initially targeted.

Increases in the potassium level in the feed should be done in increments of 10 per cent every two weeks to a final maximum 20 per cent increase in potassium. The concern with increasing potassium is related to the potential interaction with calcium uptake. Both potassium and calcium are positively charged ions, or cations, and can be considered as being in competition with respect to access by the plant. The main point is, too much potassium can interfere with calcium uptake and can cause a blossom end rot problem.

When increasing potassium levels in the feed, growers must first ensure that the amount of fertilizer feed delivered with respect to calcium uptake is optimized, as is the environment. If these conditions are met, and blotchy ripening still persists, increasing the potassium levels should correct the problem. If further increases in potassium are contemplated, calcium must also be increased at the same relative rate so as not to change the calcium/potassium ratio any further.

Blotchy ripening can also be aggravated by tomato mosaic virus (TMV) infection. Using tomato cultivars that are resistant to TMV will help avoid TMV-associated blotchy ripening. Practically all new greenhouse tomato cultivars have adequate TMV resistance, so TMV is more of a concern on older cultivars.

Cuticle cracking or russeting

Cuticle cracking or russeting is identified by the presence of fine cracks at the top of the fruit. These cracks reduce the appearance and quality of the fruit and become more noticeable as the fruit ripens. The fruit on plants that are out of balance, either outside the optimum the fruit-to-leaf ratio or too vegetative or too generative, have a greater tendency to exhibit cuticle cracking.

Overly vegetative plants tend to have fewer, larger fruit that develop more slowly and have a tendency to exhibit cuticle cracking. Overly generative plants have more fruit exposed to direct sunlight as well as higher fruit temperatures because of reductions in leaf lengths and overall canopy cover, so they show a tendency for cuticle cracking. The disorder is also more likely to occur under conditions of high humidity, such as over 85 per cent and when temperatures are too cool during fruit set. Raising the root zone E.C. will generally reduce the incidence of cuticle cracking.

Cuticle cracking is also associated with late day watering applications. As the night period begins and the natural light falls off with the sunset, the greenhouse air temperatures drop to meet the nighttime temperature targets. As the air temperatures and light levels drop, the plants also begin to cool, and transpiration is reduced. The root zone, however, can still be quite warm and the roots still active, with the uptake of water and nutrients continuing for some time. With the drop in transpiration, less of this water is drawn to the leaves and more is directed towards the fruit. This "burst" of nutrients directed to the fruit can cause a relatively rapid expansion of the fruit that subsequently results in cuticle cracking.

Cuticle cracking can be avoided by maintaining optimum growing conditions and managing the fruit load and leaf number to ensure optimum plant balance. If cuticle cracking begins to occur on well balanced plants in an optimized environment, the last watering event of the day may be occurring too late. Moving the last watering event back by one half hour should help correct the problem. Growers should always ensure that adequate water is applied over the course of the day to meet overdrain targets.

Low temperatures during flowering – catfacing

Catfacing is an example of a fruit disorder caused by low temperatures during flowering. Air temperatures below the optimal temperatures for pollination can result in fruit deformity.

Fruit affected by catfacing are misshapen, with black scarring of the blossom end (Figure 20). If problems with misshapen fruit begin to occur in the tomato crop, the first step in correcting the problem is a thorough review of actual air temperatures at the flowers.

Figure 20. Catfacing.

Magnesium deficiency

A magnesium deficiency can occur in the leaves of vigorously growing, high yielding crops even when magnesium levels in the fertilizer feed are optimum. Symptoms begin as light green spots between the veins of the leaves, with the spots becoming yellow and eventually purple as the symptoms intensify. The symptoms are first noted midway down the plant, about twelve leaves down from the top (Figure 21).

Figure 21. Magnesium deficiency.

The development of magnesium deficiency symptoms depends on cultivar; however, affected crops do not generally exhibit yield loss. A foliar application of magnesium fertilizer does not alleviate the symptoms. Growers unfamiliar with this condition will need an analysis of the fertilizer feed solution to confirm that nutrient levels, including magnesium, are adequate.

Truss kinking

Under conditions of low light, the flowering truss can elongate, resulting in a weakened truss that kinks under the weight of the developing fruit. The kinking interrupts the flow of nutrients to the fruit and results in slower fruit development and poor fruit size. Truss kinking can be prevented by using truss supports. Truss supports are typically used on the first eight trusses on the plants (Figure 22).

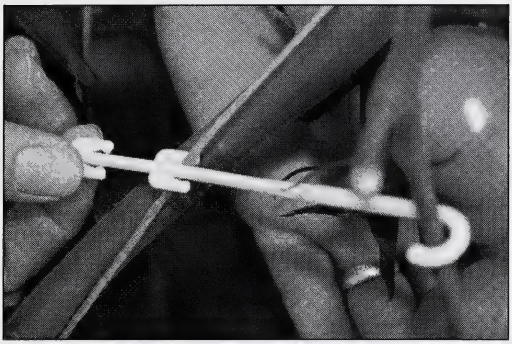

Figure 22. Truss supports are usually placed on the first eight trusses in order to prevent truss kinking.

pH-induced leaf yellowing

A rapid onset of leaf yellowing in the lower to middle canopy can occur after a dramatic drop in the pH in the root zone (Figure 23). Symptoms have occurred when the root zone pH has fallen to 3.5 from the ideal level of 5.8. The pH drop is usually caused by an equipment malfunction that results in an overdosing of acid into the fertilizer feed. The affected leaves do not recover, and the extent of the overall damage to the plant depends on the magnitude and duration of the highly acid conditions.

Figure 23. Leaf yellowing induced by a rapid drop in the pH of the nutrient solution.

Herbicide drift

Herbicides are not recommended for use in greenhouses; however, greenhouses can be located in agricultural areas, so there is the potential for herbicides to enter the greenhouse via the air vents. Some growers have used herbicides to control weeds around the greenhouse, which is a risky practice because herbicides can cause considerable crop damage if they enter the greenhouse. The damage caused by herbicide drift depends on the specific herbicide (Figure 24).

Figure 24. 2,4-D injury on the young leaves.

Growers in agricultural areas need to make sure their neighbours know that they are tomato growers and that the crop can be seriously damaged by herbicide drift. Growers can ask their neighbours for notification before a herbicide is applied to the crops, so growers can take the necessary measures to close up the greenhouse during the application. Neighbours should also be aware that they need to avoid herbicide applications when the wind is blowing towards the greenhouse. Herbicides should never be used to control weeds around the outside of the greenhouse; growers need to use mechanical methods of weed control.

Fungal Diseases

Pythium root rot and wilt (*Pythium* spp.)

Pythium root rot and wilt can affect tomato plants at any age. *Pythium* is a very common genus of fungi that are classed as water molds. For practical purposes, it is wise to consider that *Pythium* is always present in the greenhouse at some level. As with most diseases, the presence of the pathogen does not guarantee that the disease will develop.

Pythium takes advantage of plants under stress, and this situation is especially true for tomato plants. A healthy tomato crop rarely has trouble with *Pythium*. Avoiding problems with *Pythium* through maintaining healthy plants in an optimum growing environment is the best way to deal with the disease potential.

Pythium attacks the roots of the tomato plant and concentrates on the small feeder roots. In situations where *Pythium*-infected tomato plants have been examined, the bulk of the roots can remain clean and white, suggesting a healthy root system. When sections of these roots are examined in the laboratory, they often reveal only very low levels of *Pythium*, levels far below what would be expected if *Pythium* was a problem. The feeder roots where *Pythium* is causing the problem are often too small to work with or are overlooked in the examination of the roots of *Pythium*-wilted tomato plants.

The two main conditions that predispose roots to infection by *Pythium* are physical damage to the roots and overwatering. Physical damage is really only a concern during the transplanting stage where the seedlings are placed into the production greenhouse. Care must be taken to minimize the damage that can occur during handling, transporting and transplanting of the tomato seedlings. Overwatering is much more of an ongoing concern with respect to *Pythium* infection. Overwatering causes the roots to suffer from a lack of oxygen, which stresses the plant and predisposes it to infection.

A pattern often occurs in tomato greenhouses where *Pythium* has become a problem. This pattern demonstrates that the problem with *Pythium* occurs as a result of watering practices over a considerable time after transplanting.

Once the tomato seedling has been transplanted into the production greenhouse, the first priority is to establish the plant in the growing media by encouraging the development of a strong root system. A careful watering strategy is employed to deliver enough water to meet the requirements of the plant (indicated by meeting the overdrain targets of 10 to 15 per cent) and to deliver the water with, on average, one-hour intervals between watering events.

The strategy is designed to ensure the plants are not stressed due to lack of water and yet to provide enough time between watering events to avoid waterlogging and ensure a healthy root environment. Timing watering events for every hour encourages the roots to grow and actively seek water, compared to more frequent watering events that are constantly delivering water to the young roots. The concept is that more frequent watering events do not encourage healthy root system development in the same way that strategically timed water delivery does.

Unless there is so much water applied that the root systems are actually subjected to waterlogged conditions, *Pythium* rarely develops in the seedlings at this stage. The problem occurs as the light levels increase and the transpiration stress is increased, requiring the root system to supply the increased water requirements of the plants. The problem usually manifests itself during the onset of the high light period, which occurs at the end of May or early June.

Plants that have an inadequately developed or inadequately functioning root system cannot meet the light-induced increased demand for water. The result can be dramatic, with the entire crop wilting. Growers often react to this situation by applying more water, using the logic that a wilting crop is not getting enough water. The problem is with the root system at this point, not with the amount of water, and applying more water can waterlog the root zone, further stressing the plants and encouraging the development of *Pythium*.

Growers who do not change their strategy on watering by using the percentage overdrain as their guide will generally see a recovery of the plants within about two weeks of the high light-induced wilt. Growers who apply too much water will see a continual decline and the onset of problems with *Pythium* and plant death. In this situation, yield will suffer, with the most severe losses associated with prolonged overwatering.

The best way to avoid the high light-induced wilt, and the development of *Pythium* from overwatering, is to always use optimum overdrain targets to determine the amount of water delivered to the plant. Daily monitoring of the overdrain levels is a very important tool for making decisions concerning changing the amount of water delivered to the plant. Growers need to increase the amount of water when the overdrain falls below the 10 to 15 per cent target.

Monitoring the E.C. of the overdrain provides the basis for adjusting the overdrain target. For most tomato varieties, the E.C. in the root zone should be kept in the range of 3.5 to 3.7 mmho. As the light levels increase, the E.C. in the root zone will increase because the plants have a higher relative requirement for water over nutrients, and the fertilizer salts can accumulate. Overdrain targets should increase as the E.C. rises past 3.7 mmho to a maximum of 25 to 30 per cent. If the root zone E.C. continues to increase beyond 3.7 mmho at 25 to 30 per cent overdrain, the feed E.C. must be decreased by 0.2 mmho every 2 to 3 days until the root zone E.C. stabilizes at approximately 3.5 mmho.

Mature, producing tomato plants under high light summer conditions will use up to 2.5 liters of fertilizer per day with overdrain targets of 25 to 30 per cent. If wilting occurs under these watering conditions and water is increased to alleviate the wilting, the per cent overdrain will also increase beyond 40 per cent, indicating that the plant is not using the extra water. The problem with wilting will not be corrected with the application of more water because the base cause of the wilting is an inadequate root system, not insufficient watering. The addition of extra water increases the problem by fostering conditions that further the development of pythium root rot.

In short, conditions that increase stress on the root system can provide an environment favourable to the development of pythium root rot. Optimized watering practices early in the life of the plant will prepare the plant for the high light conditions and will minimize the waterlogging conditions that foster *Pythium* infection.

Other management practices to prevent *Pythium* and root diseases in general include avoiding high water temperatures (temperatures over 24°C), controlling fungus gnats and shore flies (which spread the *Pythium* spores from plant to plant), careful removal and destruction of infected plants, avoiding the introduction of soil to the watering system and using new sawdust bags for every crop. Rockwool slabs should be sterilized between every crop.

Fusarium wilt (*Fusarium oxysporum* f.sp. *lycoperisici*)

Fusarium wilt usually occurs when the tomato plants are under the stress of full fruit production and high summer temperatures (over 28°C). The problem occurs more commonly in greenhouses that are not equipped with evaporative cooling systems. Other factors associated with the onset of this disease include any shock to the root system from irrigation system malfunctions, causing either a lack of water during a few hours, loss of pH control resulting in low root zone pH (pH of 3) or high root zone E.C. (greater than 5.0 mmho). The risk of fusarium wilt is always increased when these predisposing problems occur during hot days.

In any situation where fusarium wilt occurs, the pathogen has to be present. Predisposing problems only set the stage for aggressive fusarium infection of the root system.

The onset of symptoms begins with wilting and yellowing of the lower leaves. The symptoms progress up the plant as more leaves are affected. It is not unusual for wilting and yellowing to occur on leaves from only one side of the stem, with leaves on the opposite side of the stem seemingly normal. The yellowing is commonly a more distinctive orange-yellow colouration on affected leaves that can be symptomatic of fusarium wilt. Infected plants eventually wilt completely and die.

The fusarium wilt fungus is introduced into the root system of plants via the seed or soil, and plants can remain without symptoms for quite some time. The disease may only develop when the plants come under stress.

Control can be achieved through prevention, using fusarium wilt-resistant cultivars, using new growing media for each crop and through maintaining optimum growing conditions. Infected plants must be carefully removed and destroyed.

Fusarium crown and root rot (*Fusarium oxysporum* f.sp. *radicis-lycopersici*)

Fusarium crown and root rot is caused by a close relative of the fusarium wilt fungus. Symptoms of fusarium crown and root rot first appear as wilting of the upper leaves, usually developing at the onset of the high light period when the plants begin full fruit production (Figure 25). Examination of the base of the stems will reveal a dark brown stem canker. Some development of secondary roots may be apparent above the stem lesion. A reddish discolouration is present in the vascular tissue, which can extend 25 or 30 cm up the stem from the base. The roots are typically brown and discoloured.

Figure 25. Typical chlorosis of Fusarium infected plants.

Infected plants must be carefully removed and destroyed. Growers should not reuse growing media from infected crops. A thorough clean-up of the greenhouse structure is a must between crops. The entire greenhouse floor must be securely covered in plastic, with no soil exposed. The fungus survives well in soil and can carry over from one year to the next. It can also enter the greenhouse through holes in the plastic floor. The use of resistant cultivars or tomato plants that have been grafted onto resistant rootstocks are good prevention strategies.

Botrytis blight (gray mold) (*Botrytis cinerea*)

Botrytis cinerea has a worldwide distribution and causes serious losses to a wide range of greenhouse crops and field crops. *Botrytis* is truly a disease of opportunity; it is considered one of the easiest diseases to control through proper management of the environment.

Conditions of high relative humidity, over 85 per cent, and the presence of water droplets on the plants favour disease development. All above-ground parts of the plant can be affected: leaves, petioles, stems and fruit. *Botrytis* is quick to colonize plant wounds.

The symptoms first appear as a dark discolouration in the plant tissue around the wound. As the disease progresses, more tissue is affected, and the lesion becomes larger. A gray mass of spores can develop as the fungus grows on the surface of the lesion, producing a velvety mat over the lesion. As conditions change and the relative humidity drops for a time, the gray spore mass can disappear leaving a tan-coloured lesion. If the relative humidity around the lesion increases again, the fungus can again begin to grow out onto the surface of the lesion.

The most severe symptom associated with botrytis blight is the stem canker (Figure 26). Plants can be girdled and killed by these cankers. Through the routine handling of the crop, pruning and harvesting, wound sites suitable for infection are created almost daily. If a *Botrytis* infection starts at a petiole stub where a leaf has been removed, the infection can move into the main stem and girdle the stem.

Figure 26. Botrytis stem canker with a mass of gray spores that have formed under conditions of high humidity.

Tomato fruit can also be affected and can exhibit a peculiar symptom referred to as ghost spots (Figure 27). The symptom is most prominent on ripe fruit, but can be noticed first at the mature green stage. The ghost spot symptom appears as a light coloured halo around a small necrotic spot on the tomato fruit. The necrotic spot in the middle of the ghost spot is caused by the aborted infection of the fruit where a *Botrytis* spore has landed. Ghost spot symptoms on the fruit results in downgrading the affected tomatoes.

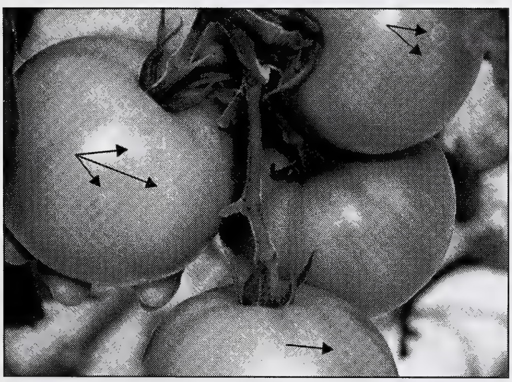

Figure 27. The ghost spot symptom on tomato fruit.

The presence of free water for a period of four to six hours is necessary for *Botrytis* spores to germinate and to begin to infect the plant. The free water on the fruit allows the spores to germinate. The failure of the infection to actually take hold is associated with the length of time the free water is actually present. Free water must be present long enough for the infection to begin, but then the infection cannot continue if the free water disappears.

Fruit can also become infected at the calyx. Free water is likely to remain longer in the depression at the calyx end of the fruit, which can hold water much like a small basin. The light halo around the small necrotic spot is due to the physiological response of the fruit to the initial infection and is associated with the plant's defense response.

The most effective approach to control is to manage the environment to avoid the formation of free water on the plants. It is useful to know the types of conditions that result in the formation of free water on the plants before the environment can be effectively managed to avoid conditions favourable to the development of *Botrytis.*

Botrytis is a problem in tomato crops in the spring and fall. Some typical situations lead to the formation of free water on the plant, all of which center around condensation. Warm air can hold more water vapour than cold air. The basic requirement for condensation is a warm, humid air mass contacting a cold surface. As the warm air is cooled by contact with the cold surface, the air loses some of the water vapour to the cold surface. The result is that the water condenses directly on the cold surface.

In the first situation, warm, humid greenhouse air contacts the cold surfaces of the structure's roof, and condensation can form. The condensation can then drip directly onto the plants.

The second situation is associated with conditions that cause the air temperature to warm faster than the plant temperature, which allows for the condensation of water from the air directly onto the plant surfaces. This situation usually occurs early in the morning when air temperatures increase more quickly from the night temperature to the day temperature than does the temperature of the plants themselves. As the air temperatures increase, and the plants begin to transpire, the water vapour in the air rises. The relative humidity increases and if the greenhouse is not aggressively dehumidified, condensation forms on the cooler plant surfaces. As the morning progresses, the plant temperatures increase to a point where they match or exceed the air temperature, and condensation formation on the plant surfaces stops.

This second situation typically occurs in late spring, when outside temperatures are still below freezing, and the natural light levels are good. The greenhouse air mass can warm quite quickly after sunrise due to solar gain. As the air temperature rises, and the plants begin to transpire due to the incoming light, the relative humidity of the greenhouse air increases. As the temperature and humidity of the air increase, there will be a point where condensation forms on the plants.

The primary approach to avoiding condensation on the greenhouse structure and plants is through dehumidificaton. Dehumidification is accomplished through heating and venting. The warm, moisture-laden greenhouse air is expelled or exhausted when the relative humidity reaches 75 to 80 per cent. As the warm humid air exits the greenhouse, colder, drier air is drawn into the vents. This air has to be warmed and mixed with the greenhouse air mass to avoid cold air contacting the plants and causing chilling injury.

Simply put, dehumidification maintains optimum relative humidity and temperature targets in the greenhouse where the airmass is constantly taking up more water vapour due to the active plant transpiration. Dehumidification ensures conditions for optimum plant transpiration, which, in turn, ensures optimum yield. Dehumidification also ensures that condensation does not form directly on the plant surfaces or in sufficient quantities on the structure that could subsequently rain down on the plants.

In the case where condensation forms on the plants early in the morning, because the plant temperature lags behind the air temperature as it is warmed by the early morning sun, it is advisable to begin to heat the greenhouse early in the day so that the plants are warmed to the daytime temperature target before sunrise.

In Alberta, the ghost spot symptom of *Botrytis* occurs when condensation forms on the plants due to cold plants in a warm air mass during the early morning hours. Ensuring that the plant temperature is already at the daytime target before the sun rises effectively eliminates the symptom.

Effective dehumidification ensures that condensation formation on the greenhouse roof, and subsequent dripping onto the plants, is minimized. The process also minimizes the opportunity for *Botrytis* to infect these wet sites on the plants. More effort to protect the plants against water droplets from problem drip sites is often required to deal with the problem completely.

Botrytis will usually establish a foothold in the greenhouse early in the season. As the season progresses into the summer, the problem practically corrects itself because of the warm, dry Alberta summer air. With the onset of fall, the conditions change to favour the buildup of humidity in the crop as the outside air temperatures drop. In most cases when there is a problem with *Botrytis* in the fall, there was almost certainly a problem with it in the spring. It is only in rare instances that *Botrytis* becomes a problem in greenhouses only in the fall without a problem having occurred in the spring.

Early and late season problems with *Botrytis* are almost always associated with poor dehumidification strategies. Effective dehumidification is aggressive dehumidification to ensure that the relative humidity in the greenhouse does not exceed 80 per cent and that the plant temperatures are always within about 5°C of air temperatures.

Dehumidification requires the simultaneous heating and venting of the greenhouse, which requires the input of energy and results in higher energy consumption and cost. Some strategies to minimize energy costs include marginal approaches to dehumidification, with a resulting high humidity and conditions that favour condensation. Such strategies not only compromise maximum crop production through reduced transpiration and subsequent plant growth, but they also encourage the development of *Botrytis* and subsequent production losses due to disease.

Other strategies to minimize the occurrence of *Botrytis*:

- maintaining good air circulation through the canopy
- avoiding the pooling of water on the greenhouse floor

- ensuring the floor is free of pruned leaves
- ensuring that tomato stems do not contact the damp floor

The use of pipe and rail heating systems ensure that the floor and canopy remain relatively dry as well as driving the humid air out of the canopy, helping to eliminate high humidity microclimates that favour *Botrytis*. Pipe and rail heating also allows for the maintenance of relatively warm plant temperatures and practically eliminates condensation on the plants.

Powdery mildew (*Erysiphe* sp.)

Powdery mildew of tomato was first detected in Alberta greenhouses in 1997. Powdery mildew is common on a number of plants; however, the causal organism is not the same for all plants. For example, the powdery mildew on greenhouse tomato is not caused by the same fungus that causes powdery mildew on greenhouse cucumber.

Powdery mildew on tomato appears as diffuse whitish powdery patches on the surface of the leaves, looking much like talcum powder dusted on the leaf (Figure 28). The white powdery material is the fungal mycelium growing on the leaf surface. The symptom is not nearly as distinct as the powdery mildew on cucumber, which causes pronounced whitish patches. As the disease progresses, the leaf tissue under the whitish patches begins to yellow.

Figure 28. Powdery mildew on tomato.

The disease usually establishes under conditions of low relative humidity. Plants that are close to furnaces and stressed are usually the first to develop symptoms. The disease can spread quickly throughout the crop.

Growers need to avoid air temperatures above 21°C, and they need to ensure a relative humidity of at least 70 per cent. Overhead misting can be effective in slowing the development of the disease in the early stages of infection. Chemical controls are also available.

Bacterial Diseases

Pith necrosis (*Pseudomonas corrugata*)

Pith necrosis usually occurs in mid to late spring, once the plants have set and begun to develop fruit to mature size. The disease typically strikes in crops where the plants are growing vigorously and have developed thick canopies. The appearance of this disease appears to defy standard logic in that it strikes plants that appear to be in excellent condition, which have been given optimum growing conditions that may have established a slightly over-vegetative plant balance.

Black lesions develop on the stem and the lesions expand along the length of the stem as the disease progresses (Figure 29). Affected plants eventually wilt and may display yellowing of the lower leaves. Affected stems can eventually collapse at the lesion sites. Examination of the stem interior reveals a dark brown to black discolouration with a ladder-like appearance of the stem, due to cross strands remaining intact (Figure 30).

Figure 29. A blackened pruning scar indicating pith necrosis.

Figure 30. Stem cross section revealing the extent of pith necrosis.

The bacterium is considered to be soil and water-borne, but little is understood about its biology. The disease does not spread readily throughout the crop, and not all affected plants will die. As the plants become more generative and light levels increase, problems with the disease stop.

Severely infected, wilted plants should be carefully removed and destroyed. Growers need to ensure that an active growing environment is maintained and that plants are not overly vegetative.

Bacterial canker (*Clavibacter michiganensis* subsp. *michniganensis*)

Bacterial canker is most common on tomato crops grown in soil. Wilting of the lower leaves is usually the first symptom. There is an associated light brown streaking along the length of the stem and leaf petioles as the disease progresses. The affected stems can take on a watery appearance, and the streaks can split open to form a canker (Figure 31). A clear to whitish coloured ooze may be associated with the cankers or wound sites along the length of the brown streaks on the stem.

Figure 31. Black streaking of the stem and bacterial ooze, characteristic symptoms of bacterial canker.

The disease is favoured by conditions of high humidity and is readily spread in several ways: from plant to plant by splashing water, by infested pruning tools and by the day-to-day handling of the crop by workers. The bacterium can survive in the soil in infected crop residue from season to season, and it is seed borne.

Growers should use disease-free, heat-treated seed. Diseased plants and adjacent plants should be removed as soon as an infection is discovered. The relative humidity has to be controlled to avoid the formation of free water on the plants. The crop should not be worked by moving from infected areas to healthy areas. Workers should wash their hands after working with infected plants.

Virus Diseases

Tomato mosaic virus

Tomato mosaic virus (ToMV) is distributed throughout the world and is found wherever tomato is grown. Tomato mosaic virus has a very wide host range that includes a number of greenhouse crops including petunia, snapdragon and pepper. In tomato crops, the virus is very easily spread from plant to plant during routine plant handling.

ToMV is both seed and soil borne and can survive in the crop residue for up to two years. There are a number of strains of the ToMV, and the symptoms expressed by the plants can vary with the strain. Typical symptoms include alternating light green to dark green mottling or mosaic of the leaves and the fern leaf symptom, where the blades of the leaflets undergo a distorted development into a very narrow shape (Figure 32).

ToMV can also reduce fruit quality when fruit symptoms occur. Infected fruit develop a blotchy appearance, which can increase in severity to form sunken areas that are dark brown to black. Severe infections can cause significant yield losses.

Most modern commercial cultivars contain resistance to ToMV, and infected plants rarely develop severe symptoms. The symptoms of ToMV are often more severe under low light conditions, and the fern leaf symptom can develop on some of the resistant cultivars under low light conditions. The infected plants improve and grow out of the symptom as the light levels increase. There is no appreciable yield loss in most cases.

Figure 32. Shoestring leaf symptom of ToMV.

Other control measures include the routine washing of work clothes and disinfection of pruning tools by dipping them in a 10 per cent trisodium phosphate solution. Limiting the year-to-year spread of the virus is done by completing a thorough greenhouse cleanup at the end of the crop year, growing in soil-less substrates and ensuring that the soil floors of the greenhouse are completely covered and sealed off with plastic.

Tobacco mosaic virus

A minor disease of greenhouse crops, tobacco mosaic virus (TMV) has a very wide host range and is one of the most infectious plant viruses. The symptoms of TMV are virtually the same as tomato mosaic virus (ToMV). Tobacco mosaic is also both soil and seed borne.

Control recommendations for TMV are the same as for ToMV. Tomato cultivars with resistance to ToMV will also have some resistance to TMV. As TMV can be present in cigarette tobacco, it is advisable to refain from smoking near plants or in the greenhouse. Hands should be washed thoroughly with soap and water after using tobacco products to prevent the transmission of the virus to the crop.

Tomato spotted wilt virus

Tomato spotted wilt virus (TSWV) also has a very wide host range, infecting a number of greenhouse ornamental and vegetable crops. As more became known about this virus, it was determined that what was thought to be a disease caused by a single virus was actually caused by two separate viruses. The two viruses are tomato spotted wilt virus and impatiens necrotic spot virus (INSV). Both viruses can infect tomato and cause similar symptoms. If tests are conducted for TSWV, they should also include tests for INSV.

TWSV and INSV are not easily spread by handling the plants. The primary vector of these viruses are thrips, particularly the western flower thrips.

Symptoms of TSWV and INSV include stunting of the plants and bronzing of the leaves. Necrotic lesions can develop on the leaves that progress down the petiole to the stem. Ring spots of alternating red and yellow can develop on the fruit. Affected plants can also wilt (Figure 33). Examination of the root system will reveal apparently healthy white roots, which is not consistent with wilts due to root rot.

There are no TSWV/INSV resistant tomato cultivars. The main approach to controlling this virus is through the control of the thrips vector. The level of thrips control routinely obtained in Alberta greenhouses is usually sufficient so that TSWV and INSV are not a common problem.

Figure 33. Wilting caused by TSWV.

Greenhouse Tomato Pests and Biological Control

Biological control (biocontrol) of greenhouse pests is an option many Alberta growers choose to use. To assist growers, this section provides descriptions of the common pests of greenhouse tomatoes followed by a list of the biocontrol agents recommended for control. Pesticides are not discussed. Pesticide recommendations can be obtained from a greenhouse crop production specialist.

Biological control agent quality

Biological control agents are living organisms, and their ability to establish and control pest populations depends on their fitness. When ordering biological control agents, growers need to ask the supplier what to look for to help assess the quality of the agents when they arrive. A hand lens or magnifying glass is very useful when inspecting packages of biological control agents.

Packages arriving during the winter should be checked immediately to ensure they have not been frozen or subjected to extreme cold temperatures. The inside of the shipping cooler should not be cold. If the ice pack contained within the cooler is frozen solid, it is likely the entire package froze, and the biological controls have been damaged or killed. Packages received during the summer months should be cool inside; if they are hot, then the biological control agents may be damaged or killed.

Growers should always release the biological control agents into the greenhouse as soon as possible after they arrive. The instructions provided with the package should always be followed.

Whiteflies

Whiteflies are the most common insect pest of greenhouse tomatoes. Two whitefly species are a problem in greenhouse crops: the greenhouse whitefly, *Trialeuroides vapariorum* and the silverleaf whitefly, *Bemesia argentifolia*. Of these two pests, it is the greenhouse whitefly that is found almost exclusively in Alberta tomato crops.

Whitefly adults are approximately 2 millimetres long, with the shape of a moth. The adults will fly up from the plants when disturbed and will generally move only a short distance before settling down on another leaf. Adult females lay their eggs, which hatch in about 10 days, on the undersides of leaves.

Whitefly damage the plant by sucking sap from the leaves. Large infestations can cause leaf yellowing and a general decline in the plant. Sooty mold is commonly found in association with whitefly.

As with aphids, whitefly feeding also results in honeydew formation, which can reduce fruit quality. The presence of the honeydew and sooty mold can mean the fruit must be washed before going to market. In addition, the presence of sooty mold on the leaves can reduce leaf productivity reducing the amount of light reaching the leaf surface.

Two parasitic wasps, *Encarsia formosa* and *Eretmocerus eremicus*, are effective against whitefly, with parasitized whitefly scale becoming yellow or black, depending on the parasite. Scale parasitized by *Encarsia formosa* is black. *Delphastus pusillus* is a small beetle that feeds on whitefly eggs and is ideal for complementing *Encarsia* and *Eretmocerus*.

Thrips

Two thrips species that are common pests in greenhouse vegetable crops: the western flower thrips, *Frankliniella occidentalis* (Figure 34) and the onion thrips, *Thrips tabaci*. Thrips feed by opening wounds on the plant surface and sucking out the contents of the plant cells. The feeding results in small whitish streaks on the leaves and fruit and can cause distortions in the young, developing fruit.

Figure 34. The western flower thrips.

The adult thrips congregate in the flowers, and regular monitoring of the flowers will allow for early thrips detection. Yellow and/or blue sticky traps placed throughout the crop, as with the other insect pests, will help in the early detection of thrips infestations. Avoid using yellow traps if *Aphidius* sp. are being used for the control of aphids in the crop.

In addition to causing direct feeding damage and resultant yield loss, both thrips species are vectors of Tomato Spotted Wilt Virus (TSWV), which can be a serious disease problem in peppers and tomatoes. One of the main control measures for minimizing the spread and infection of TSWV within the crop is to control the thrips vectors.

A number of predators are available for biological control of thrips: predatory mites *Amblyseius degenerans, Amblyseius cucumeris, Hypoaspis miles* and *Hypoaspis aculeifer* and predatory bugs, *Orius insidiosus* and other *Orius* species.

Two-spotted spider mite

The two-spotted spider mite *(Tetranychus urticae)* is a common pest of a number of greenhouse crops. Typical symptoms of two-spotted spider mite infestations include speckling of leaves and fine webbing on the underside of affected leaves. As the spider mite population increases, the leaves become brittle and brown, the amount of webbing on the leaves becomes very prominent and the mites can be seen milling about on the webs.

It is very easy for the two-spotted spider mites to be “picked up” on clothing and transported throughout the crop by workers. As the season progresses into fall, female two-spotted spider mites develop a bright orange-reddish colour as they prepare for the winter. The female mites seek shelter in crevices throughout the greenhouse, and a thorough end-of-season pressure wash cleanup is necessary to minimize the number of females that survive to the next crop.

Biological control of the two-spotted spider mite in tomato can be obtained by introducing the predatory mite *Phytoseiulus persimilis* as soon as two-spotted spider mites are detected in the crop. The mites *Amblyseius fallacis* and *Amblyseius californicus* are closely related to *P. persimilis* and should be used along with *P. persimilis*.

Carmine spider mite

The carmine spider mite is a variant of the two-spotted spider mite and takes its name from the slight reddish colour this mite displays. The carmine spider mite distinguishes itself from the two-spotted spider mite through its ability to cause rapid and extensive leaf death at very low population densities. As few as two mites per leaf have been known to kill a tomato leaflet in one week. The carmine mite is believed to introduce a potent toxin into the leaf during feeding.

Carmine spider mite infestations in Alberta greenhouses have been rare, but when they have occurred, the damage to the plants has been rapid and dramatic. In fact, growers have had to resort to chemical control to eradicate the pest.

Aphids

Aphids are not common pests of greenhouse tomatoes. When infestations occur, they are usually on plants close to the air vents.

The green peach aphid (*Myzus persicae*) is the most common aphid pest of greenhouse vegetable crops, but there are other aphid species that can become a problem in greenhouse tomatoes (Figure 35). These other aphid species include the melon aphid (*Aphis gossypii*), the potato aphid (*Macrosiphum euphorbiae*) and the foxglove aphid (*Aulacorthum solani*).

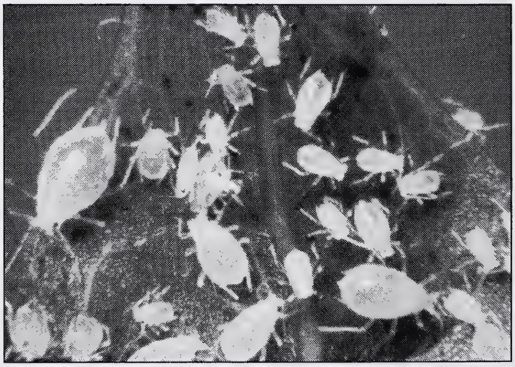

Figure 35. The green peach aphid.

Not all aphid biological control agents are equally effective on all aphid species, so growers need to be sure of the identity of the aphid species in question. All the species eventually develop winged forms.

Green peach aphids are usually light green, but can be pinkish or yellowish in the fall. The body is about 1.2 to 2.5 millimetres long and egg-shaped. The winged forms can have black or brown heads and black markings on the body.

Melon aphid adults are usually either black or green when there are just a few aphids present, but as the population grows and the aphids become crowded, the colours can range from olive green to yellowish green. Melon aphids are about the same size as green peach aphids, 1 to 3 millimetres long. The melon aphids can be distinguished from the other aphid species by the dark black cornicles and short antennae.

Potato aphids are quite large, 1.7 to 3.6 millimetres long, and the body is wedge-shaped and yellowish green to pink. The head has prominent antennal tubercles that are directed outwards. Potato aphids will drop off the leaves when disturbed.

Foxglove aphids are smaller than potato aphids, but larger than melon and green peach aphids. This aphid is shiny light yellowish green to dark green with a pear-shaped body. The only markings on the bodies of wingless adults are darkish patches at the base of the cornicles.

Aphids can be present in the crop very early, even while the plants are just in the seedling stage. They can come in on the transplants as well. Aphids feed by sucking the plant sap. Symptoms of aphid infestation include the development of sticky honeydew on the leaves and fruit. The presence of honeydew on the fruit requires that the fruit be washed before going to market.

Sooty mold is often associated with the aphid honeydew. This mold uses the honeydew as a food source and grows to resemble a layer of "soot" on the leaves and fruit. The presence of sooty mold on the fruit also makes washing the fruit a necessity. The growing points, young leaves and flowers can be damaged and distorted, and in severe infestations, flower abortion can occur.

Parasitic wasps provide effective aphid control:

- *Aphidius matricariae* for green peach aphid
- *Aphidius colemani* for the melon aphid and green peach aphid
- *Aphidius ervi* for potato aphid
- *Aphelinus abdominalis* for potato and foxglove aphid

Parasitized aphids become silvery-brown with a small exit hole at the back where the parasite emerges. The larvae of the midge *Aphidoletes aphidimyza* feed on most aphid species, but will not feed on gall forming aphids.

Growers can consult their local biocontrol supplier for information and recommendations on release rates.

Fungus gnats

Fungus gnats are commonly found in practically all greenhouse crops. Fungus gnats are an indicator of moist conditions in the greenhouse, and populations generally grow to be quite large early in the year or whenever there is water pooling on the greenhouse floor.

Adult fungus gnats range from 2 to 3 millimetres in length, while the larvae are 4 to 5 millimetres long. The larvae of the fungus gnats are the damaging stage and feed on the roots. They are generally not a problem in greenhouse tomato and pepper, but can be a serious in cucumbers, especially in young plants. Affected plants develop slowly and may eventually collapse if too much of the root system has been damaged. There is evidence that fungus gnat adults may transport root rot fungi such as *Pythium* sp. and *Fusarium* sp. from plant to plant, contributing to the spread of disease caused by these fungi.

Fungus gnats are often confused with shore flies, as both are common in the greenhouse under wet conditions. Shore flies are slightly larger than fungus gnats and look like scaled-down versions of house flies, while fungus gnats look more like tiny mosquitos that don't bite.

Biological control of fungus gnats is obtained through the use of predatory mites *Hypoaspis miles* and *Hypoaspis aculeifer*. Both these predatory mites also have activity against thrips larvae that move to the base of the plants to pupate. Nematode parasites in the genus *Steinernema* are applied as a drench to the root zone and kill the fungus gnat larvae by penetrating the larvae and consuming them from the inside.

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