Floriculture Production Guide

February 2020

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Chapter 1 - Integrated Pest Management

An integrated pest management (IPM) program considers all factors that influence plant health and vigour, and those that affect the health and reproductive capacity of pests. Typically, an IPM program will attempt to optimize growing conditions for the crop but not for pest development. The key components of a pest management strategy are:

- sanitation,
- control of the greenhouse environment,
- monitoring for pests,
- understanding the life cycle of pests, and
- timely use of biological and chemical pest control agents.

Sanitation

Growers with clean greenhouses have fewer pest problems. Greenhouse sanitation includes the removal or exclusion of factors that allow pests to gain access to the greenhouse, survive from crop to crop, or spread from plant to plant. Good crop hygiene focuses on starting clean and preventing the introduction of pathogens or insects to the crop. If possible, growers should empty the greenhouse entirely between crops and sanitize it.

Start with Clean Plants

Ensure that trays and carts with propagation material are clean before coming into your greenhouse. Plants that originated off site should be thoroughly checked upon arrival. Plants that are diseased or infested with insects should be removed.

Install a foot bath at the entrance to the greenhouse. A container with a foam mat is effective. Fill the bath with a labelled disinfectant and change the solution every two weeks. Post signage on foot bath use.

Control visitor access to production areas. Visitors should wear disposable coveralls when entering sensitive areas to reduce the risk of pests being carried into the facility on their clothing.

Meet with staff to discuss pest management. Discuss the importance of early pest and disease detection. Explain the early symptoms caused by specific pests and diseases.

Install sticky traps to monitor for certain insect pests. See the *Crop Monitoring and Scouting* section in this chapter.

Keep the growing area for growing. Do your container filling and transplanting in a non-growing area of the greenhouse.

Sanitation During the Crop

Sanitize cutting tools between cuttings or when moving to a new stock plant. There are several disinfectants available, such as Virkon®, FloraLife® DCD, 70% ethanol, 10% bleach and quaternary ammonium. The different products have different properties and uses. Chlorine bleach is very corrosive and may damage cutting tools over time. Keep ethanol containers away from flames.

Avoid putting “pet” house plants or vegetable plants in the greenhouse. These are often a source of disease and insects.

Plant Residues

Promptly remove plant residues, and diseased and dead plants. Remove plant residues from the greenhouse site, or dispose of them by burying, pasteurizing, or burning. Open refuse piles near a greenhouse are a source of re-infestation for a variety of diseases and insects. If you must have a cull pile, locate it as far away from the greenhouse as possible, downwind, and not close to your water source. Pathogens such as *Pythium* and tobacco mosaic virus can be spread in the water. The pile should be covered with plastic sheets or a soil layer after each deposit to prevent the release of spores and the build-up of insects feeding on plant tissue. The best solution is to remove cull material from the site. Recycling is fine, but don’t recycle your pests.

Weeds

There should be no weeds in the greenhouse. Weeds are a feeding and breeding site for many pests including whiteflies, thrips, and spider mites. Keep a 1 to 3-metre weed-free zone around the perimeter of the greenhouse. The weed-free zone should be at least three metres near doorways and vents.

Screening

Flying pests, such as thrips, aphids, and moths, can be excluded from greenhouses by covering vents with screens. Several materials of various mesh sizes are available. Screens reduce airflow into the greenhouse, which is usually compensated for by increasing the surface area of the vent opening or by using pleated screens. For exclusion of thrips, the increase in surface area needs to be 2 to 5 times larger than the unscreened vent area.

Algae Control

Algae build-up should be minimized in the greenhouse because it encourages and harbours fungus gnats and shore flies and can pose a safety hazard due to its slippery nature. Avoid over-watering and provide good drainage under the greenhouse. Fix any broken or improperly functioning drains as quickly as possible to prevent wet areas in the greenhouse. Algae can be controlled by following disinfection procedures.

Cleaning Up After the Crop

During crop production infectious microbes, pathogens, and algae can accumulate. For this reason, growing areas and greenhouse system components should be disinfected. In addition to managing algae, disinfectants can control specific plant pathogens. Disinfecting should be done routinely during the cropping cycle and, if possible, a thorough disinfection should be done between crops. Disinfect all benches, equipment, flats, and tanks. Pressure wash with a mild soap detergent followed by a disinfectant at label rates. **Never mix bleach and ammonia compounds together as hazardous gases may form.**

Remove debris on walkways and header-house floors, and wash with a disinfectant. High levels of organic debris on surfaces will significantly reduce the efficacy of disinfectants that work through oxidation, such as bleach or hydrogen peroxide. Mineral deposits can also protect pathogens on surfaces. It is important to remove debris with detergents and water before applying the disinfectant.

Whenever the Greenhouse is Empty

Take the opportunity to clean out irrigation lines when the greenhouse is empty. The following steps outline the process:

- Keep lines charged at a low rate prior to cleaning to prevent drying out. Once they dry out, it is difficult to remove dried salts and other debris.
- Remove EC and pH electrodes.
- Divert cleaning solutions away from slow sand filters. Keep the slow sand filter units charged with old solution.
- Pressure-flush the irrigation lines with air or water before acid or bleach treatment.
- Flush lines with nitric or phosphoric acid at a pH of 1.6 to 1.7 for 24 hours if there is scale in the lines. This is prepared by adding 1 part 60 to 70% acid concentrate to 50 parts water. Apply twice if you have older lines or narrow orifice capillary lines. CAUTION, some lines have neoprene diaphragms that can be damaged with exposure to solutions with a pH less than 3.0 or buffered bleach. Consult your supplier for information on compatible disinfectants.
- RINSE WELL. When acid contacts bleach, dangerous chlorine gas may form.
- Flush lines and tanks with a disinfectant. It is more effective to flush the lines as a ‘pulse charge’ four times, with one-hour intervals, than to flush with one pulse charge and leave the solution in the line for four hours. Do not drop the pH below 5.0 when using buffered bleach. Target a pH of 6.5 to 7 and follow all safety recommendations on the label. Use a non-phytotoxic surfactant at the rate of 1 L/1,000 L of water. Used buffered bleach solution must be collected and disposed of in accordance with Ministry of Environment guidelines.
- Rinse with fresh water.
- Disinfect regular sand filters with bleach. Do not treat slow sand filtration systems with bleach.
- Power wash the structure and glass with water to remove larger pieces of debris. Then power wash the structure with a cleaner. Use registered products and follow label directions. If you have had a virus problem, use Virkon. Apply Virkon with LVM or mist after the plastic is down. If using ammonium bifluoride, remove it within 5 minutes or it will damage glass. **AVOID MIXING BLEACH AND AMMONIA COMPOUNDS BECAUSE HAZARDOUS CHLORINE GAS COULD BE PRODUCED.**

Environmental Control

Light, temperature, water, and air quality are climatic factors that influence plant growth. When any of these factors are more or less than optimum, there are stresses placed on the plants. Actively growing root systems will often ‘outgrow’ root rot organisms. Stressed plants tend to grow slower and are more susceptible to pest damage.

Precise climate control is important. Large swings in the greenhouse climate can produce an environment that is ideal for disease development. Remember, strong and healthy plants have the best chance to fight pests and resist infections. For more information, see the *Managing the Plant Environment* section in Chapter 3.

Crop Monitoring and Scouting

Monitoring and scouting are essential to insect and disease management. In order for an integrated pest management program to be effective, it is necessary to detect pests early when their population levels are low. A successful program requires commitment and time must be allowed for crop monitoring. Inspect plants regularly for signs of pests. Examine all new material before it is brought into the greenhouse. It is easier to prevent new insect and pathogen outbreaks than to control established ones.

It is usually best to have one person assigned to maintain a scouting and monitoring program. However, all workers should be trained to be on the lookout for signs of pests. Use Tables 1.1 and 1.2 to detect insect problems early. Table 5.1 should be used for early disease diagnosis.

Yellow sticky cards or strips are available and are excellent for early detection of whiteflies, fungus gnats and thrips. Blue sticky traps are particularly attractive to Western flower thrips, but they don't provide the broad pest attraction of yellow traps. Place one trap in each 100 m^2 of greenhouse area close to the crop canopy. Check the traps for pests twice a week. More traps should be placed close to doorways and vents. Generally, you'll need six to eight per monitoring area. Evaluate the stickiness of traps after 3 to 4 weeks and replace if necessary.

Keep an on-going record of trap-catch numbers. When a pest is detected, have it accurately identified and begin control measures as soon as possible after the action threshold has been reached.

Understand the Pest

It is important to know the life cycle of the pest as some control methods will be specific to certain stages of the insect. Often the egg or pupal stages of insects and the spores of pathogens are resistant to pesticides. Many chemicals used against whiteflies will control the adults but are not effective against the pupal stages. These types of sprays must be timed to coincide with periods of high adult populations. Some insects live part of their lives in the soil (e.g. thrips, fungus gnats). At such times, pest control applications to the foliage will be ineffective, whereas treating the soil will control the pest.

When pest control is required, time the applications to control the stage of the pest for which the control agent is recommended and monitor its effect afterwards. Knowledge of a pest's life cycle will help determine the best time to apply control methods. Keep dated records of pest problems and the stages of crops attacked, and any treatments done and their level of effectiveness. Use this information to anticipate and prepare for future pest problems.

The ratio between a pest and its natural enemies is used to determine whether more biologicals need to be added or if the system is keeping the pest in check. For example, the ratio of *Encarsia*-parasitized (black) whitefly scales (larvae) compared to un-parasitized (white) scales.

Table 1.1: Monitoring Methods	**Aphid**	**Fungus Gnat**	**Leafhopper**	**Leafminer**	**Mite**	**Moth**	**Plant Bug**	**Shore Fly**	**Thrips**	**Whitefly**
Yellow sticky cards at top of plant canopy	✓	✓	✓	✓			✓	✓	✓	✓
Blue sticky cards at top of plant canopy									✓	
Trap crops/catch plants	✓								✓	✓
Potato sections on soil surface		✓								
Light traps						✓				
Visual Inspection	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 1.2: Scouting Methods	Aphid	Caterpillar	Fungus Gnat	Leafhopper	Leafminer	Mealybug	Midge, Gall Fly	Cyclamen Mite	Spider Mite	Plant Bug	Scale	Shore Fly	Slug, Snail	Thrips	Weevil	Whitefly
Flower/Shoot Tip Damage	✓	✓						✓	✓	✓				✓		
Leaf/Stem Damage																
Galls	✓						✓									
Holes		✓								✓			✓			
Lineal mines					✓											
Notches on margins															✓	
Skeletonization		✓											✓		✓	
Speckling				✓					✓					✓		
Signs of a Pest																
Dark fecal spots on leaf		✓										✓	✓	✓		
Honeydew/sooty mould	✓					✓					✓					✓
Insects clustered on stems or leaves	✓	✓				✓			✓		✓					
Insects fall out of flowers when tapped										✓				✓		
Insects seen to move in flowers when blown on														✓		
Insects or eggs on underside of leaf	✓	✓							✓					✓		✓
Insect skins on leaf	✓			✓							✓					
Pests hide under objects													✓		✓	
Slime trails													✓			
Small black flies			✓				✓					✓				
Webbing		✓							✓							

Biological Control

The term “biological control” refers to the use of natural enemies to suppress pests. Biological control tactics include both conserving naturally occurring beneficial organisms as well as introducing commercially produced biological control agents.

Many beneficial organisms will occur naturally in field grown flower crops and greenhouses, particularly when the use of insecticides is minimized. It is important to understand and recognize the natural predators and parasites since they can often limit the growth of a pest population or even control a pest outbreak.

The successful use of introduced biological control agents in ornamental crops is dependent on a number of factors. The pest level that can be tolerated in a crop is important because a biological control program seldom eliminates all the pests. The range of insects, mites, and diseases that a crop is susceptible to must be considered as compatible control methods must be available for all potential pest problems. The use of biological control is most suitable to long-term crops because the predators and the parasitoids must go through at least one generation to build-up to effective levels and establish a dynamic equilibrium with the pests.

If chemical controls are required, choose a selective pesticide that will have the least impact on beneficial insects. Suppliers should have information on the toxicity of pesticides and PGRs to biological control agents. Generally, old broad spectrum insecticides (e.g. organophosphates) are not compatible with biocontrol agents, as they kill them outright as well as impede re-establishment for several weeks. Newer insecticides tend to be more compatible with biocontrol agents. “Spot spraying” is a useful approach to limit pest hotspots and allow biocontrol agents to ‘catch up’, however, pesticide toxicity and persistence still needs to be considered or the biological control agents will not establish in the hotspot.

Getting Started with Biologicals

Switching to biologicals can’t be implemented over night and should be started on a small scale to minimize potential risks. The transition process is smoother and often more effective if it’s carried out in several phases. The three phases are: 1) monitoring and recording; 2) modifying your pesticide program; and 3) implementing biological control.

Using the three phases for implementing a biological control program breaks the process into smaller, more easily managed steps. Proceeding one phase at a time allows you and your staff to become familiar with each step before moving onto the next phase. Despite everyone’s good intentions, the program may fail because of some of the following reasons:

- the pest was incorrectly identified,
- environmental conditions weren’t suitable for the biological agent,
- host plant interference (the biological didn’t like the taste of the crop),
- pesticide residue,
- wrong biological agent was used,
- too few biologicals and too late,
- biologicals were sick or dead upon arrival,
- unexpected pests interfered with control, or
- your goals and expectations of the program were not appropriate.

Biologicals may not be a “silver bullet” to solve all your pest management problems, so don’t give up on using them. But then, no control tool should be relied on exclusively, including pesticides. Biological control agents can effectively control pests in certain stages or areas of production.

Successful biological control means no more problems with pesticide phytotoxicity and resistance, improved worker safety and access (no re-entry intervals), and it can be used as a public relations tool.

Biological Controls – Listed by Pest

Aphids

Aphids have several natural enemies; two of these are commonly used as biological control agents. *Aphidius colemani*, a small wasp that parasitizes aphids, and *Aphidoletes aphidimyza*, a predatory fly (midge), have been shown to be reliable aphid control agents and are widely available. They are most effective when used together because *Aphidoletes* provides a rapid reduction of aphid numbers and *Aphidius* seeks outs and attacks the remaining aphids.

Aphidius and *Aphidoletes* should be released while aphid populations are low; weekly or bi-weekly checks of new foliage are needed to monitor aphid population levels. The two can seek out ‘hot-spots’ to lay their eggs. Heavy aphid infestations should be treated with a pesticide.

Aphidoletes adults are small, about 2 - 3 mm in size, and delicate flyers. It is the larval stage that feeds on aphids. They’re orange and grow to about 3 mm long and eat over 60 species of aphids. Females are active at night, searching for aphids and laying up to 250 eggs over their 10-day lifespan. Eggs are laid singly or in small groups near aphids, and hatch in 2 to 3 days. Larvae attack nearby aphids and suck them dry. High aphid population levels cause larvae to kill more aphids than they can eat. Depending upon temperature, the larval stage lasts 4 to 7 days. They drop to the ground and burrow 2 to 4 cm into the growing medium to pupate. Adults emerge 2 weeks later. The life cycle takes 3 to 4 weeks.

High relative humidity increases adult longevity. If the greenhouse floor is covered with cement or plastic, population build-up cannot occur because this eliminates pupation sites. Areas of bare soil or sawdust are required to complete the life cycle. As the days shorten in fall, *Aphidoletes* go into diapause and stop reproducing. This can be prevented by using lights in the greenhouse.

Aphidoletes are purchased as pupae in moist vermiculite. They should be applied in small piles (10 mL minimum) in shaded, humid areas. To control low infestations, apply 2 to 3 midges per square metre. Because the predatory larval stage lasts for only 4 to 7 days and the pupal stage lasts for 2 weeks, it is important to do staggered releases. Make 2 to 3 releases at 2-week intervals. Protect cocoons from ants. *Aphidoletes* will not establish in low aphid populations and is not recommended for preventive use.

Table 1.3: The Three Phases of Getting Started with Biologicals	
Phase I – Monitoring and Recording	
✓ make a commitment ✓ research and choose methods ✓ allow time for them to work ✓ involve staff in the program ✓ keep good records (avoid last year's mistakes!)	The crucial step is to make the commitment to the program and, even more important, to make the commitment to the time involved. Monitoring isn't something that is only done when you have the time and is discontinued during busy periods. It has to be the primary duty of one or more workers that is carried out a specified number of times a week. Involving the rest of the staff is as easy as putting up a "pest alert" board in the lunch or shipping area. Staff can mark on the site or greenhouse plan where and what pests they saw. You don't have to give awards for "sightings", but get staff involved.
Phase II – Modifying Your Pesticide Use	
✓ continue to monitor ✓ determine pest threshold levels ✓ eliminate ineffective pesticides ✓ time your pesticide sprays (i.e. when your neighbour cuts his hay) ✓ stop unnecessary sprays ✓ spray only hot spots	This is the phase where pesticide use is scrutinized. Start evaluating whether the spray is needed or if there are other options. Check your records to see if the pesticide actually was effective or if there was any phytotoxicity. It's up to you to determine your own threshold levels for your different crops; they're not conveniently listed in a table.
Phase III – Introducing the Biological Control Agents	
✓ identify the pest and choose the biocontrol agent(s) ✓ reduce use of toxic pesticides (avoid broad spectrum, long residual, especially pyrethroids) ✓ identify the biocontrol suppliers and their routes ✓ calculate rates and timing ✓ inspect biologicals upon arrival ✓ correct any imbalances ✓ adjust your expectations	Phase III involves long-term planning that must start months before the biologicals are released. Many commonly used pesticides must be discontinued one to two months before biologicals are introduced. Don't hesitate to involve experts in pest identification and biocontrol strategies. Often biologicals are pest specific and a wrong identification can mean that the program is doomed from the start.

Aphidius are tiny, black parasitic wasps that are less than 2 mm long. They lay their eggs inside aphids. As the wasp larva develops, it kills the aphid and then uses the mummified body as its pupal case. The rigid, light brown or bronze aphid mummies show up on leaves 7 to 10 days after the aphids are parasitized and the adults emerge in 5 days by chewing an exit hole in the mummy.

Aphidius is purchased as pupae inside aphid cases. Some adults will be present by the time they are used in the greenhouse. Application rates for low infestations are 2 to 4 per square metre, applied 2 to 3 times a week apart. Naturally occurring *Aphidius* may also enter greenhouses during the summer provided insecticide usage is minimal.

Banker plants are used in the greenhouse as a rearing system for biocontrol agents. When used properly, they keep a high level of parasites present in the greenhouse on an ongoing basis with limited cost and effort. Cereal host plants infested with cereal aphids is a well-studied banker plant system for *Aphidius colemani*. Other types of banker plant systems that have proven useful include the use of pepper plants to support growth of *Orius insidiosus*, and mullen and eggplants to support *Dicyphus hesperus*.

During late summer, *Aphidius* itself often become parasitized by naturally occurring parasites. In addition, high summer temperatures may reduce its efficacy, so aphid populations should be monitored carefully during hot spells and in late summer.

Aphidius colemani is the most effective parasite for green peach aphids. However other *Aphidius* species are more effective for other aphids. Suppliers of biological agents can recommend the correct parasite. Other species include *Aphidius ervi* and *Aphelinus abdominalis*; both are bigger parasites that will control larger aphid species such as foxglove or potato aphid.

Other beneficial agents that can contribute to aphid control in greenhouses are ladybug beetles and lacewings. However these have not been found to reduce aphid numbers to acceptable levels exclusively; *Aphidius* and *Aphidoletes* must be part of the aphid control program.

Note that if your crop is susceptible to aphid transmitted viruses, using biological control agents exclusively may not be advisable because there will likely be a low level of aphids present that are capable of transmitting viruses.

Fungus Gnats (*Sciaridae*)

Biological control for fungus gnats relies primarily on *Stratiolaelaps scimitus*, a predatory mite, *Steinernema feltiae*, an insect-parasitizing nematode, and *Bacillus thuringiensis* subspecies *israelensis*, a bacterial larvicide.

The predatory mite is golden to reddish-brown and about 0.5 mm long. It's easily seen without magnification. Both immatures and adults feed on small soil dwelling insects, including fungus gnat eggs and young larvae. The mites live and feed on the surface and upper 2 cm of growing media. For successful control, the soil should be moist, but not overly wet, and the soil temperature must be at least 15°C. They should be introduced to the crop as early as possible in production at the preventive rate of 100/m^2. When they are applied to potted crops, the rate should be determined on the basis of how much area the pots occupy. Ideally, they should be applied at the plug stage to allow easy dispersal through the media and early establishment. If the greenhouse has exposed soil or other media under the tables, then *Stratiolaelaps* should also be applied to these areas. These mites do not diapause so will remain active in the fall and winter as long as the soil temperature is high enough.

Stratiolaelaps are general feeders; in addition to feeding on fungus gnats, they will also feed on thrips nymphs that drop to the soil to pupate. They must not be used as the sole thrips control measure however; they can be part of an overall thrips control program.

The insect parasitic nematodes are applied to the growing media in water to attack the larval stages of fungus gnats. Mortality usually occurs within 48 hours. These nematodes require adequate soil moisture for survival and mobility, so make sure the soil is quite wet at the time of application. This can be accomplished by applying it as a drench or by pre-wetting the soil/media if the nematodes are to be applied as a spray or through the irrigation system. Soil temperature should be 15 to 28°C. Though there is some reproduction of nematodes within the soil, this should not be relied upon for ongoing fungus gnat control. A second application should be made in 10 to 14 days, and ongoing monitoring should occur over the life of the crop.

Atheta coriaria, a predatory rove beetle can be used for fungus gnats and shore flies. For more information, see the *Shore Flies* section in this chapter.

Leafminers (*Liriomyza* spp.)

Parasitic wasps are commercially available as biological control agents for leafminers. *Opius pallipes* (a braconid wasp, is not as commonly used and may not be locally available), *Dacnusa sibirica*, and *Diglyphus isaea* parasitize and kill leafminer larvae. *Dacnusa* lays eggs within the tunneling leafminer larva. But it does not immediately kill the larva, so it continues to feed and expand mines within the leaf. The larva may drop to the ground and pupate, but an adult *Dacnusa* will emerge. In contrast, *Diglyphus* paralyses leafminer larvae, larvae stop feeding, and therefore mines are not expanded. This difference between the two should be kept in mind when evaluating their control efficacy. When using them you must be able to tolerate some leafminer damage (mines) to the crop because they will not eradicate the pest. Therefore, it is not suitable for crops where there is a zero tolerance of mine damage, for example, some export markets.

Parasites should be applied at a rate of at least 2 per m^2, three times at 2-week intervals. Initial introductions should be done when the number of mines is low. *Dacnusa* should be used during the cooler months, and their use should be discontinued once temperatures exceed 25°C. This is a good agent to use early in the season. *Diglyphus* works well when leafminer populations are moderate to high, during the warmer spring and summer months. The parasites, purchased as adults, should be applied in the morning or evening when the greenhouse is cooler. Biocontrol with parasites cannot be used as the sole control agents once the leafminer population is well established or when there are large numbers of adult leafminers present.

Parasitic nematodes, applied for fungus gnat control, will parasitize leafminer pupae in the soil. Nematodes applied as a foliar spray will enter tunnels and parasitize mining larvae, so can be a useful tool in some crops.

Mealybugs (primarily citrus mealybug, *Planococcus citri*)

The Australian ladybug beetle, *Cryptolaemus montrouzieri*, is the most successful and commonly used biological control agent for mealybugs. This predator, called the mealybug destroyer, feeds on all stages of mealybugs. The 4 mm long adult beetle is shaped like a ladybug, while the larvae are “cotton” covered and resemble mealybugs. Adults are most active in sunny conditions and temperatures greater than 20°C.

The parasitic wasp, *Leptomastix dactyopii*, can be an effective control agent for citrus mealybugs. The adults are good flyers and have excellent searching ability. Because it is effective at low densities, *L. dactyopii* can be used to supplement *C. montrouzieri*, which works best at high host densities.

Green lacewings, *Chrysopa carnea*, also feed on mealybugs, but they do not disperse well in greenhouses.

Mites – Two-Spotted Spider Mites (*Tetranychus urticae*)

The most effective biological control agent for two-spotted mites for most greenhouse crops is the predatory mite *Phytoseiulus persimilis.* This mite is widely available from producers of biological control agents. Tropical in origin, it is well adapted to greenhouse conditions but is not effective outdoors in BC. Adult *P. persimilis* are shiny orange, while immature stages are a pale salmon colour. They can be distinguished from the ‘red’ phase of the two-spotted spider mite by the lack of spots, smooth pear-shaped body, and their faster movement over leaf surfaces.

To be most effective, *P. persimilis* should be introduced at the first sign of spider mites or their feeding (stippling on leaves). Predatory mites are most effective at greater than 70% RH and from 20 to 30°C. Very hot, bright conditions favour spider mites and can result in pest outbreaks. Ideally, the plants should be in close contact, allowing the predators to move easily through the crop from one plant to another. Each female lays about 50 eggs. At favourable temperatures the life cycle is about a week, twice as fast as the two-spotted spider mite. *Phytoseiulus persimilis* consume 5 to 20 eggs or adults a day. They are not affected by day length, do not diapause, and will remain in the crop as long as pest mites are present and temperatures are adequate. The *P. persimilis* will not survive between crops in an empty greenhouse. They do not eat pollen.

Introduction rates range from 2 to 30 per plant, depending upon infestation levels and the crop involved. Suppliers can usually suggest more precise rates based on your crop and situation. The most effective and economical introduction system is to apply at least two *P. persimilis* to all infested plants and to every fifth plant in the rest of the crop. Subsequently, treat any “hot-spots” that develop. Be sure to release some *P. persimilis* into areas outside any outbreaks to encourage the predators to disperse and look for food. At very high spider mite levels it is often advisable to apply insecticidal soap or other non-residual miticides before releasing *P. persimilis*. Successful spider mite biological control programs are based on releasing predators every two to four weeks, starting early, on the assumption that there will be low levels of mites from the start of the crop.

For outdoor crops, *Amblyseius fallacis*, a predatory mite of temperate origin, is an option for two-spotted mite control. It occurs naturally in areas with habitual two-spotted spider mite populations.

Other biocontrol agents for mites include *Feltiella acarisuga*, a predatory gall midge, *Amblyseius californicus*, a predatory mite that eats pollen, other mite species and thrips, and *Amblyseius swirskii* which feeds secondarily on spider mites. These can be used in conjunction with *P. persimilis* for season long mite control.

Scales

There are several species of scales that can impact floriculture crops. It is important to know the type of scale or species of concern in order to successfully implement a biological control program for scales.

Scales are divided into soft and armoured scales, and each requires a different parasite. Armoured scales develop a waxy covering over their bodies, but it is not attached to the insects' bodies. They do not secrete honeydew. Soft scales also develop a waxy covering, but it is attached to their bodies. Soft scales produce honeydew.

Commercially available parasites are *Aphytis melinus* for armoured scales and *Metaphycus helvolus* for soft scales. These require high release rates, and even then control is variable. Some commercially available predators can contribute to scale control. The predatory ladybug beetle, *Cryptolaemus montrouzieri*, which is primarily used to control mealybugs, will feed on soft scales if food is scarce. Other commercially available ladybug beetles, including *Hippodamia convergens*, may provide some control if released in large numbers. The green lacewing, *Chrysopa carnea*, feeds on immature scales and may contribute to control.

Shore Flies (*Scatella* spp.)

Shore flies do not feed directly on plants. They feed sometimes on rotting plant material, but mostly on bacteria and other small organisms within algal communities that develop on continually wet surfaces. Shore flies deposit black 'fly specks' (excrement) on plant leaves. They are generally a nuisance pest and an indicator of wet areas in the greenhouse. They are often found in association with fungus gnats. *Atheta coriaria*, a predatory rove beetle of soil insects, is available for management of fungus gnats and shore flies. It can be released into any type of growing media, including rockwool, coconut coir, sawdust, and soil. Both adults and larvae are highly voracious and mobile, so will move around the greenhouse in search of prey.

Thrips (most common species is *Frankliniella occidentalis*, Western Flower Thrips)

Several biological control agents are available to manage thrips. Some predatory mites, predatory pirate bugs, *Orius* spp., and nematodes can be part of an effective thrips biological control program under greenhouse conditions. Biological control agents should not be used exclusively if impatiens necrotic spot virus (INSV) is a concern. Biocontrol agents do not totally eliminate thrips, so the low level of thrips that are not killed by the agents will continue to transmit the virus throughout the crop.

It is most efficient and effective to introduce predatory mites before thrips populations reach damaging levels. They will not control large populations of well-established thrips, nor will they control large numbers of adult thrips migrating into greenhouses. Their use requires a thrips monitoring program entailing sticky traps and crop examination. *Amblyseius* do best at temperatures from 20 to 25°C and a relative humidity above 70%. Lower humidity levels result in high egg mortality and can prevent establishment of *Amblyseius*. Females lay one to two eggs per day over a 10 to 20 day lifespan. *Amblyseius* kill only about 6 first instar thrips per day, so large numbers are needed for control. Rates range from 10 to 50 predatory mites per plant per week, plus 25 to 100 predators for every infested plant. Ideally a ratio of one predator per two thrips should be achieved. It will also feed on spider mites, but it cannot be relied to bring about any degree of control.

Amblyseius degenerans controls thrips in flowers better than *A. cucumeris*, is less sensitive to low humidity, has a faster population growth rate, and is more mobile than *A. cucumeris*. It also feeds on pollen. It is best to introduce *A. degenerans* early in the season, as with all predatory mites.

Amblyseius swirskii has similar characteristics to *A. cucumeris* (feeds on pollen), as well as significant advantages including: *A. swirskii* is more effective at high temperatures, and also feeds on whitefly eggs and larvae. Secondarily, it will feed on other mite species.

The predatory mite, *Stratiolaelaps scimitus*, will feed on thrips larvae that drop to the soil to pupate. They should not be used as the sole thrips control measure; but are useful in an overall thrips control program.

Orius feeds on all thrips stages and actively searches them out. *Orius* will also feed on pollen if few prey is available, so *Orius* numbers will build up and remain high even if thrips numbers are low. Successful use of *Orius* on ornamental crops largely depends on the presence of pollen in the crop. After hatching, all stages of *Orius* are predatory. The nymphs are amber-coloured, while the adults are black and white and about 3 mm long. The life cycle is about 20 days under greenhouse conditions. *Orius* reproduction is affected by day length and some species stop laying eggs when days are less than 12 hours long, limiting their use to spring and summer. In addition to thrips, they will also feed on small aphids, caterpillars, and spider mites. They will also prey on beneficial mites such as *A. cucumeris*, but the rapid movement of these predatory mites makes them more difficult to capture. On cut flowers, the tendency of *Orius* to frequent flowers may result in a large part of the population being removed with each harvest causing poor establishment. Introduction rates and number of releases vary by crop and pest level. Contact a supplier for recommended release rates. *Orius* adults will often fly to the greenhouse roof during the heat and brightness of the afternoon, so it is best to apply them in early morning or late afternoon.

The insect parasitic nematode *Steinernema feltiae* is available in a gel formulation that can be sprayed directly on the plants and flowers, where the nematodes infest and kill thrips. No residue remains from the gel.

A Western flower thrips pheromone is available that can be used in conjunction with sticky cards (blue or yellow) to increase trap sensitivity for monitoring purposes, which enables growers to detect thrips earlier than with only the sticky traps. Pheromones plus traps can be used for mass trapping. Some growers have experimented with releasing pheromone into the greenhouse shortly before pesticide sprays which appears to result in better pesticide efficacy. Thrips commonly stay hidden within flowers, so coverage is often an issue with pesticide applications. The pheromone appears to draw the thrips out of their hiding places by agitating and causing them to be more active and exposed.

Weevils (primarily *Otiorynchus sulcatus*, Black Vine Weevil)

Insect parasitic nematodes such as *Steinernema kraussei, Heterorhabditis bacteriophora,* and *H. megidis* are commercially available. Nematodes are added to water and drenched into the soil/media. They kill weevil larvae within a few days, and a new generation of nematodes are released from the host larvae. Still, a second and likely subsequent applications are recommended to keep the pest population under control. Small larvae are more susceptible to nematode attack.

Metarhizium anisopliae is a generalist insect-infesting fungus that has shown promise particularly in container stock. *Metarhizium* is applied to the soil as a drench. The fungal spore germinates on the insect surface and enters the soil-inhabiting larvae and grows within it, killing it within several days. There is evidence that *Metarhizium* remains present and active in soil or media for 1-2 years.

Whiteflies (*Trialeurodes vaporarioum,* Greenhouse Whitefly and *Bemisia* spp*.,* Sweet Potato and Silverleaf Whiteflies)

Encarsia formosa is a parasitic wasp that is commercially available for biological control of greenhouse whiteflies. The adult wasp is about the size of a spider mite, with a dark head and thorax and yellow abdomen. It makes short hopping flights, attracted by honeydew or a scent given off by the whitefly. Almost the entire population is female. Adult females lay eggs in the third and early fourth larval growth stages of the whitefly. They will also kill the first, second, and late fourth stages by feeding on them. The parasite larvae feed within the scale. The scales turn black within two weeks, which provides a convenient way of assessing the success of the *Encarsia* introductions. Development time, adult life span, and numbers of eggs laid are dependent upon temperature. The threshold for development is 13°C. Females live 15 to 30 days and can lay up to 400 eggs. The wasp larvae go through three larval and one pupal stage before the adult stage. The emerging wasp adult cuts a small exit hole in the top of the black scale.

At its optimum development temperature of 27°C, the egg laying capacity of *Encarsia* is twice that of the greenhouse whitefly. However, the wasp is more sensitive to cold than are whiteflies and the whitefly lays ten times as many eggs as *Encarsia* below 21°C. The critical average temperature for good control is approximately 23°C, however, a minimum night temperature of 15°C is satisfactory if the day temperature is enough to raise the average daily temperature to 23°C. A daily average temperature of 18°C will hold the status quo. *Encarsia* is impeded by hairy-leaved plants and by honeydew. *Encarsia* has been reported to be fully reproductive at light intensities of only 7300 lux, and intensities below 4200 lux cause high mortality. This, together with the fact that they do not become active until four hours after sunrise, probably explains the poor control sometimes obtained during the dark winter months. Supplementary lighting helps achieve better control.

Trying to control a severe whitefly infestation with *Encarsia* is unlikely to succeed, and is not cost effective because of the large number of *Encarsia* required. Chemical insecticides may be necessary to reduce heavy infestations to low levels prior to releasing *Encarsia*. A chemical with little or no persistence and minimal effect on other biological agents in the crop should be used.

Encarsia should be released preventively, before the first whiteflies are seen, at a rate of 0.5/m^2 per week. Use yellow sticky traps to detect the first whiteflies and then increase the release rate to 3/m^2 each week. Monitor the lower leaves for the presence of black (parasitized) scales, and when 90% of the scales are black the application rate can be reduced.

Encarsia are purchased as parasitized whitefly scales on thick paper cards which are placed in the crop for adult emergence. The cards should be placed in a shady position on the lower part of the plant. In potted plants, do not let the card contact the growing medium. Avoid handling the scales. Distribute the cards uniformly throughout the crop.

A few *Encarsia* adults and other predators and parasites will be trapped on yellow stick traps, but most will remain in the crop searching for whitefly scales.

Eretmocerus eremicus, another small wasp-like whitefly parasite is available for both *Trialeurodes* spp. and *Bemisia* spp. It kills whiteflies by parasitizing larvae as well as directly feeding on the whitefly. *Eretmocerus* is more effective than *Encarsia* at high temperatures (> 30°C), and is more effective than *Encarsia* against *Bemisia* spp., an occasional pest of poinsettias. *Eretmocerus mundus* is available specifically as a *Bemisia* spp. parasite. It is effective at both higher and lower temperatures than *E. eremicus*, so is well-suited to early season releases, warm mid-summer temperatures, and cool fall temperatures.

Dicyphus hesperus, a plant bug, and generalist predator, feeds on whitefly nymphs. Because it has a relatively long generation time (5 to 8 weeks), *Dicyphus* can take at least 10 weeks before significantly affecting whitefly levels. It must be introduced as soon as whiteflies are found to be economical. Release at a rate of 0.25 to 0.5 *Dicyphus*/m^2 and repeat in 2 to 3 weeks. *Dicyphus* needs high levels of prey to reproduce, however they can survive without food for a long time. It is useful to release *Dicyphus* in hotspots. This predator is fast moving and highly mobile. It will also feed on thrips and spider mites, but should not be relied on for control. *Dicyphus* will feed on plants to obtain water, but feeding damage is usually superficial and not noticeable. However caution is advised in ornamentals, for example, *Dicyphus* should not be used on gerbera due to damage to stems.

Pasteurization and Fumigation of Soil

Soil pasteurization or fumigation can be an effective treatment to control soil-borne diseases, insects, weeds and nematodes. Observe the following rules to achieve satisfactory results.

- The soil temperature at 15 cm depth must be 13°C or higher for successful treatment with chemicals.
- The soil must be in a loose condition to allow gas penetration. Sods, lumps, and organic materials must be thoroughly broken up.
- If organic materials (manure, compost, etc.) are to be used, they must be incorporated before treatment in order to prevent recontamination.
- The soil must be moist, but not wet.

When soil is pasteurized with steam or fumigated with chemicals, the number of soil micro-organisms is greatly reduced for the first few days, then it rises and eventually exceeds that of untreated soil. Pasteurization or fumigation destroys a large part of the dense population of soil microbes, and the first organisms to return after treatment meet no competition. Thus, if plant pathogens are among the first to recolonize the soil, they may develop rapidly and cause severe disease losses. Therefore, it is important that the grower make every effort to prevent recontamination. Pathogens can gain entrance to the soil by:

- splashing of rain or watering,
- contaminated cuttings,
- soil in water hoses,
- infested containers,
- infested tools and equipment,
- growers’ hands and footwear,
- placing containers on the ground,
- unsterilized tarps, and
- infected plants or seeds.

Soil Pasteurization

Steam is the most common form of heat used for soil pasteurization. For potting mixes it can be injected into the media pile. Old truck boxes are often good containers. Ground beds can be steamed through underground tile drainage pipes or through canvas hoses covered by tarps. In either case, the soil should be heated to 70°C, measured at points farthest from the source of steam and maintained for 30 minutes.

Temperatures above 82°C will destroy beneficial soil organisms. Aerated steam should be used to prevent overheating. This allows the soil to be pasteurized without the problems associated with over-steaming such as excessive ammonia release, manganese toxicity, higher salt levels, and destruction of organic matter and beneficial organisms. Unless there are specific problems, a pasteurization time of 30 minutes at 70°C should eliminate most pathogens and all but the most heat-resistant weed seeds, while leaving some beneficial, heat-tolerant organisms to compete with the re-colonization attempts of disease organisms.

Manganese Toxicity

Manganese toxicity may occur on acid mineral soils or on steamed soils with a pH below 6.0. Symptoms of toxicity include:

- root browning,
- brown spotting of the stem, petioles and veins of the lower leaves,
- yellowing of the leaf starting at the veins, and/or
- premature loss of lower leaves.

This problem may be avoided by liming the soil, by pasteurizing at a lower temperature, using a steam-air mixture, and by increasing the application of super-phosphate.

Soil Fumigation

Some fumigants, such as Basamid® (dazomet) and Vapam® (metam-sodium), control soil fungi, nematodes, insects, and weeds. Soil fumigation is not always an adequate substitute for soil steaming. Fumigants may not destroy all soil-borne pathogens harboured in root debris and other plant parts.

The soil must be prepared properly before treatment. It must be tilled and kept moist for at least two weeks after removing the plants to allow the roots to rot before treatment. Cultivate the area thoroughly, breaking up lumps and loosening the soil deeply and thoroughly. The soil should be moist before treatment; cultivate lightly if the soil has crusted. Seal the soil with a plastic cover after the chemical is injected. An approved respirator must be used during treatment and at any time when fumes remain.

After an area has been fumigated, care must be taken to avoid contaminating it with nematodes, seeds, or soil pathogens. Don’t add any untreated soil, manures, or mulches. Use clean tools and check for soil adhering to workers’ footwear. As much as possible, use certified, disease-free seeds or transplants.

Weed Control

Keep the interior of the greenhouse weed-free. Weeds in and around the greenhouse can harbour pests, including mites, aphids, whiteflies and thrips.

Never use the same sprayer for herbicides and other pesticides. Many growers have suffered economic losses from herbicide damage by using non-registered herbicides or herbicide contaminated sprayers in the greenhouse.

To kill weeds outside the greenhouse, use a contact weed killer such as Gramoxone® ☠ (paraquat) for annual weeds, or Roundup® (glyphosate) for perennial weeds. A 1 to 5 metre weed-free zone around the greenhouse is recommended. Do not use hormone-type herbicides such as 2,4-D or MCPA for weed control adjacent to greenhouses. Use low pressure (less than 275 kPa) to avoid misting and drift into the greenhouse.

For more information, see Chapter 8, *Weed Control*.

Chapter 2 - Soil, Water and Nutrient Management

This chapter covers the basic principles of soil, water and nutrient management for field-grown floriculture crops. Information specific to the production of container crops is presented in Chapter 3. Other useful resources on general soil management include two Ministry publications titled *Soil Management Handbook for the Lower Fraser Valley* and *Soil Management Handbook for the Okanagan and Similkameen Valleys* that are available from the Abbotsford Soil Conservation Association. Other useful information can be obtained through local BC Ministry of Agriculture offices.

Recommendations in all manuals, including this production guide, are general guidelines only. Qualified consultants are available on a fee-for-service basis to give recommendations specific to each farm. Growers planning to plant a new parcel of land should consult with a professional for recommendations on soil suitability, and for advice on nutrient management, irrigation and drainage.

Soil Management

Good soil management begins before planting. Assess the soil conditions of each field and understand the potential problems as a first step to planting a floriculture crop. Land may be inadequately drained, have shallow topsoil, have impermeable subsoil or be too steeply sloped for successful cropping. Soil management problems are generally related to soil texture, soil structure, drainage and erosion.

Soil Texture

The mineral components of soils are simply small fragments of rock or mineral materials derived from rock that were altered by water and chemical reactions in the soil. Soil particles are grouped into four particle sizes: gravel, sand, silt and clay. In describing soil, "texture" refers to the relative percentages of sand, silt and clay sized particles in the soil. Soil texture is a permanent characteristic. Texture will not change unless a large quantity of soil of another texture is added to it, such as might occur during land clearing or very deep plowing into subsoil of a different texture.

Problems related to soil texture are common. Stony soils can interfere with tillage and digging operations. They also reduce the overall nutrient and water storage capacity when they cover greater than 50% of the surface area or make up more than 75% of the soil volume. Coarse, sandy soils will require careful nutrient and water management.

Soil Structure

In soil, individual sand, silt and clay particles become more closely packed and bonded together to form larger particles called aggregates. "Soil structure" refers to the type and arrangement of aggregates found in soils. Aggregates occur in almost all soils, but their strengths, sizes and shapes vary considerably among soil types. Some of these aggregates are in stable forms that are not easily broken down by water or physical forces. In addition to the soil texture, the organic matter content can play a significant role in the development of good soil structure.

The formation of soil structure results from many different processes, including the growth of plant roots, activities of soil organisms, wetting and drying, freezing and thawing, and tillage. Plant roots excrete sugars and resins that bind aggregates and, upon their death, leave behind pores in the soil. Soil organisms also bind aggregates with "glues" or, as in the case of earthworms, create channels that improve drainage and aeration.

Soil structure also affects the internal drainage of the soil, water holding capacity, temperature and the growth of plant roots. In soils under cultivation, most aggregates at the surface tend to break down under the forces of rainfall, irrigation, tillage and traffic. When soils are left exposed to rainfall or are excessively cultivated under less than ideal moisture conditions, the result is the degradation of soil structure. Structure degradation leads to crusting or puddling of the soil surface, or compaction deeper within or below the root zone. This can lead to poor crop growth, poor drainage and soil erosion.

Maintaining Soil Structure

Soil structure is the most important soil characteristic to consider when managing soils as it is most affected by farming practices. It also is one of the most important factors in crop growth, along with water and nutrients. The main objective in soil management is to promote and maintain good soil structure to favor crop growth.

Soil structure degradation can be reversed by carefully using these cultural practices:

- add organic matter from manure or compost,
- use appropriate and timely tillage, and
- protect the soil surface by using cover crops.

Adding Organic Matter. Managing soil organic matter is integral to sound soil management and is a key to long-term productive field operations, particularly where significant quantities of topsoil are removed over time. Organic matter provides structure to soil, increases water holding capacity and is a major source of phosphorus, sulphur and the primary source of nitrogen. Numerous, readily available soil amendments (e.g. manure and compost) can be applied to the land to improve soil fertility and/or structure. The nutrient content of these amendments must be the first consideration for their use. Nutrients added from the amendment must match the crop's nutritional requirements.

Animal manures are abundant; however, they can be major sources of ground and surface-water pollution if not properly managed. Rates and times of manure application must be considered, as well as the nutrient requirement of the crop, soil characteristics (e.g. drainage and slope of land) and the presence of surface and ground waters. Manure should, in most cases, not be applied to bare land, due to leaching and/or volatilization potential. Generally, a late summer (July/August) manure application is recommended, followed (after approximately 1 week) by seeding a winter cover crop, which will act to 'catch' the nutrients. When manure is used, fertilization rates should be reduced.

Compost application is another option to add humus to the soil. Composts are generally low in available nutrients but should be tested for nutrient content prior to use. Non-composted materials should not be used, as they will cause nutrient tie-ups. As an example, straw and woodwaste can be beneficial to soil, however, when added directly to the soil, nitrogen can be 'tied-up'. In order to avoid this, urea or an ammonium salt should be added at the same time at a rate of 20-40 kg/ha. Woodwaste should only be applied in the top 10 cm of the soil.

Growing and tilling-in cover crops can also increase organic matter levels.

Appropriate and Timely Tillage. Tillage is used to prepare a suitable planting bed, to bury or incorporate crop residues, fertilizers, lime, manure or other soil amendments, to kill weeds, and to form raised planting beds. There are two groups of tillage implements. **Primary tillage** implements, such as plows, discs, subsoilers and rotary spaders, are used to break soil, reverse compaction and incorporate residues. **Secondary tillage** implements such as cultivators, harrows and rotovators are used to prepare planting beds and incorporate soil amendments. Secondary implements can have a large impact on soil structure by breaking soil aggregates.

Caution is advised when tilling soil because improper tillage can degrade soil structure. Repeated plowing to the same depth may form a compacted layer that can impede water and root penetration. Many growers rely on the conventional rototiller for residue incorporation or for weed control between rows. Too much cultivation with a rototiller or rotovator will pulverize the soil and compact the subsoil over time. Avoid slow tractor speeds that result in excessive pulverizing of the soil. An alternative tillage implement that is not as damaging to soil structure is the spading machine. Medium to fine textured soils are the most susceptible to structural damage. The soil moisture content also does influence the degree of soil degradation that occurs during tillage.

When a tillage operation is carried out, ask the following questions:

- What is the purpose of the tillage operation?
- Is the timing of the tillage operation best for the soil moisture and weather conditions?
- Is the tillage implement the best for the intended purpose?

Using Cover Crops. Cover crops have many benefits in addition to improving soil structure. Refer to the section on cover crops below.

Problem Soils

Most floriculture crops require moderately to well-drained soils with at least 0.5 m unrestricted rooting depth in order to obtain top yields. Most lowland soils in the South Coastal area have poor natural drainage with a high water table in the fall, winter and spring. These soils are not well suited to crop production without the use of a tile drainage system to remove excess water from the rooting zone.

Many upland soils in the Coastal region have a hardpan subsoil within 0.5 m of the surface. In most cases, this hardpan will not allow the soils to drain during the fall, winter and spring. Such soils require a tile drainage system to remove excess water from the rooting zone.

In the Coastal region, all soils are susceptible to water erosion when cultivated and left bare over the winter. Many upland soils have slopes from 5-10% or more, and have a serious problem with water erosion. Valuable topsoil is removed from the upper slopes and may be deposited deep enough to bury plants on the lower slopes. Where water erosion occurs, the soils require drainage and other special management practices such as cover cropping.

Erosion Control

Where water or wind erosion is a problem, erosion control practices should be used to reduce soil loss. Water erosion damage is most severe on long or steep slopes where the crop rows run up and down the slope, or where cropping practices leave the soil surface exposed to rainfall impact. In South Coastal areas, water erosion will occur on any site where the soil becomes saturated and is left exposed.

Where possible, use the following practices to minimize the loss of soil by water or wind erosion. Although any of the listed practices will help control erosion, the best control is achieved by using as many of the practices together that are appropriate.

Water erosion:

- install a drainage system,
- use contour planting (plant across the slope),
- maintain a protective layer of crop residues or a winter cover crop on the soil, and
- establish a permanent cover crop on field roads, field margins and water runs.

Wind erosion (slowing wind speed at the soil surface):

- establish windbreaks (e.g. tree rows, snow fences or hedges), and
- maintain a protective layer of crop residues or a winter cover crop on the soil.

Cover Crops

As mentioned above, cover crops will protect soils against erosion by wind and water. Cover crops are also used to improve soil structure, trafficability and soil fertility, to suppress some insect pests and weeds, and to promote some beneficial insects. They are not usually grown for harvest or forage. They are planted when portions of the field, or the entire field, is left bare. Cover crops are also called green manure, living or dead mulches, plow down, companion, relay, double or catch crops depending on their specific use.

Before planting a cover crop, it is important to know the soil problem that needs to be addressed. Is the cover crop for erosion-control, organic matter addition and/or trafficability? For example, cover crops will not prevent flooding, but if a field is drained they can help to improve the movement of rainwater into the soil and the drains without staying on the soil surface.

Choosing a Cover Crop

Once the purpose is established, planting date and subsequent management are important factors. Spring cereals sown in the fall are usually winter-killed leaving a protective mat on the soil. Winter cereals will usually grow slowly over the winter, producing the majority of their growth in the spring. Winter cereals require a spring management program. Grasses or white clover are recommended for permanent covers. Some varieties of cover crops have been reported to suppress pests or increase the population of beneficial insects. Others may be useful for specialized conditions such as organic production or specific soil management concerns. Table 2.1 lists the best types, seeding rates and planting dates for cover crops.

If a winter-killed cover crop is desired, then a late August or early September seeding date is desirable. Beyond this time, cover crop growth tends to be slower and winter-kill may not occur. If an overwintering cover crop is preferable, then seeding can be delayed until mid-October, although earlier seeding will ensure maximum ground cover. Winter-hardy cover crops must be controlled either by mechanical or chemical methods in the spring. Permanent cover crops such as perennial ryegrass mixes and turfgrass species (e.g. fescues) are another consideration for long-term crops and can be planted in late summer, early fall or early spring.

Spring Management of Cover Crops

For spring cereal crops, crop residues can be disced, or disced and plowed, depending on the amount of residue. Chop heavy residues first to prevent the formation of a mat of under-decomposed residue.

Winter cereal or cover crops that survive the winter should be mowed or killed with a nonselective herbicide before plowing. If large amounts of plant material are to be turned under, apply a light application of manure or 20-30 kg/ha of fertilizer nitrogen to speed decomposition. Chop and incorporate the crop residue with a disc prior to plowing. Rotovating or plowing alone is not recommended.

Table 2.1: Recommended Cover Crop Seeding Rate and Planting Dates		
Types	**Seeding Rate**	**Recommended Seeding Dates**
Spring cereals (barley or oats)	80 - 150 kg/ha (30 - 60 kg/acre)	• before September 10
Winter cereals (winter wheat or fall rye)	80 - 150 kg/ha (30 - 60 kg/acre)	• after August 15 and before September 30 • fall rye better for late seeding
Winter legumes (hairy vetch or winter pea)	15 - 30 kg/ha (6 - 12 kg/acre)	• before September 15 • best seeded in mix with winter cereals
Legumes (crimson / white clover)	10 - 20 kg/ha (4 - 8 kg/acre)	• September 10 (later plantings will fail) • needs drained conditions
Brassicas (forage rape or kale)	10 - 15 kg/ha (4 - 6 kg/acre)	• after August 15 and before September 30 • watch for 'green bridging' of insect and disease pests
Annual grasses (annual ryegrass)	20 - 40 kg/ha (8 - 16 kg/acre)	• up to September 15 • can be seeded as in-season cover
Grass mixes (containing creeping red fescue, sheep's fescue, hard fescue or perennial ryegrass)	20 - 40 kg/ha (8 - 16 kg/acre)	• generally recommended for spring seeding or when soil moisture is available in late summer (can be hydro-seeded for better catch) • can be used as a permanent cover on roads and paths
Note: If seeding late in the seeding window, use the highest seeding rate.		

Water Management

Water

Water management is an essential part of crop production. Too little or too much water can result in crop losses since natural conditions rarely satisfy crop needs. In some cases, water is also required for pest control or nutrient application. Water quality must also be considered, as unsuitable water can impact crop growth and quality.

Drainage

Removing excess water in spring, fall and winter is usually necessary in South Coastal BC and, to a lesser degree, in some Interior areas. In the Interior, drainage is frequently required for reclamation and to control soil salinity and alkalinity. Many coastal floodplain areas can also benefit from drainage to reduce or remove saline salts. The benefits that can be realized by installing a drainage system on agricultural land are:

- increased trafficability,
- extended crop season,
- increased crop yields due to improved nutrient uptake,
- improved aeration of the root zone,
- warmer soil temperatures,
- crop protection from "drown-out",
- control of water erosion, and
- increased land values.

Drainage systems usually have a surface and a subsurface component. Both components must be well planned, installed and maintained to be effective. Subsurface drainage with a functioning outlet is the best way to control water on most soils. Lightweight, continuous, flexible, perforated plastic drainpipe is used. On sloping land, porous surface or blind inlets may be needed to lead water to the subsurface drains in order to reduce overland flow and erosion. On sandy soils, geotextile filters are needed around the perforated pipe to prevent sand from clogging the drain tube. Filters should not be used on organic soils.

Drainage contractors using specialized equipment quickly install plastic drainpipe. Installation depth and spacing differs with fields and is mainly based on the climatic conditions and soil type. Pumps are sometimes needed in low-lying areas that lack gravity outlets.

Drainage systems must be maintained. This includes periodic cleaning of drainpipes, outlets and ditches, and careful in-field soil management. Soil conservation and best management practices should be followed to reduce the need for ditch cleaning and avoid damage to soil tilth. Agricultural ditches are often connected to channels and streams that contain fish and provide good fish habitat. When conducting channel maintenance, producers must follow the *Drainage Management Guide*. The guide also provides information on how to prepare a drainage management plan and on the operation of drainage systems.

Soil loosening may be a consideration where soils are poorly drained as a result of a plow pan or compacted subsoil. Soil loosening, however, may not be economically viable unless problems with compaction have led to obvious yield declines. For more information on tillage refer to either the *Soil Management Handbook for the Lower Fraser Valley* or the *Soil Management Handbook for the Okanagan and Similkameen Valleys.*

The *British Columbia Agricultural Drainage Manual* provides more information and details on installing a subsurface drainage system.

Irrigation

In almost all parts of the province, natural rainfall is insufficient to replace water lost from the soil due to evaporation or crop usage, for at least part of the growing season. At these times, irrigation can result in higher yields and, in some cases, prevent crop failure. Irrigation is especially necessary for recently transplanted stock, since it will have a small and shallow root system.

Irrigation systems include drainage systems used for subirrigation, trickle and drip systems, and various forms of sprinkler irrigation. Each system has merits. The systems must be properly designed, installed, operated, and maintained to be effective. Efficient delivery and distribution systems conserve water and save on power and fertilizers. Applying too much water or having leaky pipes may lead to soil erosion, reduced production and higher operating costs. Over-application of water will also result in leaching of nutrients such as nitrogen and boron. Check pipes, pumps and sprinklers on a regular basis, and repair or replace them if necessary. The Irrigation Industry Association of BC (IIABC) offers certification courses for designers to become Certified Irrigation Designers (CID). CIDs can provide design plans and products that are cost-effective and efficient based on the standards and guidelines set out by the IIABC. The Association has recently developed courses for installers to become Certified Irrigation Technicians (CIT Level 1 and 2) to ensure proper system installation and to develop irrigation schedules that match up with the systems and field conditions.

A water licence is required to use water from surface water and groundwater sources under the *Water Sustainability Act* (WSA), with the exception that groundwater use for domestic purpose is exempted from licensing. Please contact Front Counter BC for enquiries regarding water licences. The peak withdrawal rate and total annual volume taken from a well, as well as the total irrigated area, would be included in a groundwater licence. Therefore, the well, pump size, and irrigation system peak flow rate established will follow the licensing requirement. The BC Agriculture Water Calculator can be used to determine annual volume required and peak withdraw rate for both surface water and groundwater uses.

For more information on irrigation system design, operation and maintenance refer to the *B.C. Irrigation Management Guide*, the *BC Trickle Irrigation Manual* and the *BC Sprinkler Irrigation Manual* that are available from the Irrigation Industry Association of BC, or irrigation factsheets available online and from the BC Ministry of Agriculture offices.

Irrigation Scheduling

Irrigation scheduling is a systematic method by which a producer can decide when to irrigate, how much water to apply, and how often to irrigate. The goal of an effective scheduling program is to supply the plants with sufficient water while minimizing losses to deep percolation or run-off. Irrigation scheduling depends on soil, crop, climate, irrigation system type, and operational factors. The goal of irrigation scheduling, like other water conservation strategies, is to help in securing current and future agricultural water needs, planning for water allocation within the agricultural sector, and achieving sustainability for agriculture.

Proper irrigation scheduling requires a sound basis for making irrigation decisions. The level of sophistication ranges from personal experience to techniques based on expensive computer aided instruments that can assess soil, water and atmospheric parameters. Irrigation scheduling techniques can be based on soil water measurement, meteorological data or monitoring plant stress. Conventional scheduling methods are used to measure soil water content or to calculate or measure evapotranspiration rates. However, research in plant physiology has led to methods that use leaf turgor pressure, trunk diameter and sap flow. For more information on irrigation scheduling, refer to the factsheet *Irrigation Scheduling Techniques*, the three BC irrigation manuals mentioned above, or the Farmwest website.

Farmwest is an agricultural website that provides real-time climate information at close to 100 locations across the Province for local farmers. The climate tab contains links to a number of options for irrigation scheduling purposes, e.g., cumulative and daily reference ET, precipitation, and moisture deficit. Values can be obtained for any chosen time period up to the previous day. The ET on Farmwest is calculated based on a reference grass crop of 10 to 15 cm tall. This ET can be adjusted for a specific crop by using a crop coefficient. Having real-time climate data from the immediate area can assist producers to increase crop production and conserve water. Climate data can help decide: when and how much to irrigate; when to plant; when to apply fertilizers; and how to manage a pest.

Chemigation

Chemigation refers to the injection and application of pesticides or fertilizers (fertigation) through an irrigation system. Growers who have solid set sprinkler or trickle irrigation systems may use chemigation as a method of applying nutrients. However, pesticides must be registered for application through an irrigation system. Check the label to make sure this method can be used to apply a specific pesticide. Prior to injecting fertilizers or other chemicals into an irrigation system, proper safety procedures must be followed. The booklet *Chemigation Guidelines for British Columbia,* which is available from the Irrigation Industry Association of BC, provides information on injection rate calculations and safety considerations.

Water Quality for Irrigation

Irrigation water comes from surface or groundwater sources. In many areas, ditch water is used for irrigation. Ditch water may contain high levels of micro-organisms, salts, metals or organic compounds that can affect the performance or quality of crops. Some groundwater sources may also contain high levels of ions or nutrients that may impact crop performance.

Water quality should be checked at a laboratory before planting a crop. If the crop is established, check the water before using for crop production. Water tests should assess salt levels (both electrical conductivity and sodium adsorption ratio), pH, metals, nutrients, possible toxic elements and coliforms (see Table 2.2). Also check the levels of bicarbonate (HCO_3), calcium, and magnesium. High levels will cause precipitates to form on the crop or possibly plug a drip irrigation system.

Table 2.2: Desirable Ranges for Specific Elements in Irrigation Water

Characteristic	Quantity
Set 1 (the minimum set of analyses to be done regularly)**:**	
pH	5-7
Soluble salts	0-1.5 mmhos/cm
Phosphorus (P)	0.005-5 mg/L
Calcium (Ca)	40-120 mg/L
Sulphate (SO_4)	24-240 mg/L
Alkalinity	0-100 mg/L as $CaCO_3$
Sodium (Na)	0-50 mg/L
Boron (B)	0.2-0.8 mg/L
Fluoride (F)	0-1.0 mg/L
Magnesium (Mg)	6-24 mg/L
Chloride (Cl)	0-140 mg/L
Set 2 (desirable analyses, but not absolutely necessary)**:**	
Nitrate (NO_3)	0-5 mg/L
Potassium (K)	0.5-10 mg/L
Zinc (Zn)	1-5 mg/L
Molybdenum (Mo)	0-0.02 mg/L
Iron (Fe)	2-5 mg/L
Copper (Cu)	0-0.2 mg/L
Aluminum (Al)	0-5 mg/L
Sodium Absorption Ratio (SAR)[a]	0-4

[a] SAR quantifies the sodium level in relation to the calcium and magnesium levels.
From: *Water Quality Reference Guide for Horticulture*, Aquatrols Corporation of America

The *British Columbia Sprinkler Irrigation Manual* and the *British Columbia Trickle Irrigation Manual* provide further information on irrigation water quality guidelines. Table 2.2 shows the acceptable levels of some chemical aspects of water.

The presence of plant-available nutrients in the greenhouse water supply does not usually present a problem, unless they exceed the amounts normally fed to plants. However, they must be taken into account when formulating nutrient solutions. Certain fertilizer materials, such as phosphoric acid, will react at high concentrations with dissolved calcium and magnesium to form insoluble precipitates. The precipitates may clog drippers.

Water supplies high in calcium and magnesium may not be suitable for use in mist systems due to the accumulation of unsightly mineral residues on plant surfaces.

More information on greenhouse water quality is provided in Chapter 3 and in the factsheet *Irrigation Water Quality for BC Greenhouses* available from the Ministry of Agriculture.

Protecting Water Quality

Waste products generated during the planting, maintenance, and harvesting of floriculture crops may negatively impact water. Growers who operate at the highest environmental standards will be better able to protect themselves from possible challenges to their operations. Proper use and storage of pesticides, fertilizers, manure, and woodwaste will help to protect water quality. Growers are reminded to use best soil management practices.

Nutrient Management

Soil Testing

A soil analysis is the most accurate guide to fertilizer and lime requirements. It is especially important to determine soil fertility and pH levels before planting a crop, so that the necessary lime and fertilizer can be applied to the soil. Soil and tissue testing are useful for determining fertilizer requirements in established crops. Soil and tissue sampling must be done accurately and carefully to be representative of soil and crop conditions. Refer to the Ministry of Agriculture factsheet *Soil Sampling* for proper methods of collecting and handling a soil sample. For more information, see the section on tissue analysis in Chapter 3.

Soil and tissue testing are provided by several commercial laboratories in BC. It is recommended that you use the local laboratories as they have the knowledge and experience of local conditions to conduct the appropriate analyses and give correct recommendations. Once a lab is chosen, it should be used each year in order to obtain consistent interpretations and recommendations.

Fertilizer Application

Nitrogen should be surface applied each spring. The quantity applied will depend on the amount available in the soil, the soil environment, the plant type and size, and the objective of the grower. A rate of 150 kg N/ha is suggested but can be modified with experience. Higher rates are used in areas of intensive production. The total amount of nitrogen should be divided into 2-3 applications. Apply the first and largest amount in early spring, either before new growth begins or just after planting. Spread the remaining smaller application(s) over the next 3-4 months. Do not apply nitrogen after August 15 on the Coast and July 15 in the Interior, as the late growth induced may suffer winter injury. Slow release forms of nitrogen fertilizer can be used.

Application of fertilizer can be broadcast, banded along each side of the row or dropped around each plant by hand. Broadcast application is not recommended for most field stock because of the wasted fertilizer applied between rows. Fertilizer can also lodge in the foliage and cause chemical burn. Banding or hand dropping the fertilizer ensures application to the root zone of the plant. The placement should be 15-30 cm (6-12 in) away from the main stem to prevent chemical burn to the bark.

Potassium should be applied in split applications over the season. More nitrogen and potassium will be required in sandy soils than in clay soils.

Phosphorus is relatively immobile in the soil and is not subject to leaching. After the initial incorporated broadcast application prior to planting, phosphorus applications should be banded. An entire year’s phosphorus supply may be applied with one early spring application.

Soil analysis is the only method to determine the type and amount of nutrients required to prevent deficiencies from affecting growth. Use of a standard fertilizer formulation every year will not necessarily increase growth to the extent expected, if another nutrient is deficient or in excess.

Methods of Fertilizer Application

Broadcasting and incorporation refers to spreading fertilizer on a soil surface before the crop has been planted, then incorporating the fertilizer into the soil by tillage.

Top-dressing refers to spreading fertilizer on a field when a crop is growing. It is not incorporated, but sprinkler irrigation will wash fertilizer off the leaves and a few centimetres into the soil.

Banding refers to fertilizer application at the time of planting in continuous band ≥2.5 cm to the side of the plant and ≥5 cm deep, depending on the crop.

Side-dressing refers to the banding of fertilizer after plants are established. Care should be taken not to disturb the roots of the plants.

Fertigation refers to the application of fertilizer in irrigation water.

Deep-banding refers to banding fertilizer at a depth of 5 cm or more prior to planting. There is scientific evidence indicating that this results in greater fertilizer efficiency than surface broadcasting for deep-rooted row crops.

Calculation of Fertilizer Rates

Fertilizers are labelled by percentage according to their guaranteed minimum analysis in terms of nitrogen (N), phosphate (P_2O_5), potash (K_2O), and other nutrients when these are present. Five 20 kg bags (100 kg) of 12-51-0 contain 12% nitrogen (12 kg N), 51% phosphate (51 kg P_2O_5), and no potash (0 kg K_2O). The rest of the material in the five bags is other elements (oxygen and hydrogen) that are part of the fertilizer compounds carrying the nitrogen, phosphate, and potash. See Table 2.4 for sample fertilizer calculations.

Table 2.3: Suggested Soil Fertility Standards for Woody Plants

		Available (kg/ha)[a]		Exchangeable (meq/100 g)[b]	
Group	**CEC**[c]	**P**	**K**	**Ca**	**Mg**
Silt loam to loam	12-16	39-79	169-225	5-10	2
Sandy loam	5-10	28-39	113-169	2.5-4.0	1
Loamy sand to sand	2-4	17-28	68-113	1.5-2.0	0.5

[a] P X 2.3 = P_2O_5; K X 1.2 = K_2O.

[b] 1 meq/100 g Ca = 450 kg/ha; 1 meq/100 g Mg = 270 kg/ha.

[c] CEC = cation exchange capacity, which is a measure of the soils ability to hold certain nutrients.

Adapted from: Davidson, Mecklenburg and Peterson (1988)

Table 2.4: Fertilizer Calculations for Field Grown Crops

A. The ***amount of fertilizer*** required = (recommended rate x 100) ÷ fertilizer analysis

Example:

Recommended rate potash = 135 kg/ha
Fertilizer analysis = 0-0-60

Amount of fertilizer required = (135 kg/ha X 100) ÷ 60 = 225 kg of 0-0-60 per ha

B. The ***amount of nutrient*** applied by a fertilizer = (fertilizer applied X the fertilizer analysis) ÷ 100

Example:

Amount of fertilizer applied = 225 kg/ha

Fertilizer analysis = 13-16-10

Amount of N supplied = (225 kg/ha X 13) ÷ 100 = 29 kg of N/ha

Amount of P_2O_5 supplied = (225 kg/ha X 16) ÷ 100 = 36 kg of P_2O_5/ha

Amount of K_2O supplied = (225 kg/ha X 10) ÷ 100 = 22.5 kg of K_2O/ha

Starter Solutions

High analysis, readily soluble or liquid concentrate starter solution fertilizers are available for use with seedlings and transplants to help get them off to a quick start. Often, during warm, dry weather, the addition of water by itself is of benefit. Starter solutions are particularly helpful in cool planting weather, since the dissolved nutrients are immediately available to immature root systems. Most starter solutions are high in available phosphorus. Some typical fertilizers include 0-52-0, 20-20-20, 10-50-10, 10-52-17 and 21-53-0. Fertilizers containing about 50% P_2O_5 should be dissolved at a rate of 0.8-1.0 kilogram per 100 litres of water. If a highly soluble type of fertilizer is used, such as 20-20-20, it should be dissolved at 0.2-0.3 kilograms per 100 litres.

Fertilizer Reactions in Soils

Fertilizers added to the soil may become more or less available depending on the type of fertilizer, the soil moisture, the pH conditions, the nature of the soil and the amount of organic matter, rainfall and temperature. Some nutrient elements may be completely lost; others may be 'tied-up'.

Plants often display characteristic symptoms of nutrient imbalance (e.g. chlorotic, necrotic, abnormal, stunted, or cracked growth). Table 3.4, *Generalized Plant Nutrient Deficiency Symptoms*, is useful when diagnosing crop disorders that are suspected to be caused by a nutrient deficiency.

Fertilizers

Nitrogen

The most common forms of fertilizer nitrogen are nitrate (NO_3^-), ammonium (NH_4^+) and urea ($CO[NH_2]_2$). All three forms are highly soluble in water. Urea is converted to the ammonium form by enzymes in the soil. Ammonium nitrogen is adsorbed (chemically bound) to clay minerals and organic matter and is, therefore, not easily lost from the soil. Some ammonium and urea nitrogen may be converted to ammonia gas, which escapes into the atmosphere. This usually occurs in dry soil with surface-applied fertilizer. Ammonia losses are reduced or eliminated by ensuring that the fertilizer is well covered with moist soil. Losses are minimized by banding, immediate incorporation after broadcasting, irrigation following application or broadcasting onto moist soil in cool weather.

Nitrate nitrogen is not held by the soil and can be lost by leaching with water. Leaching losses are greatest in sandy soils and in areas with high rainfall. Some nitrate nitrogen may be converted to gases, which escape into the atmosphere. This frequently occurs in wet soils during fall, winter and spring.

Phosphorus

All phosphorus fertilizers are phosphate salts. They are water soluble, but tend to form insoluble compounds when incorporated into the soil. Unlike nitrogen and potassium, phosphorus does not readily move in the soil and very little leaching occurs. Phosphorus tends to remain where it is placed. Therefore, it is important to place phosphorus fertilizer in the rooting zone of the crop before the crop is established, or to band it next to the roots in established crops. Surface application without incorporation is the least efficient way to use phosphorus fertilizer. In some soils, phosphorus becomes "tied-up" if the pH is below 6.0 or above 7.5.

Potassium

Potassium fertilizers are all simple potassium salts, such as potassium chloride, potassium sulphate, potassium-magnesium sulphate or potassium nitrate. All are readily water-soluble. Potassium is adsorbed to some extent to organic matter and clay minerals. However, it is subject to leaching, especially in sandy soils.

Secondary Nutrients

Magnesium and sulphur levels in the soil may be inadequate for good crop growth. Soil and tissue testing are the only accurate ways to determine if they are lacking. Since calcium is applied as lime it is rarely deficient in soils. Many common fertilizers contain calcium. Sulphur and magnesium fertilizers are also available.

Micronutrients

The soil levels of iron (Fe), manganese (Mn), copper (Cu), zinc (Zn) and boron (B) are sometimes inadequate for optimum crop production. Micronutrients are required in very small amounts and it is important to ensure that micronutrient fertilizers are applied at the correct rate. High levels of micronutrients, especially boron and manganese, are toxic to plants. Soil and/or tissue testing are the only accurate ways to determine if these elements are lacking. If they are needed, micronutrients can be added to blended fertilizers and applied along with the routine fertilizer program. If necessary, micronutrients can be applied in irrigation water or with a crop sprayer.

Boron

Boron deficiency may cause a wide variety of abnormalities in crops. Fertilizers that include boron can be obtained in most areas. **Caution:** Do not exceed the recommended amount of boron per hectare as it may cause plant injury. If boron-deficiency symptoms occur during the growing season, boron can be applied as a foliar spray. Apply Borospray, Solubor or Borax at manufacturers' directions.

In the Interior, boron should be applied in the fall. At the Coast, it should be applied in the spring where a need for it has been shown.

Managing Soil pH

pH is a measure of the acidity or alkalinity of the soil. Soil pH is very important because it affects the availability of nutrients to the plant. Most floriculture crops do not respond to fertilization when the pH is very low (extremely acid soils, pH less than 5.0) or very high (extremely alkaline soils, pH above 7.5).

Calcium, phosphorus, magnesium, and molybdenum are the nutrients that are most likely to be deficient under acid soil conditions. Test the soil to determine pH before planting and every 2-3 years to monitor changes. Soil pH can usually be modified to obtain a suitable pH.

Raising Soil pH

Soils in South Coastal BC are typically acidic and, therefore, many acid-loving crops do not require modification of soil pH. Lime application to raise soil pH is usually required for species that are not acid-loving. When the soil pH is not known, a soil test should be performed.

On extremely acidic soils, most crops will not respond to fertilization or other management factors. Agricultural grade limestone (calcium carbonate or $CaCO_3$) is generally recommended to correct soil acidity. For the Fraser Valley, the general application rate is 1-2 tonnes/ha/yr (400-800 kg/acre) for pH sensitive crops. Rates higher than 2-4 tonnes (800-1,600 kg/acre) are not recommended due to soil reactivity and the difficulty of incorporation. Lime should not be applied within 1 week of applying nitrogen fertilizer or manure. The high soil pH that occurs shortly after liming will increase the loss of ammonia.

Lime does not move through the soil, it must be incorporated.

Some soils limed heavily over a period of years may not require further applications. Some light-textured soils that have an adequate pH occasionally test very low in calcium, and therefore require lime. If calcium levels are low, gypsum or fertilizers such as calcium nitrate may also be used to supply calcium, rather than using lime. Gypsum ($CaSO_4$) is not a liming agent. It will not increase soil pH, and under certain conditions it is used to lower soil pH. The use of some dolomitic limestone is recommended since it contains a significant quantity of magnesium, an essential and often deficient plant nutrient.

The positive effects of lime application include:

- reduce soil acidity,
- improve the physical condition of the soil,
- provide calcium and magnesium (if dolomitic limestone is used),
- favour bacterial action and, thereby, hasten the decomposition of organic matter and the release of nitrogen,
- improve conditions for availability of other nutrients, notably phosphorus and some minor elements, and
- reduce the toxicity of some elements such as manganese and aluminium.

Growers need to be careful when applying lime. If applied at too high a rate (above 5 tonnes per ha), lime may tie up some micronutrients (e.g. boron) or cause nutrient imbalances. Lime application may aggravate magnesium deficiencies, especially in sandy soil. Where this is a problem, some dolomitic lime should be used. Liming can also increase the rate of organic matter depletion and encourage the germination of some weeds. Lime should always be used in conjunction with a planned soil testing and fertilizer program.

Forms of Lime Used

Calcium oxide: quicklime, caustic lime, burnt lime. Not recommended for use on agricultural land.

Calcium hydroxide: hydrate or slaked lime. Should only be used as a spring application for rapid results. "Agricultural Lime" refers to this form but the use of this term is not recommended. It is the quicker acting form of agricultural lime. It will correct soil acidity quickly, but is usually two or more times as expensive. Excessive rates above 1,100 kg/ha (450 kg/acre) may be quite caustic and "burn out" organic matter.

Ground limestone: calcium carbonate. The most convenient form to handle. May be applied at any time of the year. It dissolves slowly and lasts longer in the soil. (Usually grey lime material sold in bulk in South Coastal BC.)

Ground dolomite: calcium-magnesium carbonate. May be substituted for ordinary limestone. It contains magnesium in addition to calcium.

Note: Fineness of grind is very important. Fine grinds (100 mesh and above) react in soil much quicker than coarse grinds (10-100 mesh). Very coarse limestone (less than 10 mesh) is not recommended. Some coarse material is desirable to facilitate lime handling. Excessively fine material will not flow readily and is subject to wind drift during spreading.

Lowering Soil pH

Sometimes it is advantageous to lower or acidify the soil pH. In Interior areas, alkaline mineral soils may need to be acidified for crop production.

The principal materials used to lower soil pH are elemental sulphur, sulphuric acid, aluminum sulphate and iron sulphate (ferrous sulphate). Ammonium sulphate, ammonium phosphate and other ammonium containing fertilizers are also quite effective when the soil receives sufficient water, though they are primarily sources of plant nutrients.

For large areas, elemental sulphur is probably the most economical product to use. The finer ground the sulphur, the more quickly it will react in the soil to lower the pH. Flower sulphur is very fine (powder) and reacts relatively quickly. Solid sulphur prills (granules) are less finely ground and therefore react more slowly and are more convenient to apply. Finely ground sulphur is sometimes available in prills that contain a mixture of flower sulphur and bentonite clay that improves the handling, stability, and safety of the material.

Soil test laboratories can, by request, determine total soil acidity and calculate the sulphur required to attain a desired pH. As a general recommendation apply the equivalent of 2 tonnes/ha (800 kg/acre) in a band where the planting beds will be formed. For more information refer to the Ministry's factsheet, *Acidifying Soils*.

Soluble Salts in Soil

Elevated salt levels in soil will interfere with water uptake and eventually plant growth. The effects range from delayed or non-germination of seed to death of new transplants and serious reduction in growth of new or established plants (see Table 2.5). Most soils in BC are low in soluble salts. However, there are regions where salts can accumulate, such as lowland areas adjacent to ocean dykes, areas where salt-water intrusion may affect irrigation water, alkali seep areas in the Interior, and areas where road salts or fertilizer salts have accumulated. The problem with soluble salts is most severe when soil moisture is low and salt concentration is high.

Table 2.5: Soil Conductivity Readings (derived from field soil samples using a 2:1 water and soil paste mixture)

Conductivity Reading (milliSiemens/cm)	Rating	Plant Response
0-0.25	Low	Suitable for most plants when using recommended amounts of fertilizer.
0.26-0.45	Medium	
0.46-0.70	High	May prevent emergence and cause slight to severe damage to most plants.
0.71-1.00	Excessive	
1.00	Excessive	Expected to severely damage most plants.

Source: OMAFRA Nursery & Landscape Plant Production, Publication 383

Agricultural By-Product and Wood Residue Management

Code of Practice for Agricultural Environmental Management

The use of livestock manure and agricultural vegetation wastes is covered by the *Code of Agricultural Practice for Waste Management*. This Code is part of the *Agriculture Waste Control Regulation* under the *Environmental Management Act*. The Code describes general practices for the use, storage and management of agricultural by-products in an environmentally sound manner. Also refer to the *BC Environmental Farm Plan Reference Guide*. The guide describes in general terms many of BC's diverse farm practices. It also refers the reader to existing government legislation, industry guidelines, and other sources of information related to farm practices in BC.

Solid Manure Storage

The code requires that solid agricultural by-products (e.g. poultry litter) be stored in a permanent storage structure or as temporary field storage. Producers must prevent leachate, contaminated runoff or manure itself from escaping any manure storage and going into watercourses.

As the name indicates, temporary field storage is meant to be temporary with a maximum allowable storage period of 7 months from the date storage began. If longer storage periods are required, then move the material to a permanent storage structure. Based on the length of storage, setbacks to certain features will change as shown below:

Table 2.6: Temporary Field Storage Setbacks

	Less than 2 Weeks	2 Weeks to 7 Months
Drinking Water Source	30 m	30 m
Watercourse (e.g. creek)	15 m	30 m
Property Boundary	4.5 m	4.5 m

If storing by-products for 2 weeks or more, temporary field storage cannot occur in the same location for 3 years. Regardless of the duration of storage, vegetation must be grown on the storage location by the next growing season. It is important that the piles are located away from areas prone to flooding or areas with standing water or water-saturated soil.

Farms in an area that receives 600 mm of precipitation from October 1 through April 30, known as a high-precipitation area, must cover the storage pile during that period. Additionally, the field storage pile cannot be located on coarse-textured soil if in a vulnerable aquifer recharge area.

It is important to keep records to show you are meeting the expectations of the Code. While records are not submitted to anyone, you are required to provide the records within 5 days that show:

- type and source of materials being stored,
- location of the storage pile, and
- weekly monitoring results.

If using a permanent storage structure to store solid agricultural by-products, the structure must be 30 m from a drinking water source, 15 m from a watercourse and 4.5 m from the property boundary. Permanent storage structures require a protective base if you are located within a vulnerable aquifer recharge area. A typical example of a protective base is a concrete pad.

Wood Residue Storage

Like solid agricultural by-products, wood residues (e.g. hog fuel, wood chips, sawdust) may be stored in permanent storage structures or as temporary field storage for no more than 12 months.

Generally speaking, it is required that wood residue, contaminated runoff, leachate and solids do not escape from the storage. Additionally, runoff must be diverted away from the storage. If storing the wood residue in the field, ensure the piles are located away from areas prone to flooding or areas with standing water or water-saturated soil.

The required setbacks for both permanent and temporary storage are 30 m from drinking water sources, 15 m from watercourses and the pile must not be located on the property boundary.

While not explicitly stated in the Code, it is recommended that wood residue piles are covered in high precipitation areas to minimize leachate.

Nutrient Value

Manures supply plant nutrients over time. Table 2.6 shows the typical amount of nutrients supplied in various types of livestock manure. The moisture and nutrient content vary as a result of storage method, litter content, and manure age.

The nitrogen values given in Table 2.7 are for total nitrogen. For all types of manure, the amount of nitrogen that is available to the crop after it is applied may vary from the value listed in the table. Incorporate all manures (solid or liquid) within 12-24 hours of spreading to reduce ammonia volatilization and to achieve the greatest benefit from the manure nutrients. If the manure is incorporated soon after spreading, 20% of the nitrogen may be lost. However, as much as 50% of the nitrogen can be lost if the manure is left on the soil surface after being spread.

Test the nutrient content of the manure after it is delivered to the farm. The nutrient content will not change significantly if the manure is kept covered. If a manure test is unavailable, the table values can be used but they may require adjustment for the moisture content of the manure. Nutrient applications from all sources, including manure and commercial fertilizer, should be balanced to meet the crop requirements. The release of nutrients from manure is not consistent. Therefore, in any year manure should only be used to supply up to 75% of the crop's nitrogen requirement. About 70% of the phosphorus in manure is readily available in the year it is applied. Where manure has been used repeatedly, phosphorus is assumed to be 100% available. All potassium from manure is available in the year of application.

Using Compost

The nutrient content of composted manure is slightly higher than fresh manure. However, the availability of the nutrients is lower as they are held in a more stable form by the organic matter of the compost. Note that use of compost or composted manure may be expensive for large-scale field production. The benefits of using composted manure include reduced nitrogen leaching and, its usefulness as a supplement or replacement for other organic matter in plant production. Compost increases the soil's organic matter content and moisture-holding capacity. It also enhances plant growth, helping to develop a sound root structure, and has been reported to suppress or control soil-borne diseases.

It is very important to know the nutrient availability and salt content of compost, whether the compost is derived from animal manure or plant wastes. Nutrients will be released slowly from compost, but there is often a flush of readily available nutrients and salts from compost that has not been fully cured or slightly weathered prior to use. It is critical to check salt content prior to use as a medium for seedling or transplant production. Generally, less than 50% of the growing medium by volume should be made up from compost, and this may be even lower for composted manure.

Table 2.7: Typical Nutrient Content of Various Types of Manure

		Nutrient Content[a] kg/tonne (kg/m^3)		
Type of Manure	**Moisture %**	**Total Nitrogen**	**P_2O_5**	**K_2O**
Beef (solid)	68	4.2 (2.1)	4.8 (2.4)	8.2 (4.1)
Dairy (solid)	77	3.9 (2.0)	3.4 (1.7)	9.0 (4.5)
Dairy (liquid)	91	2.9 (2.9)	2.1 (2.1)	4.5 (4.5)
Swine (covered pit)	93	6.3 (6.3)	3.3 (3.3)	3.9 (3.9)
Swine (uncovered pit)	98	3.5 (3.5)	1.5 (1.5)	1.7 (1.7)
Horse (with shavings)	72	2.4 (1.2)	1.7 (0.8)	3.2 (1.6)
Spent mushroom compost	70	5.8 (2.9)	2.5 (1.2)	8.5 (4.2)
Poultry (broiler)	25	31.6 (15.8)	22.8 (11.4)	12.2 (6.1)
Poultry (layer)	50	22.8 (11.4)	29.2 (14.6)	11.2 (5.6)

[a] Nutrient values for manure assume proper storage, handling, and application to minimize losses.

Conversions:
1 tonne of liquid manure = approximately 1,000 litres = 1 m^3 = 220 Imp. gallons
1 m^3 = 1.25 yd^3 = 28 bushels
1 tonne of solid manure = approximately 2 m^3 = 2.5 yd^3
To convert kg/tonne to lb./ton, multiply by 2.0
To convert kg/m^3 to lb./yd^3, multiply by 1.7

Soil Conditioner

Manure can be used as a soil conditioner if its nutrient content is known and no more is applied than the crop requires. Using manure together with cover crops can improve soil structure. The decomposition of the manure in the presence of cover crop roots stimulates biological activity, and increases aeration, permeability and water-holding capacity of the soil. Do not apply manure to bare ground in the fall or winter (mid-September to March 1). Manure may be applied in January, except in areas with high precipitation, and February to fields that have a well established and actively growing cover crop.

Applying Manure

Under the Code, manure can only be applied to land as a fertilizer or soil conditioner.

In South Coastal British Columbia, apply manure to field crops between mid-March and early July. Be sure that the amount of manure applied is no more than what is needed to fertilize the crop. Manure can be applied to a cover crop or permanent grass crop between July and October if, based on a soil test, the application rate matches the crop's nutrient requirements. Manure should not be applied to bare land after July. Manure application is prohibited from November through January, while application in October, February and March is dependent on the results of an application risk assessment, which considers field conditions and forecasted precipitation.

In the Interior of British Columbia, spread manure only when the risk of run-off is near zero. Manure should not be applied to frozen or snow-covered ground. Manure may be applied in the fall if the application rate is equivalent to the crop's nutrient requirements, and if there is a cover crop or perennial forage in place and no run-off will occur.

Additional Precautions

Concerns have been raised recently over the potential contamination of watercourses with constituents of manure. Floriculture growers are encouraged to use best management practices to avoid direct discharge or run-off losses of manure into watercourses. This concern applies not only to the nutrient and solid fractions, but also to the potential pathogens that may exist in animal manure.

Water in ditches is often used for irrigation and crop washing, so its quality is important. Growers are encouraged to avoid direct contact between the harvestable portions of plants and any manure applied to the crop as a fertilizer. Growers may wish to follow the *British Columbia Certified Organic Production Operations Policies and Farm Management Standards* that state the use of raw manure is allowed only prior to seeding a cover crop or a green manure crop.

Crop production standards of organic certification organizations may recommend the use of composted manure or the incorporation of manure prior to planting a cover crop. In either case, it places enough time between the application of manure and the growth of the crop to allow the soil to effectively assimilate nutrients and for the pathogen risk to be eliminated.

The levels of pathogenic micro-organisms in manure, such as *Salmonella* and fecal coliform, are reduced by 99% in about 18 days when soil temperatures are at 15°C. It may take as long as 45 days to reduce the numbers when the soil is about 5°C.

Non-Agricultural Wastes (Biosolids, Whey, Yard Waste, Pulp Sludge, Fish Waste, Etc.)

Caution: Many wastes generated off-farm are being offered or sold to farmers for use as soil conditioners or fertilizers. The use of all agricultural wastes is covered by the *Environmental Management Act* in BC. Use of these materials may be allowed under Regulation or an authorization under the Act. Many of these materials can provide benefits to the soil or crop. However, they come with characteristics or contaminants that can be undesirable to growers. Refer to the Ministry's factsheet, *Use Caution When Bringing Non-Agricultural Waste or Products on to Your Farm*.

Determining the Amount of Manure to Spread on the Field

To spread manure as a fertilizer the following must be known:

- the nitrogen content of the manure,
- the amount of nitrogen supplied by the manure to the crop,
- the amount of manure the spreader can hold (its capacity),
- the nitrogen needs of the crop, and
- the number of loads of manure per area in the field.

Table 2.8 outlines the steps to follow to calculate the amount of manure to spread based on crop requirements.

Environmental Considerations

- Application of fertilizer around each plant, but not touching the stems or foliage, will ensure efficient application to the root zone. This reduces weed growth between rows and nutrient loss to the environment through leaching or run-off.
- Irrigating in the early morning will prevent or reduce the incidence of foliar diseases and reduce the need for fungicides.
- Weed control around each plant will improve plant quality, while reducing damage by rodents and insects.

BC Environmental Farm Plan Program

The long-term prosperity of BC's agricultural sector is linked to its environmental sustainability. With increasing agricultural production intensity and expanding knowledge of our biological and physical environment, the need to improve farm practices has been recognized. The goal of the program is to enhance environmental farm stewardship through the implementation of Environmental Farm Plans (EFP).

The EFP concept has been around for over two decades. Since 2004, all Canadian provinces have had an EFP program in place. EFPs are voluntary. There are no government laws or regulations that require a farmer or rancher to prepare a plan. However, institutions such as banks, insurance companies, and food processors and buyers are paying increasing attention to the impact of agriculture on the environment and are requesting some form of environmental risk assessment from their customers. Farmers may find their environmental farm plan to be a very useful tool when dealing with these other organizations.

An EFP is an agriculture-environment risk identification process. Planning advisors provide participating farmers with a Planning Workbook and Reference Guide. These materials are designed to meet current environmental regulations and beneficial management practices. The workbook is used to develop a farm plan that identifies on-farm environmental risks and subsequently establishes a priority sequence of action items to address the risks. The plan is developed through a comprehensive review of activities and facilities that exist on the farm or ranch and their impact on the environment. The review also considers the impact of the environment on the farm, for example impacts from wildlife or flooding.

Why Should a Greenhouse Operation Do an EFP?

- To determine the farm's standing with respect to environmental rules and regulations and the environmental risk of management practices.
- To sustain the resources used and affected by farming practices.
- To increase public confidence that BC farmers are "doing it right" with respect to the environment.
- To improve farm/ranch profitability. Some potential economic benefits include making fertilizer dollars go further through nutrient management planning, reducing tillage costs by converting to conservation tillage practices, and minimizing the cost of pesticides by using integrated pest management techniques.
- To differentiate your product(s) in the market-place and thereby maintain or enhance marketing opportunities.
- To help plan for unforeseen contingencies such as floods, spills or fires.
- To demonstrate due diligence.
- To improve relationships with regulatory agencies and to reduce the need for further regulation.

The EFP program is delivered by ARDCorp, which is a subsidiary of the BC Agriculture Council. Contact ARDCorp for more information on the program or to apply to conduct a farm plan.

Table 2.8: Calculating the Quantity of Manure to Apply

Step 1. Determine the nitrogen content of the manure.

Refer to Table 3.8 for typical total nitrogen contents of various types of livestock manure. Use these values if a laboratory or quick test value is not available. Nitrogen comes in several forms in manure. The amount of nitrogen in manure also varies and is subject to many management and environmental conditions that can result in nitrogen losses.

Step 2. Calculate the approximate amount of nitrogen supplied by the manure (kg N/yd^3).

Losses of nitrogen upon application of manure can range from a low of 20% if manure is incorporated within 24 hours, to as much as 50% by volatilization if the manure is left on the soil surface.

$$\frac{\text{N supplied by manure (kg/m}^3\text{) (see Table 3.8) X initial application loss factor*}}{1.31\ \text{m}^3/\text{yd}^3}$$

*Initial application loss factor = 100% - % nitrogen lost

Step 3. Determine the capacity of the manure spreader (yd^3).

$$\frac{\text{Box length (ft) X width (ft) X average depth of manure in spreader (ft)}}{27\ \text{ft}^3/\text{yd}^3}$$

Step 4. Determine the nitrogen needs of the crop (kg/ha).

Refer to specific crop recommendations in the results of a soil test.

Step 5. Calculate the number of spreader loads of manure per area in the field (loads/ha).

$$\frac{\text{Crop N requirements (kg N/ha)} \div \text{spreader capacity (yd}^3\text{/load)}}{\text{N supplied by the manure (kg N/yd}^3\text{)}}$$

Example:

A spreader has a box that is 7.5 feet long and 4 feet wide. It is filled with solid poultry (broiler) manure to an average depth of 2.25 feet. The manure will be spread prior to planting a crop that, based on soil testing, requires about 80 kg/ha (32 kg/acre) of nitrogen. The manure is to be broadcast over the entire area using a conventional spreader. How many loads are needed to supply the crop's nitrogen requirements?

Step 1. Determine the nitrogen content of manure.

From Table 3.8, poultry manure contains 15.8 kg N/m^3

Step 2. Calculate the approximate amount of nitrogen supplied by the manure (kg N/yd^3).

$$= \frac{\text{15.8 kg N/m}^3\text{ (from Table 3.8) X 0.80}}{1.31\ \text{m}^3/\text{yd}^3} = 9.6\ \text{kg N/ yd}^3$$

Step 3. Determine the capacity of the manure spreader (yd^3).

$$= \frac{\text{7.5 ft long X 4 ft wide X 2.25 ft deep}}{27\ \text{ft}^3/\text{yd}^3} = 2.5\ \text{yd}^3/\text{load}$$

Step 4. Determine the nitrogen needs of the crop (kg/ha).

80 kg N/ha (32 kg N/ac) (based on soil testing)

Step 5. Calculate the number of spreader loads of manure per area in the field (loads/ha).

$$= \frac{\text{80 kg N/ha} \div \text{2.5 yd}^3\text{/load}}{9.6\ \text{kg N/yd}^3} = 3.3\ \text{loads/ha} (\div 2.47 = 1.3\ \text{loads/acre})$$

Chapter 3 - Managing the Plant Environment

There are factors other than pests that affect optimum plant performance, such as:

- light, temperature, water and air,
- nutrient levels and balances,
- planting media,
- pollution and chemical injury, and
- mechanical injury.

In many cases, weakening of plants due to problems with these factors can predispose them to disease and insect problems. For this reason, it is important to be aware of the specific needs and sensitivities of each crop.

Principle of Limiting Factors

In any crop system, the level of production can be no greater than the genetic potential of the plants. However, the full genetic potential is often not realized due to some other limiting factor. The most limiting factor will determine how much of a plant's genetic potential can be realized. For instance, if nitrogen is in short supply, it will limit crop growth even though the other inputs (e.g. light and water) are in abundance.

A good cropping strategy should aim to maximize and exploit the full potential of the crop by providing optimum amounts of all of the factors required for growth, and by applying these inputs in a cost effective and environmentally responsible manner.

Temperature

Generally, the warmer the air temperature, the faster a plant will grow and develop, assuming all other conditions are optimum. Plant leaf temperatures are related to light levels and air temperature, and are regulated by transpiration. Sudden changes in air temperature will affect humidity and transpiration rates and can result in plant stress and unwanted condensation on leaves and greenhouse surfaces.

The difference between day and night temperature is as important as the actual temperature values. The processes that produce food for plants to grow and develop (photosynthesis) stop working at about 35°C and above. The processes that make the plant grow and develop (respiration) continue at night. At a certain low temperature (specific to the crop) these processes will also stop.

Recent research has brought about a re-thinking of greenhouse temperature control. Researchers have found that high night in combination with low day temperatures will reduce or eliminate the need to apply plant growth regulators for certain plant species such as chrysanthemums, lilies and poinsettias.

The technique of temperature control of plant height is based on the concept of average temperature. Plants grow and develop at a rate dependent on the average temperature they receive over the 24 hour period.

Average Temperature =
[(day temp x hrs day) + (night temp x hrs night)] ÷ 24

If plants are behind schedule, the daily average temperature can be raised to speed up development. If plants are ahead of schedule, the daily average temperature can be lowered to slow down development.

Plant height is influenced by the difference (DIF) between day and night temperature. A positive DIF (higher day than night) will produce taller plants. A negative DIF (higher night than day) will produce shorter plants. Plant height can be decreased by lowering the day temperature and also by increasing the night temperature. It can also be decreased by introducing a relatively cooler temperature, or DIP for two hours starting just before sunrise. DIP and DIF affect the length of the stem internodes rather than the number of leaves.

If plants are behind schedule, then raise the daily average temperature to speed up development. If plants are ahead of schedule, then lower the daily average temperature to slow down development.

Accurate temperature control is important for optimum plant performance. High temperature injury results in tissue collapse due to desiccation or overheating of cellular fluids and is more prevalent on young tissues and at leaf margins.

Unless freezing occurs, low temperature problems are more subtle. Slow growth, chlorosis of the leaves, defoliation, and various nutritional and pathogenic diseases often occur after plants are exposed to low temperatures. When propagating plants, the soil temperature must be monitored, since the rooting medium is often cooler than the air temperature due to evaporative cooling. Low temperatures can slow the growth of seedlings, or the rooting of cuttings. A sudden rise in air temperature may result in moisture condensing on leaf surfaces, providing conditions favourable to some plant diseases.

Light

Light intensity, quality, and duration are important for optimum plant growth and development. Generally, plants grow more with blue light because each unit contains more energy than red light. Plants need red light for timing their daily and seasonal clocks. Many growers have successfully used supplemental lighting to increase the light intensity during cloudy days and during the fall, winter and spring (see Table 3.1). For more information on light measurements, see *Light Measurement Conversions*, Appendix C.

Table 3.1: Common Supplemental Light Intensities for Various Ornamental Crops (Using High Pressure Sodium Vapour Lights)*

Crop	W/m^2 (PAR)	Intensity (klux)	Foot Candles	Daylength (Hours)	Stage of Crop	Comments
Alstroemeria	6	2.16	200	13	Flowering	13+ hrs will promote flowering
African Violets	6	2.16	200	18	Stock Plants	
Bedding Plants	12	4.40	400	18	Seedlings	Will prevent stretching on cloudy days
Begonias, Fibrous	6	2.16	200	18	Seedlings	Avoid high light intensities
Begonias, Rieger	6	2.16	200	14	Stock	
Bromeliads	6	2.16	200	18	Seedlings	
Cactus	9	3.24	300	18	Seedlings	
Calceolaria	3	1.08	100	24	Flower forcing	
Carnations	12	4.40	400	18	Seedlings Flowering	
Chrysanthemums	15.5	5.6	500	20	Stock plants and cuttings	Can be used for long day treatment
Cyclamen	6	2.16	200	18	Seedlings	
Geraniums	6	2.16	200	18	Cuttings	
Gerbera (cut)	6	2.16	200	18	Continuous	
Gerbera (potted)	6	2.16	200	16	Seedlings	
Gloxinia	9	3.24	300	18	To flowering	
Hydrangea	18	4.4	600	24	Cutting	
Kalanchoe	6	2.16	200	18	Stock plants	Long days to prevent flowering
Lilies	9	3.24	300	18	Bud blasting	Prevents bud drop
Orchids	9	3.24	300	16	Flowering	
Poinsettias	4.5	1.62	150	18	After pinch	During periods of cloudy weather
Roses	15.5	5.6	500	18	Flowering	Winter
Snapdragons	9	3.24	300	16	Seedlings	
Stephanotis	4.5	1.62	100	18	Flowering	

*Growers with lower cost electricity may supplement with higher light intensities in some cases.

Greenhouse plants may be divided into two broad groups: those tolerant of full sun and those requiring partial shading. Insufficient light levels can result in poor colouration, leggy growth and slow development. Excessive light causes bleaching of foliage in sensitive crops and, in severe cases, high temperature injury since light radiation raises the leaf temperature. Problems associated with high light levels can be corrected by proper spacing, timely watering and shading when necessary.

The acclimatization of tropical plants to maintenance levels is done over a 3 to 6-week period. This involves lowering the intensity and adjusting the duration of light to similar levels encountered in indoor plantings. When plants do not undergo this gradual change, leaf yellowing and leaf drop usually occur. Acclimatization also requires adjusting the fertilizer rates to 10 to 20 percent of original levels and adjusting soil moisture according to the size of plant, ambient humidity, air movement and temperature.

Water

The moisture requirements of plants are closely tied to light and temperature factors. Potting mediums should be well drained. Under-watering encourages salt accumulation and may lead to serious damage when plants wilt during bright, hot weather. Over-watering is a common cause of root disease. Roots are unable to obtain enough oxygen in a constantly saturated media. This leads to tissue death and provides an entry site for plant pathogens.

Watering methods should be used to provide accurate delivery of water and nutrients to the crop with a minimum of waste, leaching and undesirable wetting of foliage. Many greenhouse potted flower producers have converted to capillary mat, trough, or ebb and flood recirculating systems. These systems offer accurate watering and great flexibility in crop configuring and spacing. They can also reduce or eliminate problems associated with run-off from greenhouses. However, subirrigation systems increase the risk of spreading soil borne diseases between plants within a production unit.

An abundant supply of good irrigation water is the first step to produce high quality greenhouse crops. Small amounts of impurities are found in almost all water sources, and while some of these may be beneficial, others can be harmful to plant growth. It is even possible for irrigation water to be too “pure”, leading to undesirable instabilities in pH. Therefore, every greenhouse fertilizer program should start with a complete irrigation water quality analysis for initial nutrient, salt, pH and alkalinity levels.

Factors Affecting Water Quality

Ionic Content

When elemental compounds dissolve in water, they separate, or dissociate into their respective ions. Therefore, sodium bicarbonate is present in its dissolved state as sodium ions (Na^+) and bicarbonate ions (HCO_3^-). Ions having a positive charge are called cations and those having a negative charge are called anions. In any solution, the total number of anions tends to balance with the total number of cations. The actual balance between anions and cations is not the most important factor in determining the quality of an irrigation source. The relative amounts of ions in the water and which of those ions tend to predominate is more important.

Hard Water and Soft Water

Pure distilled water is said to be very soft since it contains no dissolved minerals. Likewise, rainwater and most surface water supplies are soft because they contain relatively few minerals. However, soft water does not always mean the absence of minerals. Highly mineralized water supplies where sodium is the predominant cation are also said to be soft. Soft water will produce a soap lather easily. Hard water contains high amounts of dissolved calcium and/or magnesium and does not produce a soap lather easily. Although not as desirable for washing and cleaning purposes, hard water is usually preferable to high sodium soft water when it comes to greenhouse production. Some types of water softening equipment replace the calcium and magnesium in water with sodium. This makes them unsuitable as water treatment devices for greenhouse production.

Salinity

The total amount of dissolved salts in a water supply constitutes its salinity. The cells of plant roots absorb water as a result of the difference in osmotic pressure between the cell contents and the surrounding soil water. Whenever the salinity of the soil solution is near to or greater than that of the cell contents, plants are unable to take up sufficient water for growth, cell pressure maintenance, and transpiration. Some species are more sensitive to high salts than others and mature plants can tolerate higher salts than young seedlings. Since liquid feeding programs add additional fertilizer salts to the irrigation water, it is usually desirable to start with water sources that have as low a salinity level as possible.

Non-fertilizer salts tend to accumulate in soils since they are not removed or used by the crop. Therefore, water sources with a high salinity content of non-fertilizer elements may require heavy leaching to reduce salt build-up in the growing media. This can lead to wasting of fertilizers and unacceptable levels of greenhouse run-off. High salinity water sources are less suited for use in sub-irrigated or recycled systems. When used in misting systems, highly saline water can leave a residue on plants and mineral precipitates may cause clogging of emitters.

Salinity is usually measured as a determination of the electrical conductivity (EC) of a solution. Conductivity increases with salinity. The standard unit for measuring conductivity is the millisiemen (mS). Another commonly used unit is the millimho (mmho) which is equal to the millisiemen (mS). Sometimes salinity values are reported in microsiemens (µS) or micromhos (µmmho) when the water is very pure. One µS is 1/1000th of a mS. Yet another commonly used unit of measurement for salinity is total dissolved salts (TDS), measured in parts per million (ppm). An EC reading of 1 mS is equal to about 666 ppm TDS.

Common Toxicity Problems

- **sodium:** high sodium levels can contribute to salinity problems, interfere with magnesium and calcium availability, and result in foliar burns associated with poor water uptake and sodium accumulation in the tissues. The sodium absorption ratio (SAR) is an indication of the sodium hazard. Most labs now report SAR adj. (adjusted), which includes a variety of other chemical factors that are taken into account to more accurately assess the sodium hazard.
- **chloride:** often associated with sodium since sodium chloride (table salt) is a common constituent of some water supplies, particularly well water. Levels above 140 ppm are considered toxic to plants. Some fertilizers also contain chlorides, such as potassium chloride.
- **fluoride:** levels above 1 ppm may cause foliar problems on sensitive crops such as lilies and freesias. Fluoride can accumulate in greenhouse media; therefore, it is best to find water supplies as close to zero as possible. The small amount of fluoride that is applied to drinking water in some cities for dental health purposes does not usually pose a problem for horticulture (see the section on *Fluoride Injury* at the end of this chapter).
- **boron:** although a necessary plant nutrient, boron may sometimes be present in quantities toxic for plant growth. High boron levels are commonly associated with alkaline soil formations in areas of low rainfall.

pH

pH is a measure of the relative acidity (hydrogen ion concentration) in the water supply. It is influenced by alkalinity. The pH of the soil solution affects the relative availability of nutrients. Most greenhouse crops require a pH of about 5.5 to 6.5 in the growing medium. The pH of the irrigation source may influence medium pH depending on the buffering capacity of the medium (its ability to neutralize acids). In general, water with high alkalinity will tend to raise medium pH. The amount of acid or base needed to change the pH of a water supply is determined by the alkalinity of the water. The purer the water the easier it is to change the pH. Water that is “too pure” may require the addition of a small amount of buffering agent, such as potassium bicarbonate, to stabilize the pH and prevent nutrient precipitation in the feeding solutions.

The pH of the growing media and water is one of the most important factors in production because it directly affects nutrient availability. Figure 3.1 shows that as you move from a pH of 4 to 7 the amount of calcium and magnesium available increases, while the amount of iron available decreases. This is why geraniums suffer from iron toxicity when the pH drops below 5.8.

Measuring pH is a relatively quick test that can prevent many nutritional problems. Tests should be carried out on a regular basis because many factors influence media pH. Some common factors that raise media pH include lime, alkaline water, root activity and several nutrients (e.g. calcium, potassium and magnesium). Some factors that lower media pH include the decay of organic matter, acid forming fertilizers, and acidic water.

Alkalinity

The alkalinity of a water source is more significant than its pH because it takes into account the main constituents that affect its ability to influence media pH. An alkalinity test measures the combined amount of carbonate ($CO_3^{=}$), bicarbonate (HCO_3^-)

and hydroxyl (OH^-) ions. Alkalinity test values are usually reported in ppm (parts per million) or meq (milliequivalents per litre) of calcium carbonate ($CaCO_3$). A pH measurement, on the other hand, only indicates the relative concentration of hydrogen ions and provides essentially no information on how the water will affect medium pH. Alkalinity rises as the amount of dissolved carbonate and bicarbonate rises. Since bicarbonate and carbonates will neutralize acidity, and acids will neutralize them, it is possible to correct water and media pH once the alkalinity is known. Highly alkaline water can be adjusted by adding phosphoric, sulfuric, or nitric acids. This will tend to reduce media pH over time. Similarly, overly acidic conditions can be corrected by increasing the alkalinity of the irrigation water.

Plant Nutrients in Water Supplies

The presence of plant-available nutrients in the greenhouse water supply does not usually present a problem, unless they exceed the amounts normally fed to plants. However, they must be considered when formulating nutrient solutions. Certain fertilizer materials, such as phosphoric acid, will react at high concentrations with dissolved calcium and magnesium to form insoluble precipitates that may clog drippers. Water supplies high in calcium and magnesium may not be suited for use in mist systems due to the accumulation of unsightly mineral residues on plant surfaces.

For more information on water quality, a factsheet: *Irrigation Water Quality for BC Greenhouses* is available from the Ministry of Agriculture.

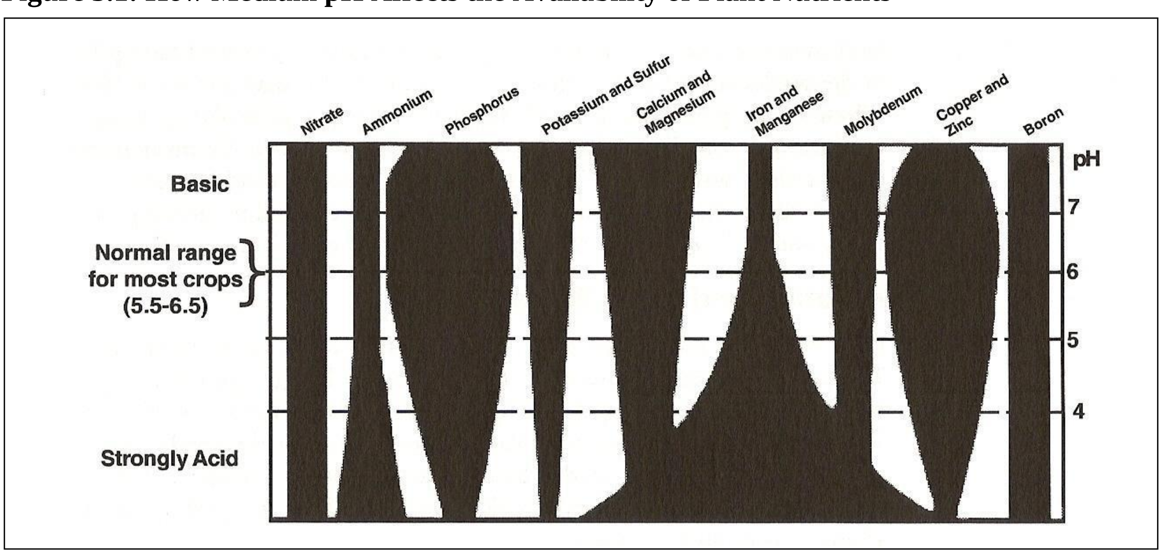
Planting Media

A wide range of commercial materials are available for use as planting media. Most planting mixes used today in greenhouses are soilless. Growers can either prepare their own mixes or have custom blends made for them. Whatever your preference, you should be aware that proper selection and management of your planting media is critical to the success of your crop. Some planting mixes are inert, containing essentially no available fertilizers. Other mixes may contain lime, which will supply calcium and, in the case of dolomitic lime, magnesium. Some mixes may also come pre-charged with soluble and slow release fertilizers. It is important to know the nutritional and pH status of your media before planting, as it will affect the water and nutrient management strategy required.

Air and Water Porosity

Inadequate drainage and aeration of container media is a major limiting factor in the production of quality crops. In severe cases this may lead or contribute to the premature death of the plant. Placing a particular growing medium in a container reduces its aeration porosity due to the phenomenon of a 'perched' water table. Therefore, it is important to consider various options to increase the drainage and aeration in the container growing medium, and in doing so, promote healthy and vigorous plant growth.

Figure 3.1: How Medium pH Affects the Availability of Plant Nutrients



Aeration and Plant Roots

Plant roots, like other plant parts, require air for the process of respiration. This essential metabolic process is fundamental to living organisms, and involves oxygen from the air reacting with stored foods within the plant cells. This releases energy for essential plant functions, such as the uptake of mineral nutrients. If the media does not supply adequate oxygen for the root system, then the plant will exhibit slow growth and will be predisposed to adverse environmental stresses.

Aeration is also necessary for the diffusion of carbon dioxide away from the roots. This gas is formed from the respiration of root cells and microorganisms, as well as from the decomposition of organic matter. The growing medium must be sufficiently porous to avoid the accumulation of carbon dioxide that would lead to the suffocation and eventual death of plant roots.

A lack of aeration caused by poor drainage leads to a wet, waterlogged, oxygen starved condition that can result in root death. The presence of dead roots predisposes the plant to attack by soil borne pathogens, such as *Phytophthora* and *Pythium*, which are responsible for root rots and damping-off.

Porosity

Aeration is a function of soil porosity. Growing media consists of solid particles, such as peat or bark, as well as the pore spaces both between and within these particles. These pore spaces are categorized into either large pores, which are normally filled with air, or smaller pores that can be either air or water filled. Although increasing aeration results in a corresponding decrease in water retention, this is the preferred situation. It is usually better to irrigate more frequently than to not have sufficient aeration. However, planting media that retains very little water will cause problems with post-harvest care of potted plants. A good compromise is to use a growing medium that has sufficient large pore spaces to allow for good aeration, while still having high water holding capacity.

The best way to achieve good aeration is to select media ingredients of sufficiently large particle size. In general, there should be a good proportion of coarse textured components in the size range of 1 to 2 mm. For example, a good quality, fibrous sphagnum peat moss should be used rather than a more decomposed, less fibrous type of peat moss, like hypnum. Additional components such as perlite are often added to increase the overall air porosity.

Stability

The stability of a planting mix needs to be considered. Although sawdust initially gives a mix a high aeration porosity, its rapid decomposition may reduce the porosity over time, as well as tie up nutrients during decomposition. Peat, composted bark and coco peat products tend to be quite stable organic amendments. Inorganic components such as perlite and vermiculite have the advantage of not being subject to decomposition, although vermiculite can lose much of its porosity through compaction.

Perched Water Table

Placing a growing medium in a container creates the phenomenon of a “perched” water table where all pore spaces at the bottom of the container are filled with water. A perched water table cannot be corrected by increasing the number of drainage holes in the container. This is usually not a problem in a field situation, since the water table is usually relatively deep, as opposed to being almost at the surface in a shallow plug tray.

The only way to reduce the effects of a perched water table is to increase the depth of the container. For any planting mix, deep containers result in greater overall gravitational drainage and higher media air porosity. The impact of container depth on media properties is demonstrated by the data in Table 3.2. Air porosity is significantly higher in a 6 inch pot (21%) relative to a shallow plug tray (3%).

Table 3.2: The Effect of Container Size on Media Aeration

	6" Pot	4" Pot	BP Cell	Plug Tray
% Air Space	22%	15%	9%	3%
% Water Space	49%	56%	62%	68%
% Solid Material	29%	29%	29%	29%

Therefore, increasing the depth of the container will increase the drainage and aeration. In many cases economics and aesthetics preclude the use of deep containers. But where saturated media can be a problem, such as during propagation, deep containers should be considered. This may make particular sense with difficult to establish species where excess water is not immediately taken up by roots. The increase in aeration and the concurrent reduction in water, particularly at the surface, can help reduce the presence of moisture dependent pests like algae, liverwort, moss and fungus gnats.

Improving Aeration

This can be achieved by using sufficiently coarse media components and deeper containers where feasible. In addition, growers should avoid:

- using finer components that may plug up the larger pore spaces,
- overmixing the media, which could reduce the particle size of components,
- irrigation and handling practices that may compact growing media, and
- using media components that may decompose and result in the loss of large pore spaces.

On-site Testing of Planting Media

Nutritional problems are a primary cause of economic losses associated with poor crop quality and yield. Two of the most important indicators of nutrient availability and water quality, pH and total soluble salts, are easily monitored under greenhouse conditions. With routine testing of salts and pH, and occasional complete laboratory analyses, it is possible to eliminate almost all nutritional problems of potted and cut flower crops.

pH

The pH of the growing medium and the irrigation source can affect the availability of nutrients in solution, and the health of root systems. Most plants have a relatively narrow range of preferred pH levels. The preferred range for most greenhouse crops grown in organic substrates is a pH of 5.5 to 6.5. Acid tolerant crops, such as azaleas, are usually grown at a pH of 5.0 to 5.5. Some crops are tolerant of a wide range of pH values, while others, such as geraniums require a relatively narrow range (pH 5.8 to 6.2). Although pH can be measured by chemical titration and with the use of color indicating litmus papers, an electronic pH meter provides the most accurate and practical means of on-site testing.

pH Meters

Portable pH meters are available for greenhouse use. Most meters use a remote semi-permeable glass electrode filled with a solution of mercury or silver chloride. In some cases the electrodes are refillable, which extends their useful life. Whenever an electrode cannot be accurately calibrated between two standard buffer ranges, there is usually a problem with the electrode, or the batteries are low. These instruments must be handled and stored carefully, and the electrode end must usually be kept immersed in a liquid according to manufacturer's directions. A new type of pH meter is now available that uses a flat electrode which does not require wet storage. Other features to look for in a pH meter are automatic temperature compensation and calibration. Digital readouts are now standard in most meters. The level of accuracy needed for horticulture is to one decimal point, i.e., pH 6.2.

Electrical Conductivity (EC)

Fertilizers and other dissolved salts change the ability of a solution to conduct electricity. Pure water is not a particularly good conductor, but as the salinity level increases, its conductance also increases. Salt meters (conductivity meters) are used to measure the electrical conductivity of solutions. This provides a rough idea of the fertilizer content of the irrigation water and the media solution. One factor that must be kept in mind is that not all salts are fertilizers. Some water sources are high in non-fertilizer minerals that tend to increase the overall conductivity. So while EC measurements are a good indicator of relative fertility levels, particularly if measured regularly and tracked over time, it is important to establish the background mineral content of irrigation sources and to have an occasional complete mineral analysis performed on the media. Another point to remember is that different fertilizers have different salt indexes.

EC Meters

A range of portable EC meters are available for use in horticulture. There are a variety of inexpensive 'pen type' meters that are quite accurate and convenient to use for spot checking irrigation solutions and media salts. Standard solutions are available for calibrating the meters. Some features to look for are auto calibration, auto temperature compensation, easy to read displays, and probe replaceability. EC meters usually provide a readout in millimho's (mmho) or millisiemens (mS). They are numerically identical units. Some auto ranging meters may provide a readout in micromho's (µmho) or microsiemens (µS). These units are 1/1000th of a millimho or millisiemen respectively.

Testing Methods

For irrigation water and fertilizer solutions, testing is a straightforward matter of monitoring the pH or EC directly. Follow the instructions provided with the meter and be careful to rinse the electrode surfaces after use and store the instruments properly. Buffered calibrating solutions are usually supplied with pH meters, and standard salt solutions are available to check and adjust the accuracy of EC meters. These calibrations should be performed often.

Water and Nutrient Solutions

Well or tap water should be checked before fertilizers are added to determine any background levels of salinity and the initial pH. It is important to allow tap water to sit for about 60 minutes when measuring pH. This allows any carbon dioxide gas dissolved in the water to come to equilibrium with the air. Dissolved $C0_2$ will tend to lower pH readings. If the water shows any substantial salt content (0.5 mS or above), an irrigation water quality analysis should be performed by a testing laboratory to determine the background mineral content. The report should include the elemental content, including the level of bicarbonates. Once a background EC is known, it must then be taken into account when measuring fertilizer content with a salt meter. For instance, if your water has an initial EC of 0.8 mS, then you will need to subtract this amount from your fertilizer solution readings to determine the actual fertilizer content of your nutrient solutions. This is important whenever you are checking the accuracy of injectors. Most commercial soluble fertilizers will indicate the EC values on the bag for various feeding concentrations. In order to check the calibration of your injectors, you must subtract the background EC levels from your measured fertilizer EC values after injection.

Record Keeping

Growing media should be tested for salts and pH on a routine basis. Testing should begin before the crop is planted and be performed at least every two weeks. It’s important to keep records so that you can chart pH and EC levels over time. Graphically charting your pH and EC values will show whether the pH and EC are rising, falling, or staying steady. This is at least as important as the actual reading. It will enable you to make informed decisions about fertilizer concentrations, watering frequencies, and leaching rates. Growers who use routine media testing often can produce superior crops with less fertilizer and lower leaching rates, thereby reducing waste and the possibility of environmental contamination.

Collecting a Media Sample

There are two strategies available for media sampling. First, you could take several samples and measure them individually. This would provide you with a good indication of the uniformity of your watering and fertilizing program. If the results are dramatically different between pots or locations, it might provide a clue to uneven growth or other crop problems. However, collecting and measuring 10 or more separate samples and measuring them individually can be very time consuming, and may not provide information that is any more useful than a representative or average sample. In any case, it is not practical to water and fertilize each plant individually therefore, the representative sample method is usually the one to use.

To obtain a representative sample it is necessary to combine several sub-samples to obtain an average value. Depending on the size of the crop, samples from about 10 or more pots or growing bed locations are required. Combined samples should always be from within one distinct growing unit, environment or irrigation zone. The samples should be obtained from uniform plants that are the same type, age and in the same size container. Try to collect your samples at the same time between irrigations, i.e., just before the next watering. Avoid sampling the top 2 cm of media since there are usually very few roots in this zone, and the salts tend to be higher due to evaporation of water from the soil surface. Salt accumulation on the surface of the media is most pronounced with subirrigation. Collect samples from the mid-range of the pot, making sure to include more than just the soil at the outside edge of the container. You can usually remove about 10% of the media without harming the plant. Fresh, moistened growing media can be used to replace the soil removed by your sample. Follow the same procedure for growing beds, by avoiding the top 2 cm and making sure that your sample is from the area of most active root growth.

It is very important to be consistent in your sampling methods, so that your results will be accurate when tabulated over time. When all the sub-samples have been collected, they are placed in a clean container or bag and mixed thoroughly, taking care not to crush any controlled release fertilizer prills. The sample can then be sent in for professional analysis, or measured on-site.

Extraction Methods

Only the media solution can be tested, and there is usually not enough of it to sufficiently immerse the EC or pH probes without adding water. Also, the EC in the growing media changes with moisture content, becoming more saline as the media dries. It is therefore necessary to add enough water to the sample to immerse the electrodes and to have comparable readings from one sampling date to another.

Over the years, several dilution and extraction methods have been devised. All have advantages and disadvantages, and all may provide different instrument readings. This often leads to confusion when trying to discuss or compare values obtained from different extraction methods.

Three methods are described in the factsheet: *On-Site Testing of Growing Media and Irrigation Water* available from your nearest Ministry of Agriculture office. The factsheet details the materials and procedures for the 1:2 extraction, the saturated media extraction (SME), and the pour-through method. Other methods such as the 1:5, and the 1:1.5 dilution methods are described briefly, although they are not as commonly used.

Air

Carbon Dioxide

CO_2 is essential for plant growth. Next to water it is the nutrient used in the greatest quantities by the plant. Plants will stop growing when the CO_2 concentration in the air drops below 180 to 200 ppm. CO_2 can be supplemented to 1,000 ppm whenever daytime ventilation is reduced. Supplemental CO_2 will have a minimal effect on plant growth under very low light conditions.

Supplemental CO_2 can be provided from pure liquid sources, or from the clean combustion of natural gas. There may be an economic advantage to supplemental CO_2 at 350 to 400 ppm during periods of ventilation since crop canopy levels can drop to 200 to 250 ppm when the greenhouse is fully vented. CO_2 burners can be placed overhead but it is often better to inject CO_2 at the crop level. CO_2 levels should be maintained with an automatic controller. Using a time clock system does not provide precise control for optimum production. Some sensitive species may be damaged by CO_2 levels above 2,000 ppm. Humans should not work in levels exceeding 5,000 ppm.

Humidity Control

Adequate ventilation and air circulation can reduce the incidence of many foliar diseases. The humidity in the air is crucial to the health of plants. Humidity levels must often be reduced in greenhouses to avoid water condensation on leaves and flowers. High humidity levels can result in guttation and oedema. Guttation occurs in some species as a seepage of cellular fluids from the margins or edges of leaves. Although guttation may not harm the plant, it can indicate a humidity problem. Oedema is a disorder brought on by wet conditions and high humidity. Cells rupture due to excessive turgor pressure (internal plant water pressure), creating calloused, corky spots on the undersides of leaves and sometimes on the stem. Ivy geraniums are especially sensitive. In addition, certain minerals such as calcium, which move only through the water conducting vessels, may not be translocated efficiently at high levels of humidity.

Humidity can be the most difficult environmental factor to control in greenhouses. Maintaining desired humidity levels can be a challenge for even the most sophisticated monitoring and control equipment. Humidity levels fluctuate with changes in air temperature, and plants are constantly adding water to the air through transpiration. Although automated controls have added a higher level of precision to the art of sensing and correcting humidity levels, it is still important to have a good understanding of the dynamics of atmospheric water vapour. There is a natural tendency with sophisticated equipment to just ‘set it and forget it’. However, lost yields, plant stress, disease outbreaks, and wasted energy are still as possible as ever unless we realize the limitations of our equipment and the implications of environmental control decisions.

A factsheet, *Understanding Humidity Control in Greenhouses* is available from the Ministry of Agriculture.

Dehumidification

In greenhouses, it is usually desirable to avoid humidity levels near the dewpoint since free water condensing onto plant surfaces can promote the growth of disease organisms. Under saturated humidity conditions, plants cannot evaporate water from their leaves, so the uptake of nutrients such as calcium and boron may be limited. It is important to remember that when the relative humidity reaches 90%, it takes only a slight drop in temperature to reach the dewpoint. The problem is compounded by the fact that not all surfaces in the greenhouse are necessarily at the same temperature as the air. Any surfaces that are cooler than the air at high relative humidity will condense water vapour. This is why dripping can be such a problem with glazing materials during the heating season.

Monitoring and controlling the relative humidity of the greenhouse air is not always a guarantee that the dewpoint will be avoided. Local condensation problems can still occur due to uneven heat distribution and the thermal mass of plant materials, particularly on plants with fruits and other large water-filled parts. This causes their surface temperatures to lag behind when sudden changes in air temperature occur. It's the same reason a glass of ice water sweats when the relative humidity of the room air is well below the dewpoint. Cold surfaces within the greenhouse cool the air immediately surrounding them. If the cooling reaches the dewpoint temperature, water condensation occurs.

Excess humidity is usually more problematic in the spring and fall seasons when the weather is cool and moist. High humidity is not as much of a problem during freezing weather, since the relative humidity of the outside air is very low. Humidity levels in the greenhouse can be reduced by venting, which exchanges moist inside air with drier outside air, and by heating. In addition to reducing relative humidity levels, heating raises the temperature of plant surfaces and warms the incoming air. Glass panes and other cold surfaces in the greenhouse serve as natural dehumidifiers when the outside air is colder. However, this may cause problems with dripping, even though the relative air humidity is low.

Preventing Condensation Problems

- Make sure your temperature and humidity sensors are accurate and located in the crop canopy. Test your temperature sensors regularly against an accurate thermometer. Bring various humidity sensors to one spot to see that they are the same. Relative humidity can also be checked with a sling psychrometer.
- Use thermal screens at night to reduce radiative heat loss from plant surfaces.
- Avoid sudden temperature elevations at sunrise by programming a gradual pre-dawn temperature rise and dehumidification period. (A sudden drop in temperature can cause condensation problems as well, particularly on cold glazing materials because the capacity of the air to hold water decreases. However, in this case, thermal lag should prevent condensation and disease on plant surfaces, at least temporarily.)
- Place radiant heat sources near the crop to keep plant surfaces as close as possible to, or slightly warmer than, air temperatures.
- Use horizontal air flow fans or poly tubes to maintain even temperatures throughout the crop.
- Use a combination of venting and heating to reduce excessive humidity.
- Start dehumidifying at about 85% RH. Relative humidity above this level is not easily managed without an increased risk of condensation, disease problems, and nutrient uptake interference due to inactive plants (lack of transpiration).

Raising the Humidity

Although dehumidification is sometimes expensive, it is usually easier to reduce humidity levels than to increase them. Raising humidity levels without creating excessive free water requires an evaporative device such as misters, fog units or roof sprinklers, all of which add water vapour to the air. Alternatively, screens can be used to help hold in the water that is being evaporated from the plant canopy.

Evaporative devices accomplish three things. First, they cool the air, raising the humidity and relieving stress on the crop. Second, they add water vapour to the air, further increasing the relative humidity. Third, they reduce the vapour pressure deficit which is the force that evaporates water from the leaves. Screens may also reduce leaf temperatures and help to trap the large amount of water that the plants are evaporating. Evaporative cooling and screening are often used together. When humidifying under sunny conditions, some venting is necessary. Without venting the greenhouse would soon become a steam bath. Venting is necessary to introduce fresh, dry air that will evaporate more water and displace hot greenhouse air.

Plants, by themselves, can do an excellent job of cooling and humidifying a greenhouse. Evaporative cooling equipment works with the plants, helping relieve transpirational stress and allowing them to grow at optimum rates. The benefits of maintaining a humidification set-point include better plant quality, faster cropping, and lower disease and insect problems.

Fogs, Mists, Roof Sprinklers and Pan & Fan Systems

Many evaporative cooling and humidifying systems are available. They add water vapour to the air, and may subsequently reduce the amount of water that the plants need to transpire. Systems should be sized to permit a maximum vapour pressure deficit of 7 grams/m^3 (11 millibars) when operated in conjunction with a transpiring crop.

Roof sprinklers add water vapour and cool the incoming air. On large ranges, it is possible to decrease the temperature by 3 to 5°C and increase the humidity 5 to 10%. Pad and fan systems consist of porous wet pads at the inlet end of a fan ventilated greenhouse. As the exhaust fans draw air through the wet pads, water evaporates to cool and humidify the air. Temperatures tend to be coolest nearer the fans and hottest at the exhaust when using these systems. Mist and fog systems produce tiny water droplets that evaporate, thereby cooling and humidifying the greenhouse air.

Points to Remember About Humidification

- Plants are the primary humidifiers/coolers of greenhouse air. Ensure adequate irrigation for evapotranspiration needs on hot days.
- Greenhouses with sealed floors tend to be drier since evaporation from the soil is prevented.
- Heat and humidity levels are easier to manage in taller greenhouses.
- If wetting of floors or foliage occurs, stop humidifying in the late afternoon or early evening to allow enough time for drying.
- Evaporative cooling depends upon the total amount of water that can be evaporated. Evaporative cooling systems must therefore be engineered with water output needs in mind.
- Evaporative cooling requires good ventilation rates. It is the *evaporative* process that cools the air. Fresh, dry air must be continually introduced and warm, humid air exhausted.
- To measure leaf vapour pressure deficit, accurate sensors for leaf and air temperature, as well as an accurate relative humidity sensor, are required.

Plant Nutrition and Fertilization

A plant's health and performance is dependent on the availability of the necessary macronutrients (e.g. nitrogen, phosphorus, potassium, calcium, magnesium, and sulphur), and the micronutrients (e.g. iron, boron, manganese, zinc, copper, molybdenum, and chlorine) (Table 3.3). Some crops require more of certain elements than others. For example, poinsettias are known to require molybdenum in higher quantities than most other crops. Micronutrients, especially copper, molybdenum, and boron, can reach toxic levels fairly quickly if too much is applied.

Nutrient deficiencies often result in slow growth and poor leaf shape or colouration. Excess nitrogen can produce soft leaf tissue that is more susceptible to diseases such as *Botrytis.* Chrysanthemum leafminers appear to be attracted to plants grown with high nitrogen levels. Nutritional deficiencies or excesses may be avoided by checking feeding formulas and verifying that all of the required elements are available in the correct quantities. Ensure that the correct amounts of fertilizers are incorporated into potting mixes. A soil test may be necessary. A simple test of pH and conductivity can help indicate if soil conditions are adequate. Tissue analysis can be used to determine the levels of elements present in a plant and to verify fertilizer imbalances.

Table 3.3: Essential Elements for Plant Growth

From Air & Water	Macronutrients	Micronutrients
Oxygen*	Nitrogen	Iron
Carbon*	Phosphorus	Manganese
Hydrogen*	Potassium	Boron
	Calcium	Copper
	Magnesium	Zinc
	Sulphur	Molybdenum
		Chlorine**

* Oxygen, carbon, and hydrogen are assimilated from the air and water and are not normally considered under the heading of plant nutrition. All other nutrients are absorbed primarily through the root system.

**Chlorine is required in minute quantities and is not normally applied intentionally. It is usually available in quantities far in excess of plant needs as chlorides in water supplies and in various fertilizer compounds.

Commercially prepared 'complete feed' fertilizers contain macro- and micronutrients. Generally the micronutrients in the mix will be sufficient to produce a good crop. Iron, especially if the media has a pH greater than 6.5, may need to be supplemented. These fertilizers often do not contain calcium, sulphur and magnesium in sufficient levels to satisfy plant needs. Therefore, premixed fertilizers may have to be supplemented with calcium nitrate and Epsom salts or magnesium nitrate unless calcium, magnesium and sulphur are available from other sources. Dolomitic limestone in the media will also supplement calcium and magnesium levels, and gypsum (calcium sulphate) will supply calcium and sulphur. Complete feed fertilizers have been introduced that contain higher levels of calcium, magnesium, sulphur and micronutrients, thereby reducing the need for supplements. See Appendix B for more information on liquid fertilizers.

Tables 3.4 and 3.5 list some of the more common symptoms of plant nutrient deficiencies and toxicities. Table 3.6 shows how the availability of nutrients varies with other nutrients and with changes in pH. Use the three tables together when analyzing potential nutritional problems.

Table 3.4: Generalized Plant Nutrient Deficiency Symptoms

Symptoms		Deficient Nutrient
Stunting of Shoot Tips		
Young leaves are thick, leathery and chlorotic; stems are brittle; “Witch’s broom” appearance; poor flowering	⇒	**Boron**
Young leaves chlorotic or distorted (crinkled, strap-like, downward curling of leaf tips); roots may become short, stunted and thick; weakened stems	⇒	**Calcium**
Wilting and dieback of shoot tips; poor pigmentation	⇒	**Copper**
Interveinal Chlorosis		
A. Young leaves		
Veins usually remain distinctly green; chlorosis progresses to older leaves; leaves may appear white; twig dieback	⇒	**Iron**
Gradation of colour from yellow to dark green at the midribs, often not a sharp distinction between yellow and green areas; leaves may develop brown or purple spots, and become necrotic	⇒	**Manganese**
Terminal growth stunted, forming a rosette	⇒	**Zinc**
B. Older leaves		
Upward curling along leaf margins; mid-rib areas remain green	⇒	**Magnesium**
Overall Leaf Chlorosis		
A. Occurs first on young leaves		
Associated with leaf wilting	⇒	**Chlorine**
Stunting and lack of vigour; distorted ‘whiptail’ leaves or leaf scorch	⇒	**Molybdenum**
Slow, spindly growth; leaves may turn beige	⇒	**Sulphur**
B. Occurs first on older leaves		
Leaves may become necrotic; stunted, slow, spindly growth	⇒	**Nitrogen**
Plants Dark Green with Purple Coloration of Older Leaves		
Slow growth; stunted plants; older leaves turn chlorotic, then necrotic	⇒	**Phosphorus**
Necrotic Spots on Margins or Tips of Older Leaves		
Weak stems and stalks that fall over easily; slow growth; small flowers	⇒	**Potassium**

Table 3.5: Generalized Plant Nutrient Toxicity Symptoms	
Element	**Toxicity Symptoms**
Ammonium Nitrogen	• Wilted appearance of older leaves, margins of older leaves curl, may become chlorotic and eventually necrotic, root tips may burn. • *Factors that contribute to ammonium toxicity:* high ammonium-based fertilizers at soil temperatures below 15ºC, low light levels, saturated media or when soil pH is below 5.5.
Iron	• Chlorotic and necrotic speckling - common on geraniums and marigolds. • *Factors that contribute to iron toxicity:* over feeding of iron nutrients and low pH.
Manganese	• Chlorosis and death of the growing terminal. • Some sawdust may contain toxic levels of manganese. • *Factors that contribute to manganese toxicity:* over steaming and low pH.
Boron	• Blackening and death of the growing terminals. • Marginal chlorosis or necrosis of older leaves. • *Factors that contribute to boron toxicity:* excessive level in irrigation water, soil or fertilizers; low pH.

Table 3.6: Nutrient Interactions with Other Nutrients and pH			
Element	**Excessive Amounts Inhibit**	**Availability as pH**	
		Falls Below 5.5	**Rises Above 6.5**
Nitrogen	Potassium		
Ammonium	Calcium, Copper		increases
Phosphorus	Copper, Iron, Zinc, Boron	decreases	decreases
Potassium	Nitrogen, Calcium, Magnesium	decreases	
Calcium	Magnesium, Boron	decreases	increases
Magnesium	Calcium	decreases	decreases
Sulphur		decreases	
Iron	Manganese	increases	decreases
Manganese	Iron, Molybdenum	increases	decreases
Copper	Manganese, Iron, Molybdenum	increases	decreases
Boron		increases	decreases
Zinc	Manganese, Iron	increases	decreases
Molybdenum		decreases	
Sodium	Calcium, Potassium, Magnesium	increases	

Plant Nutrients

Most plants can convert simple elements into more complex molecules such as sugars, starches, proteins and lipids. Plants require carbon, hydrogen, oxygen and several macro- and micronutrients for growth. These nutrients are described in Tables 3.7. Plants can assimilate some from the air, all the rest must be provided by either the media or the fertilizer program. Plants need nutrients in varying amounts.

Nutrient ratios are as important as the actual levels in the media. Some nutrients will interfere or promote the uptake of other nutrients. For example, the calcium:magnesium ratio should be maintained at 1:0.4 for optimum uptake of both nutrients. The ratio of some nutrients will influence the growth of the plant. For example, a nitrogen:potassium ratio of 1:1 will generally produce normal growth and height development, whereas a nitrogen:potassium ratio of 5:8 will often produce darker, shorter plants.

Another principle to consider is that plants which are active in vegetative growth will require more calcium and nitrogen, while plants that are actively flowering with little growth will require more phosphorus and potassium.

Table 3.7: Nutrient Absorption Form, Role in the Plant, and Sources		
Nutrient - Absorption Form	**Role in Plant**	**Sources**
Nitrogen - nitrate (NO_3^-), ammonium (NH_4^+), organic urea ($CO(NH_2)_2$)	used to synthesize amino acids, proteins, chlorophyll, enzymes, and nucleic acids	**inorganic:** ammonium nitrate, ammonium sulphate, potassium nitrate, and calcium nitrate **organic:** blood meal, bat guano, fish meal, and manures
Phosphorus - primary and secondary orthophosphate ($H_2PO_4^-$& HPO_4^-)	used in the formation of nucleic acids, enzymes, sugar phosphates, a key element in energy transfer reactions in plants, important for root system development, rapid growth, and quality of floral parts	**inorganic:** single and triple superphosphate, phosphoric acid, monopotassium phosphate, ammonium phosphate **organic:** manures, rock phosphate, guano, tankage, fish meal
Potassium - K^+ (tends to remain in ionic form in the cells and tissues)	an activator for a wide variety of chemical reactions, essential for translocation of sugars and starch formation, required for the opening and closing of the stomata by guard cells, needed for good, sturdy growth and disease resistance, balances the runaway growth effects of excess nitrogen	**inorganic:** potassium chloride, sulphate, and nitrate **organic:** greens and, manures field soils
Calcium - Ca^{++}	Important cell wall constituent, calcium pectate helps to ‘glue’ cells together, improves resistance to fungal and bacterial infections, important in cell division and elongation	liming materials, calcium nitrate
Magnesium - Mg^{++}	chlorophyll molecule contains magnesium, an activator for many chemical reactions and enzyme processes	dolomitic lime, magnesium sulphate, magnesium ammonium phosphate
Sulphur - $SO_4^{=}$	a constituent of amino acids, plant hormones, and certain oil compounds	sulphate fertilizers, gypsum
Iron - Fe^{++} or Fe^{+3}	a catalyst for chlorophyll formation	iron chelates, ferrous sulphate, and fritted iron (slow release)
Manganese - Mn^{++}	acts as a catalyst in oxidation reductions and is involved in chlorophyll formation	manganese chelates and manganese sulphate
Boron - BO_3^{-3}	necessary for sugar translocation, nucleic acid synthesis, and pollen formation, plants vary greatly in their requirement	borax, solubor, and sodium pentaborate
Copper - Cu^{++}	activator for several enzyme processes and may be involved in vitamin A synthesis	copper chelate and copper sulphate
Zinc - Zn^{++}	important constituent of several enzyme systems, and works as a growth regulator for several plant processes	zinc sulphate and zinc chelate
Molybdenum - $MoO_4^{=}$	essential to transform nitrate nitrogen into amino acids, legumes use Mo to fix atmospheric nitrogen, poinsettias have a higher demand	sodium molybdate, ammonium molybdate
Chlorine - Cl^-	container in chlorophyll, essential for photosynthesis	water supply and various fertilizers

Table 3.8: Typical Tissue Analysis Values of Representative Floriculture Crops*					
Crop	**Nitrogen**	**Phosphorus**	**Potassium**	**Calcium**	**Magnesium**
Azalea	1.50 - 2.50	0.20 - 0.50	0.50 - 1.50	0.50 - 1.50	0.25 - 1.00
Chrysanthemum	3.50 - 5.00	0.23 - 0.70	3.50 - 5.00	1.20 - 2.50	0.25 - 1.00
Poinsettia	4.00 - 6.00	0.30 - 0.50	1.50 - 3.50	0.70 - 2.00	0.30 - 1.00
Rose	3.00 - 5.00	0.25 - 0.50	1.50 - 3.00	1.00 - 2.00	0.25 - 0.50
Snapdragon	3.08 - 5.00	0.30 - 0.50	2.00 - 3.00		1.00 - 1.50
*From: *Agricultural Schedule of Services*, Norwest Labs, March 2003					

Tissue Analysis

Tissue analysis is a method to determine nutrient imbalances within a plant. The technique is an excellent diagnostic tool when used to compare healthy and "poor" growth. Based on the results, corrective actions can be implemented. Foliar feeding can be effective as a short-term solution for micronutrient deficiencies. But it is not effective for macronutrient deficiencies, since the amount of fertilizer required to correct the deficiency is more than can be supplied.

Correct sampling is important. Before collecting a sample, contact the lab for advice on how to collect a good tissue sample. The following is a basic guide to taking plant tissue samples:

- Nutrient levels vary widely with tissue age. The general rule is to sample recently matured leaves.
- Submit a 500-gram sample of leaf tissue.
- Sometimes the damaged portion of the leaf is very small, such as with marginal necrosis. If the entire leaf was analyzed, the nutrient imbalance in the leaf margins could be masked due to nutrient levels in the rest of the leaf. In such cases, it is recommended to only collect tissue from the damaged portions of the leaf.
- Collect as little woody material as possible, since it is relatively low in nutrients and will reduce the nutrient levels detected in the sample.
- Rinse foliage in clean water if it is dirty, otherwise submit as is.
- Samples should be stored and shipped in a paper bag or box.
- Keep the sample cool and deliver to the laboratory as soon as possible. If the sample cannot be delivered immediately, air-dry the samples to avoid spoilage.

As mentioned above, it is important to submit comparative samples from healthy and affected plants.

Pollution and Chemical Injury

Pollution of soil, air, or water is an occasional cause of greenhouse and field grown plant disorders. Symptoms can sometimes be confused with those produced by plant pathogens.
Some pollutants that may cause problems are: sulphur dioxide, ozone, PANs (peroxyacetyl nitrates), carbon monoxide, and ethylene. Small amounts of ozone can be produced from metal halide and very high output (VHO) fluorescent lights. This will not be a problem unless the growing structure has a low air exchange rate and lights are placed close to the foliage. Some brown flecking from ozone may appear on tender bedding plant seedlings grown close to VHO fluorescent lights.

Fluoride Injury

Some crops, including calathea, cordyline, dracaena, freesias, gerberas, gladioli, lilies, maranta, tulips and zebrina, are sensitive to fluorides that are sometimes found in water supplies, certain fertilizers (e.g. superphosphate), and soil aggregates (e.g. some perlites). Fluoride toxicity can be reduced if the soil pH is raised above 6.5.

Carbon Monoxide and Ethylene

Carbon monoxide (CO) injury can occur when improperly vented or operating oil or gas heaters are used. CO is odourless and is a severe health risk to humans. Ethylene damage can be associated with incomplete combustion of propane or natural gas, or an excess of senescing or ripening vegetation. Operation of gasoline engines, such as those found on some sprayers, can produce injurious levels of both carbon monoxide and ethylene in a greenhouse. Symptoms vary from burning of flowers and foliage to twisted, deformed or 'blind' growth. Ethylene damage can also occur in storage and shipping when sensitive crops are exposed to ethylene sources, such as combustion engines and ripening fruit.

Pesticide Injury to Crops

Given the right circumstances, most pesticides can injure a plant. Greenhouse pesticides are formulated to be as safe as possible to target crops, but injury to certain varieties or species may occur.

Wherever pesticide recommendations are given in this publication, some of the more commonly damaged plants have been listed. This information is by no means complete, and growers are strongly advised to use caution when using unfamiliar materials, or familiar ones on new crops.

Spray injury can occur as marginal or complete leaf burning, leaf spots, flower spots, or distorted growth. Damage from drenched materials may also produce root death, resulting in the sudden wilting, and sometimes death of part or all of the plant.

Misuse is a frequent cause of pesticide damage to plants. Some common causes are over-application (too much chemical or too frequent), application to wet foliage (especially with fumigants), improper timing, and application to non-registered crops.

Few herbicides are labelled for flower crops. Misuse, spray drift, and residual damage from previously applied herbicides are a common cause of chemical injury (see Chapter 8).

The following precautions can minimize pesticide injury problems:

1. **READ THE LABEL:** be sure of the proper use, application rates, and methods of applying the product. Labels often specify varieties and species that may be harmed.
2. **CHECK THE FORMULATION:** the specific formulation of a pesticide (e.g. dust, wettable powder, emulsifiable concentrate, etc.) can affect its safety to plants. If you use a new formulation of a familiar product, test it on a small group of plants first and monitor them for several days for signs of phytotoxicity.
3. **TIMING:** the state of plant growth is an important consideration for a pesticide application. Young seedlings and flower parts are generally more susceptible to injury than are vegetative phases of growth.
4. **PLANT ENVIRONMENT:** plants may be more susceptible to pesticide injury when under stress. This can occur when plants are under water stress. A good time to spray is often in the early morning or late afternoon. Pesticides should not be applied when temperatures exceed 25 - 30^{o}C. Injury may also occur when pesticides are applied to wet foliage.
5. **TESTING:** before using a new material or mixture, or whenever a new pesticide is being used on a crop, it is a good idea to test it on a small number of plants. If no symptoms occur within several days, it is likely safe for crop use.

Mechanical Injury

Plants can be severely damaged through mishandling. Seedlings are particularly susceptible to injury during transplanting, so care must be taken to avoid stem and root damage.

Improper watering practices such as too much pressure, or volume, and the application of excessively cold water can be very harmful. Fans can cause damage by 'whipping' and desiccating foliage.

Plants are usually capable of recovering from some degree of mechanical injury, however, it may serve as a starting point for further problems once infections set in on damaged tissues. By using common sense in avoiding injuries, it is possible to prevent a lot of further problems and expense.

Chapter 4 - Plant Growth Regulators

Plant growth regulators (PGRs) are used to control plant height and enhance flowering. Their main mode of action is to reduce stem growth (i.e. shorten internodes). Generally, they do not interfere with flower development, however late applications or high application rates can delay flowering and affect flower size. Most PGRs inhibit the production of gibberellic acid within plants, which are involved in cellular elongation. Without gibberellins, cell elongation is reduced and plants do not grow as tall. Used properly, plants will be more compact and will have deeper green foliage and an improved post-harvest life. Applying PGRs at the incorrect rate or time can result in stunted plants, delayed flowering or market unsuitability. This is especially true for products that are effective at extremely low concentrations (e.g. paclobutrazol, uniconazole-P).

The effectiveness of PGRs varies from cultivar to cultivar. Environmental and cultural factors will also influence the degree of height control obtained. Care should be taken when using PGRs for the first time or for the first time on a new cultivar. Always double check your calculations. When using a PGR for the first time, leave some untreated plants to evaluate its effectiveness. To improve subsequent years' height control, keep records of the effects of PGRs on each plant cultivar.

Information on the PGRs registered for use on ornamental plants is presented in the document *Pesticides Registered for Ornamental Crops*.

Be sure to read labels and follow their recommendations carefully.

Factors that Affect PGR Performance

Environmental Conditions

- Growing conditions directly affect the effectiveness and the amount of PGR needed.
- Rates may differ between winter and summer months for the same crops because of the differences in environmental conditions.
- Plants grown under high light conditions will need higher rates than those grown under low light conditions.
- Stem elongation increases under high temperature conditions, so plants will need more PGRs than those grown under cool conditions.
- Do not apply PGRs when the temperature exceeds 22°C.

Production Practices

- Crops grown with tight spacing, high fertilizer levels and optimum irrigation may require higher PGR application rates.
- Stressed, dry or weak plants will be more susceptible to the effects of PGRs and more prone to damage.
- A well-watered plant is better able to translocate PGRs.
- A pine bark based media will reduce the efficacy of paclobutrazol and uniconazole-P drenches.

Cultivar Differences

- Optimum rates vary with each plant species and even by cultivar.
- Generally, short, slow growing varieties require a lower rate than fast growing varieties.
- Most labels suggest that growers do small-scale tests using low-label rates on each cultivar to gain experience in using the product and to determine the optimum rate under their growing conditions.
- Keep records of cultivar response to PGR treatments to improve height control in subsequent years.

Timing

- Timing is critical; plants must be in the right stage of growth to achieve the desired effects. Generally, plants must have sufficient foliage to prevent excessive stunting.
- Drenches should only be applied to plants with well-developed root systems.
- Base the application time on the stage of plant growth, rather than its age. Labels give general timing recommendations, but it is plant size that ultimately determines when to apply a PGR.
- Applications late in the production cycle may result in reduced flower size or delayed flowering.

Application Techniques

- Uniformity and consistency are two key components of application technique. Use precise spray techniques when doing foliar applications. This is essential for success with products that are active at extremely low concentrations, such as paclobutrazol and uniconazole-P. Any variation in spray coverage will lead to variation in plant height.
- Caution should be taken when applying foliar sprays of paclobutrazol and uniconazole-P to avoid excessive run-off. If product drips into the soil, then it can result in plants becoming shorter than expected.
- Double check application rate calculations. The correct rate is essential for success.
- Do not tank-mix PGRs with any fertilizers, insecticides, or fungicides.
- Sprayers should have a pressure gauge and pressure regulators for uniform spray distribution. A reliable output is crucial in delivering a uniform rate over the entire crop.
- Sprayer nozzle size affects droplet size and spray dispersal. For consistent results, always use the same nozzle size.

Chapter 5 - Diseases

Most microorganisms do not cause plant diseases. In fact, many are beneficial to plants because they increase nutrient availability by breaking down dead organic matter, or deploy antagonistic activity against plant pathogens and, thereby, protect plants. A number of microorganisms (e.g. certain fungi, bacteria, protists, viruses, viroids, phytoplasmas, and nematodes), however, do cause plant diseases.

There are three requirements for a plant disease to occur. First, the pathogen must be present. Second, the environmental conditions must be favourable for disease development. Third, the plant must be susceptible due to age or genetic make-up. If a single requirement is lacking, the disease will not develop. Therefore, an integrated strategy is the most effective approach to manage diseases. This strategy focuses on preventing the introduction of disease-causing microorganisms (pathogens), managing the environment to promote healthy plant growth, using resistant cultivars, monitoring for early signs of disease, practicing good sanitation, correctly identifying problems and efficient use of fungicides.

Table 5.1: A Simplified Disease Diagnostic Key (symptoms and possible causes)	
PLANT	STEMS
Decay of seed/seedlings	**Cankers, branch dieback**
• damping-off (pre- and post-emergence)	• *Phytophthora ramorum* (Sudden Oak Death)
• low temperatures	**Stem rot**
• insect feeding on roots	• *Botrytis, Sclerotinia*
• high salts and/or improper pH	• *Erwinia chrysanthemi, Erwinia carotovora*
• poor water management (too much or too little)	• viruses (tomato spotted wilt or impatiens necrotic spot)
• viruses (tomato spotted wilt or impatiens necrotic spot)	**Necrotic stem lesions**
Stunting of plants	• tomato spotted wilt virus or impatiens necrotic spot virus
• root rot	• chlorine damage (poinsettias - bleach)
• poor water management (too much or too little)	**Girdling of stem at crown**
• viruses/viroids/phytoplasma	• *Fusarium, Rhizoctonia*
• insects or nematodes feeding on roots	• damping-off caused by *Pythium* or *Phytophthora*
• low fertility	LEAVES/FLOWERS
• high salts and/or improper pH	**Chlorosis (yellowing)**
Poor rooting of cuttings	• poor root growth (check for root rot)
• *Pythium* rot	• poorly drained medium
• low rooting temperature	• low pH; nutrient deficiency
• desiccation of leaves	**Leaf reddening**
Wilting, dieback	• poor root growth (check for root rot)
• *Xanthomonas* blight	• low nutrition levels
• root rot caused *by Fusarium, Pythium, Phytophthora, Rhizoctonia* or *Thielaviopsis*	**Raised corky spots** • oedema caused by a saturated media & high RH
• *Fusarium, Ralstonia, Verticillium*	**Leaf spots**
• poor root growth (check for root rot)	• *Botrytis, Alternaria, Septoria, Xanthomonas, Pseudomonas*
• viruses (tomato spotted wilt or impatiens necrotic spot)	• tomato spotted wilt virus or impatiens necrotic spot virus
• poor water management	• miscellaneous fungi and protists
	White, powdery growth
	• powdery mildew (don't confuse with spray residue)
	Corky pustules that are not the same colour as the leaf
	• rust (can be red, brown, yellow, white or black)
	Small spots on petals
	• *Botrytis*, miscellaneous fungal blights

Prevention is the best way to avoid diseases. (Refer to the section on sanitation in Chapter 1.) Use disease-free propagation material where possible, but remember that material advertised as ‘disease-free’ is only free of specific pathogens for which it has been tested or indexed. Keep new plant material isolated from established plants until you can examine them for the presence of diseases and insects.

Disease treatment begins with an accurate diagnosis. The disease must be properly identified so that the best control measure can be used (see Table 5.1). If you are unsure of the cause of a plant disorder, you may wish to submit a sample to the BC Ministry of Agriculture Plant Health Laboratory: 1767 Angus Campbell Road, Abbotsford, BC, V3G 2M3.

Fungicide Resistance

Fungi and protists express genetic variability and, in every pathogen population, there may be some individuals that are not affected by a fungicide. Fungi that produce large numbers of spores and have multiple generations are more likely to develop resistant populations. Most fungicide resistance develops by selection pressure on the population. Susceptible fungi and protists are killed when a fungicide is applied at the correct rate. This leaves less competition for food for the resistant strains that will then flourish. If the same fungicide is applied again, there will be no control.

Fungicides work by affecting a specific biochemical process (site specific) or several biochemical processes (multi-site) of the organism. It takes longer for resistance to develop with the latter group. It is recommended to rotate fungicides, where possible, to avoid the selection of resistant microorganisms. Rotate fungicides from different resistance management groups (i.e. chemical group) as each group has a different mode of action. Always use the recommended label rate.

The discussion on diseases is grouped into the following main areas:

- Seed and Seedling Decay;
- Bulb and Corm Diseases;
- Root and Crown Diseases;
- Leaf Spot, Flower Spot and Blight Diseases; and
- Vascular/Foliar Wilt Diseases.

Information on the pesticides registered to manage a particular disease is presented in the document *Pesticides Registered for Ornamental Crops*. When a pesticide is required to control a pest, the grower should select a product based on efficacy, and safety for the applicator and environment. Please note that all efforts were made to ensure the pesticide tables are accurate, however, always refer to the product label for full use instructions.

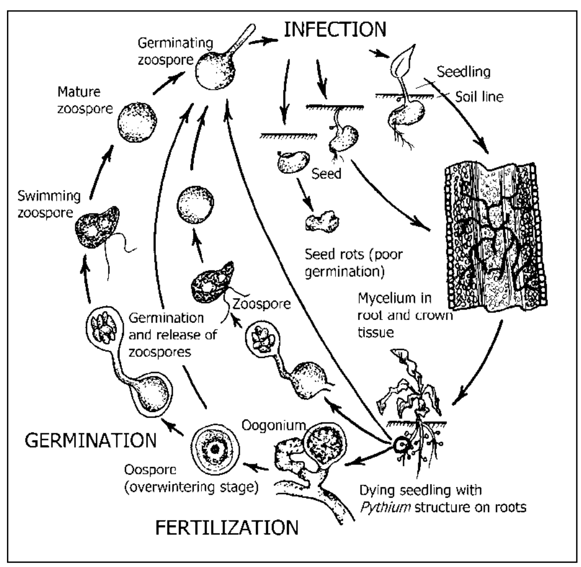
Seed and Seedling Decay

Damping-Off

Damping-off occurs when seeds and seedlings are infected by soil-inhabiting fungi and protists. In pre-emergence damping-off, the seed is killed before it germinates or the seedling emerges from the soil. This may be misdiagnosed as ‘poor seed’. Post-emergence damping-off occurs when emerged seedlings are attacked near the soil line or at the roots. The seedling wilts, the stem collapses and the seedling dies. Infection near the soil line often results in a spindly stem known as ‘wire stem’ that cannot support the top of the plant, causing it to topple.

Rhizoctonia and *Pythium* are the most common causes of damping-off, although *Phytophthora*, *Fusarium* and *Sclerotinia* are occasionally responsible. *Rhizoctonia* causes pre- and post-emergence damping-off and wire stem. *Pythium* generally infects seeds and the tips of rootlets.

Figure 5.1: Disease Cycle of Damping-Off and Seed Decay Caused by *Pythium* spp.



When tender young tissue is infected, the plant usually dies from damping-off. Older plants may become stunted due to infection of the fine roots, or they may develop small stem lesions that could cause girdling.

Prevention

- Identify the cause of damping-off.
- Always maintain a high level of hygiene in your greenhouse by removing crop debris and sanitizing the facility.
- Use pasteurized media (see *Soil Pasteurization* in Chapter 1).
- Prevent contamination of growing media.
- Use clean tools, equipment, pots and flats.
- Use a porous, well-drained, seedling mix.
- Maintain adequate heat for germination.
- Do not sow seeds too densely or too deeply (avoid overcrowding).
- Buy fungicide-treated seeds.
- Avoid overhead watering if possible.
- Ensure pH and soluble salt levels are suitable to promote seedling growth.
- Manage shore flies and fungus gnats.

Bulb and Corm Diseases

Fusarium Diseases

Fusarium diseases affect a wide range of bulb crops. *Fusarium* spores are spread by water in soil or in storage. Plants infected with *Fusarium* typically die down prematurely and frequently have a chocolate brown decay on the bulb. Under damp conditions, a covering of white to pink mycelium may be evident.

The most important disease in this group is basal rot of narcissus. Others include sour rot of tulip, gladiolus yellows, and *Fusarium* rots of lily, iris and freesia.

Prevention

- Harvest promptly in dry weather, if possible, and take care not to damage the bulbs.
- Protect harvested bulbs from the heat of the sun.
- Discard infected bulbs but do not leave them on the field.
- Provide cool, well-ventilated storage.
- Follow as long a rotation as is practical for your operation.

Gladiolus Dry Rot

The most serious disease of gladiolus is dry rot, which is caused by the fungus *Stromatinia.* The fungus enters the leaves near the soil line and causes them to turn yellow and then brown. Examination of the leaf and stem bases will reveal tiny black sclerotia. This differentiates the disease from *Fusarium* yellows in which most of the damage is done to the corms and there are no sclerotia on the leaves. The fungus overwinters in the soil and in dark surface lesions on the corms.

Prevention

- Carefully examine corms for signs of disease and discard any that are mummified or that have superficial lesions.
- Avoid 'old' gladiolus soil.
- Rogue out and destroy yellowed or stunted plants.

Gladiolus Scab

This bacterial disease, which is caused by a species of *Pseudomonas*, is serious only on gladiolus but can also infect crocus and freesia. Slightly infected corms produce normal flowers but exhibit sunken, shiny black lesions that are most numerous on the base of the corm. Severely affected plants develop a neck rot that may cause the top to collapse.

Prevention

- Avoid planting in poorly drained soils.
- Examine corms carefully prior to planting and discard any with scab lesions.
- Follow a three year rotation.
- Carefully rogue out infected plants as they are seen.

Hyacinth Yellow Disease

Yellow disease is caused by the bacterium, *Xanthomonas*. It is very destructive to hyacinth bulbs. Symptoms progress rapidly from a few small yellow spots within the bulb to complete decay accompanied by bacterial slime. Spread to other plants is by wind and rain splash. Common bacterial soft rot caused by *Erwinia* also infects hyacinths but in this case most of the damage is below the neck.

Prevention

- In bulbs containing some yellow disease, storage at 30-37ºC will encourage the breakdown of slightly infected bulbs so that they can be discarded prior to planting. The storage room must be well ventilated because the warm, moist storage conditions encourage bacterial soft rot.
- Avoid overcrowding, over fertilizing and overwatering to help prevent both bacterial diseases.
- At the first sign of disease, carefully remove infected plants and surrounding soil. This should be done in dry weather to reduce the chances of infecting nearby plants.
- Tools used during propagation should be disinfected to avoid the transfer of bacteria from diseased to healthy bulbs.

Penicillium Diseases

Penicillium is a pathogen of bulbs, causing most damage on bulbous iris and tulips in storage and in forcing. The infection may originate on the side of the bulb and then progress to the basal plate. Infection of the basal plate interferes with rooting and the bulb becomes soft and collapses. The presence of blue or green masses of spores identifies the pathogen as a *Penicillium.* On gladiolus corms, *Penicillium* causes sunken reddish-brown lesions that may contain numerous spores.

Prevention

- Dig bulbs when mature and avoid bruising.
- Protect harvested bulbs from sunburn and desiccation.
- Discard infected bulbs.
- Store bulbs between 70 to 85% relative humidity.
- Disinfect trays with 1% Formalin ☠ (formaldehyde) solution.

Rhizoctonia and White Mould Diseases

Sclerotia-forming fungi in the genera *Rhizoctonia* and *Sclerotinia* attack a number of bulb crops. The most important of these diseases are grey bulb rot of tulip and crown rot of iris and tulip. The fungi survive as sclerotia in the soil and on infected bulbs. Infected plants fail to emerge. When dug up, they are often totally decayed with a mass of soil and sclerotia clinging to them.

Prevention

- Inspect bulbs carefully at harvest and again prior to planting and discard any with decay or adherent sclerotia.
- Avoid planting in fields that are known to be infested.
- Provide a 3 to 5-year rotation between tulip or iris crops.

Root and Crown Diseases

Most root rots are caused by the protists, *Phytophthora* and *Pythium*, and fungi such as *Fusarium*, *Rhizoctonia* and *Thielaviopsis*. Plants of all ages can be infected, and the degree of infection will depend on environmental conditions and plant susceptibility.

Root and crown organisms are soil-borne. The presence of root exudates stimulates *Pythium* and *Phytophthora* spores to move toward and infect the roots. Infected plants have discoloured roots that are reduced in number and lack the healthy rootlets that absorb water and nutrients from the soil.

Environmental conditions play an important role in root diseases. Roots can be injured by factors that stress plants, such as over or under watering, soil pH, temperature extremes, or high salts. Weak pathogens that might not cause disease on their own can invade the injured tissue and cause further damage. Insects, such as fungus gnat larvae, can spread fungi and protists. Their feeding damage can provide an entry site for infection. Maintaining conditions that favour plant growth and promote good overall plant health will reduce disease severity.

Irrigation water from storage ponds collected from run-off water may contain root rot pathogens, whereas water from municipal treatment systems, or deep wells is normally pathogen-free. Most natural soils contain a diverse population of microorganisms, including those that cause root rot and beneficial microbes.

The components of artificial growing media (e.g. perlite, vermiculite, and rockwool) start off sterile and slowly build up low populations of microorganisms during the crop cycle. If a pathogenic organism is accidentally introduced into a sterile media, there are few or no antagonistic fungi or bacteria present to suppress it. This gives the pathogen the opportunity to spread. Naturally occurring media components, for example peat moss, may contain pathogenic organisms (e.g. *Pythium* or *Thielaviopsis*) and beneficial organisms.

General Root Rot Prevention

- Use pasteurized media (see *Soil Pasteurization* in Chapter 1) and keep it clean.
- Use porous, well-drained media.
- Don't over-water.
- Maintain optimum root temperatures.
- Maintain proper soil pH for the crop.
- Don't propagate from diseased plant material.
- Handle plants carefully and use good sanitation during transplanting.
- Control fungus gnats and shore flies (see Chapter 7, *Insects and Mites*).
- Clean tools, hoses, walkways, benches, and tables between crops (see Chapter 1, *Sanitation*).
- Avoid anything that may stress the crop, such as sudden swings in EC, pH or temperature.

Crown Gall (*Agrobacterium tumefaciens*)

Crown gall disease is caused by a soil-borne bacterium called *Agrobacterium tumefaciens*. Over 600 plant species in more than 90 families can be infected. Common hosts include aster, chrysanthemum, *Cydonia*, daisy, *Malus*, marigold, *Prunus, Pyrus*, roses and willows.

Galls may develop on the crown, roots or, in some cases, on the aerial shoots and branches of infected plants. Galls are usually soft, spongy and white at first, but later turn hard and brown. They range in size from a few millimeters to several centimeters in diameter. Infected plants often first show symptoms of nutrient deficiency, such as yellowing or discolouration of leaves, followed by a general decline and stunting. A large gall at the crown may be more damaging than several smaller galls on roots or stems, since it interferes with the main vascular system of the plant.

Disease Cycle: The bacterium can survive for at least 2 years in soil. It spreads on diseased nursery stock, in irrigation or ground water, and on cultivation and pruning equipment. The bacterium infects roots and crowns, often entering through wounds caused by pruning tools, insects, freezing, or pathogenic nematodes. Rain splash can spread bacteria from soil to stems and leaves.

Bacterial DNA enters the genome of the plant cells and stimulates the cells to divide rapidly, producing a tumour-like mass of tissue in which bacteria multiply. As old galls break down, the bacteria are released into soil and water.

Diagnosing crown gall is difficult because some susceptible plants also produce physiological plant growths that resemble galls. If in doubt as to the cause of galling, it is best to obtain a laboratory analysis to confirm the cause. However, it is often impossible to recover *Agrobacterium tumefaciens* in laboratory culture from older galls. There are also saprophytic strains of these bacteria in soil that do not cause disease. Thus, even a laboratory diagnosis may not be definitive.

If a definite diagnosis is not possible, the grower must decide whether or not to remove the plants, keeping in mind:

- the potential market or outcome for the plants,
- whether there was a previous crown gall problem in that soil,
- large physiological galls can also be damaging to plants,
- the risk of disease spread to other nearby susceptible plants through ground water, soil particles or plant maintenance activities, and
- galls that appear only on the branches, main trunk or at the graft union, but not on roots, are likely caused by a physiological factor.

Management and Control

- Purchase new stock only from a reputable supplier. Plants grown in soil infested with crown gall may appear clean but can carry latent infections that will produce galls.
- Inspect new stock for crown gall before planting and do not plant any with gall symptoms.
- Avoid injuring the roots and bark in the crown area when planting or cultivating because this creates potential entry-sites for bacteria.
- If only a few plants are affected, remove and destroy them to prevent spread. Remove all roots and soil from around infected plants and take to a landfill. Do not compost infected plant debris or soil.
- If only a few branches are affected, prune off galls. Disinfect pruners between cuts.
- Do not take cuttings or propagate from diseased plants.
- Do not re-plant susceptible species into previously infected soil for at least 2 years.

- Rotate with grasses or small grains. Grasses do not develop crown gall disease, although they may harbour the bacterium.
- Soil solarization has been successful in some areas on light, sandy soils, but it is doubtful whether temperatures would reach high enough levels in most BC soils to kill the bacterium.

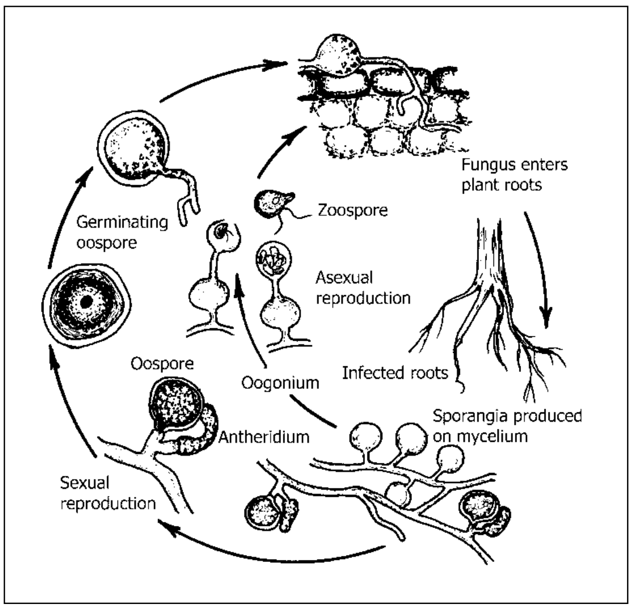
Pythium and Phytophthora Root Rot

Infected roots are often soft, mushy and various shades of brown. The outer covering of roots (the cortex) infected with *Pythium* or *Phytophthora* is usually rotted and slides off easily, leaving the string-like vascular bundles behind. Above-ground symptoms include stunting, wilting and yellowing as a result of nutrient and water deficiencies occurring from root loss. Most ornamental crops are susceptible to at least one of these protists. High soil moisture favours *Pythium* and *Phytophthora.*

Prevention

See *General Root Rot Prevention* at the beginning of this section.

Figure 5.2: Pythium and Phytophthora Life Cycle



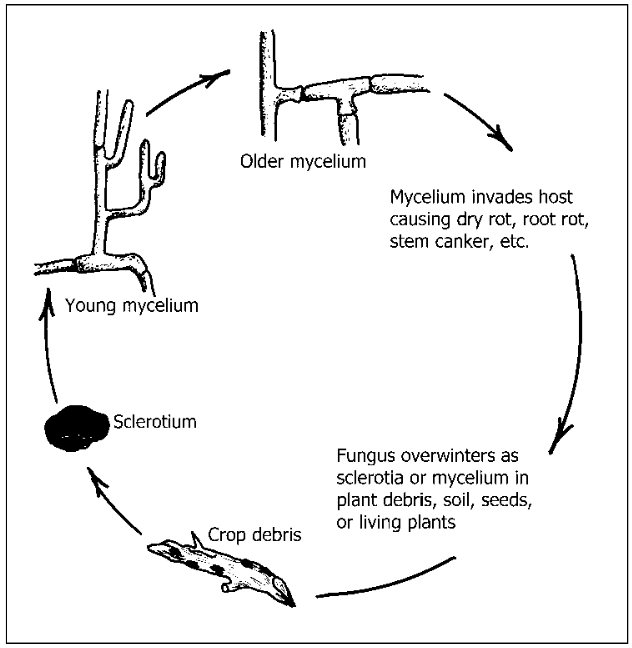
Rhizoctonia Root Rot

Infected roots are often reddish-brown, with a dry rot. Cool, moderately wet conditions encourage *Rhizoctonia.* This disease can cause infections of the stem as well as the roots. Above ground symptoms include stunting, yellowing and wire stem. Plants with wire stem have a severely constricted stem, to a width of 1 to 3 mm, usually at the crown.

Prevention

See *General Root Rot Prevention* at the beginning of this section.

Figure 5.3: *Rhizoctonia* Life Cycle



Sclerotinia (White Mould)

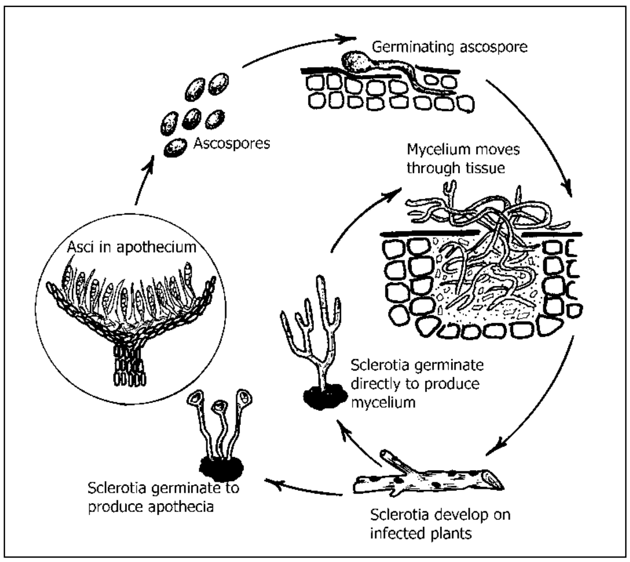
This fungal disease can attack a wide range of crops. It is soilborne and is more commonly a problem in field grown crops, but can also be found in greenhouses. It causes crown and stem rot. The fungus enters the crown at the soil line or through other plant parts such as leaves touching the soil. Infected plants turn yellow, wilt and fall over. It also causes pre-emergent and post-emergent damping-off. Stem rot occurs when spores land on blossoms or leaf axils and grow into the stem tissues.

Sclerotinia is often characterized by masses of white, cottony mycelial growth arising from infected areas of stems and crowns. Dark, irregular-shaped sclerotia, which are similar in appearance to mouse droppings, form inside plant tissues or in the cottony growths of the fungus. These bodies are able to persist in the soil for many years. The fungus will produce spores when conditions become favourable, usually the following spring in outdoor situations. Look for white, fluffy mycelium and grey or black sclerotia about the size of a fat grain of rice lodged in the rotting tissues or in the surrounding mycelium.

Prevention

- Rotate crops so susceptible ones are not grown every year in the same location. Choose your growing site to avoid growing next-door to fields which had a disease infestation, as the spores are spread by wind.
- Don't plant in fields following a susceptible crop such as lettuce, beans or carrots.
- Clear debris out of the field before sclerotia are formed, if possible.
- Space crops to allow air movement, avoiding shady or "dead-air" pockets.
- Avoid over-head irrigation which provides favourable conditions for infections.

Figure 5.4: *Sclerotinia* Life Cycle



Thielaviopsis Root Rot

Thielaviopsis (also referred to as *Chalara*) causes black root rot on cyclamen, fuchsias, geraniums, impatiens, kalanchoes, pansies, petunias, poinsettias, primulas, and other crops. Infected roots may have black lesions covering all or part of the root. This can be observed after the growing mix has been washed off. Above ground plant parts are stunted and the leaves are pale or may have symptoms of nutrient deficiency.

Wet soils and neutral to alkaline pH levels favour black root rot. Plant stress arising from high soluble salts or excessive fungicide applications can promote disease development. Prevention is the best method of control.

Prevention

Thielaviopsis is suppressed at low pH levels. Adjust the pH of the potting mix to 5.5 or below if the crop will tolerate it. Good sanitation is important to prevent the introduction of the fungus. Careful disposal of infected plant material and infested soil is critical because these items may contain fungus propagules. Shore fly adults can spread the disease.

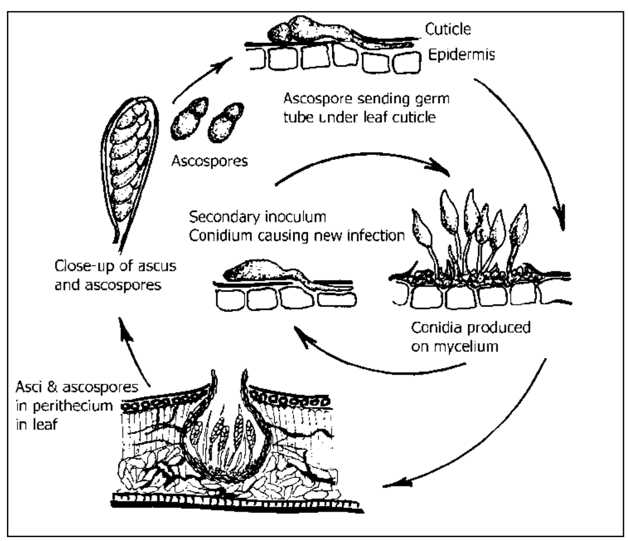
See *General Root Rot Prevention* at the beginning of this section.

Leaf Spot, Flower Spot and Blight Diseases

Leaf and flower spots can be caused by fungi, protists, bacteria, viruses, viroids, phytoplasms or physiological disorders. Spots can vary in size from a pinpoint to lesions encompassing the entire leaf (a blight). Most spots are tan to dark brown, and may be circular, angular or irregular in shape.

The more common fungi causing leaf spots are *Alternaria, Ascochyta, Botrytis, Cercospora, Gloeosporium* (*Colletotrichum*), *Helminthosporium, Phomopsis, Phyllosticta, Ramularia* and *Septoria*. See the discussion under *Botrytis* for further information on this disease. Bacteria such as *Pseudomonas* and *Xanthomonas* may also cause leaf spots. *Xanthomonas* is covered in the *Vascular/Foliar Wilt* section at the end of this chapter. The spots caused by bacteria are often sunken, water-soaked and angular in outline. Tomato spotted wilt virus and impatiens necrotic spot virus can cause chlorotic or brown leaf spots.

Figure 5.5: Leaf Spot Disease Life Cycle



It is difficult to determine the cause of leaf spots by symptoms alone. Proper identification of the cause is necessary to select the best control measures. The section below deals with spots caused by the most common pathogens only. Note that a fungicide will not cure an established leaf infection; treatment is aimed at protecting plants from new fungal infections.

Prevention

- Use disease-free propagating material.
- Water carefully and in the morning hours. Keep the foliage and flowers as dry as possible.
- Remove infected plant parts from the greenhouse and bury or dispose of off-site.
- Provide good air circulation and adjust environmental controls to avoid condensation forming on plants.

Botrytis (Grey Mould)

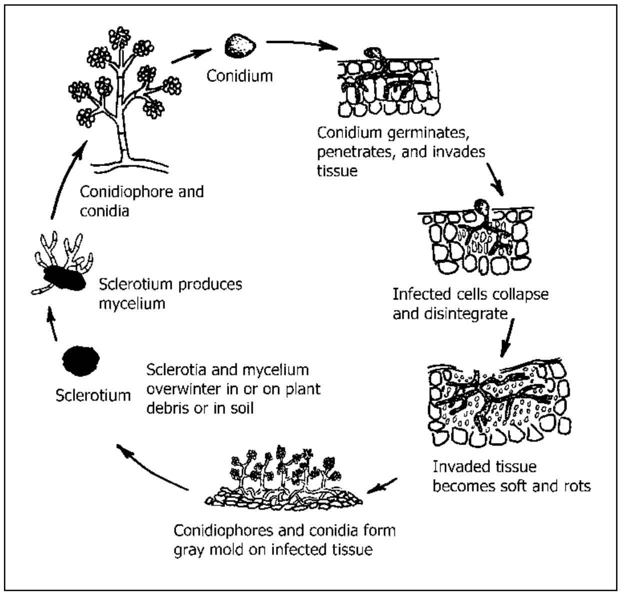
Botrytis infects immature, senescent (dying) and wounded tissues of many crops. It can also infect healthy tissue if conditions are well-suited to the fungus, or if a piece of infected plant material comes in contact with healthy leaves or stems.

Botrytis can grow in a wide range of temperatures; anywhere from 0 to 25°C. Optimum conditions for growth are 18 to 23°C and high humidity (greater than 85%) or free moisture. Free moisture can occur whenever plant tissue temperatures are lower than the air, or the air cools below the dewpoint. These conditions often occur at: 1) night when cooling air reaches the dewpoint, or 2) in early morning when the air heats more quickly than plant tissues resulting in condensation on colder plant surfaces.

In the greenhouse, good air circulation and accurate environmental control are essential to avoid conditions favourable to the growth and reproduction of *Botrytis*.

Infected tissue first appears as tan or brown water-soaked areas that may become grey upon drying out. Infected flower petals usually show small water-soaked areas which enlarge rapidly and then turn brown or black. The characteristic signs of *Botrytis* are the fuzzy grey spore masses that develop on infected tissue. Since *Botrytis* will only sporulate on dying tissues, routine removal of plant debris will reduce the incidence of infection.

Figure 5.6: *Botrytis* Life Cycle



Botrytis is almost always present in greenhouses. New infections occur when conditions are optimum for spore spread and germination. Spores are spread by air currents and splashing water. *Botrytis* overwinters in soil and plant debris.

Bulb Crops: Most bulb crops are susceptible to *Botrytis*. The most important disease is tulip fire. The first sign of this disease is the shoots fail to open, and they may be covered with black sclerotia and grey spores. Under wet conditions these 'primaries' release spores that cause numerous leaf and flower spots on other nearby tulips. Other *Botrytis* diseases that may be serious from time to time include fire of hyacinth, core rot of gladiolus, fire and smoulder of narcissus, and blight of lily.

Prevention

- In the greenhouse, keep the relative humidity below 85% by heating or venting of moist air.
- Don't overcrowd plants. Ensure adequate air circulation around the plants.
- Minimize dripping of water onto plants from roof condensation or overhead sprinklers.
- Plan your irrigation to minimize the time that plants are wet.
- If possible, water in the mornings.
- Remove dead or diseased plant material.
- Don't leave large stubs (heels) or joints on stock plants after taking cuttings.
- Remove senescent flowers and leaves before they drop onto other plant parts.

- Clean and examine bulbs and corms before planting and discard any with lesions or sclerotia.

It is best to correct environmental and management problems before applying a pesticide to manage a plant disease.

Bulb Viruses

Bulb stocks are vulnerable to a buildup of viruses over the years since they are vegetatively propagated. At least 15 different viruses have been identified in narcissus alone. Some of these viruses are specific for narcissus and others have a wider host range.

Most bulb viruses are transmitted by the feeding of aphids or nematodes that had previously acquired the virus from other infected plants.

Symptoms of virus infection vary greatly depending on the crop and the number and combination of viruses present. They range from stunting of plants to leaf mosaics and flower distortions.

The best known is tulip breaking virus. It causes flower streaking in otherwise solid coloured flowers. Infected bulbs were in demand as novelties in Europe during the 1600s. It wasn't until the 1920s that the cause was identified as an aphid-transmitted virus.

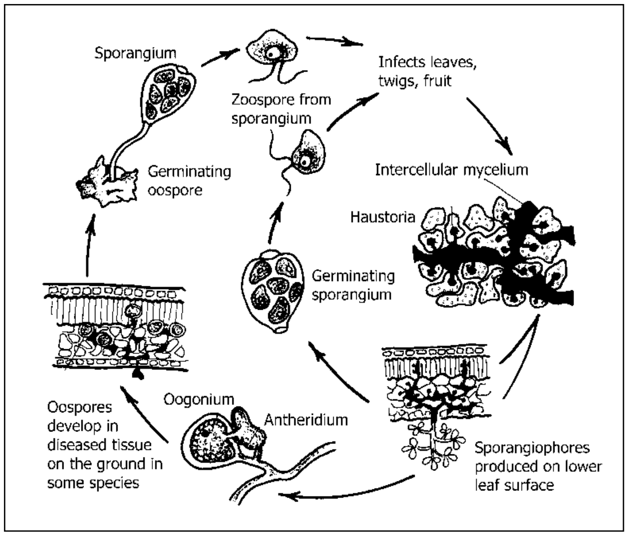
Prevention

- Plant disease-free bulbs and corms from a recognized meristem culture program if available.
- Grow the virus-free stocks in isolation away from old, infected crops.
- Control aphids.
- Rogue off-types early and often.
- Avoid fields with known populations of the main nematode vectors within the genera *Longidorus*, *Trichodorus* and *Xiphinema*.

Downy Mildew

Roses, snapdragons and violas are commonly infected by downy mildew. Infection occurs under conditions that cause leaf wetness. Leaf wetness is more common during periods of cool temperatures and high humidity. Downy mildew spores enter plants through leaves and stem buds, and grow systemically in the stem, crown and even the roots. It may produce reddish-purple splotches on the upper leaf surface. When humidity levels are high, a mauve-grey, felt-like mat appears, usually on the lower leaf surface. Many spores are present in the mat and can be spread between plants via air movement and water splash. The pathogen carries over to new crops on dead plant material and may also persist in the soil.

Figure 5.7: Downy Mildew Life Cycle



Symptoms on rose: sudden defoliation may be the first symptom that is noticed. Foliar symptoms may resemble pesticide phytotoxicity. Careful examination of leaves should reveal pale, reddish-coloured blotches on the upper surfaces of leaves.

Symptoms on snapdragons: greyish downy growth may be present on lower surfaces of leaves, but the first symptom could be overall stunting due to systemic infection, distortion of new leaves and downward leaf curling.

Prevention

- Monitor for infections.
- Keep relative humidity below 85% and prevent condensation on the crop and in the greenhouse.
- Clean up all crop debris at the end of the season and remove from the greenhouse site.
- Rotate with less susceptible crops, if possible.
- Control weeds in and around the greenhouse because downy mildew may survive on them.
- Rouge out affected plants and put them in a bag prior to moving them through the greenhouse.
- Space plants to allow for air circulation.

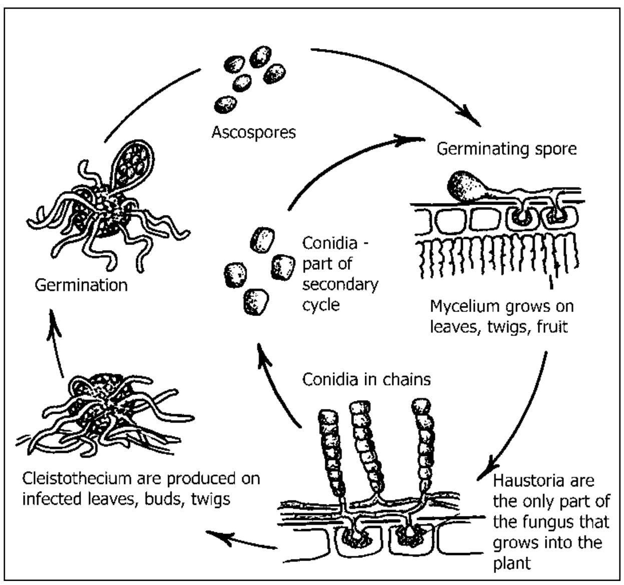
Powdery Mildew

Powdery mildew is sometimes confused with spray residues. It causes whitish-grey patches of fungal growth on the upper leaf surface. Lower leaf surfaces, flowers and stems can also be infected.

Many ornamental crops are infected by various powdery mildew fungi. Each of the many species of powdery mildew is specific to one or a limited number of host plants. They cause serious economic losses through loss of plant vigour, a reduction in the number of blooms and reduced aesthetic appeal.

Powdery mildews can occur either in a warm, dry environment, or in a cool to warm, humid environment. Spores will be released, germinate and cause infection without a film of water on the plant surface. A fairly high relative humidity, approximately 95% and above, is required for the initial infection. Once the plant is infected, the fungus can continue to grow regardless of the relative humidity. The fungus grows on the leaf surface but obtains nutrients from the plant by penetrating into leaf cells with specialized structures called haustoria. Spores of the powdery mildew fungus are spread by air movement. Powdery mildew fungi overwinter by producing sexual spores (ascospores) in enclosed fruiting bodies.

Figure 5.8: Powdery Mildew Life Cycle



Prevention

- Choose resistant varieties when available.
- Eliminate weeds in and around the outside perimeter of the greenhouse. Some may be sources for powdery mildew.
- Avoid high humidity and large swings in humidity.
- Maintain optimum plant growing temperatures.
- Space plants to allow for air circulation.

Rusts

Rust diseases appear initially as small, yellow swellings or pustules on lower surfaces of leaves. These become blisters that contain either white, yellow, orange, brown or black spores. The pustules are often on the underside of the leaves, but may also occur on the top surfaces and stems depending on the rust species and the stage in the life cycle. The leaf surface directly above the pustule is frequently yellow or discoloured. Plants may be infected with rust but not show any symptoms.

Spores are spread by splashing water or moving air. They require wet conditions for infection. There are several important rust diseases of greenhouse ornamentals, notably on asters, carnations, chrysanthemums, fuchsias, geraniums and snapdragons.

Geranium rust is no longer regulated and is not considered a quarantinable disease by Canadian Food Inspection Agency. However, growers should inspect all new stock carefully to avoid introducing this disease into their operation.

Prevention

- Inspect new plant materials carefully before bringing them into the greenhouse.
- Avoid wetting foliage and control greenhouse environment to avoid condensation on plants.
- Remove and destroy infected plant parts where possible.

Chrysanthemum white rust, *Puccinia horiana,* is not established in Canada and is a quarantine disease that if detected must be reported to the Canadian Food Inspection Agency. It has been over a decade since a few isolated outbreaks of white rust were eradicated in home gardens and greenhouses in southern BC. Flower growers are at risk to white rust which could be introduced into greenhouses on symptomless but systemically infected chrysanthemum cuttings. Growers receiving suspect imported stock should immediately notify the Canadian Food Inspection Agency.

Symptoms of white rust begin as light coloured spots the size of a pin head to 5 mm in diameter on the leaf surface. The spots become sunken and whitish, and raised pustules form on the under surface below the leaf spot. Under severe conditions the flowers and stems can also become infected. Plants with white rust become stunted, twisted and defoliated. White rust pustules increase to 2 cm in diameter and become a light brown in colour.

The life cycle of white rust is completed on the single host, chrysanthemum, unlike many other rust fungi which require two host plant species. White rust has two spore forms, the overwintering, resistant teliospores and infective basidiospores. The microscopic, infective spore stage is spread by air currents, splashing water and by workers, on clothing, equipment and greenhouse surfaces.

Prevention

- Verify that imported chrysanthemum cuttings originate from *P. horiana*-free production facilities.
- Thoroughly inspect imported cuttings before bringing them into an isolated area of the greenhouse where they can be frequently monitored and handled last.
- Do not wet the foliage and control the greenhouse environment to ensure plant surfaces remain dry.
- Plants should be spaced to reduce crowding.
- Between crops, debris should be cleaned out from the greenhouse, and the benches, floors and equipment washed down with a bleach solution (10%).
- Mother plants for overwintering should be heat treated. This involves placing the crowns (stools) into water heated to between 45 to 51°C for five minutes and then plunging them immediately into a solution of cold water and fungicide. Crowns should be fully dormant before undergoing treatment.

Sudden Oak Death and Ramorum Blight & Dieback

Sudden oak death is caused by the protist, *Phytophthora ramorum*. The disease has attracted considerable interest since 2001, when it was determined to be responsible for the death of tens of thousands of native oaks in California. The disease leads to tree death due to the development of bleeding cankers that girdle the trunk of tanoaks and coast live oaks. Girdling cankers occur on a few hosts, including tanoak, European beech, rhododendron, viburnum, horse-chestnut and oak species. *P. ramorum* does not cause trunk cankers on the majority of hosts. More commonly, it causes non-lethal brown leaf spots and/or branch dieback, and this disease is referred to as ramorum blight & dieback. Therefore, *P. ramorum* is responsible for two distinctly different diseases of woody plants.

P. ramorum is primarily a pest of nursery plants. Although it affects few floriculture crops, it has disrupted the importation of florist azaleas and Easter lily bulbs (associated with soil) from regulated areas in California and Oregon. The disease primarily infects woody trees and shrubs, such as camellia, kalmia, oak, *Pieris*, rhododendron, and viburnum.

P. ramorum is a cool-temperate organism with an optimum temperature for growth of around 20°C, although laboratory studies have shown that it will grow at 2 to 30°C. The pathogen is spread locally by the release of spores from leaf and shoot tip lesions by rain splash or wind-driven rain. Spores can also be spread in irrigation or ground water, and in soil.

The Canadian Food Inspection Agency has imposed strict regulatory controls to prevent the entry of this pathogen into Canada. The importation of propagative (seeds) and non-propagative material (e.g. branches, wreaths, greenery, cuttings and prunings) of host plants and soil, which is either alone or in association with a plant, is regulated. Neither Canada nor the US regulates the movement of cut flowers.

The current list of plants regulated for *P. ramorum* includes over 120 species of plants from 80 genera. Host plants and plants associated with soil can only be imported from regulated areas of the Continental US that have been grown in a pest-free place of production. Canada regulates all countries of the European Union, Norway, Switzerland, 15 counties in California and Curry County in Oregon.

Recommendations

- Verify that all imported host material originates from *P. ramorum*-free sites or is produced under an approved pest-free place of production.
- Check with the Canadian Food Inspection Agency for current disease quarantine regulations.

Tomato Spotted Wilt Virus and Impatiens Necrotic Spot Virus

Tomato spotted wilt virus (TSWV) and impatiens necrotic spot virus (INSV) can infect over 1,000 plant species, including many ornamentals. They are spread by thrips and infected propagation material, but are not easily spread by crop handling. They are the two most common viruses found in floriculture crops.

Table 5.2: Tomato Spotted Wilt Virus (TSWV) and Impatiens Necrotic Spot Virus (INSV) Crop Symptoms	
Calceolaria	Symptoms of TSWV and INSV resemble a fungal wilt disease. Central areas or one-sided wilt patterns develop on leaves with a greasy-grey colour. Plants eventually collapse without recovery.
Chrysanthemum	Susceptible cultivars such as 'Polaris' develop necrotic stem lesions and leaves become necrotic and collapse. Flowering plants have a blighted appearance and appear to be infected with Fusarium wilt.
Cineraria	Young plants may develop symptoms similar to those on gloxinia while older plants develop ring spots and line patterns on leaves. Dark purple to brown sunken lesions develop on petioles, frequently at the leaf junction. The petiole may be girdled or the lesions may move into the stem.
Cyclamen	Initial symptoms include necrotic leaf spots and vein necrosis. Occasionally, lesions radiate along several veins from the base of the leaf, which produces an oak-leaf pattern. Chlorotic leaf lesions develop into necrotic spots or concentric rings. Leaf collapse can result from petiole necrosis or coalescence of numerous ring spots. Necrosis in the vascular bundles of the corm has been observed in some plants. Symptom development is optimum at 13^{o}C. Infected plants tend to be symptomless at 22^{o}C. Symptoms develop approximately 3 to 4 months after infection when plants are grown at 13^{o}C.
Exacum	TSWV and INSV cause straw-coloured necrotic leaf lesions 7 to 14 mm in diameter. Leaves may become completely necrotic and collapse. Stem lesions become slightly sunken and light to dark grey or straw coloured. On larger plants, one branch or the entire plant may collapse and die.
Gloxinia	Infected plants that are less than six weeks old develop symptoms resembling Phytophthora root rot. The base and central part of lower leaves darken and plants collapse. Older plants develop spots and line patterns on upper and lower leaf surfaces which begin as chlorotic patterns that become necrotic. Necrotic areas may coalesce and plants develop a ragged appearance. Flowers may become distorted.
Marigold	Infected plants exhibit leaf strapping symptoms, particularly on the youngest leaves. Marigolds planted outside the greenhouse should be examined for symptoms.
New Guinea Impatiens	TSWV and INSV cause local leaf lesions that include ring spots and papery necrotic areas. The virus becomes systemic and causes faint purplish ring patterns or a mottle on newer leaves. Growing points may abort. Susceptible cultivars may die, or more often, some branches will die back while others survive. 'Mojave' produces some leaves with necrotic ring and spotting symptoms, but many leaves will be symptomless while cultivars in the 'Sunshine Series' are often killed.
Pepper	Fruit ripens unevenly if infected after fruit set. If infected before fruit set, fruit develops unevenly and becomes misshapen. Dark brown soft spots may develop on fruit and ring patterns may occur. Look for stem lesions, petiole, and peduncle necrosis, loss of leaders, branch dieback, and tan, dry lesions on leaves.
Tomato	The most common symptoms are rapid browning of the young leaves followed by cessation of growth. The leaves later become distorted with necrotic spotting and fruit formed after infection may develop blotches or mottling. None of the cultivars currently being grown exhibit resistance.

The two strains of tomato spotted wilt virus (impatiens and lettuce) are now recognized as two separate diseases. The impatiens strain has been renamed ‘impatiens necrotic spot virus’ (INSV) while the lettuce strain has retained the original name ‘tomato spotted wilt virus’ (TSWV). INSV infects floriculture crops more frequently than TSWV. They both belong to the tospovirus group.

Both viruses cause stunting, leaf distortion, mosaic mottling of leaves, leaf vein clearing, necrotic areas on leaves, wavy lines on foliage, concentric rings on foliage or flowers, and stem necrosis. The necrotic leaf lesions can easily be mistaken for pesticide toxicity. The symptoms vary depending on host age, host species, cultivar, the level of nutrition, temperature, and the virus strain. See Table 5.2 for further information on symptom expression on specific crops.

Method of Spread

Three species of thrips that are present in Canada can spread TSWV and INSV. They are *Frankliniella occidentalis* (Western flower thrips), *F. fusca* and *Thrips tabaci*. The Western flower thrips is the most dangerous vector due to its ability to develop insecticide resistance faster than other thrips species.

Thrips must feed on infected tissue while they are larvae to acquire the virus. They introduce the virus when they pierce the plant surface to feed. Once a thrips picks up the virus it remains infected for the rest of its life. During this period many plants can be infected. There is a direct relationship between the number of thrips and incidence of the virus. Thrips must feed on infected plants for at least 15 minutes to acquire the virus. They have a latent period of at least four days after picking up the virus during which they cannot transmit it.

TSWV and INSV are also reportedly transmissible through the seed of cineraria.

Control Strategies for TSWV and INSV

An effective insecticide program is an essential component in the control of TSWV and INSV, but sole reliance on insecticides to control Western flower thrips is a short-term solution due to the development of resistance. An integrated approach must be used.

- Start with clean stock. Plants infected with TSWV and INSV usually have a latent period during which they show no symptoms. Also, some hosts may be infected but remain symptomless. These are a threat to more susceptible hosts that may be present in the greenhouse. When purchasing cuttings or seedlings ensure there are no thrips on the plants, which may have already infected them or may be a source of infection for other crops already in the greenhouse. Look for signs of thrips feeding or other damage.
- Separate plants grown from seed and cuttings. Vegetatively propagated material can be a source, whereas seeds usually are not. Do not hang vegetatively propagated baskets overtop of bedding plant seedlings. Young seedlings are highly susceptible.
- Monitor Western flower thrips populations with yellow or blue sticky traps. Place cards at the crop level to monitor any population changes and near doorways and vents to detect movement of thrips into the greenhouse.
- Screen vents and cover open doorways with heavy plastic strips to reduce movement into the greenhouse.
- Ensure that greenhouses are weed-free and that a weed-free border 3 to 6 metres wide is maintained around the greenhouse. Many weeds are hosts for the Western flower thrips and TSWV/INSV and act as virus reservoirs or banks. The ground next to doors and vents should have a weed-free border at least 6 metres wide. Avoid planting susceptible bedding plants around the greenhouse.
- Place potted petunia indicator plants among your crop along with non-sticky blue cards to detect thrips. Small, papery tan leaf spots will appear on petunias within 3 to 5 days after infection. Several petunia cultivars, such as ‘Red Cloud’, ‘Summer Madness’ and ‘Super Magic Coral’, are good indicator plants. Remove any flowers to force the thrips to feed on the leaves.
- Destroy all infected plants. If the virus has been confirmed in one or two plants of a certain batch or cultivar you must presume all these plants are potentially infected. Spray all diseased plants with an insecticide to kill thrips on the plants. This prevents virus-carrying thrips from flying to healthy crops when their host is disturbed. Infected plants should be placed in plastic bags at the bench

or bed site to prevent thrips from spreading through the greenhouse as they are removed from the area.

- Bio-control agents are generally not effective at preventing virus spread because they will not eradicate the population of thrips and, even a low number of virus-carrying thrips can cause economic damage.
- Planting beds should be steam-treated or fumigated to kill thrips and larvae. Larvae are found in the top few centimetres of soil, so they may be treated with a soil spray. See *Thrips* in Chapter 7 for larval control strategies.
- If the greenhouse is cleared out before a new crop begins, increasing the temperature to 35°C for 5 days or 40°C for 2 to 3 days will help control thrips pupae. The pupal stage will be shortened at these temperatures and emerging adults will starve because there is no food source.
- Educate your staff so that they can identify the symptoms of TSWV and INSV.
- If TSWV and INSV are suspected, submit a sample to a virus testing laboratory.

Vascular/Foliar Wilt Diseases

Wilt occurs when the water flow to affected plant parts is stopped or slowed. Wilt symptoms can develop slowly or suddenly; they may be temporary, as on hot days, or they may be permanent. Wilt can be caused by moisture stress, although this is usually temporary, except where water has been withheld for long periods. Wilt can also be caused by excessively wet soil, which results in an oxygen deficient root zone, followed by natural root decay. Other causes of wilting are high soluble salt levels in the media, root rot organisms and chewing insects.

There are several species of fungi and bacteria that cause wilt diseases. Plants wilt when infected by a wilt organism because the organism plugs or damages the water conducting vessels. Symptoms include the wilting of a leaf, a number of branches of the plant, or of the whole plant. Affected plants may be yellow and stunted, and may have discoloured vascular tissue. The fungi most often involved in wilt diseases are *Fusarium oxysporum, Verticillium dahliae* and *Verticillium albo-atrum*. *Verticillium* fungi infect many types of ornamental plants, while special forms of *Fusarium oxysporum* infect specific host plants. For example, *Fusarium oxysporum* f.sp. *cyclaminis* infects only cyclamen, and *Fusarium oxysporum* f.sp. *dianthi* infects only members of the carnation family.

One of the most common bacterial wilt pathogens in BC is *Xanthomonas campestris*. Various forms (pathovars) of *Xanthomonas campestris* exist which attack specific hosts. For example, *Xanthomonas campestris* pv. *pelargonii* causes bacterial blight of *Pelargonium* species, and *Xanthomonas campestris* pv. *syngonii* causes bacterial blight of *Syngonium*. Wilt diseases may also be caused by three other bacteria, *Erwinia carotovora, Erwinia chrysanthemi* and *Ralstonia solanacearum*. They are usually serious only at temperatures above 27°C.

See the following sections for information on *Ralstonia* and *Xanthomonas* diseases of geraniums.

Fungal wilt pathogens enter plants primarily through the roots. They do not require wounds. Bacteria require wounds or natural openings to enter plants. Symptomless cuttings may be infected with wilt diseases if the mother plant was infected. Both can be spread in propagative material, by water movement through soil, by soil movement, by equipment (especially cutting knives), by contaminated flats and by splashing water. Wilt fungi can survive in the soil for several years, whereas bacterial wilt pathogens generally survive for only one to six months in soil. Both fungi and bacteria have good survival rates in infected plant debris.

High temperature and relative humidity generally favour wilt diseases. Conditions that contribute to plant stress will also increase disease severity.

There are no effective fungicides or bactericides available for the control of wilt diseases. Infected plants usually must be destroyed.

Prevention

- Use disease-free propagating material.
- Use pasteurized growing media (see *Soil Pasteurization* in Chapter 1).
- Where possible, grow varieties that have been selected for resistance to wilt diseases.
- Avoid high salts caused by overfeeding and/or underwatering. Monitor the crop’s EC levels (see *On-site Testing of Planting Media* in Chapter 3).

- Minimize the risk of contaminating crops with soil pathogens by keeping hose ends and pots off the ground.
- Minimize heat stress by shading or ventilating.
- Scout for symptoms; a simplified disease diagnostic key is provided in Table 5.1.
- Avoid water stress events that may damage roots.
- If possible, use nitrate nitrogen rather than ammonium nitrogen.

Ralstonia Bacterial Wilt of Geranium

Ralstonia solanacearum race 3 biovar 2 is a quarantine bacterium in Canada and the US that is not known to occur in either country. It causes severe brown rot of potato and a wilt disease in tomato and geranium. Symptoms on geraniums include water-soaked leaf spots, lower leaf yellowing and wilting. Several isolated outbreaks of geranium wilt were detected in 2003 and 2004 in eastern Canada and the US. These outbreaks were traced to geranium imports from offshore propagators. The detections lead to the suspension of importations of all *Pelargonium* from the source countries.

The pathogen is transmitted through contaminated media, cuttings, irrigation water, cutting knives, and staff. The pathogen is not believed to spread readily from plant-to-plant in water splash, although it can spread in subirrigation systems.

In 2003, the Canadian Food Inspection Agency implemented regulations for *R. solanacearum* race 3 biovar 2 (D-03-09). Importations of host plants from regulated countries must be accompanied by a Phytosanitary Certificate that states they were produced in a facility that was sampled, tested and found free of the pathogen in accordance with Canada's import requirements.

Recommendations

- Verify that all geranium imports are free of *R. solanacearum* race 3 biovar 2 and have a Phytosanitary Certificate with the correct documentation if they are from a country where *Ralstonia* exists.
- Provide a disinfectant foot bath at each doorway to geranium production compartments.
- Do not sub-irrigate geraniums.
- Disinfect hand tools and implements during and after use.
- Destroy weeds in and around the greenhouse, since weeds are hosts of *Ralstonia* (e.g. lamb's-quarters, mustards, nightshade, pigweed and purslane).
- Regularly scout crops for disease symptoms and immediately report *Ralstonia*-like symptoms to the Canadian Food Inspection Agency or the BC Ministry of Agriculture.

Xanthomonas Blight of Geraniums

Bacterial blight, which is caused by *Xanthomonas campestris* pv. *pelargonii*, is the single most important disease of geraniums. This disease becomes systemic in the plant and can quickly kill it. The most common symptom of the disease is wilt, which will occur even though the roots appear healthy. Leaf spot and stem rot may or may not occur. Leaf spots are most likely to be observed on plants in advanced stages of the disease.

Xanthomonas bacterial blight may occur wherever geraniums are grown and is a continual threat to their production. It infects all varieties of zonal (*Pelargonium* X *hortorum*), ivy *(P. peltatum)*, Regal/Martha Washington *(P.* X *domesticum)* and perennial geraniums. Ivy geraniums are especially susceptible. Martha Washingtons and specialty types (e.g. *P. acerfolium, P. 'Torento', P. tomentosum*, and *P. scarboroviae*) have some tolerance to the disease but can be symptomless carriers of the bacterium.

Debris from infected plants is a source of seasonal carry-over of *Xanthomonas.* In addition, it can survive on the leaves or wounded stems of other ornamentals, such as tuberous begonia, chrysanthemum, coleus, fuchsia, impatiens, lantana, verbena and vinca. The surface of pots, benches and tools can also be a source of infection. Research has found that the disease may also survive on weeds. It is uncertain how long the bacterium can survive in soil.

Sources of Infection

- infected cuttings
- carry-over of stock plants
- debris from infected plants

Sources of Spread

- mechanical
- taking cuttings

- workers' hands and clothing
- water splashing during irrigation from diseased tissue or contaminated surfaces
- recirculating irrigation systems and water films
- pesticide spraying
- insects such as whiteflies and fungus gnats

There is no cure for this disease, so the focus must be on prevention of introduction and spread.

Steps to Early Detection of Bacterial Blight

- ✓ *Xanthomonas* spreads quickly and easily, so early detection is of paramount importance. What makes the disease even more devastating is that there can be a considerable time lag between infection and symptom expression. By the time plants begin to show symptoms, thousands of plants may already be infected and have to be destroyed.
- ✓ Do routine weekly checks of the geranium crop, looking out for any browning or yellowing of leaves, and be cautious of any signs of wilting. Suspect plants should be isolated from the growing area and tested. When moving plants through the greenhouse, make sure they don't become a disease vector. Make your staff aware of what symptoms to look for and encourage them to report suspicious plants to you. If a crop is doing poorly even though pH and EC levels are within acceptable parameters, consider sending plants to a lab for testing for *Xanthomonas*.
- ✓ Look for dark brown, sunken leaf spots that are 1.5 - 3 mm in diameter. Note: Not all geranium varieties will show leaf spot symptoms.
- ✓ Look for V-shaped, yellow wedges that form at the leaf margin and taper down to the base of the leaf. The wedge is usually bound by leaf veins on both sides. *Botrytis* can cause similar symptoms, but the infections usually do not taper down to the leaf base and are not confined by leaf veins.
- ✓ Cut the base of the leaf petiole and the stem in half to check for a dark discolouration in the vascular tissue.
- ✓ Wilting caused by *Xanthomonas* can usually be differentiated from root rot caused by *Pythium/Phytophthora* by observation of the roots. *Xanthomonas* affected plants will usually have healthy roots.
- ✓ Symptoms usually do not develop when the temperature is below 21°C. The optimum temperature for disease development is 27 to 29°C. Symptom development is highly dependent on the geranium species or variety, the growing conditions, and environmental conditions. In the cooler months of winter and early spring, affected plants may not show the "classic" symptoms.

Steps to Minimize the Spread of the Bacterium

Strict sanitation combined with the exclusive use of culture virus indexed (CVI) stock from reputable propagators is the only way to minimize losses from bacterial blight.

Start of Season

- ✓ Purchase CVI disease-free plants each year.
- ✓ Use a sterile, soilless mix, and new or clean pots.
- ✓ Provide a disinfectant foot bath at each doorway. Clean and recharge it daily.
- ✓ Keep the greenhouse weed-free and maintain a 3 m weed-free zone around each greenhouse.

Production Techniques

- ✓ Break off cuttings from stock plants rather than using cutting knives. Keep exact records of the plant source of cuttings to enable infections to be traced back to the source stock.
- ✓ Isolate incoming material and keep shipments in different greenhouse, or at least in different blocks in the greenhouse. It is important to be able to locate specific shipments in case any problems develop at a later date.
- ✓ Entry into the stock plant growing areas should be tightly restricted and limited. Entry into the growing area should also be tightly controlled. Consider providing visitors with disposable overalls and boot covers. This is especially true if they had been in another geranium production greenhouse that day.
- ✓ Start work from the cleanest production area to the dirtiest, i.e. stock plants → propagation area → production area → end at the cull pile.

- ✓ Isolate your scented and Regal/Martha Washington geraniums from the zonals. They can be carriers of the disease and not show symptoms.
- ✓ Separate seed and cutting geraniums. *Xanthomonas* is not thought to be transmitted by seed, but seedlings can catch the disease from other geraniums.

Management Techniques

- ✓ Adequate spacing will promote air circulation and minimise water splashing affects.
- ✓ Keep hoses off the ground. Avoid splashing when watering.
- ✓ Do not have ornamental plantings of geraniums outside the greenhouse.
- ✓ Do not hang geraniums above other geraniums, whether they are ivies, zonals or mixed spring baskets. Dripping irrigation water will quickly spread any disease.
- ✓ Avoid plant-to-plant contact, common water films (e.g. capillary mats, ebb and flood benches), and overhead watering, particularly for stock plants.

End of Season Clean-up

- ✓ Discard all geraniums at the end of each season, including old favourites that may not be commercially available. Do not save outdoor-grown geranium plants for use as stock plants.
- ✓ Clean up and remove all debris on tables and the floor of the greenhouse. Wash down all bench surfaces with a disinfectant. **Do not mix these compounds as hazardous gases can result.**
- ✓ Disinfect watering lines.
- ✓ Discard all returned plants and do not allow them to be brought into growing areas.
- ✓ Do not reuse pots for a geranium crop.

When Plants Test Positive for the Bacterium

- ✓ Discard all plants found to be infected. They should be buried or removed off site.
- ✓ Do not compost them on the greenhouse site or spread them on adjacent fields.
- ✓ Do not carry infected or suspicious plants through the greenhouse; place them in a plastic bag or box before moving them.
- ✓ Geraniums immediately next to an infected plant should be discarded, as well as the flats or boxes they might be growing in. Do not reuse pots or trays from infected plants.
- ✓ Wash down all greenhouse surfaces (benches, walls, drippers, walkways) and disinfect all tools used to handle the plants with a disinfectant.
- ✓ Disinfect the irrigation system if you have a recirculating system.

Do not grow geraniums of any type in the area for three months.

Chapter 6 - Nematodes

Nematodes are microscopic worms that inhabit soil and water. Free-living species feed on bacteria, fungi and other nematodes while others parasitize insects, plants and animals. This chapter will focus on nematodes that parasitize plants.

Plant parasitic nematodes are a diverse group of organisms with species that can be found in foliage, stems, roots and soil. Most species feed on the roots of plants. They range in size from about 0.3-5.0 mm in length. Most feed by inserting a syringe-like mouthpart into plant tissue, which wounds the cells and creates entry sites for other disease causing organisms. Generally, nematodes do not kill the plant but produce vague symptoms such as yellowing, stunting and general poor growth. They are often part of a complex of problems that result in plant decline. Some nematodes are capable of vectoring viruses. In the field, nematodes can spread through movement of infested soil and symptoms are often exhibited as patchy areas that expand every year. Nematodes that live in the roots and stems can spread by moving infested plants to new areas.

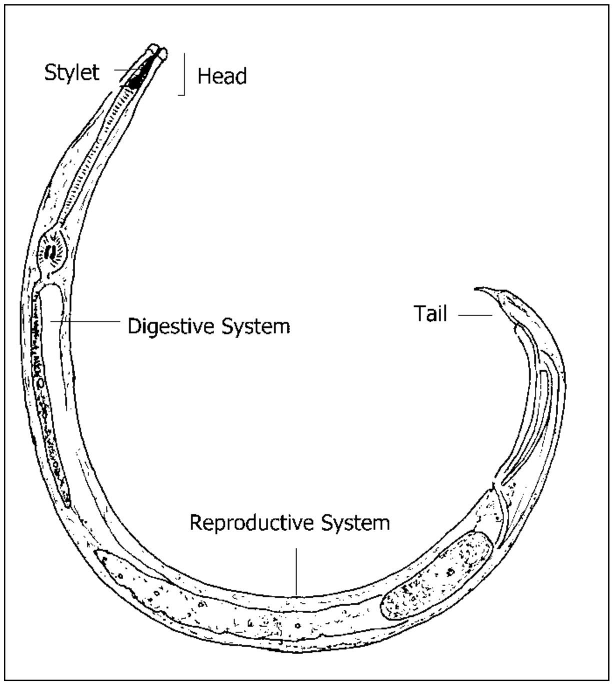
Nematodes commonly found on ornamental crops are meadow or root lesion nematodes (*Pratylenchus* spp.), root knot nematodes (*Meloidogyne* spp.), foliar nematodes (*Aphelenchoides* spp.), and stem and bulb nematodes (*Ditylenchus* spp.). Root lesion and root knot nematodes are found in the soil and the roots. Foliar and stem & bulb nematodes can be found in the soil, roots, stem and foliage. The populations increase with temperature and low initial populations in spring can reach damaging levels by autumn.

Damage level is dependent on factors such as susceptibility of the host, soil type, temperature, type and number of nematodes present, plus stress factors affecting the crop such as drought and low fertility. Generally, damage is more severe in sandy soils. Crops in organic soils can tolerate higher numbers of nematodes.

Weeds are an important host that help to maintain populations over the winter.

Most damage occurs in the first year of planting. It is important that plants establish a healthy root system, especially perennials, since this enables them to tolerate some nematode feeding. Proper soil pasteurization as well as clean storage of the potting soil is essential to prevent damage caused by nematodes.

Figure 6.1: Microscopic View of a Nematode (lateral section)



Most nematode species have similar life cycles. After mating, the female lays eggs in the same area where she is feeding. The larvae go through four moults, completing their life cycle within 3 to 4 weeks. Some types or species of nematodes may go into a dormant stage if conditions are unfavourable, remaining in the soil or plant debris for many years. Movement is through soil and plant roots, as well as through films of water on leaves.

Root Lesion Nematode

Meadow or root lesion nematodes, *Pratylenchus* spp., can be found in the soil and inside the roots of many ornamental plants including bulbs. High populations in the soil and roots result in poor growth, often causing patches of dying plants in the field.

Root Knot Nematode

Root knot nematodes (*Meloidogyne* spp.) cause stunting, poor plant vigour and discolouration of leaves. The roots of infested plants usually exhibit knots or galls. The damage to the root system may cause plants to wilt under the slightest water stress. Damaged host plants are more susceptible to secondary disease pathogens like *Pythium*, *Rhizoctonia* and *Phytophthora*. They are primarily a problem of long-term greenhouse crops, such as roses and carnations grown in soil beds. Transmission occurs via soil-contaminated machinery, hands, feet and irrigation water.

Foliar Nematode

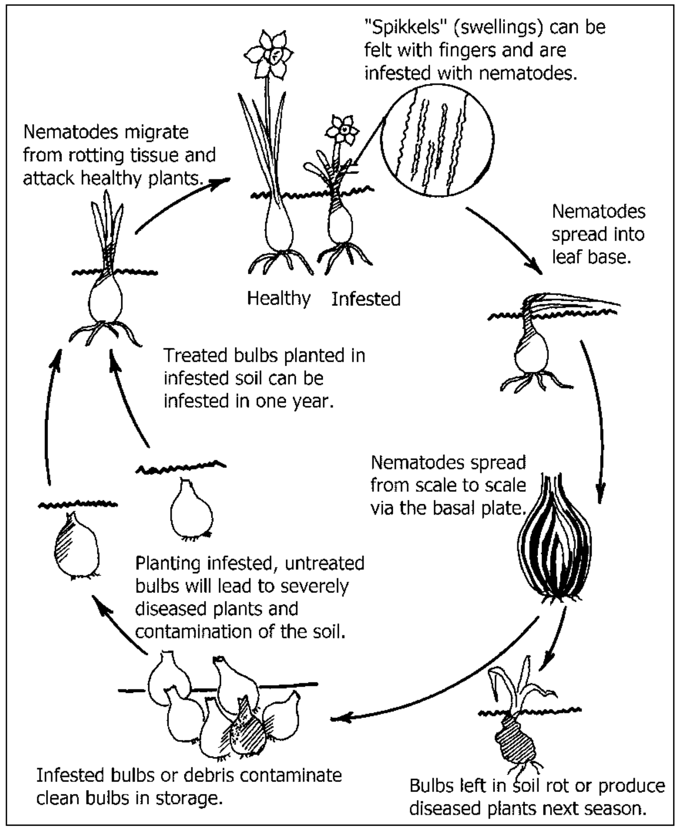
Foliar nematodes (A*phelenchoides* spp.) can attack a wide range of plants including anemones, begonias, chrysanthemums, crocus, iris, narcissus, strawberry and tulips. They feed on the outside of young foliage, stems and buds, causing curling, twisting and stunting damage to new growth. They can also crawl into the leaf through wounds or via the stomata, resulting in water soaked or yellow areas that eventually turn brown. Affected areas tend to be limited by veins. Leaves later dry up and turn brown. Foliar nematode symptoms may be similar to sunburn, high temperature or pesticide damage, which makes accurate visual diagnosis difficult. If allowed to build up they can cause serious losses in crops such as Easter lilies and begonias. Infested plants exhibit stunted, blotched and curled leaves that fade from green to yellow, and finally to brown. During wet weather, nematodes can move between leaves that are touching. They survive from year to year in bulbs, leaf tissue and the soil.

Stem & Bulb Nematodes

The most important nematode pest of bulbs is the narcissus stem and bulb nematode (*Ditylenchus dipsaci*). As many as 400 different species of plants including all of the bulb crops, strawberries, onions, alfalfa, cereals, perennial flowers including phlox, and numerous weeds may be attacked by one or more races of this nematode. Some populations can attack a wide range of hosts while others are restricted to only a few. A related species, *Ditylenchus destructor* is a pest of dahlias and potatoes, however this nematode has not been found in BC.

In the field, infested narcissus plants tend to start growth early, but the leaves are shorter and often wider than normal. Leaves may be bent or otherwise deformed and exhibit pale areas with elongated swellings known as 'spikkles'. These swellings contain nematodes that become dormant when the leaves dry up and then fall to the soil where they can be reactivated when conditions are favourable.

Figure 6.2: Life Cycle of Bulb Nematodes



Infected bulbs are softer than normal and may exhibit a dark neck rot. When suspect bulbs are cut in cross section, concentric rings of dark infested scales are seen alternating with white uninfected scales.

Management of Nematodes in Soil

Nematodes can be introduced to a field in infested soil adhering to farm equipment and in infested planting stock. To reduce the risk of introducing nematodes to a field, test the roots and associated soil of planting stock for nematodes (e.g. root lesion, stem & bulb and root knot nematodes) prior to planting out and, clean equipment before moving between fields. It is also recommended to periodically sample field and greenhouse soils for nematodes. If plant-feeding nematodes are detected, the following management options can be applied to reduce nematode numbers and crop damage.

- **Fumigation and Pasteurization -** For large fields, soil fumigation with Vapam (metam-sodium) is recommended to lower populations.

Smaller areas may be treated with Basamid (dazomet) or steam. Efforts should be made to minimize the movement of 'dirty' soil into the field following fumigation. A waiting period of at least 4 weeks will be required post-fumigation before the field is planted.

See the *Pasteurization and Fumigation of Soil* section in Chapter 1.

- **Keep the Field Fallow -** Populations can also be lowered by keeping the field black to starve out the nematodes. However, every weed must be removed for this option to be effective and the field will be out of production for the season. Weeds are a good reservoir and overwintering host for nematodes.
- **Soil Solarization –** Solarization is achieved by covering the soil with clear polyethylene in the summer. However, it can be difficult to achieve the required temperature for enough time in Coastal regions. Under good conditions, populations in the top 10 cm of soil can be reduced by about 50% after 4 weeks of solarisation between early July and late August. Removing the tarp, rotovating the soil as deeply as possible, and re-applying the tarp for another two weeks should increase efficacy. Combining a soil fumigant with solarization increases the success level of reducing nematode populations.
- **Cover Crops -** The use of cover crops has many beneficial properties such as improving soil fertility, increasing water retention capacity, preventing soil erosion and competing with weeds. Increasing the organic matter in the soil by using compost, manure, or cover crops is also known to reduce crop damage from nematodes. Organic matter often has an abundance of microbial life and can include fungi and nematodes that feed on nematodes. Cover crops, such as Wheeler rye, have been shown to suppress root lesion nematodes although the mechanism of suppression is not known. Other rye cultivars are good hosts to nematodes so selecting the correct cultivar is extremely important when choosing a cover crop to suppress nematodes.

Other cover crops have been tested for nematode control with promising results. French marigolds (*Tagetes patula*) produce phytochemicals called polythienyls that have been effective in controlling root knot and root lesion nematodes. In addition, some cultivars of brassica release compounds that are toxic to nematodes (e.g. isothiocyanates) when incorporated into the soil. It is important to note that there is variability between cover crops and the type of nematode that they suppress.

Table 6.1: Hot Water Treatments for Root Knot (*Meloidogyne* spp.) and Root Lesion (*Pratylenchus* spp.) Nematode Management

Crop	Nematode	Treatment
Agapanthus, Aloe, Anemone, Astilbe, Begonia tubers, *Bletilla hyacinthine* bulbs, *Cactus, Campanula, Cestrum, Cimicifuga, Cissus, Clematis, Cyclamen, Dahlia* tubers, *Dracaena, Eupatorium, Euphorbia, Gardenia, Gentiana, Gerbera, Gladiolus, Helleborus, Hibiscus, Hosta, Hoya, Iris, Jasminum,* orchid, *Ornithogalum, Paeonia, Primula, Sanseviera, Scabiosa, Sedum, Senecio, Verbena, Zantedeschia*	Root knot	Hot water at 48ºC for 30 min.
Calla rhizomes	Root knot	Dip in hot water at 50ºC for 30 min.
Rosa spp. except multiflora	Root knot	Dip in hot water at 51ºC for 10 min.
Chrysanthemum, not including *Pyrethrum*	Root knot & Root lesion	Dip in hot water at 48ºC for 25 min.
Astilbe, Clematis, Dicentra, Gardenia, Helleborus, Hibiscus, Kniphofia, Primula	Root lesion	Hot water at 48ºC for 30 min.
Source: USDA-APHIS, *Schedules for Plant Pests or Pathogens (T500)*		

- **Crop Rotation** – Consider rotating with a non-host crop to reduce the population of nematodes in the field.
- **Resistant Varieties** – If available, grow crop cultivars that are resistant to nematodes.
- **Soilless System** – For greenhouse crops, use a hydroponic or soilless growing system. Take steps to ensure nematodes cannot move from the soil into the containers of soilless media, i.e. do not place the soilless media in direct contact with infested soil.

Management of Nematodes in Plant Roots

Hot water treatments can be used to kill nematodes in roots before planting in clean media or soil. The success of hot water treatments is dependent on accurate time and temperature controls. Various plants have different sensitivities to the treatments. Refer to Table 6.1 for recommended treatments for specific crops.

Management of Nematodes in Foliage and Bulbs

- **Use Nematode-free Stock** – Although leaf and stem cuttings will be free of root feeding nematodes, they will not necessarily be free of foliar nematodes. Test the stock prior to use. Use only clean or hot-water-treated stock for propagation.
- **Discard Heavily Infested Bulbs.**
- **Hot Water Treatment** – Refer to Table 6.2 for recommended treatments to manage foliar and stem & bulb nematodes. Cultivars vary in tolerance to hot water treatment. Bulbs of uniform size should be treated in the same batch.

  If basal rot is present, **hot water treatment with Formalin ☠** is recommended as the hot water treatment alone can spread basal rot from infected to healthy bulbs. Cured hyacinth, iris and narcissus bulbs should be pre-soaked in water at 24^{o}C for 2 hours to activate the nematodes from the resting state. Treat bulbs for 4 hours in a 44^{o}C Formalin ☠ solution (500 mL of Formalin ☠ in 100 L of water). Dry and return to cool storage.

  Read the label for detailed information.

- **Crop Rotation** – Follow a 3 to 4 year rotation between crops. During that time, weeds must be controlled and all volunteer bulbs must be removed from the field to manage stem & bulb nematodes. If it is not feasible to follow long rotations between susceptible crops, infested fields may be fumigated to reduce the nematode population.

  Sanitation – Rogue and destroy symptomatic plants and plants adjacent to them. Small infestations of foliar nematodes on individual leaves can be removed and destroyed. Remove plant debris in greenhouses, propagation and equipment storage areas because it can harbour these nematodes. Take care in disposing of infested material as foliar and stem & bulb nematodes can survive in plant debris for long periods of time.

  Thoroughly wash tools and equipment that contacts infested soil or bulbs with a solution of 1-part Formalin ☠ (formaldehyde) and 9 parts water.

- **Irrigation** – Space plants so that they do not touch one another and avoid overhead watering to prevent splashing of nematodes to new plants. Water carefully.

To test the soil before planting, contact your agricultural advisor. The samples should be tested in a private lab.

Table 6.2: Hot Water Treatments for Foliar (*Aphelenchoides* spp.) and Stem & Bulb (*Ditylenchus* spp.) Nematode Management		
Crop	**Nematode**	**Treatment**
Allium, Amaryllis, Bulbs (general)	Stem & bulb	Presoak bulbs in water at 24ºC for 2 hours, then in hot water at 43-44ºC for 4 hours.
Bletilla hyacinthina	Foliar	Hot water at 48ºC for 30 min.
Hyacinthus bulbs, *Iris* bulbs and rhizomes	Stem & bulb	Presoak in water at 21-27ºC for 2.5 hours, followed by hot water immersion at 43-44ºC.
Narcissus bulbs	Stem & bulb	Presoak cured bulbs in water at 21-27ºC for 2 hours, followed by hot water immersion at 43-44ºC until all bulbs reach that temperature and hold for 4 hours.
Begonia	Foliar	Dip in hot water at 48ºC for 5 min.
Astilbe, Bletilla hyacinthina, Cimicifuga, Hosta, Paeonia	Foliar	Presoak in water at 20ºC for 1 hour followed by hot water soak at 43ºC for 1 hour. Then dip in cold water and let dry.
Senecio	Foliar	Treat with hot water at 43ºC for 1 hour.
Crocus	Foliar, Stem & bulb	Hot water at 43ºC for 4 hours. Should be done immediately after digging.
Amaryllis, Gladiolus, Scilla	Stem & bulb	Hot water at 43ºC for 4 hours. Should be done immediately after digging.
Muscari, Ornithogalum	Stem & bulb	Dip in hot water at 45ºC for 4 hours.
Source: USDA-APHIS, *Schedules for Plant Pests or Pathogens (T500)*		

Chapter 7 – Insects and Mites

This chapter contains a description of and management recommendations for common insects and mites that damage floriculture crops. Some information is provided on biological controls. See Chapter 1 for additional information on biological control. **Information on the pesticides registered to manage a pest is presented in the document *Pesticides Registered for Ornamental Crops*.**

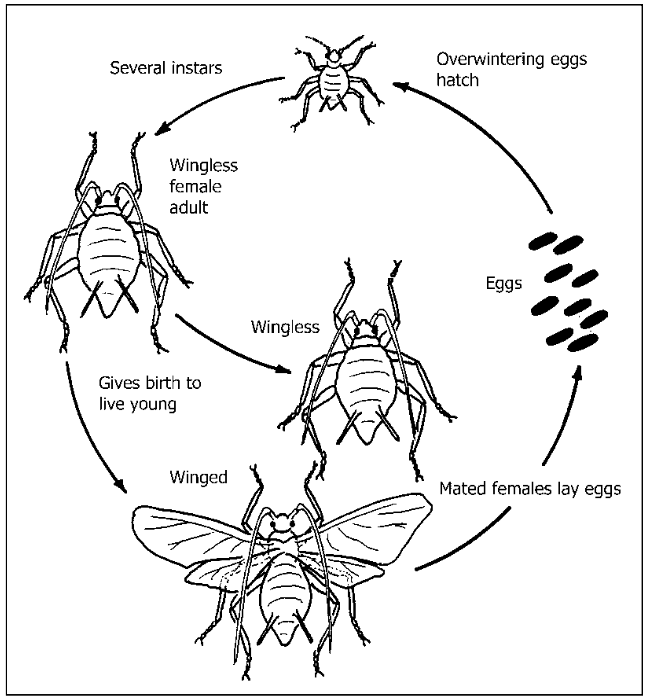
Aphids

Aphids are small pear-shaped, soft bodied, winged or wingless insects. There are more than 4,000 species worldwide. Some are restricted to one or a few host plants, while others have large host ranges. Many species infest ornamental crops in both greenhouse and field production. They are often pale green in colour but are sometimes black, orange, pink, yellow or brown. The adults can be from 2 to 3 mm in length, and the nymphs up to 1.8 mm. They are usually found on the tender portions of stems, new shoots and the underside of leaves.

Aphids extract plant fluids from the phloem tissues by means of specialized piercing-sucking mouth parts. Because many aphids prefer the soft new tissues near the growing points, plant growth is often interfered with and new buds may be malformed. The honeydew that aphids secrete can produce a shiny, sticky film on plant surfaces. Honeydew provides a medium for the growth of a black sooty fungus that gives the plant a dirty appearance and interferes with photosynthesis. Leaves are often littered with white 'skins' (exoskeletons) that are shed as the young aphids grow and moult.

Some important aphid pests of floriculture crops include: green peach aphid (*Myzus persicae*), cotton or melon aphid (*Aphis gossypii*), chrysanthemum aphid (*Macrosiphoniella sanborni*), rose aphid (*Macrosiphum rosae*), foxglove aphid (*Aulacorthum solani*), and potato aphid (*Macrosiphum euphorbia*). Most aphid pests of floriculture crops are found in the open. However, some ornamental species may be infested by aphids that can live underground on roots for a portion of their life cycle, or within plant galls that form as a result of insect feeding, or under a woolly substance that provides a protective barrier. Aphid species vary considerably in their susceptibility to pesticides and suitability for biological control.

Figure 7.1: Aphid Life Cycle (6 – 14 days)



Life Cycle

Under greenhouse conditions, many aphids can remain active year-round. Outdoors, they overwinter as eggs, emerging in spring as wingless females. They give birth to living young that are capable of reproducing within 7 to 10 days. A single aphid can produce 60 to 100 young over a 20 day period. Subsequent generations may develop wings when conditions become crowded. This allows the aphids to fly to other host plants. In fall, males are produced to fertilize females who then lay the overwintering eggs. In milder climates, adult aphids can overwinter in the ground or in plant debris. Upon emerging in the spring, females often produce a winged generation that disperses to host plants.

Prevention

- Remove weeds from inside the greenhouse and a three-metre-wide band around it.
- Do not bring infested plants into the greenhouse.
- Screen vents and other openings to prevent entry from the outside.
- Monitor winged populations with yellow sticky traps; visual examination of new shoots is necessary for early detection of wingless aphids.

Biological Control

Aphidius colemani, a small wasp that parasitizes aphids, and *Aphidoletes aphidimyza*, a midge that is an aphid predator, can control aphids on greenhouse crops. Apply *A. colemani* at a rate of 5/10 m^2 and *A. aphidimyza* at the rate of 10/10 m^2. The two should be used in combination to achieve the best control; *Aphidoletes* quickly reduces large populations and *Aphidius* provides on-going control of low populations.

Tulip Bulb Aphid

Tulip bulb aphid (*Anuraphis tulipae*) adults are wingless and greyish in colour with dark heads. They are found under the dry outer skins of bulbs, where they feed by sucking sap. They infest tulip bulbs in storage. Crocus, gladiolus, freesia, iris and lily bulbs are also hosts. When infested bulbs are planted, the foliage is stunted, weak and unhealthy, and the flowers may be also stunted. Tulip bulb aphids are a vector of the lily-symptomless and tulip-break viruses.

Prevention

- Rogue and destroy plants that appear abnormal.

Bulb Flies

Narcissus Bulb Fly

The narcissus bulb fly (*Merodon equestris*) is the most serious insect pest of narcissus. The adult female resembles a small bumble bee. The males are slender and, when they fly, their wings produce a high pitched sound. The adults are about 12 mm long. Adult activity is from mid-May through June in the field. If the bulbs are greenhouse forced for early sales, flies will become active earlier. Damaged bulbs are soft, scarred and may produce spindly and dwarfed leaves, or they may fail to grow and rot. While narcissus is the main host, it also affects bulbs of amaryllis, hyacinth, iris, scilla and tulip.

Life Cycle

The eggs are laid singly in soil cracks around bulbs or in the foliage in the neck of the bulb. The eggs are susceptible to both desiccation and excessive dampness. They hatch within 10 to 15 days to produce whitish or yellowish-white maggots that are from 1 to 2 mm long. They make their way to the bottom of the bulb and bore into it. Usually only one maggot is found per infested bulb and they overwinter inside the bulbs either in storage or in the field. The maggots usually exit from the bulb when they are fully grown (18 mm long). The maggots then bore upward in the soil and pupate just below the soil surface sometime in late April. Adult flies emerge 4 - 6 weeks later. It takes one year for the life cycle.

Lesser Bulb Fly

Adult flies (*Emmerus tuberculatus* and related species) are about 6 mm long, the size of house flies, and are usually associated with damaged, sick, or rotting bulbs. Occasionally they have been found attacking healthy bulbs in storage. They occur from late April and last throughout the year under favourable conditions.

Life Cycle

The first generation of adult flies emerges from April to the end of June. The second generation starts to appear in July and lasts until October. The female begins to lay eggs within 5 days. Eggs are laid in groups on or near weak, injured or decaying bulbs. Depending upon temperature, eggs hatch in 2 - 12 days. The maggots are 8 mm long when fully grown and are found mainly in the neck of the bulb. They pupate after 2 - 4 weeks and the adults emerge 1 - 3 weeks later. The second generation may mature the same year, but most overwinter as maggots in the bulbs, which pupate and emerge the following spring as adult flies.

Prevention

- Rogue and destroy plants with spindly or abnormal growth.
- Destroy rotten bulbs in storage.

Caterpillars, Loopers, Leafrollers and Cutworms

Many species of *Lepidoptera* will feed on floriculture crops. The adult moths tend to be dull-coloured and about 18 mm long. Many fly at night and may be attracted to greenhouse lights. Caterpillar infestations begin when adult moths or butterflies lay eggs on host plants. The emerging larvae feed on their preferred plant parts. Young looper and armyworm larvae skeletonize leaves, later consuming entire leaves as they grow. Cutworms are usually dull-coloured caterpillars up to 4 cm long that feed at night. Some species cut off plants at the soil surface. Others feed on plant parts above the ground. They usually hide during the day below the soil surface or in plant debris, or sheltered within the plant foliage. Leafrollers fold or roll leaves together with silk and feed on the inside. Leafroller larvae wriggle violently out of these shelters when disturbed and drop on a silk strand.

Some common caterpillar pests of floriculture crops include cabbage loopers (*Trichoplusia ni*), variegated cutworms (*Peridroma saucia*) and omnivorous leafrollers (*Platynota stultana*).

Life Cycle

Depending on the species, there may be from one to several generations per year and life cycles are highly variable. Adult moths lay eggs on the leaves or stems of host plants. The newly hatched larvae begin feeding immediately and disperse on the plant as they grow. At maturity they enter a pupal stage, often inside a silken cocoon that may be located on the host plant or in debris on the ground. Leafrollers often pupate inside the rolled leaves. Overwintering may occur as partially grown larvae, eggs or adults, in foliage, soil or on structures.

Prevention

- Examine new shipments carefully for signs of caterpillar infestation, particularly if received from a new supplier or out-of-country.
- Screen vents and other greenhouse openings.
- Remove weeds from inside greenhouses and from a three metre wide band around the outside perimeter of greenhouses.
- Look for signs of feeding, caterpillars and dark coloured droppings.
- Examine plants frequently and remove caterpillars by hand if numbers are low.

Biological Control

Bacillus thuringiensis var. kurstaki (Btk) is registered and available for use on some greenhouse and outdoor ornamentals. This microbial pesticide works best on young caterpillars, as the larvae must eat a lethal amount of Btk. After eating a sufficient dose, larvae stop feeding and die in 2-5 days.

Fungus Gnats and Shore Flies

Fungus gnats are small, delicate, dark grey or black flies about 3 mm long. They are often seen running on the soil surface or flying around potted plants, particularly in wet areas. The slender white larvae have shiny black heads, no legs and live in the potting media or soil. Most species feed on decaying organic matter and algae; they are common in compost. Larvae may damage roots on seedlings, rooted cuttings and young plants. Root feeding can provide an access point for disease organisms.

Shore flies are similar in appearance to fungus gnats but they do not inflict significant damage. They may, however, contribute to the spread of diseases. Adult shore flies can be distinguished from fungus gnats by their apparent lack of antennae and faint spots or mottling on wings while at rest. They are also stouter and are stronger fliers than fungus gnats (see Figure 7.2). Shore fly larvae develop in standing water and lack the distinctive black head of fungus gnat larvae.

Life Cycle (Fungus Gnats)

Females live about seven to ten days, laying a hundred or more eggs. The tiny white eggs are laid singly or in groups on the soil surface near host plants, and hatch in four to six days. Mature larvae are about 5.5 mm long with shiny black head capsules and white translucent bodies. They feed for about two weeks before pupating in the soil. Adults emerge in about one week. Many overlapping generations occur throughout the year. Fungus gnats become more active and reproduce faster as temperature increases.

Figure 7.2: Distinguishing Characteristics of Fungus Gnats and Shore Flies

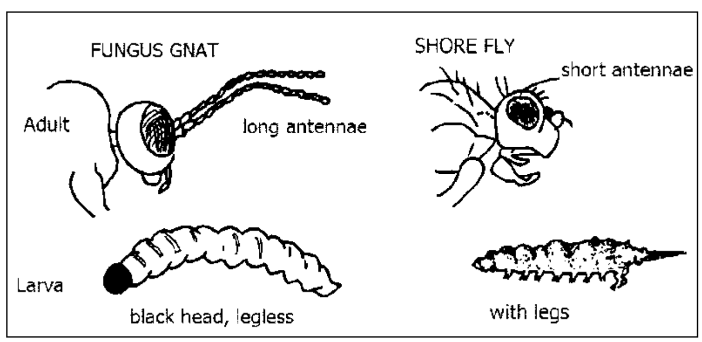
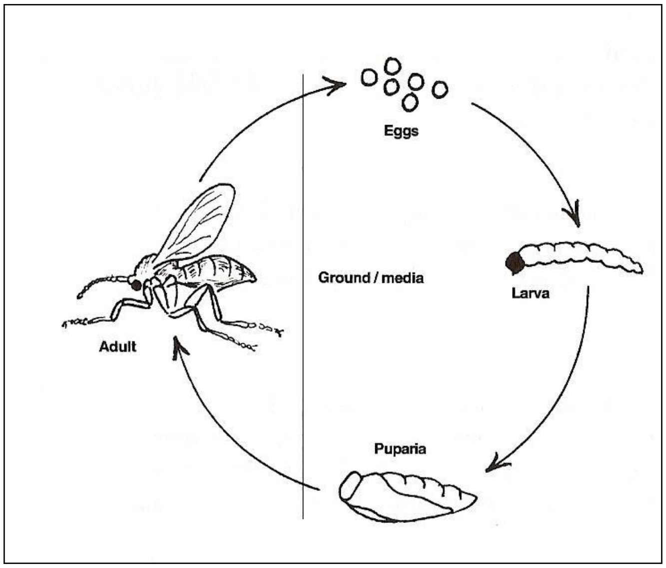


Figure 7.3: Fungus Gnat Life Cycle (22 – 40 days)



Prevention

- Avoid over watering.
- Provide good drainage under the greenhouse.
- Control algae. (See Algae Control in Chapter 1.)
- Practice strict sanitation.
- Remove weeds from inside greenhouses and from a three meter band around the outside perimeter of greenhouses.
- Monitor populations with yellow sticky traps hung above crop canopy and close to the soil surface.

Biological Control

Predatory mites, *Stratiolaelaps scimitus*, feed on the eggs and larvae of fungus gnats. They do not feed on plant tissue. They can be purchased in plastic bottles or cardboard tubes containing 10,000 or more mites in vermiculite. They should be applied on a preventive basis at the rate of 100 mites per m^2 (2 mites/15 cm pot) or 5 cc vermiculite and mite mixture/pot. A predatory rove beetle, *Atheta coriaria*, feeds voraciously on eggs, larvae and pupae of fungus gnats and shore flies, and will feed on thrips or other insects in the media/soil. *Bacillus thuringiensis* var. *israelensis* (Bti) is registered and available for use in greenhouse ornamentals. Bti kills larval stages of fungus gnats and shore flies. Apply as a soil/media drench when larvae are present.

Leafhoppers

Leafhoppers are small (up to 6 mm) sap sucking insects that feed on foliage and or young shoots. They are usually pale green, white or yellow, and may have patterns on their wings. Leafhoppers are very mobile and will readily walk or fly when disturbed. Leaves that are fed on may appear stippled, scorched, or burned. Leafhoppers that feed on vascular tissues can cause severe deformities in new growth. Aster or six-spotted leafhoppers (*Macrosteles quadrilineatus*) transmit the aster yellows phytoplasma disease to many susceptible ornamental plants. Rose leafhoppers (*Edwardsiana rosae*) are also a notable pest in ornamental plantings.

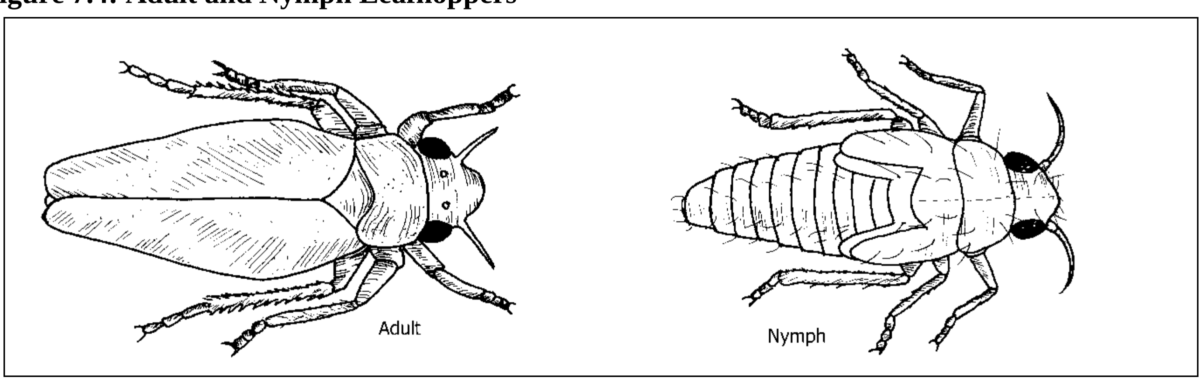
Life Cycle

Leafhopper eggs hatch in spring. Immature leafhoppers are wingless, and progress through several stages (instars) before becoming winged adults. Depending upon the species and climate, a second generation may be produced in August or September.

Prevention

- Start inspecting outdoor plantings for signs of leafhopper presence and damage by mid-May.

Figure 7.4: Adult and Nymph Leafhoppers



Leafminers

The chrysanthemum or serpentine leafminer (*Liriomyza trifoilii*) is a particular problem on chrysanthemum, gerberas, and related species. Damage results from the production of pale-yellow tunnels in the leaves. Vigour of the plant may be reduced with high populations. The pea leafminer (*Liriomyza huidobrensis*) has been collected from ornamental greenhouse crops in the Fraser Valley. This pest has a wide host range and growers noticing leafminer damage should have samples identified. Other leafminers that cause occasional problems on ornamental crops include the boxwood leafminer (*Monarthropalpus buxi*), azalea leafminer (*Caloptilia azaleella*), holly leafminer (*Phytomyza* spp.) and lilac leafminer (*Caloptilia syringella*). A thorough understanding of the life cycle of the species of concern is important for good control.

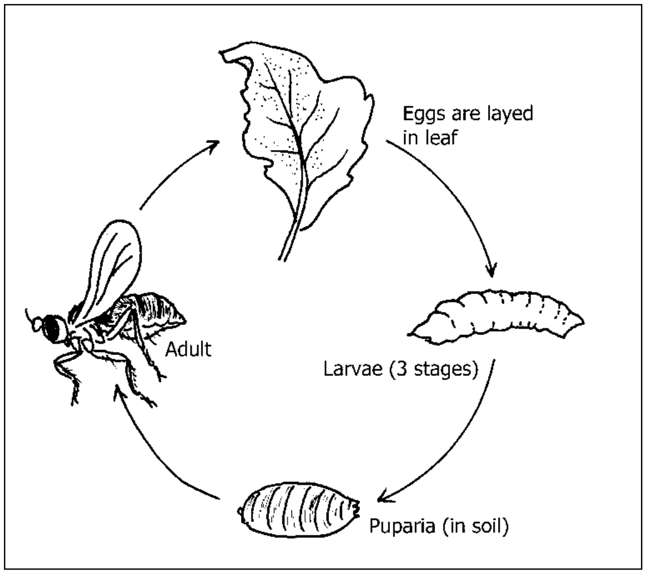
Life Cycle (Chrysanthemum or Serpentine Leafminer)

Adult flies are about 2.5 mm long with black and yellow markings. Adult activity begins at sunrise, peaking during mid-morning. Mating can occur at any time. Females feed on leaves by puncturing the surface. These sites are speckled or stippled, usually near the leaf tip. About 15% of all feeding punctures are used for egg laying. After 2 - 5 days, the eggs hatch and the larvae begin to feed inside the leaves, causing characteristic snake-like 'mines', tunnels or tracks. In 5 - 7 days, the larvae cut a hole in the leaf, crawl out of the mine and drop to the ground to pupate. They emerge as adults in 10 - 12 days. The length of the life cycle is directly affected by temperature. There can be several generations per year particularly in the greenhouse.

Prevention

- Inspect all new plant material coming into the greenhouse and destroy any affected tissue.
- Have a diligent sanitation program. Plant debris can harbour leafminers.
- Remove weeds inside greenhouses and from a three metre wide band around the outside perimeter of greenhouses. Many weeds are alternate hosts.
- Choose leafminer-tolerant varieties when possible. Avoid highly susceptible chrysanthemum varieties.
- Monitor continuously using yellow sticky cards or tapes hung just above the crop and dispersed evenly among the plants (1 trap/100 m^2). Yellow sticky traps may be used to trap very low adult populations. Adults will be caught on them long before they are detected in the crop. Early detection is essential for effective control and prevention of leaf damage.
- Timing and coverage are critical for effective chemical control.
- Leafminers are prone to development of resistance to pesticides; be sure to rotate pesticides from different groups.

Figure 7.5: Leafminer Life Cycle (24 – 30 days)



Mealybugs

Mealybugs are closely related to scale insects, but have a white waxy covering instead of a hard scale. They are often found under bud scales and in leaf axils. Mealybugs feed on plant sap, which can cause infested plant parts to dry and turn yellow. Affected areas eventually die. Some species called ground mealybugs feed on the roots of the plants. Like most sucking insects, mealybugs excrete large quantities of sticky honeydew which hosts the growth of black sooty mould. Sooty mould gives the plant a dirty appearance and interferes with photosynthesis. Common species of mealybugs attacking floriculture crops include the citrus mealybug (*Planococcus citri*), long tailed mealybug (*Pseudococcus longispinus*) and root mealybug (*Rhizoecus* spp.).

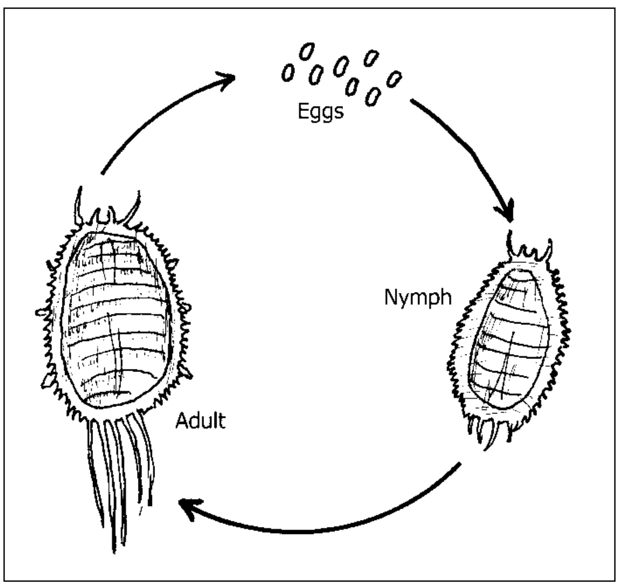
Life Cycle

Mealybug development is favoured by high temperatures and humidity. Females deposit their eggs in a cottony, waxy sac under their bodies. When egg laying is complete, the female dies. The eggs hatch in about 10 days; less if the temperature is higher. The larvae or crawler stage moves about the plant to feed. As their life cycle progresses, they develop the waxy covering and move about less. The adult males are winged and do not feed on the plant. About 30 days are required for one generation, so several generations can occur per year in greenhouses or interior plantscapes.

Prevention

- Examine new plants carefully before introducing into the greenhouse.
- Isolate and treat infested plants. Avoid keeping "pet" plants in the greenhouse.
- The crawler stage is most susceptible to chemical controls; direct contact and good coverage of infested plant tissue is important when spraying.

Figure 7.6: Mealybug Life Cycle (30 – 60 days)



Mites

Mites are arachnids, not insects, and belong to the same class as spiders. Several mite species can cause damage to floriculture crops, most notably spider mites and cyclamen mites. European red mites, McDaniel spider mites, broad mites, bulb mites, bulb scale mites and clover mites may occasionally become pests of greenhouse or field-grown floriculture crops. Blister, gall and rust mites (family: Eriophyidae) are microscopic and therefore hard to see and identify; but they can cause significant plant damage.

Bulb Mite

Bulb mite (family: Acaridae) (*Rhizoglyphus echinopus*) adults are smooth, colourless, shiny and about 0.5 to 0.7 mm in length. They are plump, oval in shape, and move sluggishly. Bulb mites are considered secondary pests of bulbs, invading them at points of bruising or other mechanical injury. It is a pest of various bulb species during storage. The longer the storage period, the greater the mite build-up and damage that may occur. Bulbs become soft as a result of mite damage. Infested bulbs, when planted, develop weak or sickly looking foliage, or fail to grow. Once a population is established, the bulbs are quickly reduced to a rotten pulp. During storage the mites can move between bulbs. Mite feeding may provide access for and vector plant diseases, particularly *Fusarium* species. Bulb mites are found on gladioli, hyacinths, lilies, narcissi, freesias and tulips.

Prevention and Control

- Rogue and destroy plants and bulbs that appear abnormal. Clean and disinfect bins and storage areas before use.
- Handle bulbs carefully to avoid bruising.
- Maintain low humidity in storage.
- Hot water treatment can be used to destroy mite infestations on some bulbs. See the section on hot water treatment in Chapter 6.
- Steam pasteurization has been found to eliminate bulb mites from the soil.

Biological Control

The predatory mite, *Gaeolaelaps aculeifer*, will help manage bulb mites, and can be applied as a preventive measure to bulbs in soil, or once the bulb mites are present (curative). *Gaeolaelaps aculeifer* will feed on other small soil insect pests and can survive without food for several weeks.

Bulb Scale Mite

Bulb scale mites (family: Tarsonemidae) (*Steneotarsonemus laticeps*) are very tiny, about 0.2 mm in length and pale amber-coloured. They will infest healthy bulbs. Infestation occurs in the neck area of the bulbs while in storage. Infested bulbs are abnormally dry, small and soft, and the outer scales may adhere tightly to the bulb. When infested bulbs are planted, the growing foliage and flower stems will have yellowish brown streaks that are the result of mite feeding on the tissue in the neck of the bulb. Affected leaves may develop a 'saw-tooth' disfiguration. Mite populations do not increase rapidly during the cool, early spring period. As temperatures rise, populations explode and mites spread freely over the leaves. Excessive feeding leads to premature wilting, which reduces food reserves within the bulb and results in a smaller bulb. As the foliage dies back, the mites move deep down within the bulb scales to survive the dormant season. When the bulbs are first lifted, the mites are concentrated in the neck region. During storage, as the bulbs dry and shrink, the mites move deeper between the bulb scales.

Prevention and Control

- Remove and destroy infested bulbs during sorting and any abnormal plants.
- Clean and disinfect bins and storage areas before use.
- Hot water treatment can be used to destroy mite infestations on some bulbs. See the section on hot water treatment in Chapter 6.

Cyclamen Mite

Cyclamen mites (family: Tarsonemidae) (*Stenotarsonemus pallidus*) are very tiny, about 0.2 mm in length and pale amber-coloured. Because cyclamen mites avoid light, they congregate within unopened buds and between the halves of folded leaflets. They suck the sap from buds and growing points. They cannot be easily seen with the naked eye, so the first sign of a problem is often plant symptoms. Infested plants will have leaves that are curled, twisted and brittle. Infested buds may fail to open and flowers are blotched and distorted. Cyclamen are usually the most seriously affected crop, but other flowering and tropical plants may also be attacked. Other favoured hosts include African violets, fuchsia, geraniums, ivy, snapdragons and strawberry.

Life Cycle

Females lay eggs around the crown of the plant and along the midrib of new unfolded leaves. Development is similar to two-spotted spider mites. The life cycle takes around 18 days, varying with temperature. Cyclamen mites thrive in cool temperatures and high relative humidity.

Prevention and Control

- Examine new plants carefully for symptoms before placing in the greenhouse.
- Remove weeds from inside greenhouses and from a three-metre-wide band around the outside perimeter of greenhouses.
- Lowering relative humidity will reduce infestation levels. If only a few plants are infested, they should be removed and destroyed.
- When spraying, good coverage deep into the growing points is critical; use a high water volume. Two to three applications at 7 day intervals may be necessary.

Lewis Mite

Lewis mites (family: Tetranychidae) (*Eotetranychus lewisi* McGregor) have been found in several locations in BC on greenhouse-grown poinsettias. Lewis mites are similar in appearance to two-spotted spider mites, but they are smaller, greenish or straw coloured, and have several distinctive spots when viewed under a microscope or a powerful hand lens. The mite pierces the epidermis of the plant leaf and removes the cell contents, resulting in a characteristic stippled appearance. Eventually the entire leaf becomes bleached and falls off.

Life Cycle

The life cycle from egg to adult is approximately 12 - 14 days. Females will oviposit 2 - 3 eggs per day for approximately 30 days. Lewis mites do not enter diapause (resting stage) in the fall and winter as do two-spotted spider mites.

Prevention and Control

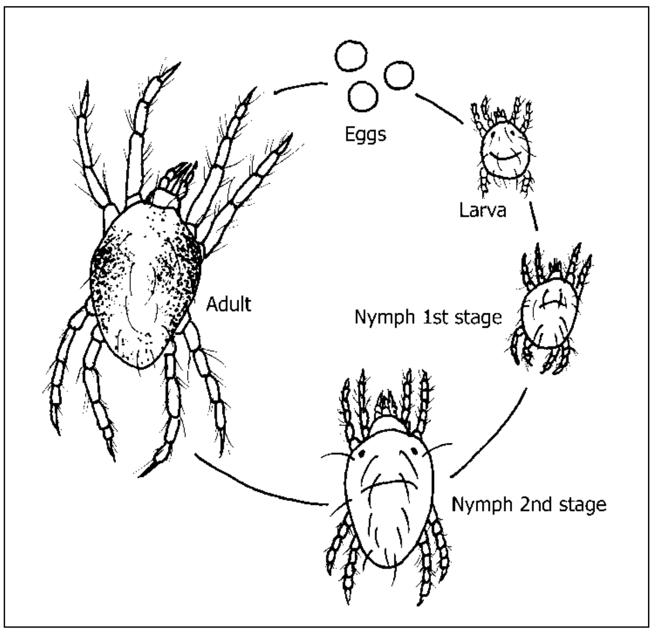
See the recommendations for two-spotted spider mites.

Two-Spotted Spider Mite

Two-spotted spider mites (family: Tetranychidae) (*Tetranychus urticae*) may be called 'red spiders' because of their red colour during diapause (winter resting stage). The mites are yellowish-pale green with two dark spots on the back. They vary in size from near microscopic to visible with the unaided eye. Size can vary depending on the stage and the plant species they have infested (mites are smaller on chrysanthemums). They feed mostly on the underside of leaves, sucking plant juices. Infested foliage develops a yellow mottling on the upper surface. Leaves become brittle and parchment-like or bronzed as mite feeding progresses. Webs of fine silk strands are formed on upper leaves of highly infested plants. Entire plants may eventually be enveloped in sheets of webbing. Two-spotted spider mites thrive in warm and dry conditions.

Females lay an average of 100 eggs in a lifetime. Eggs are laid on the underside of the foliage. The newly hatched mites go through a larval and two nymphal stages before becoming adults. The life cycle depends upon temperature. During periods of high temperatures, spider mite populations can increase very rapidly, with a life cycle taking only 10 days. More time is required in colder conditions. As temperatures and day length decrease, females enter diapause (winter resting stage) by about mid-September. They stop laying eggs, turn orange or red, and crawl down into a crack, crevice or soil where they remain until spring. This stage is highly resistant to pesticides.

Figure 7.7: Two-Spotted Spider Mite Life Cycle (8 – 40 days)



Prevention and Control

- Eliminate weeds inside and from a three metre wide band around the outside perimeter of greenhouses.
- Monitor for early signs of presence and damage. Mites will not show up on sticky traps, so it's necessary to visually inspect plant leaves.
- Discard heavily infested plants. Orient holes in overhead poly tubes so that plants are not under a direct blast of hot dry air. For example, have the holes point up instead of down onto the crop.
- Good coverage of the upper and undersides of leaves is required when using sprays.

Biological Control

Predatory mites, including *Phytoseiulus persimilis* are available for biological control. Apply at rates of 2 per m^2 as a preventive treatment and 6 - 20 per m^2 to control light to heavy infestations.

Plant Bugs

Several plant bugs may attack floriculture crops, including lygus or tarnished plant bugs (*Lygus lineolaris*), four lined plant bugs (*Poecilocapsus lineatus*) and stink bugs (*Acrosternum* spp.). The immature stages resemble large aphids, but they are fast moving compared to aphids and easily disturbed. They can cause considerable damage, such as distortion and stunting of new shoots, terminals and flower buds. Adults are shield-shaped, flattened and fly when disturbed. Many species have distinctive dark and light markings and wing patterns.

Prevention and Detection

- Yellow sticky traps will catch adult lygus bugs, so can be used to detect insect presence usually before they are seen within the plants. Set traps around the edges of plantings in spring (April, May) to detect the movement of adults into the crop.
- From spring onwards, look for adults and nymphs in the crop. Nymphs often hide in the growing points or flowers, but they can be shaken loose on to a collection pan, a white beating tray or sheet of paper.
- Look for distorted growth and feeding injury on new tissues and flowers.

Rose Midge

The rose midge, *Dasineura rhodophaga*, is an increasing pest of nursery grown roses in the Fraser Valley. The larvae (maggots) feed in developing shoot tips and flower buds, which become black and shrivelled and usually die. Rose midge is primarily a pest of outdoor grown roses, but has been known to invade greenhouses.

Life Cycle

The insect spends the winter as pupae in the soil below plants infested the previous season. The tiny flies leave the soil in mid-spring and fly to the tips of nearby roses. Eggs are laid and within two days larvae begin feeding on the new growth. After about a week they move to the soil to pupate and soon new flies emerge. There can be several generations a year.

Prevention

- Un-infested rose nurseries should be cautious when importing container stock from other nurseries. The midge will not be present in dormant, bare root stock.
- Removal and safe disposal of obviously infested shoots and buds will reduce rose midge numbers.
- Rose midge has no known natural enemies in BC.
- Pesticides may not be very effective because the larvae are protected from sprays within folded leaves.

Scales

Scales are small, wingless insects up to 3 mm in length. Their body shape is usually oval or hemispherical with a waxy or scale-like covering. Scales feed on the sap of their host plants, reducing plant vigour and causing wilting, yellowing and distortion of leaves. Excess sap is secreted as honeydew, upon which a black sooty mould grows, giving the plant a dirty appearance and interfering with photosynthesis. Many scale species can infest floriculture crops, particularly woody plants including roses (rose, oystershell, lecanium scales), lilacs (oystershell and lecanium scales) and holly (holly scale). The soft brown scale (*Coccus hesperidum*) can attack a wide range of crops.

Life Cycle

Mature females lay large masses of eggs under their bodies. Each egg hatches into a small pale crawler that moves about for a few days to find a suitable feeding site. The crawler will settle down and become stationary on a leaf, branch, or the trunk of the plant and begin to feed. The crawler is the best stage to target for chemical control measures as mature scales are protected by waxy or hard coverings that are difficult to penetrate.

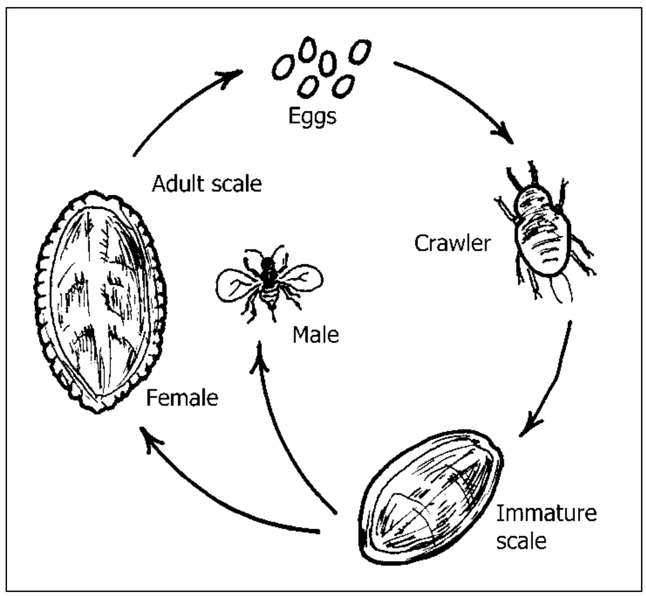
Prevention

- Examine new plant material carefully before bringing it into the greenhouse.
- Do not keep “pet” plants in the greenhouse.
- Read labels carefully for information on proper timing and application methods for specific crops. The crawler stage is most susceptible to pesticide application. Direct contact is important when using sprays.

Biological Control

Use of biocontrol agents cannot be relied upon for complete control of scale; an integrated approach is required.

Figure 7.8: Soft Scale Life Cycle



Sowbugs

Sowbugs, also called woodlice or pillbugs, have dark, segmented, flattened, oval-shaped bodies with 7 pairs of legs. These are actually crustaceans (related to lobsters and crabs) that live entirely on land. They feed mostly at night, hiding in dark and damp places during the day. Sowbugs feed mostly on decaying plant material. At high population levels they will occasionally feed on roots and stems or eat holes in leaves. They may cause severe damage to seedlings.

Prevention and Control

- Soil pasteurization.
- Habitat management is the most effective way to decrease populations, which includes: Removing old boards and other rotted organic materials from the greenhouse, and reducing moisture levels on the greenhouse floor.

Spittlebugs

Spittlebugs are a group of sap-sucking insects that cover themselves in a saliva-like froth during their immature stages. Damage results from the general unsightliness of infested plants, and distorted or irregular growth due to feeding injury and/or the transmission of viruses or phytoplasmas. The meadow spittlebug (*Philaenus spumarius*) has a wide, almost indiscriminate host range and is common on many ornamentals grown in the field.

Prevention and Control

- Pesticides are registered for use against spittle bugs; however, spittlebug nymphs are easily dislodged with a stream of water from a hose.

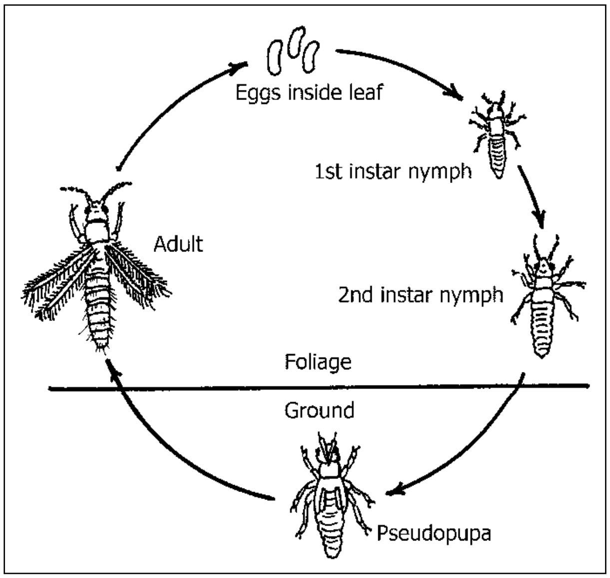
Thrips

Thrips are small, slender insects that are 0.5 - 1 mm in length. Adults have two pairs of narrow wings fringed with long, fine hairs. Their colour varies from yellow to brown or blackish-brown. Thrips are found on the underside of leaves and within flower buds and new shoots. Adults and larvae feed by removing sap from punctures of the plant tissue made by mouthparts. Damaged leaves have a silver-flecked appearance, flowers are malformed and distorted, and foliage is dwarfed and mottled. In the greenhouse, the two principal species are onion thrips (*Thrips tabaci*) and Western flower thrips (WFT) (*Frankliniella occidentalis*) and. WFT are particularly harmful because they build up pesticide resistance very quickly.

WFTs are vectors of tomato spotted wilt and impatiens necrotic spot viruses. (See Chapter 5.) Larvae acquire the virus when they feed on infected tissue and introduce it into plants when their stylet pierces the leaf tissue. Once a thrips picks up the virus it will remain infected for the rest of its life. When viruses are a concern, early detection and control of thrips is essential. Use sticky traps for monitoring.

Other thrips have been identified on floriculture crops in the Fraser Valley including *Echinothrips americana* and *Frankliniella intonsa* (European flower thrips). These thrips have a wide host range.

Figure 7.9: Thrips Life Cycle (13 – 40 days)



Life Cycle

The female lays eggs in a slit cut in the plant tissue by the ovipositor. The eggs hatch in 5 to 7 days and the emerging nymphs feed on leaves and flower petals. They pass through nymph and pupal stages before becoming adults. Many species pupate in the soil. Timing of the complete life cycle is temperature dependent. The adults can live and feed for up to 45 days.

Prevention and Control

- Remove weeds from inside greenhouses and from a three metre wide band around the outside perimeter of greenhouses. Weeds are often alternate hosts for thrips.
- Screen vents to prevent entry into the greenhouse.
- Use yellow or blue sticky traps to monitor populations. WFT are more attracted to blue than yellow trays.
- Be especially vigilant when nearby hay fields are harvested.

- Thrips are difficult to control using pesticides because they are often hidden within plant parts. Good coverage is critical for good control.
- Thrips are prone to developing resistance to pesticides. Rotation of products and less reliance on pesticides is important.

Biological Control

There are several commercially available predatory mites (*Amblyseius cucumeris*) and insects (*Orius* spp.) for control of thrips in greenhouses. These are most effective and economical when applied on a preventive basis. Apply *A. cucumeris* at a rate of 50/m^2 every 2 weeks and *Orius* spp. at 2 introductions (or 1 if the crop has pollen) 2 weeks apart at a rate of 0.5/m^2. *Amblyseius swirskii* will feed on thrips, whitefly and mites. *Amblyseius degenerans* controls thrips well in flowers and feeds on pollen when prey numbers are low. Beneficial nematodes (*Steinernema feltiae*) sold in a specially formulated product for application to foliage can be used for thrips control on plants and flowers.

Weevils

Several species of root weevils are present in BC. Control is often directed at the adult beetles. Adults are dark coloured with long snouts and feed nocturnally, usually hiding in debris on the ground during the day. Look for fresh notches on the outer edges of leaves. The white or cream coloured grubs have dark heads and c-shaped bodies, and they feed on root and crown tissues in the soil. Several root weevils are common to BC including the black vine weevil (*Otiorhynchus (*syn. *Brachyrhinus) sulcatus*), strawberry root weevil (*Otiorhynchus ovatus*), clay coloured weevil (*Otiorhynchus singularis*), rough strawberry weevil (*Otiorhynchus rugosostriatus*), and woods or bush weevil (*Nemocestes incomptus*).

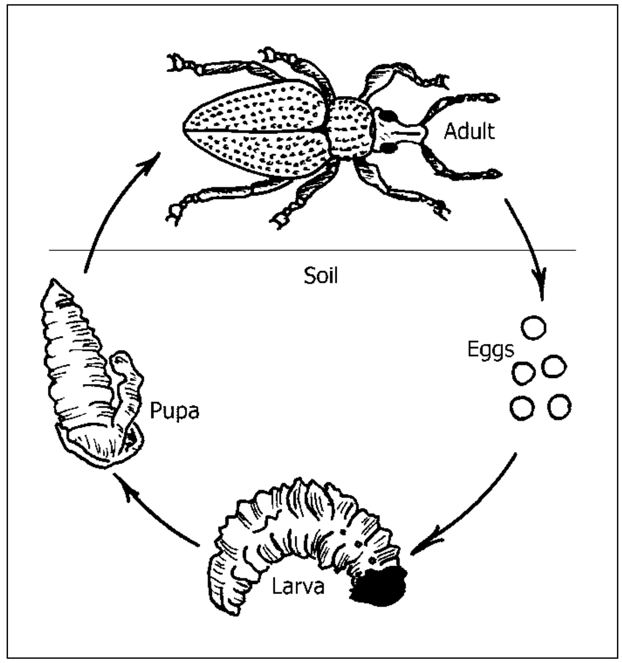
Life Cycle

There is one generation per year. Adult weevils emerge throughout the spring and feed on foliage for about four weeks before mating and laying eggs. Eggs are laid in the soil near target plants where the hatching larvae begin to feed on roots. They overwinter as nearly full grown, non-feeding larvae. The following spring they pupate and emerge as adults. Adult weevils can overwinter in trash and debris in the field and at the margins of cultivated fields. Adult weevils travel by walking and do not fly.

Prevention and Control

- Barriers and/or ditches can prevent movement into new plantings or clean stock.
- Control weeds at the edges of fields and around greenhouses.
- Woody perennials can be banded with sticky traps to prevent adults from climbing the plants to feed. This prevents damage to leaves but not larval feeding on the roots or crowns.
- Place susceptible plants such as cyclamen on benches with sticky barriers attached to the legs.

Figure 7.10: Weevil Life Cycle



Biological Control

Beneficial nematodes are available for weevil management in Canada, including *Steinernema kraussei* and *Heterorhabditis* spp. Nematodes are applied as a drench treatment into the growing media and require adequate watering in to move the nematodes into the soil where the weevil larvae are present. Best results will be achieved if used when the larvae are small, from mid-August until the soil temperature cools to 10ºC in the fall. It may be necessary to water before and after the nematodes are applied in late summer. Results have been best in potted plants, but success has also been achieved in field-grown stock and landscapes as well.

Whiteflies

The two main whitefly species are the greenhouse whitefly *(Trialeurodes vaporariorum)* and the sweet potato whitefly (SPW) *(Bemesia tabaci)*, which is also called Tobacco or Silverleaf whitefly. Greenhouse whiteflies have wings that lay relatively flat across their backs, while the SPW's wings lie upraised at a tent-like angle. The SPW's body is smaller and is more yellow in colour. See Figure 7.11 for a visual description.

Infested plants may lack vigour, wilt and turn yellow. Whiteflies excrete large amounts of honeydew onto the leaves and flowers of infested plants. The honeydew may become colonized with a black sooty fungus giving the plant a dirty appearance and hindering photosynthesis. The SPW will not overwinter outdoors in BC. Greenhouse whitefly will overwinter in protected areas under leaves outdoors in BC. Some hardy whiteflies such as the rhododendron whitefly are occasional problems on cut woody greens.

In 2007, the 'Q bio-type' of the SPW was confirmed in poinsettia crops in Ontario and BC. The Q bio-type is noteworthy because it is more resistant to pesticides than other SPW strains. Trials in Ontario poinsettia crops indicate that a biocontrol program is highly effective in managing SPW, including Q bio-type. The BC Ministry of Agriculture Plant Health Laboratory is equipped to run the molecular test to determine SPW strain, which can be useful to growers at the start of the season as they plan their pest management program for whiteflies.

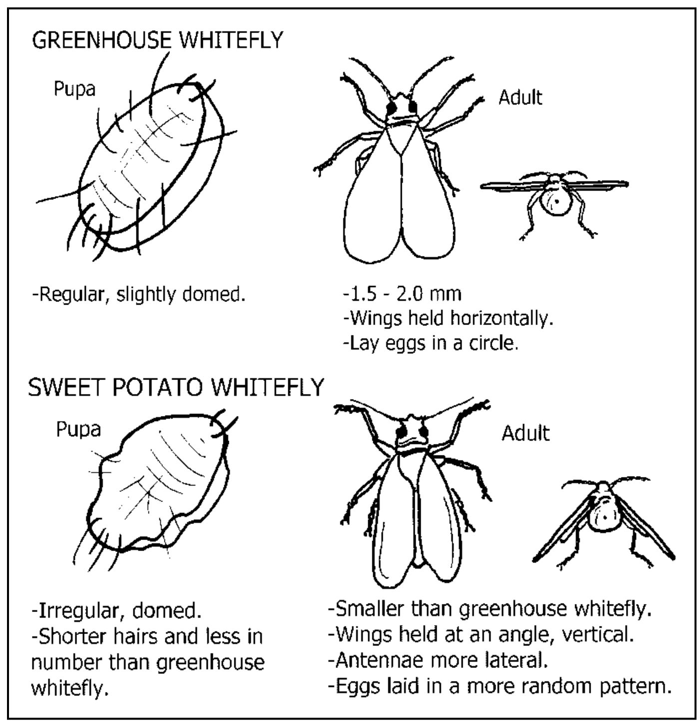
Life Cycle

Adult whiteflies are about 1 mm long and resemble tiny white moths. Adults congregate on the undersides of leaves. Whiteflies are very prolific and have many overlapping life cycles. Females lay a number of small, whitish, oval eggs on the underside of leaves. Eggs are too small to see with the unaided eye. A female can lay up to 400 eggs. After 5 to 10 days the eggs hatch into flat, scale-like nymphs or crawlers that move about the leaf before becoming immobile. After 3 nymphal stages and 1 pupal stage, the adults emerge. The pupae of whiteflies are scale-like and white in colour. They are often mistaken for the eggs. A complete life cycle requires about 3 - 4 weeks.

Prevention and Control

- Remove weeds inside greenhouses and from a 3-metre-wide band around the outside perimeter of greenhouses, as these can harbour whiteflies
- Carefully inspect the foliage of incoming plants for nymphs, scales, honeydew, sooty mould or adults.
- Monitor with yellow sticky traps dispersed evenly among plants, about 1 trap/100 m^2. Traps may be used to control very low adult populations. They can be used alone or in combination with parasites. Adults will be caught on sticky traps long before they are detected in the crop. This early detection is essential for early control.
- Thorough spray coverage of the undersides of leaves is essential for control.

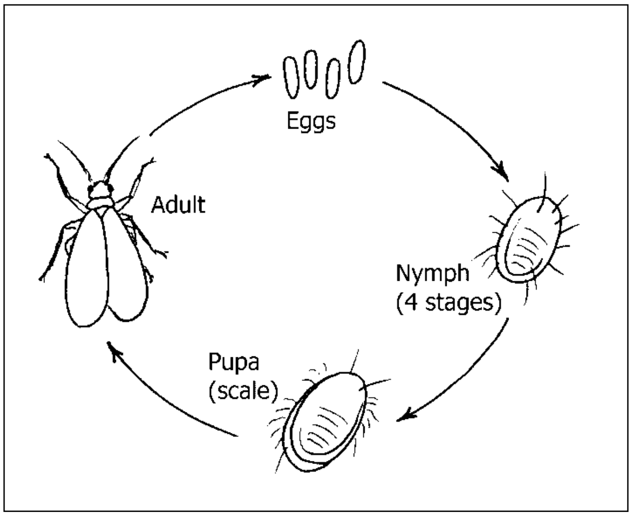
Figure 7.11: Distinguishing Characteristics of Greenhouse Whitefly and Sweet Potato Whitefly



Biological Control

SPW is resistant to more pesticides than the greenhouse whitefly. Biological control is slightly different for the two whiteflies. Biocontrol for the greenhouse whitefly includes the use of the parasitic wasps *Encarsia formosa* and *Eretmocerus eremicus*. For SPW, the biocontrol program includes these wasps in addition to *Eretmocerus mundus*, particularly for early season introductions. A predatory mite, *Amblyseius swirskii*, feeds on whitefly eggs and larvae. It also feeds on thrips and pollen so can be applied before whiteflies are present.

Figure 7.12: Greenhouse Whitefly Life Cycle (18 – 57 days)



Wireworms

Wireworms are the larval stage of click beetles, a shiny, dark beetle capable of leaping into the air with a distinct clicking sound. Only the larvae cause crop damage. They prefer to feed on the roots and underground storage parts of grasses and cereal grains, but when unavailable, they will feed on the roots, rhizomes, corms and bulbs of almost all ornamentals grown in the field. There are several native species, as well as a few major European species (*Agriotes* spp.) that are increasing in range and causing significant field crop damage in BC and the rest of Canada. The larvae are highly attracted by carbon dioxide given off by germinating seeds and roots. Newly hatched larvae must feed within 1 to 3 weeks or starve, but older larvae are able to survive up to 2 years without feeding. Wireworm populations are usually at their highest and most damaging when crops are planted in newly broken sod. Damage is caused by the small tunnels or bore holes they make in the roots and secondary infections that establish. The damage often results in wilting and death of the seedling.

Life Cycle

In spring, batches of 40 - 100 eggs are laid on or near the soil surface. These hatch in 5 - 6 weeks into (3 mm) grubs that are shiny, white and worm-like at first, with three pairs of thoracic legs. The later stages become longer (3 cm), slim and orange as they mature, with tough segmented wiry bodies. All larval stages are spent in the soil and, depending upon the climate and the availability of food, may require 3 - 11 years to reach maturity. They then pupate in the soil, emerging as adults. Larvae move up and down in the soil profile dependent on season, temperature and moisture. Because they can spend a significant time deep in the soil, they can be hard to find and control.

Prevention, Detection, and Control

- In the spring, use baits consisting of 30 g of whole wheat flour buried at 10 cm to detect the presence of wireworms in newly broken fields. Mark the location of the bait with a stake. Baits should be placed at the rate of 50 per hectare. Dig up the baits after four days. An average of 1 or more wireworms per bait can cause severe damage to susceptible crop.
- Avoid planting susceptible crops into infested fields.
- Plant non-host crops for a season at least before planting susceptible crops. This has limited impact because it takes a number of years for wireworms to mature.
- Before planting, sow a “trap crop” of insecticide-treated wheat. This is ideally done in April or May when the wireworms are near the surface.

The most effective wireworm insecticides have been removed from the Canadian marketplace, causing an apparent resurgence of these insects.

Chapter 8 - Weed Control

Weeds reduce crop yields because they compete with for water, light and nutrients. Reductions in yield may be small if only a few weeds are present. However, complete crop failure can occur with high weed pressure. In some cases, when perennial weeds get established, the land cannot be cropped until the infestation has been controlled. Weed control is critical, especially during the early growth stages of a crop. Weeds may also pests that will increase the need for pest controls.

Integrated Weed Management

An integrated approach to weed management is a program that includes prevention as well as physical, cultural and chemical control methods. The following six processes are involved in maintaining a successful integrated weed management program:

- manage resources to prevent weeds from invading;
- proper identification and knowledge of weed species;
- map and monitor weed populations and damage;
- make control decisions based on knowledge of potential crop damage and cost;
- use a combination of control methods to reduce weed levels to an acceptable level; and
- evaluate the effectiveness of methods used.

Prevention

Prevention is the most important but least used method to manage weeds. Wind, water, wild animals, livestock and man are agents of weed dispersal. When weeds are spread by these or other natural agents, control can be very difficult or impossible. Limiting the introduction of weeds and weed parts, and preventing existing weeds from going to seed are two important means of prevention.

Weeds have evolved very effective survival and dispersal mechanisms. Therefore, it is easier to prevent or exclude weeds than to treat established populations. Seed production, particularly for annual weeds, is very high and the seeds can remain dormant in the soil for many years. Perennial weeds are equally insidious since a new plant can arise from a root fragment. Weeds or weed parts are often introduced to the greenhouse or field inadvertently on growing media, planting stock, machinery and contaminated seed or through improperly managed compost and manure.

Careful sanitation practices can go a long way to prevent the introduction and spread of weeds in a greenhouse or the field. Anything that enters the site may carry weeds or weed parts. Machinery should be washed regularly and staff must be aware of the risk of bringing weed parts and seeds in with them on their clothing or other materials. Be sure that all composts and manures are well rotted and always choose certified weed-free seeds for sowing.

Before purchasing soil and media from a new supplier, investigate the steps they take to keep the product clean. The media can be checked for weed seeds using a germination test. Media and plants brought onto a site should be visually inspected for weeds prior to use. If weeds are present, quarantine (if possible) the plants until the problem is corrected. Where weeds or weed seeds are seen or suspected, follow-up treatments will likely be required to prevent them from spreading at the site.

It is important to keep media clean once it arrives at the site. It should be kept dry and clean, and not stored outdoors where it will be exposed to contaminants. If storage outdoors is the only option, then it is recommended to store the media on an impermeable pad and cover with a tarp. It is important not to allow surface water run-off to contact the pile since it may contain pests.

Weeds and weed parts can also be avoided by keeping fence lines, irrigation ditches and farm roads weed free. It is recommended to keep a three to five-meter strip around the greenhouse free of weeds to decrease the potential of weed parts being carried into the structure. Seeds from nearby weeds can also be carried through greenhouse vents by wind. It is important to control weeds on the entire site before they go to seed.

Physical Control

Physical methods can effectively reduce weed levels. Physical controls include mechanical removal (e.g. tillage, hand weeding and mowing), cover cropping and mulching.

Mechanical Removal

Tillage can be an efficient way to remove weeds, although it is a laborious process and great care must be taken not to injure the lower stems and surface roots of desirable plants. This method involves discing or scuffing between planted rows to disturb weed growth. Tillage should be done in the spring or fall. Only the top 10 cm of soil should be worked. Tillage should be timed to catch the first flush of weeds before sowing the crop. Post seeding tillage, if possible, should be done on a dry and warm day so that disturbed weed seedlings are not able to transplant themselves. Remember that weed seeds can germinate even after many years of burial, so while deep tillage buries weed seeds and temporarily minimizes problems, subsequent tillage can bring these weed seeds to the surface again. Keep in mind that poor cultivation practices can damage soil structure and tilth. Do not cultivate too often or when the soil is too wet or too dry.

When weeds are too large or there are too many to control by hand, some alternative control methods include mowing and mechanical removal. Mechanical removal may simply consist of chopping off the tops with a hoe, or using a line trimmer to cut the weeds as low as possible. Food reserves in the root system are depleted following repeated treatments, or the weed is sufficiently stressed to succumb to a pest or environmental stress. Established perennial weeds will usually require several years of frequent cutting before the food reserves in the roots are exhausted. If only a single mowing is possible, the best time is just prior to blooming to prevent the formation and spread of seeds.

Hand weeding and hoeing are possible control options, but the size of commercial operations often limits the practicality of these methods. Hand pulling, burning and even steaming of emerged weeds can be effective but should be done when weeds are young (prior to flowering and seeding) and the soil is moist. Keep in mind that hand pulling established weeds must be done very carefully as leaving any seeds and/or weed parts in the soil will permit the weeds to re-establish.

Mulching and Cover Cropping

Mulches control weeds by creating a relatively dry surface that is inhospitable for weed seed germination and by smothering small weeds. Mulches can exclude light from the tops of the weeds until the reserve food supply is depleted and the weeds starve. In addition to weed control, they moderate soil temperature and retain soil moisture.

Mulching materials include clean straw, hay or manure, tar paper, sawdust, landscape fabric and black plastic. Organic mulches have the additional benefits of providing nutrients and organic matter to the soil. Always remember that plant roots and the inner bark are living tissues. Anything that restricts gas exchange from these tissues will stress and perhaps kill them.

Mulches can be effective in controlling weed growth in container-grown plants. There are a number of drawbacks that limit the use of mulches in containers. Mulches can be difficult and expensive to apply uniformly and efficiently, they do not all hold up well with heavy irrigation, and their effectiveness is dramatically reduced if the integrity of the layer is disrupted by shrinkage or shifting of the mulch. At times the mulch can be phytotoxic. Toxic levels of boron have been found in some mulches. The decomposition of woody mulches can reduce nitrogen availability and lead to slower crop growth. To avoid or correct the situation, about 0.5 kg of nitrogen per cubic meter of sawdust must be added to the crop.

The need for weed control can be reduced for winter annual weeds by sowing a fall cover crop between the rows. Cover crops also provide erosion control and increase trafficability. More information on cover crops is provided in Chapter 2.

Cultural Control

Modifying habitat is an effective method of weed control that is often overlooked. Creating growing conditions that favour the crop relative to weeds can provide a successful and long-term solution to a weed problem. Weeds have evolved particular adaptations to environmental conditions. Changing soil conditions (e.g. correct drainage, pH or compaction problems) and cultural practices (e.g. fertilization, irrigation and pest control) can provide an effective solution to a weed problem, since healthy and vigorous plants are better able to compete against weeds. The advantage of cultural methods, relative to herbicides, is they provide a longer-term solution to weed problems.

Chemical Control – Herbicides

Herbicides are classified in several ways. It is important to understand these classifications because they will help to determine the most appropriate herbicide to deal with a specific weed issue. It is important to know whether a pre- or post-emergent herbicide is required. In addition, it must be decided whether a selective or non-selective, and contact or systemic herbicide is the best option. Understanding these terms is critical to use herbicides effectively.

Pre- and post-emergence refers to the timing of herbicide application relative to the stage of weed growth. Post-emergent herbicides are applied to young, actively growing weeds. They control emerged weeds; they are not active on seeds or seedlings that emerge post-application. In contrast, pre-emergent herbicides are applied to weed-free soil to destroy seedlings as they germinate and emerge. In general, pre-emergent herbicides do not control established weeds.

Selective herbicides control specific weeds. For instance, some herbicides only control grassy weeds. These products do not damage broadleaf plants and are safe to apply over-the-top of them. Nonselective herbicides kill any green foliage or bark that the spray contacts. Nonselective herbicides are commonly used on non-crop areas, such as roadsides and fence lines. However, some nonselective herbicides are registered for use as a directed spray in an established crop. Directed sprays are applied around but not on the crop. Systemic herbicides are absorbed by the roots of foliage and translocated throughout the plant. Systemic herbicides are the most effective option for perennial weeds since they will move into and kill the plant's root system. Contact herbicides are applied to the foliage and kill above-ground portions of the plant.

Information on the herbicides registered to manage weeds in floriculture crops is presented in the document *Pesticides Registered for Ornamental Crops*.

If herbicides are used, they must be applied accurately, under the correct climatic conditions and at the right stage of weed growth for maximum effect. Always read and follow label instructions. Application equipment must be correctly adjusted and used to make accurate and thorough applications. The spray pattern must be even and uniform. **Never use the same sprayer for herbicides and other pesticides.** Always use clean water in the spray tank because dirty water can reduce herbicide effectiveness. In addition, salty or hard water may result in gumminess or precipitates that can plug spray nozzles and result in uneven spray application.

Chapter 9 - Pesticide Regulations and Safety

Legislation

Laws protect applicators, bystanders, consumers and the environment. You can be fined for breaking the laws.

Canadian Laws

Pest Control Products Act & Regulations

All pesticides used in Canada must be registered and have a Pest Control Products number on the label. The intent of the legislation is to ensure the safety, merit and value of pesticides used in Canada. It is an offence under the Act and its regulations to use an unregistered pesticide or to use a product in a way that is inconsistent with the product label. Using a pesticide without a PCP Act # (i.e., from other countries) is allowed if it is in the Own Use Import Program, which can be obtained through the Pest Management Regulatory Agency. Each label must also list the crops and pests it can be used on. The latest versions of all labels can be found at https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php .

Pesticides are labeled as Domestic, Commercial or Restricted. Restricted products are more hazardous and have special restrictions on the label.

Agriculture and Agri-Food Administrative Monetary Penalties Act (AMPs)

AMPs provides an enforcement tool which can be imposed when a person has violated the Pest Control Products Act (PCP), rather than pursuing prosecution under the PCP Act itself. It imposes monetary penalties (like court-imposed fines) through an administrative process with no criminal record or imprisonment.

The Food and Drugs Act

All foods must be free of harmful amounts of substances. Health Canada sets levels of allowable pesticide residues on crops at harvest. These levels are called maximum residue limits or MRLs. The Canadian Food Inspection Agency takes random samples of crops to test for pesticide residues at the time of sale. If residues are more than the MRL the crop may be seized and not saleable. If you follow the label recommendations and wait the required days before harvest, listed on the label as Pre-Harvest Interval (PHI), residues should not be over the MRL.

The Fisheries Act

This Act is established to manage Canada's fisheries resources, including fish habitat. The Act applies to all Canadian waters that contain fish, including ditches, channelized streams, creeks, rivers, marshes, lakes, estuaries, coastal waters and marine offshore areas. The Act includes provisions for stiff fines and imprisonment to ensure compliance.

This Act was updated in 2019 and now empowers the Minister to make regulations for the purposes of the conservation and protection of biodiversity.

Provisions of the 2019 Fisheries Act relevant to agricultural operations include:

- protection for all fish and fish habitats; and
- prohibition against the death of fish or the 'harmful alteration, disruption or destruction' of fish habitat.

Specific sections of the Act include:

- 34.4 (1) No person shall carry on any work, undertaking or activity, other than fishing, that results in the death of fish.
- 35 (1) No person shall carry on any work, undertaking or activity that results in the harmful alteration, disruption or destruction of fish habitat.

Every person who contravenes subsection 34.4(1) or 35(1) is guilty of an offence and liable.

It is illegal to introduce pesticides into waters either directly or indirectly through spray drift or run-off.

Migratory Birds Convention Act

Under the Act, it is an offence to harm the habitat of any migratory bird while the bird is resident at the site or to release any substance (including pesticides) harmful to migratory birds into areas frequented by them.

Transportation of Dangerous Goods Act

Dangerous goods may include pesticides. Transportation of large quantities (more than 500 kg) of pesticides requires shipping documents, special product labels and vehicle placards. Growers are usually exempt from this when they are transporting pesticides for their own use. Farmers transporting more than 1,500 kg of pesticides in a licensed farm vehicle more than 100 km must comply with special requirements.

British Columbia Laws

Integrated Pest Management (IPM) Act and Regulations

The BC Ministry of Environment administers the *IPM Act*. This Act has numerous requirements regarding the use, containment, transport, storage, disposal and sale of pesticides in BC.

Under the *IPM Act*, a person must not "use, handle, release, transport, store, dispose of or sell a pesticide in a manner that causes or is likely to cause an unreasonable adverse effect." It is important for producers to ensure that their pesticide application practices adhere to this because it may be applied when an incident is being investigated.

Rules that apply to farmers include:

1. Pesticides labeled Restricted or Commercial must be kept in a storage area that is vented to the outside, locked and has a warning "Pesticide Storage" sign on the door.
2. Anyone buying or using pesticides labeled Restricted or a pesticide that is listed as "Very Toxic or Moderately Toxic" by WorkSafeBC must have a valid Pesticide Applicator Certificate.
3. An authorization such as a pesticide use license, pest management plan or permit is required to apply pesticides to public land. Contact your local Ministry of Environment office for details.
4. Businesses must be licensed to sell pesticides and their sales people must have a Pesticide Venders Certificate.
5. Anyone applying pesticides in exchange for a fee must have a Pesticide Applicator Certificate and a Pesticide Use License. But if you spray your neighbour's crops you do not need a license if the work is done as a favor and no money is exchanged.
6. Empty pesticide containers should be triple rinsed and taken to an empty pesticide container collection site for recycling. Unused pesticide should be taken to a local Obsolete Pesticide Collection location that occurs every 3 years.

WorkSafeBC (formerly the Workers' Compensation Board)

WorkSafeBC Regulations for Occupational Health and Safety apply to farmers who must be registered by WorkSafeBC. If you are unsure whether they apply to you, call WorkSafeBC at 1-888-621-7233. AgSafeBC, formally known as FARSHA, can also provide information on WorkSafeBC regulations. Call AgSafeBC at 1-877-533-1789.

The WorkSafeBC regulations cover conditions of workplaces such as general safety procedures, hazardous substances, pesticides, confined spaces such as silos and storage bins, protective clothing and equipment, tools, machinery and equipment, and animal handling.

The regulations on pesticides outline requirements for pesticide applicator certification, emergency medical care, washing facilities, personal protective clothing and equipment, application equipment, pesticide application, posting warning signs, re-entry into treated areas, record keeping, drift prevention, and aerial application. Copies of the regulations are available from any WorkSafeBC office.

Their pesticide regulations state that workers must be over 16 years old and must have a valid pesticide applicator certificate from the Ministry of Environment if they mix, load or apply moderately or very toxic pesticides, or if they clean or maintain application equipment for these pesticides.

Anyone under the age of 25 years is considered a young employee and must complete a "new or young employee" orientation. AgSafeBC (1-877-533-1789) can help develop or present a program for your farm.

The WorkSafeBC re-entry requirements are listed in this chapter in the *Re-entry Restrictions* section. The record keeping requirements have been incorporated into the grower's spray record. Refer to the regulations for the rest of WorkSafeBC's requirements.

Pesticide Toxicity

Some pesticides are more poisonous or toxic than others. The categories of pesticide toxicity used in this guide are listed in Table 9.1. The categories indicate toxicity and are based on the LD_{50} of the active ingredient. The LD_{50} values are only a guide to the toxicity of a pesticide to humans.

Table 9.1: Oral and Dermal LD_{50} Values of the Short-Term Toxicity Categories		
Toxicity	**Oral LD_{50}** (mg/kg)	**Dermal LD_{50}** (mg/kg)
Very Toxic	0 to 50	0 to 200
Moderately Toxic	51 to 500	201 to 1,000
Slightly Toxic	over 500	over 1,000

Hazard

The hazard of using a pesticide depends on both its toxicity and the amount of exposure. Reduce hazards by selecting pesticides with low toxicity and by reducing exposure. Wear protective gear and follow safety guidelines.

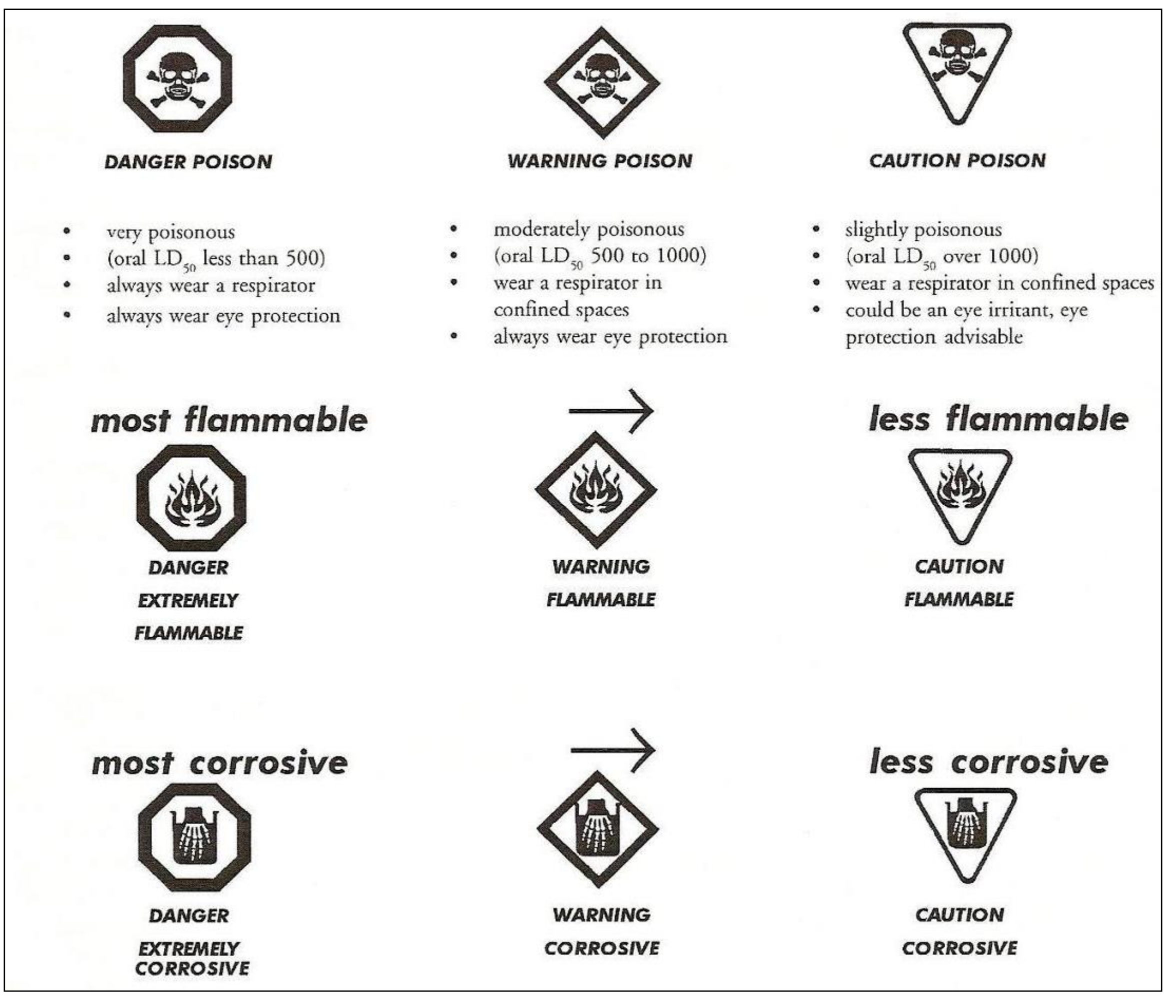
Hazard Shapes and Symbols

Shapes and symbols on pesticide labels indicate how harmful a pesticide can be. The shapes indicate the level of hazard and the symbols inside the shapes specify the type of hazard. If symbols are not on labels, the pesticide has very low hazard and does not require a warning symbol.

Exposure

Pesticides can enter your body through the skin (dermal), the mouth (oral), the lungs (inhalation), or the eyes. The skin is the most common route of poisoning for pesticide applicators. Skin contact may occur from a splash, spill or drift. Your skin is most likely to get contaminated when mixing and loading pesticides.

Figure 9.1: Pesticide Warning Symbols



Poisoning and First Aid

Symptoms of Pesticide Poisoning

Know the poisoning symptoms of the pesticides you use. Read pesticide labels for symptoms. Effects from pesticide poisoning vary from person to person and are often hard to recognize. Some poisoning symptoms are headache, fatigue, nausea, dizziness, irritation of the skin or nose or throat, blurred vision, tiny pupils, trembling, perspiration, difficulty breathing, vomiting, and unconsciousness.

Call the Poison Control Centre or a doctor immediately if you suspect poisoning and follow their instructions.

Poison Control Centres are open 24 hours a day. They give first aid information and treatments for poisoning.

The phone number of the **Poison Control Centre** is **1-800-567-8911**.

First Aid

Make sure you, and other people on the farm, know what to do in case of an emergency. Consider taking a first aid course and CPR course.

If someone has been poisoned:

1. Protect yourself.
2. Move the victim from the area of contamination.
3. Check if the victim is breathing. If breathing has stopped or is very weak, clear the airway and begin artificial respiration. Continue until the victim is breathing normally or until medical help arrives. When doing mouth-to-mouth resuscitation, use a plastic mask to protect yourself from poison.
4. Call the Poison Control Centre or ambulance. Be ready to tell them the pesticide name, active ingredient, and the PCP Act registration number.
5. Unless the Poison Control Centre or doctor tells you otherwise, follow the procedures listed below, then transport the patient to the nearest hospital.

If a pesticide contacts the eyes put on waterproof gloves and hold the eyelids open and rinse with clean water for 15 minutes or more. Do not use an eye cup. Do not use chemicals or drugs in the wash water.

If pesticide contacts the skin, put on waterproof gloves, remove the contaminated clothing, and wash the affected area of the skin with lots of soap and water. Cover burned areas with a loosely applied, clean cloth. Do not apply any drugs or medications to the burned area. Do not use ointments, greases, creams, lotions or other drugs. If the victim is in shock, keep the person lying down and warm until medical help arrives.

If pesticide was breathed in, take the victim to fresh air as quickly as possible, loosen tight clothing and watch for signs of unconsciousness or convulsions. Keep the airway open and begin resuscitation if breathing has stopped or is difficult. Use a plastic facemask to protect yourself. To prevent chilling, wrap the patient in blankets but do not overheat. Keep patient as quite as possible.

If a pesticide is swallowed:

- If a person is conscious and able to swallow, give them ½ to 1 glass of milk or water. Larger quantities may cause vomiting.
- Do not induce vomiting.
- Call the Poison Control Centre for further advice.
- If the patient is retching or vomiting, place the patient face down with their head lower than their body in the recovery position. This prevents vomit from entering the lungs and causing more damage. Do not let the patient lay on their back. Clean the vomit from the patient and collect some in case the doctor needs it for chemical tests.
- When medical advice cannot be obtained, check and follow the pesticide label for directions.
- The doctor may recommend administering activated charcoal to adsorb pesticide still in the stomach. Follow the doctor’s instructions. Activated charcoal should be administered only with the advice of a medical attendant or doctor.

Protective Clothing and Equipment

Wear protective clothing and equipment to minimize exposure to pesticides. Remember to wear safety equipment during mixing, loading, application, and clean-up. Always wear coveralls, waterproof boots, waterproof gloves, and a proper hat. You may also need to wear eye or face protection, a respirator, waterproof apron, waterproof pants and jacket. The equipment you wear depends on the pesticide and type of application. Follow the safety recommendations on the pesticide label.

Coveralls - Wear long-sleeved coveralls over full-length pants and long-sleeved shirts. Make sure the coveralls are closed at the neckline and wrists. Remove your coveralls as soon as you have finished your pesticide activities. Remove them immediately if they become wet through with pesticide. Wear waterproof clothing if you might get wet during pesticide application.

Some disposable coveralls are suitable for pesticide use. Check with your supplier to see which ones can be used for pesticide application. When removing disposable coveralls, take care not to contaminate the inside if you will wear them again. Between wearing, hang them in a well-ventilated area away from other clothing.

Do not launder disposable coveralls but do wash clothing worn underneath the coveralls as you would other clothing worn during pesticide use. Replace with a new coverall when severe pilling (balls on the surface), rips or holes appear. To discard, place in a plastic garbage bag and take to a landfill site. Do not burn used coveralls.

Gloves - Always wear gloves when handling pesticides. Use unlined, waterproof gloves unless the pesticide label recommends a specific material. Do not use gloves made of leather, cloth, or natural rubber, or gloves with cloth linings. Make sure the gloves have no holes or leaks. Keep your coverall sleeves over the gloves and fold down the tops of the gloves to make cuffs. Wash your gloves before removing them and after each use.

Boots - Wear waterproof, unlined knee-high boots of rubber or neoprene when you load, mix or apply pesticides. Wear your pant legs outside of your boots. Do not wear boots made of leather or fabric. Wash the outside of your boots after each use.

Goggles and Face Shields - Wear goggles if there is a chance of getting pesticide spray or dust in your eyes. Do not use goggles with cloth or foam headbands. Do not wear contact lenses when handling pesticides. Face shields provide extra protection when mixing and loading toxic pesticides. Wash goggles and face shields after use.

Hats - Wear a waterproof hat when pesticides may be splashed or when you could be exposed to drift. Wear a wide brimmed rubber rain hat when you will get wet with spray. Do not wear baseball caps, fabric hats, or hats with leather or cloth inner bands.

Aprons - Wear a waterproof apron when you pour and mix concentrated pesticides.

Respirators - Wear a respirator when the label says to wear one; or when the label says to avoid inhalation of dust, vapour, or spray mist; or if there is a danger poison symbol on the label; or if you are applying pesticides in an enclosed space. Make sure your respirator fits. Men should shave before using a respirator as facial hair prevents a proper fit.

Full-face respirators give more protection and may be more comfortable than a half facemask and goggles.

Do not use dust masks when applying pesticides. They do not protect you from the fumes.

Specially designed, enclosed tractor cabs fitted with air-purifying devices can protect you from pesticide vapours. A regular enclosed cab is not adequate protection if a respirator is required.

Respirators must be approved by NIOSH or an agency sanctioned by WorkSafeBC. The cartridges remove toxic fumes from the air. Cartridges labeled for organic vapours or pesticides are needed for most pesticides. Filters remove dust and mist. Both filters and cartridges must be replaced regularly for the respirator to work.

When you use your respirator:

1. Check the intake and exhaust valves.
2. Make sure there are no air leaks around the facemask. Do an inhalation or exhalation test.
3. Change the dust filter after 4 hours of use or more often if breathing becomes difficult.
4. Change the cartridges after 8 hours of use or sooner if you can smell the pesticide. Replace cartridges at least once a year and more often if you use them frequently.

Protective Equipment for Fumigants, Smoke Bombs and Foggers

Use a full-face gas mask with correct canister when applying very toxic pesticides indoors. Keep a spare canister on hand as they can lose their effectiveness. A self-contained breathing apparatus that supplies clean air is recommended for indoor work with gases or extremely toxic compounds.

Wear a full-face mask when lighting smoke bombs and when airing the house. Light the bomb farthest from the door and work toward the door. If smoke bombs are placed in more than one path, they should be lit at the same time by a separate person in each path.

When using fogging machines, wear complete protective clothing, including hat, jacket, pants or coveralls, waterproof gloves and full-face mask.

Cleaning Protective Clothing and Equipment

After application, wash your gloves, boots, goggles, face shield and apron. Wash your respirator face piece with soap and warm water. Then rinse it with clean water and dry it with a clean cloth. Keep the cleaned respirator in a plastic bag in a clean, dry place. Store the respirator and protective clothing away from pesticides and spray equipment.

Discard clothing that has been soaked with a pesticide.

Launder all your clothing after each day of applying pesticides. Wash protective clothing separately from the rest of the laundry. Do not touch contaminated clothing with bare hands. Use rubber gloves. Pre-rinse clothing using the presoak cycle. Use a high-water level and the hottest water setting on your machine. Use a heavy-duty detergent.

If clothes are heavily contaminated, run through two complete cycles. Hang clothes outside to dry in the sunlight if possible. Clean the washing machine by running it through a full cycle with detergent and no clothes to remove any pesticide residue.

Personal and Environmental Safety Guidelines

Buying Pesticides

- Make sure the pesticide is registered for your specific use (crop and pest).
- Only buy what you can use up in a year.

Transporting Pesticides

- Never transport pesticides with food, feed, fertilizer, clothing, or household goods.
- Lock up the pesticides if you leave your vehicle.
- Never transport pesticides in the passenger section of any vehicle.
- Ask the supplier if you need shipping papers and vehicle warning signs.

Storing Pesticides & Shelf Life

Pesticides vary in their stability and response to storage conditions. Try to only purchase quantities of pesticides that can be used up in one growing season. However, under proper storage conditions most pesticides can be used after at least one year of storage.

Follow these guidelines for storage:

- The law says Commercial and Restricted pesticides must be kept in locked and vented storage that has a warning sign on the door.
- Store pesticides in their original container with the original label. If a label is illegible or missing, label it with the trade name, active ingredient, quantity in the container and PCP number. Then obtain a replacement label from your dealer or the PMRA website.
- Never keep pesticides near livestock, food, feed, fertilizer, seed, wells, water supplies, or in your home.
- Pesticide storage should be 30.5 metres from any well.
- Keep herbicides separate from other pesticides.
- Return pesticides to storage when not in use.
- Keep a list of the pesticides in storage.
- Protect the pesticides from extreme temperatures. Freezing destroys some liquid pesticides.
- Close containers when not in use.
- Dispose of unwanted, unmarked and damaged containers.
- Keep containers above floor level to protect from dampness and flooding.
- Post emergency numbers nearby.
- Keep a fire extinguisher, broom and shovel, absorptive material, and protective clothing near-by in case of emergencies.

Mixing and Loading Pesticides

- Wear protective clothing and equipment.
- Read and follow label directions.
- Choose a mixing and loading site away from people, livestock, pets, wells, and water bodies.
- Measure accurately.

- Do not rip open paper pesticide bags. Slit them open with a sharp knife.
- Mix pesticides in still or low wind conditions. Stand upwind of the pesticide.
- Hold the container below eye level when measuring or adding pesticide into the spray equipment.
- Only use mixing equipment for pesticides and return it to locked storage when not in use.
- Triple rinse pesticide containers as soon as they are empty. Rinse measuring and mixing equipment. Put rinse water into the sprayer.
- Use clean water. The pH of the water should be from 5.0 to 7.0, and the alkalinity should be below 60 to 80 ppm.
- Prevent overflow. Don't leave the tank unattended.
- Prevent contaminating the water supply by leaving at least a 15 cm air gap between the end of the filler hose and the water in the spray tank. You can also use a backflow preventer valve.

Applying Pesticides

- Read and follow label directions.
- Use calibrated application equipment.
- Use the label or production guide rate.
- Wash before eating, drinking, smoking, or using the toilet.
- Have fresh water and emergency supplies on hand.
- Make sure the area to be treated is clear of people and animals.
- Don't work alone when handling very toxic pesticides.
- Post warning signs, if necessary, to keep people out of treated areas.
- Use separate equipment for applying herbicides.
- Cover or remove animal food and water containers near the treatment area.
- Wear gloves to replace or clean plugged nozzles. Do not blow out a plugged nozzle or screen with your mouth. Use a soft brush or toothpick.
- Shut off the spray nozzles when you turn and stop the flow of granulars at the end of rows.
- Use and maintain the tractor speed chosen during calibration.
- Pesticides must be registered for chemigation before they can be applied through irrigation systems. Therefore, only apply pesticides through the irrigation system when the label has instructions for chemigation. If chemigation is used, follow *Chemigation Guidelines for BC.* This publication is available from the Irrigation Association of BC.
- Prevent pesticides from contaminating non-target areas. Leave an untreated area around lakes, streams, ditches, and wells. Spray downwind from sensitive areas.
- Minimize drift by:
  - not spraying in strong winds or dead calm. There is usually less wind in the early morning and late evening.
  - not spraying when temperatures are >30°C.
  - using boom sprayers with as low pressure as possible, the correct nozzles, large volumes of water, and setting the boom as near to the ground as possible to still get uniform coverage.
  - using a drift control agent.
  - using drift guard or other specialty nozzles that reduce drift.

After Applying Pesticides

- Clean equipment away from water supplies.
- Remove and clean protective clothing and equipment.
- Shower.
- Keep records of every application.

Disposal of Unwanted Pesticides

- Calculate the amount needed so none is left over.
- Do not re-spray an area to get rid of leftover spray.
- Apply left over material according to label directions on another site or crop listed on the label. Do not put unwanted pesticides into sewers, down drains, or on the land.
- Contact the regional office of the BC Ministry of Environment or Ministry of Agriculture for information on the disposal of unwanted pesticides.

Disposal of Containers

- Drain the container into the spray tank for at least 30 seconds or shake out the bag.
- Triple or pressure rinse drums, glass bottles, plastic and metal containers. Single rinse plastic and paper bags.
- Put the rinse water into the spray tank.
- Crush, puncture or damage empty containers so they cannot be re-used.
- Hold the containers in the pesticide storage room until they can be taken to a public dump, back to the supplier or to a collection site. Containers can be buried on your land 0.5 metres below the surface. The burial site must be flat, not a bog, gravel or sandy soil and at least 200 metres from wells, lakes, rivers, streams or ponds.
- Do not burn pesticide containers.

Re-entry Restrictions

Poisoning may occur when people work in treated areas too soon after pesticides have been applied. Such poisoning may be from breathing pesticide fumes or handling treated plants. Most pesticide labels state when treated areas can be re-entered. Follow these directions.

When there is no re-entry time on a pesticide label, follow the WorkSafeBC regulations, which state that people may not enter a treated area until the re-entry interval has passed. The re-entry intervals are:

- 24 hours for a slightly toxic pesticide,
- 48 hours for a moderately or very toxic pesticide, and
- the most restrictive of the re-entry intervals for tank mixes of moderately and very toxic pesticides.

If a person needs to enter a treated area before the re-entry period is over, wear protective gear. Farmers must post a sign that informs workers when they can enter a field. The sign must state the application date and the re-entry time. Signs can be obtained from AgSafeBC.

Grazing Restrictions

If animals are to graze a treated area, check the pesticide label for grazing restrictions. Wait the required time before grazing.

Special Environmental Precautions

Buffer Zones

Many pesticide labels now contain buffer zone information. Buffer zones are strips of land next to sensitive areas that cannot be treated with a pesticide (see Figure 9.2). The purpose of the buffer zone is to protect sensitive areas from pesticide drift.

Applicators are required to leave a buffer zone when the label says to. A buffer zone only needs to be left between the end of the spray boom and the downwind sensitive area. Labels will tell you what sensitive areas must be protected and the size of the buffer zone. Labels may require protection of water bodies (aquatic) or planted areas (terrestrial).

Protecting Fish and Other Wildlife

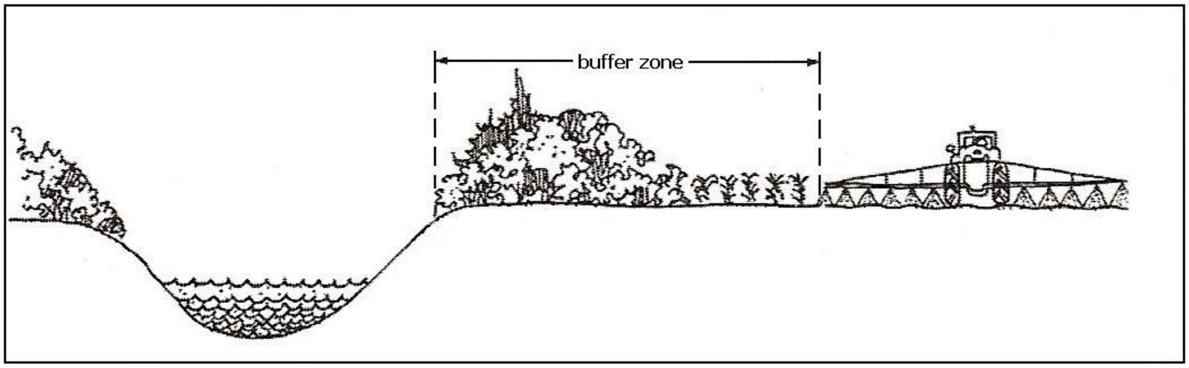
Some pesticides are very toxic to fish, birds and wildlife. Exposure to trace amounts of these pesticides may kill fish or birds. Destroying the vegetation along fish-bearing water harms fish by removing food and shelter.

Although migratory birds may be pests and damage crops, it is an offence under the Migratory Birds Convention to release any substance that may harm them. Responsible pesticide use helps to protect migratory birds.

Protect fish and wildlife from pesticide poisoning by following label precautions and the guidelines below:

- Use pesticides only when necessary.
- Select the least toxic and least persistent pesticides.
- Follow label directions regarding the size of buffer zones from downwind bodies of water to keep pesticides out of the water.
- Do not destroy vegetation along fish bearing waters and do not spray with pesticide.
- Incorporate granular pesticides.
- Use precautions to prevent drift, leaching and run-off to areas outside the treated area.
- Store treated seed where it cannot be eaten by animals.
- Place baits in approved covered bait stations.

Figure 9.2: Schematic of Pesticide Buffer Zones



Protecting Bees and Beneficial Insects

Bees and other pollinating insects are essential to produce many horticultural crops. Some beneficial insects help control pests. Many pesticides, particularly insecticides, are very toxic to honeybees, wild bees, and beneficial insects. Protect these insects from pesticide poisoning.

- Tell nearby beekeepers about your spray program.
- Do not apply pesticides near hives.
- Do not apply pesticides toxic to bees when plants are in bloom.
- Select formulations least harmful to bees. Microencapsulated formulations are very hazardous; dusts are more hazardous than sprays; wettable powders are more hazardous than EC and liquid formulations; granular formulations are least hazardous to bees.
- Reduce drift.
- Time applications carefully. Evening sprays are less hazardous than morning sprays. Both are safer than spraying in the midday.

Protecting Groundwater

Groundwater is the source of water for wells and springs. It is very difficult to clean contaminated groundwater. The solution to groundwater contamination is prevention.

Groundwater contamination is most likely to occur where soils are gravelly or sandy, the water table is close to the soil surface, there is high rainfall or extensive irrigation, or the pesticide is injected or incorporated into the soil.

Remember to avoid spills, drift, and irrigation run off and to properly dispose of unwanted pesticides and empty containers. Never store pesticides near wells or pumphouses and guard against leaking containers. Mixing, filling and cleanup sites must be at least 30.5 M away from any well or water.

Well construction, maintenance and location can be factors in contamination. Maintain proper seals between pump and pump base, as well as seals between well casings.

Streamside Protection

Protecting stream bank or riparian habit is an important part of environmental health, fish protection, and water quality.

There are numerous laws related to the protection of fish habitat, wetlands and streamside areas, including the *Water Act*, *Fisheries Act* and the *Integrated Pest Management Act and Regulations*. Farmers and producers are expected to exercise due diligence to ensure that they are conforming to regulations. They should also recognize that voluntary actions help to protect the environment.

Growers are encouraged to:

1. identify fish habitat, wetlands, and streamside areas on their farms,
2. assess whether any farming practices could harm these areas, and
3. modify practices to ensure they do not harm fish habitat, wetlands, and streamside areas.

The BC Agriculture Council’s (BCAC) Environmental Farm Plan Program (EFP) will facilitate these activities. Contact your grower association or the BCAC for more information on the program. EFP materials include a riparian management guide that will help to assess streamside areas.

The federal *Fisheries Act* prohibits the deposit of deleterious substances into streams. This includes farm products such as pesticides, fertilizers or wastes. It also prohibits harmful alteration or destruction of fish habitat. This includes changes in fish habitat that reduces its capacity to support fish (i.e. removal of streamside vegetation).

The provincial *Integrated Pest Management Act and Regulations* prohibits the use of a pesticide in a way that would cause an unreasonable adverse effect.

Emergency Response

- Keep the phone numbers for the Poison Control Centre (1-800-567-8911), doctor, ambulance, and Provincial Emergency number (1-800-663-3456) for dangerous goods spills nearby.
- Have protective gear and equipment available.
- Keep absorptive material, a container for contaminated waste, tools to pick up contaminated material, bleach and hydrated lime available.

Spills

- Protect yourself.
- Keep bystanders away.
- Don't eat, smoke or drink during clean up.
- Work upwind of the spill.
- Contain the spill. Surround and cover it with absorbent material.
- Clean up the spill.
- Decontaminate the area using bleach or detergent. Absorb excess liquid with absorbent material.
- Put contaminated absorbent material in the special waste container and seal it.
- Remove and wash protective gear. Shower.
- If you need help, call the Provincial Emergency number (1-800-663-3456).
- All pesticide spills of ≥5 kg (or 5 L) must be reported to the Dangerous Goods Incident Report (DGIR) by calling 1-800-567-8911

Fires

Fires involving pesticides can be very dangerous because toxic fumes may be released that are poisonous to firefighters, bystanders and animals, or that may contaminate the environment.

Pressurized containers can explode, and pesticides can spill out of containers damaged by the fire. Runoff can contaminate a larger area.

Ahead of time, provide your fire department with a list of pesticides in storage (e.g. brand names, active ingredient, PCP #'s). Update the list each year.

In case of a fire, call the fire department and tell them there is a fire involving pesticides. Keep people and animals away from the fire.

For more information on practices to reduce the risk of pesticide fires, see the Ministry of Agriculture Pesticide Wise website.

Tank Mixing Pesticides

It is often both economical and convenient to apply a mixture of two or more pesticides when more than one pest is to be controlled. However, if the pesticides are not compatible, applying the tank mix may result in damage to the application equipment, poor pest control or plant injury.

Many pesticide labels contain a list of compatible pesticides. Some labels even contain directions for mixing it with other pesticides. Compatibility charts are also available on the Internet. This information is useful to determine whether two pesticides are compatible, but additional precautions should be taken when trying new pesticide mixtures.

The compatibility of the mix should be tested by mixing the pesticides in a small volume of water in the relative proportions the grower plans to use them.

The components should mix well when the mixture is stirred or shaken. The mixture should not separate nor should components settle out rapidly upon standing. Apply new mixtures initially on a small scale.

In general, it is riskier to mix two different types of formulations, for example wettable powders with emulsifiable concentrates. When using emulsified concentrates, always read the warnings on the manufacturer's label. When two or more chemicals are combined in the tank, the solution should be applied promptly to reduce the risk of crop injury or a decrease in effectiveness.

Spray injury can also arise from a variety of other causes. Improper operation of sprayers, excess dosage of chemicals, sudden weather change during or following spraying, sprays applied at low volume, or spraying during extremely hot periods, (32°C or higher) may cause either fruit or foliage injury.

Chapter 10 - Pesticide Application Equipment

Sprayer Basics

High-Volume Sprayers

Conventional pesticide application involves chemicals diluted in large amounts of water. The large amounts of water (high-volume) are used because conventional sprayers produce large spray droplets (100 to 400 microns in diameter) and the spray is applied until the foliage is visibly, thoroughly sprayed to get uniform coverage. High-volume or dilute sprays are well suited to low pressure back-pack sprayers, whereas using low-volume back-pack sprayers it is next to impossible to achieve uniform coverage. Run-off occurs if excessive high-volume spray is used and the active ingredient will not cover the foliage well with the large droplets if too little spray is applied. The large droplets minimize the risk of drift in field conditions. High-volume spraying is sometimes referred to as dilute spraying.

Low-Volume Sprayers

Low-volume is a relative term that is used differently by various groups. A low-volume rate for field application is not the same as a low volume rate in greenhouses. Low-volume (LV) pesticide application normally refers to spraying pesticides at the labelled rate (per area) with much less water, resulting in a more concentrated spray mixture. Thus low-volume equipment applies the same quantity of pesticide active ingredient to a given area as high-volume spraying equipment. The term low-volume refers to the small amount of water or diluent used to apply the pesticide. Low-volume spraying is sometimes referred to as concentrate spraying. Conventional field sprayers can be operated as both high and low volume sprayers depending on nozzle selection and travel speeds. Low volume in greenhouses is typically associated more with misters and foggers that are used only in greenhouses. Misters and foggers are ultra-low-volume when compared to most field sprayers.

Droplet Size

Spray droplets are categorized based on their size and size can vary greatly depending on the spray equipment. Spray droplet size and typical uses are shown in Table 10.1.

Very small droplets are typically used in greenhouse misting or fogging operations and are generally termed low-volume, or even ultra-low-volume applications. The droplets are tiny enough to remain suspended in the air for long periods.

Spraying with smaller droplets results in less spray used to cover the surface. Because the volume of the droplet is based on the cube of the droplet diameter, one thousand 10-micron diameter droplets have the same volume of water as one 100-micron diameter droplet. Relative to a single large droplet, the 1,000 small droplets will cover the surface area much better, are less prone to run-off, and are more easily carried by the swirling airstream to the undersides of leaves. While the science behind droplet transport and impact on plant surfaces is complicated the results are not; smaller droplets mean more area is covered with less water and less run-off.

The disadvantage of smaller droplets is that they are more prone to drift in field applications due to wind conditions. Smaller droplets are also more vulnerable to dry air conditions which may cause the water carrier to evaporate before the droplet lands on the target. In greenhouses this may restrict mister and fogger use to night-time when workers are not present and when the venting systems can be closed to contain the mist and fog within greenhouses. This would cause overheating during warm, sunny days. The air circulation system of LV sprayers is used to help distribute the pesticide spray throughout the greenhouse, so it is possible to apply pesticides without any workers in the greenhouse. By venting the greenhouses and observing the re-entry times, potential worker exposure to pesticides is reduced.

In field operations, reducing droplet size is limited by the greater risk of smaller droplets drifting away from the application area.

Table 10.1: Typical Droplet Sizes for Various Types of Pesticide Applications		
Type of Spray	**Average Droplet Size** (microns)	**Examples of Uses**
Fog	0.1 - 5.0	greenhouse foggers
Fine mist	5.0 - 50	greenhouse misters
Coarse mist	50 - 100	air-blast and high pressure boom sprays of insecticides or fungicides
Fine spray	100 - 250	typical insecticide or fungicide sprays
Medium spray	250 - 500	typical flat fan nozzle herbicide sprays
Coarse spray	500 - 700	low pressure flat fan nozzle herbicide sprays
Very coarse spray	700 - 1,000	large droplet flooding fan and raindrop nozzle sprays for soil applied herbicides

Monitoring Spray Coverage

Decisions on the type of pesticide application equipment to use and whether to use high or low volume spraying should be based on which provides the best coverage. If purchasing new equipment, arrange a trial where the new technology can be tested for coverage. Obtaining complete coverage is critical to good pest control and good coverage is not as obvious when spraying with lower volumes that do not "wet the crop to the point of run-off".

Water sensitive paper available from most sprayer supply companies can be attached to tops and bottoms of leaves with paper clips. Spray drops of water will be visible as small coloured dots on the paper. Very fine droplets such as fogs and smaller mist droplets may be too small to register on the water sensitive paper. For these sprays buy a florescent dye to be mixed in the water then view the leaves under a black light to see the coverage of the spray droplets. Contact your local Ministry of Agriculture office for more information.

High-Volume Spray Equipment

Backpack Sprayer

The most common spraying equipment on small operations is the backpack sprayer. It is suitable for high-volume or dilute spraying both in field and greenhouse conditions. Basic, low cost backpack sprayers will generate only low pressures and lack features such as diaphragm pumps, agitators, pressure adjustment controls (regulator), and pressure gauges found on commercial grade units. Low pressure sprayers that lack pressure regulators and gauges should not be used to apply pesticides that require uniform. This is especially true with some of the plant growth regulars where uniform coverage is a crucial part of their effectiveness. These sprayers with their limited control options are better suited for the home gardener situation.

Diaphragm pumps and agitators will allow sprayers to be used with wettable powder sprays more effectively. Pressures should be above 80 psi to achieve the finer sprays suitable for applying insecticides and fungicides. Pressure gauges and pressure regulators enable the sprayer to operate at higher pressures (80 to 200 psi) and the operator to achieve a more uniform output from the sprayer. Note that a smooth, uniform walking speed and spray wand motion is also required to achieve uniform coverage. Nozzles must be selected for the operating pressure of the sprayer and spraying conditions. Backpack sprayers should have a positive shut-off spray control valve to eliminate pesticide drips from the wand and nozzle. Drip-proof nozzle assemblies are also available as an alternative. Ball check valves in the nozzle body require 5 to 10 psi of liquid pressure to start spraying and close when the pressure drops below this level to prevent drips.

Powered Boom Sprayers

Electric or gas engine powered backpack sprayers can be compared to tractor mounted low powered boom sprayers for field use or to cart mounted boom systems for greenhouse use. These sprayers are typically classed by the pressures they attain; low pressure (up to 60 psi) hydraulic sprayers forming coarse droplets are suitable for herbicide applications and high pressure systems (80 - 300 psi) forming finer droplets are suitable for insecticide and fungicide applications. The higher pressure causes the spray to travel at higher speeds, creating air currents and penetrating plant canopies more effectively than the low pressure coarse sprays. The downside is that the risk of off-target spray drift is much greater with high pressure, fine droplet sprays than with low pressure, coarse droplets. Tractor operated sprayers have an advantage over hand operated sprayers because they can maintain a steady forward speed. With a properly set-up boom, tractor based sprayers provide a more uniform coverage than hand operated sprayers, especially when smaller droplets and lower spray volumes are used.

Specialized Greenhouse Pesticide Equipment (LVMs)

Pesticide application equipment for greenhouses is often differentiated by the kind of particle they produce, namely mists, fogs, or smokes. A more accurate method to group them is by the method used to make the droplets rather than by the particle size. Technically the four pesticide applicators, mist blowers, thermal foggers, high pressure applicators, and compressed air systems, are all low volume mist (LVM) systems. They produce fine droplets, less than 100 microns in size and they use very low water volumes. However, industry terminology generally only refers to the compressed air systems as LVMs. Table 10.2 compares the four specialized greenhouse sprayers.

Mist Blower

A small engine and fan creates an air stream with a velocity of 100 to 200 mph. Concentrated spray injected into the air stream by a special nozzle is carried to the target by the air. Application is done by the applicator walking through the greenhouse directing the nozzle into the plant canopy to get good penetration and coverage. Nozzles held too close to the plants may cause blast damage. For good coverage, the nozzle should be moved at a pace that replaces the air within the canopy with air from the mist blower. They are suitable for large and small treatment areas. Greenhouses do not have to be tightly sealed during application; vents may remain open, but fans should be turned off. Rotary misters use a spinning disc to break up the spray into small droplets. The spray stream must be directed at the crops and moved up and down to take advantage of air turbulence and get good distribution. Some manufacturers also include a fan behind the disc to propel the spray towards the target and create a turbulent air stream. They are also referred to as controlled droplet applicators and rotary atomizers. Trade names include: “Ulvafan”, “Electrafan”, “Motafan”, and “Turbair”.

Thermal Fogging Machines

Thermal foggers have been used for many years. They are usually gasoline-powered backpack or cart mounted units that are moved throughout the greenhouse as they operate. The pesticide is sprayed onto a hot element and evaporates. As it condenses it produces a heavy fog that drifts through the greenhouse and penetrates the foliage. It covers both upper and lowers surfaces of the crop. Thermal foggers require specialized carrier solutions to produce a visible fog, eliminate the evaporation of droplets, and to ensure uniform particle sizes. The pesticide usually is sold as a ready to apply mixture with the carrier. Greenhouses must be tightly sealed during application and for several hours afterwards to allow the fine particles to settle out of the air. Trade names include: “Pulsfog”.

High Pressure Pesticide Applicator

This specialized greenhouse pesticide applicator uses extremely high pressures (1,000 to 3,000 psi) to create extremely fine sprays. Sprayers working at 3,000 psi can produce spray droplets averaging 30 to 60 microns in diameter that are projected 20 to 25 feet from the spray gun. A small spray tank, motor, pump, long high pressure hose, and hand gun are all mounted on a small wheeled hand cart. Applicators walk slowly through the greenhouse directing the spray ahead and into the crop. They do not require special fogging solutions. It is not necessary to tightly seal the greenhouse during application; vents may remain open, but fans should be turned off. They are also referred to as mechanical foggers. Trade names include: “Coldfogger”.

Compressed Air or Aerosol Generators

These devices use compressed air to break the spray liquid into small drops using an air atomizing nozzle. The nozzles are typically placed in front of a fan which disperses the spray into the greenhouse space. These units are often used as stationary sprayers that rely on the greenhouse’s air movement system to circulate the spray throughout the area to be treated and through any dense foliage.

Table 10.2: Comparison of Specialized Greenhouse Sprayers				
Sprayer	**Droplet size (microns)**	**Tightly sealed greenhouse**	**Moved by applicator or stationary**	**Special carrier solution**
Mist blower	60 - 80	no	moved by applicator	no
Thermal fogger	12 - 25	yes	moved by applicator	yes
High pressure	30 - 60	no	moved by applicator	no
Compressed air	5 or less	yes	stationary	no

These sprayers are designed to operate unattended from a single location in the greenhouse. The spray mixture is placed in the tank and a timer set to start the application when staff are not present. Good coverage depends upon proper placement in the greenhouse and good air movement throughout the greenhouse. Special fogging solutions are not required. Greenhouses must remain tightly sealed during application and for several hours afterwards. Trade names include: “Autofog”.

Electrostatic Sprayers

This is not a separate class of sprayer, rather it’s a feature that is found on some of the previously mentioned sprayers. Electrostatic sprayers electrically charge droplets as they leave the nozzle. The charged droplets penetrate the foliage and adhere to all plant surfaces, including the underside of leaves.

Smoke Fumigators - Cans

A pesticide fog or smoke that comes in ready-to-use cans. When the fumigant is ignited, the smoke carries the pesticide throughout the greenhouse on air currents. Each can is sufficient for a certain volume of greenhouse. Greenhouses must be tightly sealed during and after application. Use only when there are no staff in the area.

Sprayer Components

Power Source

The power-sprayer is normally driven by the PTO (power take off) of the tractor or by an auxiliary engine. The power rating of these should be double the theoretical power required by the pump.

Pumps

A pump creates the pressure required for atomization and penetration of the spray. Choose a pump that has the specifications required for your job. The capacity of the pump should be determined by the highest rate of application the sprayer is expected to deliver, plus an adequate volume for agitation.

Common pumps include:

- roller pump: excessive wear can occur with wettable powders
- piston pump
- diaphragm pump

Tanks

The size of the spray tank will depend on the intended rate of application and the mounting space available. For proper mixing, it is important to know the volume capacity of your spray tank. The tank should be equipped with a large screened opening for easy filling and cleaning. Tanks may be constructed of steel, stainless steel, epoxy-coated steel, fibreglass, aluminum or polyethylene. Stainless steel, polyethylene and fibreglass tanks are preferred because they do not rust or corrode. Neither the herbicide glyphosate nor liquid nitrogen should be put into galvanized steel tanks as hazardous chemical reactions can occur. Rusting of steel tanks can be reduced by proper draining, cleaning and airing of the tank after use and by using rust-proofing compounds. Either hydraulic by-pass or mechanical agitation must be provided. If hydraulic agitation is used in the spray tank, additional pump capacity is required. Mechanical agitation is preferred for wettable powders.

Nozzles

The size of droplet produced by various nozzles depends upon operating pressure and nozzle design. The droplet size decreases with an increase in pressure and with a decrease in nozzle orifice diameter.

Types

The main nozzle types used for chemical application are (see Figure 10.1):

- Tapered flat-fan spray nozzles are used for low volume, low pressure spraying such as the application of herbicides and insecticide drenches. They are also known as fan type or T-jets. They produce a fan type pattern with less material applied along the edges of the spray pattern. By properly over-lapping the spray, a uniform application is produced across the area covered by the spray boom. Nozzle spacing on the boom and height of the boom above the target are critical in obtaining a uniform coverage. Sprayer equipment suppliers can advise growers as to the correct height of the boom at different nozzle spacings.
- Even flat-fan spray nozzles produce an even spray pattern across the entire fan width. These nozzles are used in band spraying of herbicides where there is no overlap from other nozzles.
- Cone nozzles are used for high pressure spraying (mostly fungicides and insecticides). These nozzles produce a swirling mist so the spray material can reach the undersides of leaves. They are available as either hollow cone or solid cone types - both produce the same swirling mist but the solid cone nozzles are used when larger volumes are required. The most commonly used cone nozzles are the two-piece disc-core nozzles. They must be correctly installed with the rear nibs facing the nozzle body. See Figure 10.2.
- The size of droplet produced by various nozzles depends upon operating pressure and nozzle design. The droplet size decreases with an increase in pressure and with a decrease in the orifice and swirl plate openings. Various sizes of swirl plates and orifices can be fitted in the same nozzle body.

Sizes

Various sizes of flat and cone nozzles may be used to obtain the volume of water desired. Your sprayer equipment supplier should have information on nozzle flow rates for different nozzle sizes.

Materials

Nozzles are made from a variety of materials. Choice of material depends upon the abrasiveness of the spray mixture. Wettable powders are more abrasive than emulsions. Brass tips are cheap but the metal is softer and the tips wear faster. In sequence of durability the following materials are used: brass, stainless steel, hardened stainless steel, ceramic, and tungsten carbide.

As nozzles wear out, the rate of application increases. Tests have shown that some wettable powders wear nozzles sufficiently to increase the rate as much as 12% after spraying only 20 ha. For this reason, frequent calibration of equipment is necessary. Spray patterns are distorted and uneven applications result from worn nozzles.

Figure 10.1: The Main Nozzle Types Used for Chemical Application

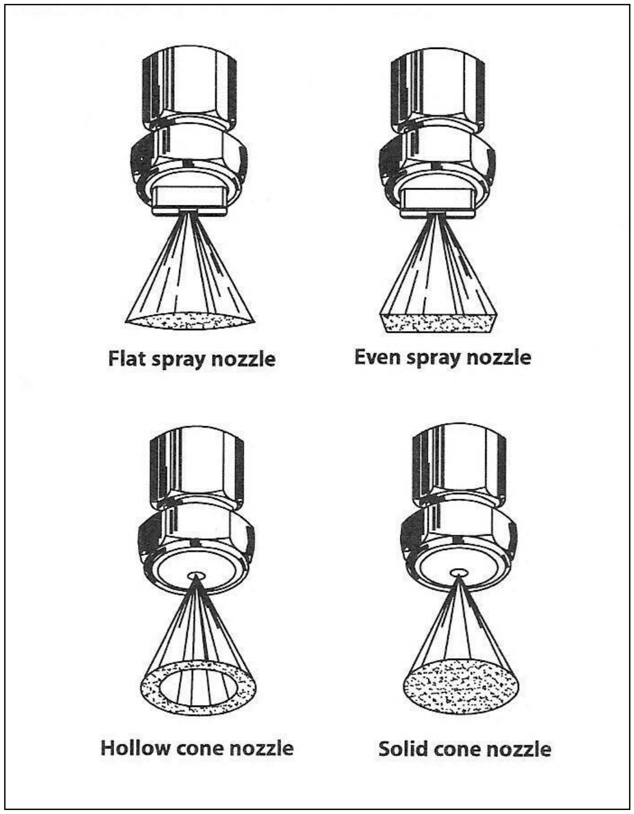
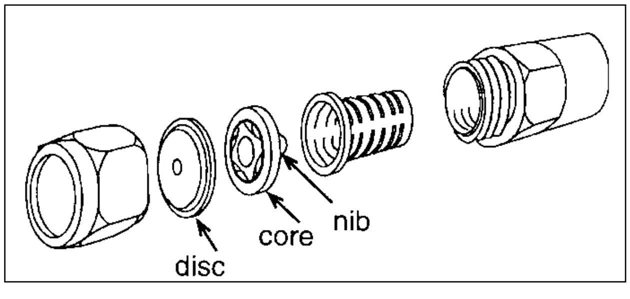


Figure 10.2: Assembly of Disc-core Cone Nozzles



Screens

Screens prevent larger particles from entering the system, clogging nozzles, and wearing out the pump.

There should be screens in the tank opening, between the tank and the pump, and in the nozzle tips. Suction strainers, line strainers and nozzles should all be equipped with 50 mesh screens when wettable powders are to be used. Screens finer than 50 mesh, for example 100 mesh, may prevent the unrestricted flow of some wettable powders. Screens are generally used in fine nozzles, but slotted strainers can be used in those that have a larger opening, and with cone nozzles. Clean screens and strainers are essential to the efficient operation of the spray system. They should be cleaned often and checked for breaks in the mesh.

Mixing Chemicals

When mixing the chemical in the sprayer tank, **NEVER** put the chemical in first and then top up with water. Always fill the tank ⅓ to ½ full with clean water, start the agitator and then add the required quantity of chemical. Continue the agitation while continuing to fill the tank. If two or more chemicals are to be applied together, first check the labels for compatibility and then add the first chemical at the ⅓ to ½ full stage and the second chemical at the ⅔ to ¾ full stage. Mixing by this method will ensure that the chemical is completely mixed in the water. Wettable powders can be premixed before being added to the spray tank. Make a slurry of wettable powder and water and then pour it into the spray tank. Always follow manufacturers' directions when mixing. Always keep the agitator running once the spray materials have been added to the tank.

Sprayer Cleaning

Immediately after use, drain and collect any excess spray mixture. This excess solution can be very difficult to dispose of properly, therefore spray applications should be properly calibrated to avoid any excess. Flush the sprayer with soapy water and then rinse with clean water. Select a cleaning area where water will not contaminate wells, streams, or crops.

Separate equipment is recommended for applying 2,4-D, MCPA or similar hormone-type herbicides. If this is not possible, use separate sprayer hoses when using these chemicals as they cannot be properly washed out of the hose lines. To thoroughly clean equipment after applying 2,4-D, MCPA, etc., follow these steps:

- Drain and collect any excess spray solution from the tank.
- Rinse tank, lines, screens, pumps, and nozzles thoroughly with warm water.
- Remove pressure chamber and line strainer and drain.
- Fill tank with 100 L of warm water and then add one of the following:
  - 1 litre of household ammonia or Agri-Kleen; or
  - 500 g washing soda, lye or Nutrasol.
- Spray out small amount of solution and leave remainder in tank overnight.
- Drain and rinse the equipment several times with warm soapy water. Rinse out the soapy water with clean water.

Even stainless steel nozzles will rust if left in the sprayer. Nozzles and nozzle screens should be removed and cleaned each fall and stored in a can of light oil or diesel fuel if the sprayer is not going to be used over the winter. After a spray application the nozzles should be cleaned and coated with a light coat of oil to prevent corrosion. Ceramic nozzles are not subject to corrosion. Before winter storage, remember to drain the pump, boom, and all the lines to prevent frost damage. Add light oil or antifreeze during the last rinsing to leave a protective coating on all parts.

Chapter 11 - Pesticide Sprayer Calibration

Calibration helps ensure good pest control. It also helps prevent potential crop damage, high pesticide residues, and environmental contamination. All application equipment should be calibrated to ensure that pesticides are applied accurately and uniformly at the recommended rate. Calibration involves preparing the equipment so it is working properly, measuring the delivery rate, adjusting the equipment to change the delivery rate, and calculating how much pesticide to add to the sprayer tank. Calibrate equipment regularly, at least once per year, to make sure the output is not changing. Also calibrate equipment when it is new and when making changes that affect the delivery rate. Proper calibration will minimize, if not eliminate, left-over pesticide solutions in the sprayer tank that can be very difficult to dispose of properly.

There are four basic procedures to be carried out when calibrating almost any sprayer. Details on these procedures are given below. (Also refer to the *Pesticide Applicator Course for Agricultural Producers*.) Use the *Calibration Worksheet* in Appendix E to follow these four procedures when applying pesticides to your crop.

1. Set-up
2. Measuring delivery rate
3. Adjusting delivery rate (if different from recommended rate)
4. Calculating how much pesticide to add to the spray tank

Calibration of backpack sprayers, boom sprayers, and specialized greenhouse sprayers will be discussed. All spraying equipment should be calibrated using the same basic steps; more complex equipment may require more set-up.

Set-Up

Set-up is often the most neglected component of calibration and without proper set-up the likelihood of good spray coverage and uniformity is greatly diminished. The reason why set-up is often neglected is that it takes time, lots of time, if the sprayer is not well maintained. During sprayer set-up, check that the sprayer nozzles, forward speed, and spray pressure suit the pesticide, the weather, and the crop conditions. Check the equipment to ensure all parts are in good condition, clean, and working properly. Refer to the sprayer's operating manual for specific operational information. The sprayer must emit the pesticide solution uniformly across the width of the boom or spray swath to properly cover the application area. The *Calibration Worksheets* in Appendix E give a thorough checklist to use for boom sprayer set-up, whether it is a tractor operated system in the field or a stationary or cart based sprayer with a hand boom in greenhouses.

All sprayers should be properly set-up before you move on to the second step in calibration, measuring the delivery rate. The last page of the worksheet gives formulas for checking the speed of your tractor gears. Knowing the speed of each gear will help to make adjustments in the sprayer's delivery rate. To use the calibration formulas you must also determine your sprayer's swath width.

Select Spray Volume

Most pesticides used for floriculture crops are given as dilution rates where the crop is to be sprayed thoroughly. Spraying a test area of the crop with water will allow the operator to determine the amount of water required to adequately cover a hectare or given area. This technique is useful to determine the amount of pesticide needed per hectare when labels only provide dilution rates. The same technique can be used to identify a spray volume to use when the label rate is expressed as a certain amount of pesticide active ingredient per area. The spray volume (and amount of water) may depend on crop, stage of growth, the pest, the pesticide, weather and soil conditions, and the method of application.

For herbicides, spray volumes range from 50 to 1,000 L/ha. Refer to the product label for specific recommendations. Pesticide application rates and spray volumes for herbicides are normally given as a broadcast treatment as if the entire field is sprayed. However, in some crops, herbicides are often applied in bands along the rows spraying only a part of the field. Therefore, to spray only bands and not the entire field, the amount of area actually treated must be calculated to determine how much herbicide to add to the sprayer.

For fungicides and insecticides, volumes of 300 to 1,000 L/ha are typically used. For foliar sprays, just enough water should be used to obtain thorough coverage of the leaves without run-off. Early in the season when growth is light, 300 L/ha of water may be adequate. In situations where foliage is dense and coverage is critical, at least 1,000 L/ha of water should be used. For drenches (high-volume, low-pressure sprays directed to the soil for control of soil-borne pests), usually at least 2,000 L/ha is used.

Use of drop pendants in tall, leafy field crops will permit lower spray volumes and better coverage than a conventional straight boom. To maintain effective coverage of the foliage with lower spray volumes, finer droplets are required to cover the same area. Finer droplets will be more prone to drift in windy conditions. In hot, dry weather, low ambient relative humidity may cause the water in fine droplets to evaporate before the pesticide reaches the target. This is another cause of drift. Sprayer operators should carefully monitor the foliage including the lower stems and undersides of lower leaves to ensure thorough coverage. Water sensitive spray cards are available to assist in carrying out this task. The spray operator should also monitor for spray drift.

Select Nozzle Pressure

Herbicides are generally applied at low pressures, 100 to 275 kPa, or 15 to 40 psi, to keep drift to a minimum. Do not use higher pressures unless they are specifically recommended. Some new nozzles are available that work over extended pressure ranges. Insecticides and fungicides are applied at pressures up to 2,000 kPa (300 psi) in conventional spraying equipment depending upon the pest to be controlled, the type of pesticide, and the density of the foliage. For non-systemic pesticides and high, dense plant canopies, high nozzle pressures should be used to penetrate and cover the foliage. Systemic pesticides and plants with open canopies can be sprayed at lower nozzle pressures, generally 550 kPa or 80 psi and higher, to avoid spray drift. Commercial quality backpack sprayers will produce sprays up to 1,000 kPa (150 psi). These units should be equipped with a pressure gauge and pressure regulator just like powered sprayers. Some manufacturers supply kits to convert backpack sprayers that do not have these components.

Many nozzle manufacturers have chosen to report nozzle outputs with pressures in “bars” not kilopascals (kPa). The bar unit is equal to 100 kPa. Pesticide labels report pressures in kPa. Use a pressure gauge on the sprayer marked in both psi and kPa (or bar) so both units can be read directly from the gauge. The maximum pressure on the pressure gauge for powered sprayers should be twice the maximum spray pressure used to protect the gauge from damage and allow it to be read accurately.

Determine Sprayer Swath Width (Boom Sprayers)

Swath width is the width of treated area over which spray droplets are distributed in one pass of the applicator. See Figures 11.1 to 11.4. In a broadcast spray, it is the nozzle spacing multiplied by the number of nozzles and for band treatments it is the sum of the treated band widths. For row crops it is the row spacing (from center-to-center) multiplied by the number of rows. When crops are grown in beds, usually the plant canopy covers the whole field area. The sprayer swath width is the bed spacing (from center to center of wheel tracks) multiplied by the number of beds.

The swath width is used in sprayer calibration to calculate the sprayer’s delivery rate. As the sprayer swath width is based on the treated area, the delivery rate will also be based on the treated area when band spraying herbicides.

When sprayers are set-up during calibration, check to make sure that the driving pattern used in spraying does not cause skips – areas where portions of the crop are not sprayed between successive passes of the sprayer. The sprayer boom may also overlap the first pass when spraying the next strip or swath. Skips and overlaps can be caused by not matching the nozzles on the boom to the driving pattern of the sprayer. Sometimes different nozzles are needed at the end of the boom when spraying beds or row crops to get a uniform spray coverage of the crop. With skips and overlaps, either pests will go uncontrolled or high spray residues can occur which may be dangerous to humans, plants and the environment. *While spraying, the true swath width of the sprayer is determined by the driving pattern of the sprayer through the field.*

Figure 11.1: Broadcast Swath Width

= # of nozzles x spacing
= 5 nozzles x 50 cm
= 250 cm
= 2.5 m

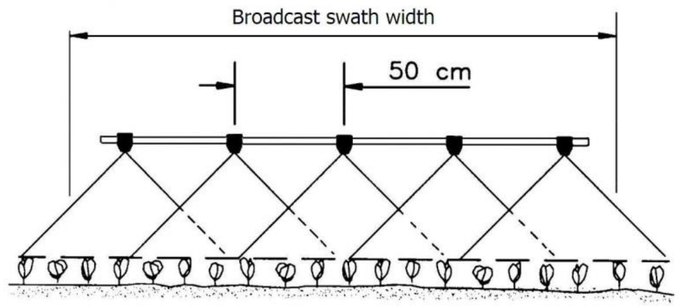


Figure 11.2: Broadcast Swath Width

= # of beds x bed width
= 2 * x 180 cm
= 360 cm
= 3.6 m

***Note that the number of beds**
= ½ bed + 1 bed + ½ bed = 2 beds

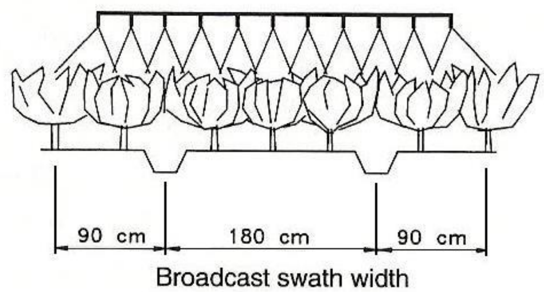


Figure 11.3: Band Swath Width

= # of bands x band width
= 3 bands x 30 cm
= 90 cm
= 0.9 m

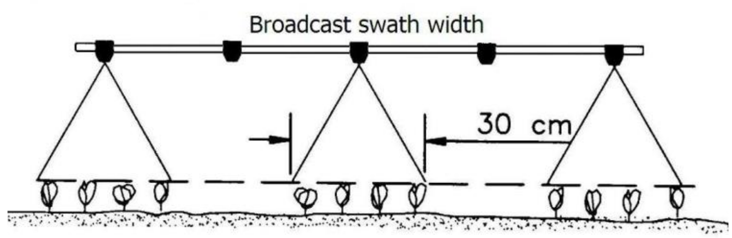
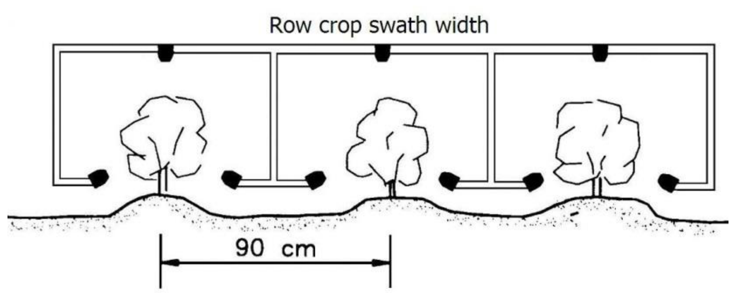


Figure 11.4: Row Crop Swath Width

= # of rows x row width
= 3 rows x 90 cm
= 270 cm
= 2.7 m



The swath width is used in sprayer calibration to calculate the sprayer's delivery rate. As the sprayer swath width is based on the treated area, the delivery rate will also be based on the treated area when band spraying herbicides.

When sprayers are set-up during calibration, check to make sure that the driving pattern used in spraying does not cause skips, i.e. areas where portions of the crop are not sprayed between successive passes of the sprayer. The sprayer boom may also overlap the first pass when spraying the next strip or swath. Both skips and overlaps can be caused by not matching the nozzles on the boom to the driving pattern of the sprayer. Sometimes different nozzles are needed at the end of the boom when spraying beds or row crops to get uniform spray coverage of the crop. With skips and overlaps, either pests will go uncontrolled or high spray residues can occur that may be dangerous to humans, plants and the environment. *While spraying, the true swath width of the sprayer is determined by the driving pattern of the sprayer through the field.*

Measure Delivery Rate (Boom Sprayers)

There are two basic methods used to measure sprayer delivery rates, the test area method and the timed output method.

1. The test area method uses fewer calculations, however, it can take longer to carry out. If an entire acre or hectare is used as the test area, then the measured discharge of water is the delivery rate per acre or hectare and no further calculations are required. The most common problem with the test area method is measuring the amount of spray water discharged. If too small a test area is used or it is not covered with enough passes, the actual amount of water discharged will be too small to accurately measure in the tank. The tractor and sprayer tank should be parked in the exact same location and the water must settle in the tank after stopping, before measuring the tank level after spraying.
2. The timed output method can avoid these problems; however, it will require more calculations. It involves using forward speed and output per minute.

By using both the test area and timed output method, the accuracy of your sprayer calibration can be checked.

Adjust Delivery Rate (All Portable Sprayers)

If the measured delivery rate of the sprayer is different than the spray volume listed on the pesticide label or recommended in the production guide, it can be adjusted in three ways:

1. Nozzle size should be changed before making large changes in delivery rate. Check with the nozzle supplier or agricultural advisor. Obtain a catalogue listing nozzles and nozzle outputs in litres per minute (L/min).
2. Forward speed changes will adjust the delivery rate. Slower speeds increase the amount sprayed in a field, and faster speeds reduce the amount. If the delivery rate is 112 L/ha at 6 kph, then by halving the speed to 3 kph, the delivery rate is doubled to 224 L/ha. Speed changes are usually made by using a different gear to keep tractor RPM's and spray pressure constant and within the range recommended for the sprayer pump.
3. Spray pressure should be set for the correct droplet size. Changing pressure is recommended only for very small changes in delivery rates. Otherwise the droplet size will change and lead to drift or run-off. Since pressure must be increased four times to double the delivery rate, this is not a good way to adjust delivery rate.

After making the adjustments, measure the delivery rate again!

Calculate How Much Pesticide to Add to the Spray Tank

Once the sprayer delivery rate is known, then calculate how many hectares can be sprayed by a full tank and how much pesticide to add to the spray tank. Formulas to use when spraying only a partial tank are given in the *Calibration Worksheets* in Appendix E. Be very careful to accurately measure the area to be covered by the last tank to minimize left-over spray solution.

Calibrate Hand Operated Sprayers

Sprayer Set-up

Hand operated sprayers should be checked to make sure that there aren't any leaks, especially where the hose enters the tank and around the trigger valve. The nozzle should deliver a uniform spray pattern. Many nozzles can be adjusted to produce the desired droplet size. Adjust the nozzle to produce a coarse spray with large droplets for herbicides, and medium to fine spray with small droplets for insecticide and fungicide applications.

For uniform spray application it is important to maintain a constant spray pressure. Some manufacturers offer pressure regulators and pressure gauges as optional accessories that enable the operator to set specific pressures depending on the spraying job. Commercial quality backpack sprayers should have these options as standard equipment. Uniform spray application also requires the operator to co-ordinate the walking speed with uniform sweeping movements of the nozzle. The back and forth movements determine the swath width.

Most pesticide labels give instructions as a specific amount of pesticide per unit area (e.g., apply 2.4 L/ha). Some pesticides give directions to dilute an amount of pesticide in water and apply with thorough and complete coverage.

Application Rate Given as a Dilution with Water

When the application rate is given as a dilution rate, then the amount of pesticide to mix in a full tank can be calculated directly.

Also estimate how much spray mixture is needed so pesticide solutions are not left over. Do this by applying water to a measured test area to determine the total solution needed. If large areas are being sprayed (more than one backpack tank-full), then a full tank of pesticide can be sprayed and the area measured to determine how many tanks are needed for the whole area. If smaller areas are to be sprayed, then use the same procedures as for pesticide application rates given as an amount of pesticide per unit area to determine how much pesticide to add to the tank.

Example:

A label recommends mixing 1 L of pesticide in 100 L of water and applying to foliage with thorough coverage. A 12-litre backpack will be used. How much pesticide will be needed per tank?

Method - The amount of pesticide to add to the tank can be calculated with the following formula:

Amount of pesticide = label rate (product amount ÷ water volume) X sprayer volume

Amount of pesticide = 1 L product ÷ 100 L water X 12 L tank = 0.12 L product/tank

If only a partial tank full (e.g. 8 L) of pesticide mix is required, use that figure as the “sprayer volume” in the formula.

Application Rate Given as Amount of Pesticide per Hectare

Measuring delivery rate of the hand-operated sprayer follows the same basic steps as with the tractor mounted boom sprayer but on a smaller scale. Remember during set-up of the sprayer that a steady walking speed and swath width must be used.

1. Mark out a measured length of test strip at least 60 feet long.
2. Fill the tank about half full with water and record the volume or level of water. Pump the tank to the pressure level that will be used.
3. Carefully spray the measured test strip while maintaining a steady forward speed and pumping action. Repeat enough runs over the test area until at least 10% of a full tank has been sprayed.
4. Measure the volume of water sprayed in the test strip by refilling the tank to the starting level.

Follow these steps to determine the application rate:

1. Calculate the test area:

   Test area (ft^2) = strip length (ft) X swath width (ft) X # runs
2. Calculate the delivery rate:

   Delivery rate (L/acre) = water sprayed (L) ÷ test area (ft^2) X 43,560 ft^2/acre

   Adjust the delivery rate as necessary by changing the walking speed.
3. Calculate the amount of area sprayed by a full tank:

   Area sprayed (by full tank) = tank volume (L) ÷ delivery rate (L/acre)
4. Calculate how much pesticide to add to the spray tank:

   Amount of pesticide to add to tank = application rate X area sprayed by one tank

Example:

A grower wants to apply a foliar spray at a rate of 0.5 kg/800 L of water per ha. A test strip of 20 m long and 1 m wide is sprayed with one pass of water to measure delivery rate. To refill the spray tank, 1.7 L of water is required. What is the delivery rate, area sprayed by a full tank, and the amount of pesticide to add to a 12 L tank?

Method

Test area	= 20 m X 1 m X 1 run = 20 m^2
Delivery Rate	= 1.7 L ÷ 20 m^2 X 10,000 m^2/hectare = 850 L/ha
Area sprayed (by full tank)	= 12 L ÷ 850 L/ha = 0.0121 hectare
Amount of pesticide to add to one tank	= 0.5 kg/ha X 0.0141 ha = 0.007 kg = 7 mg

Calibrate Granular Applicators

Calibration of granular applicators involves the same first three steps as a liquid pesticide sprayer:

1. Set-up
2. Measuring delivery rate
3. Adjusting delivery rate

Granular pesticides may be applied by broadcast, band, or in-furrow methods. Granular pesticides used in the floriculture industry are typically broadcast in the field. There are several factors that can cause variation in output including, size of meter openings, roughness and slope of the field, forward speed, and granule flowability.

Set-up

Set-up includes inspecting the equipment to make sure it is clean, lubricated, and operating properly according to the operator's manual. Set the equipment to the approximate settings to deliver the recommended application rate. Swath width on tractor mounted spinning disc and oscillating spout spreaders is dependent on the PTO (and engine) RPM. Proper spreading width, overlap of tapered patterns, and swath width will require several test runs to determine settings that will work in your field. Pneumatic spreaders that use air to carry the granules through hoses to individual distributing nozzles will drop the granules directly over the target. On a smaller scale, gravity drop granular applicators are available with in-furrow applications or with distributing nozzles for broadcast applications.

Measuring Delivery Rate

Delivery rate is generally determined by measuring the amount of granules discharged while the applicator is run over a test area or test length for in-furrow applications. It is usually necessary to capture the output and weigh it.

1. Mark out a measured test strip at least 60 m or 200 ft long.
2. Fill the applicator hopper(s) about half full of granules.
3. Choose a tractor gear and throttle setting.
4. Attach bags or other containers under each downspout to catch the granules during calibration. For granular equipment that uses air flow for distribution, either use porous mesh bags (e.g. nylons) or shut off the air flow and catch the granules from directly under the metering device.
5. Drive towards the first stake at the correct speed and discharge granules over the test strip only.
6. Repeat until enough granules are discharged to allow for accurate weights to be measured. Record the number of runs.
7. Weigh the granules from each bag or container and record the amounts. Compare the individual weights for uniformity across the swath. If outputs are uniform, then add them together. Otherwise, make adjustments and retest.

Determine the delivery rate (kg/acre) using the following formula:

$$= \frac{\text{amount collected in test (kg) x 43,560 (ft}^2\text{)}}{\text{test area (ft}^2\text{)}}$$

Adjusting Delivery Rate

Increase the meter opening to discharge more granules or decrease the meter opening to discharge less granules and retest.

Calibration Example – Boom Sprayers

Refer to the Calibration Worksheet (Boom Sprayers) in Appendix E when working through the following example.

A grower has set-up a 1,000 L sprayer to spray foliage with a fungicide at the recommended rate of 2.5 kg/ha in 500 L/ha of water. The sprayer boom uses 11 nozzles spaced at 50 cm. After spraying a 100 m test strip with four runs (to discharge enough water from the spray tank to accurately measure it), 105 L of water were required to refill the tank.

What is the sprayer swath width?

From Calibration Worksheet under Set-up - Swath Width

Row crop swath width = 11 nozzles X 50 cm = 550 cm = 5.50 m

What is the delivery rate (litres per hectare) of the sprayer?

Follow Steps 1 - 8, *Measuring Delivery Rate – Test Area Method*, from the Calibration Worksheet

Test area = 100 m X 5.50 m X 4 runs = 2,200 m^2

Follow Step 9, *Measuring Delivery Rate - Test Area Method*, from the Calibration Worksheet

Delivery rate = 105 L ÷ 2,200 m^2 X 10,000 m^2/ha = 477 L/ha

The sprayer is operating at a delivery rate of 477 L/ha. The delivery rate is close enough to the desired spray volume of 500 L/ha. Use the delivery rate of 477 L/ha when calculating how much pesticide to add to the tank.

How many hectares will be covered with one full tank of spray?

Follow *Calculating How Much Pesticide to Add to the Tank – Full Tank*, from the Calibration Worksheet

Area = 1,000 L ÷ 477 L/ha = 2.10 ha

One full tank of spray will cover 2.10 ha.

How much pesticide must be added to a full tank of water?

Follow *Calculating How Much Pesticide to Add to the Tank – Full Tank*, from the Calibration Worksheet

Pesticide = 2.5 kg/ha X 2.10 ha = 5.25 kg

Add 5.25 kg of pesticide to make one full sprayer tank of spray mixture.

Appendix A. Metric Conversion Factors

Imperial Units	Conversion Factor	Metric Units
LENGTH		
inches	2.5	centimetres (cm)
feet	30	centimetres (cm)
feet	0.3	metres (m)
yards	0.9	metres (m)
miles	1.6	kilometres (km)
AREA		
square inches	6.5	square centimetres (cm^2)
square feet	0.09	square metres (m^2)
acres	0.40	hectares (ha)
VOLUME		
cubic inches	16	cubic centimetres (cm^3)
cubic feet	0.03	cubic metres (m^3)
cubic yards	0.8	cubic metres (m^3)
fluid ounces (Imperial)	28	millilitres (mL)
pints	0.57	litres (L)
quarts	1.1	litres (L)
gallons (Imperial)	4.5	litres (L)
gallons (U.S.)	3.75	litres (L)
bushels	0.36	hectolitres (hL)
WEIGHT		
ounces	28	grams (g)
pounds	0.45	kilograms (kg)
short tons	0.9	tonnes (t)
TEMPERATURE		
Fahrenheit (°F - 32)	0.56	Celsius (°C)
POWER		
horsepower	750	watts (w)
	0.75	kilowatts (kw)

Imperial Units	Conversion Factor	Metric Units
oz./acre	70	g/ha
lb./acre	1.12	kg/ha
bu./acre	0.9	hL/ha
tons/acre	2.24	t/ha
fl. oz./acre	70	mL/ha
pt./acre	1.4	L/ha
qt./acre	2.8	L/ha
gal./acre	11.2	L/ha
gal./acre (US)	9.35	L/ha
plants/acre	2.47	plants/ha
oz./gal.	6.2	mL/L
lb./gal.	0.1	kg/L
oz./sq.ft.	305	g/m^2
lb./sq.ft	4.9	kg/m^2
oz./ft.row	93	g/m row
lb./ft.row	1.5	kg/m row
ft./sec.	0.3	m/s
m.p.h.	1.6	km/h
p.s.i.	6.9	kPa

To convert from imperial to metric, multiply by the conversion factor. For example: 10 inches x 2.5 = 25 centimetres

To convert from metric to imperial, divide by the conversion factor. For example: 25 centimetres ÷ 2.5 = 10 inches

Imperial Conversions:

lb/acre x 0.0033 = oz/yd^2

gal/acre x 0.033 = oz/yd^2

Useful Measurements

1 Imperial gallon = 4 quarts = 8 pints = 160 fluid ounces = 10 pounds of water = approximately 1.2 U.S. gallons

1 U.S. gallon = 0.8345 or approximately 5/6 Imperial gallon = 8.3 pounds

1 Imperial pint = 20 fluid ounces = 570 mL

1 U.S. pint = 16 fluid ounces = 475 mL

1 pound = 16 ounces

1 tablespoon = 3 teaspoons = 14 mL

2 tablespoons = 1 fluid ounce = 28 mL

1 pound in 100,000 gallons of water = 1 ppm (part per million)

1 mile = 5,280 feet = 1,760 yards

1 yard = 3 feet = 36 inches

1 foot = 12 inches

1 acre = approximately 209 by 209 feet or 43,560 square feet.

1 square yard = 9 square feet

1 square foot = 144 square inches

1 mile per hour = 88 feet per minute

1 cubic yd = 27 cubic feet

1 cubic centimetre = 1 mL = 1 gram (for water)

Parts Per Million

1 per cent = 10,000 parts per million

Imperial: 1 fl. oz./gallon = 6,250 ppm

1 gallon in 1,000,000 gallons of water = 1ppm

1 litre in 1,000,000 litres of water = 1ppm = 1 mL/1,000 L

Metric: 1 mg/litre (water) = 1 ppm

1 g/litre (water) = 1,000 ppm

1 mL/litre = 1,000 ppm

Metric Units for Farm Sprayers

Tank Capacities				**Pressures**	
Imperial Gallon	**Litres (L)**	**US Gallon**	**Litres**	**Pounds per Square Inch (PSI)**	**Kilopascals (kPa)**
100	455	100	379	10	70
200	910	200	758	15	100
250	1,138	250	948	20	140
300	1,365	300	1,137	25	175
400	1,820	400	1,516	30	200
500	2,275	500	1,895	35	240
600	2,730	600	2,274	40	275
800	3,640	800	3,032	45	310
1,000	4,550	1,000	3,790	50	345

Appendix B. Preparing a Complete Fertilizer Solution

There are many 'complete' fertilizer products on the market for use in liquid feeding programs. However, most of the single package dry or liquid concentrate formulations available are unable to supply all the fertilizers required for growth since some of the elements react with one another in concentrated form. Most commonly, calcium will react with the phosphate and sulphate sources to form insoluble precipitates. Magnesium sulphate may also react with other dry fertilizer ingredients. For this reason, calcium and magnesium are often omitted from soluble fertilizer products or they are provided in very small quantities.

For short term potted crops this is seldom a problem. It is not always necessary to feed calcium and magnesium in the fertilizer solution since the dolomitic limestone used to buffer the low pH of most peat based potting soils usually supplies sufficient quantities of calcium and magnesium as the lime slowly dissolves. However, many growers find it useful to supply calcium and magnesium supplements in their feed solutions as well, particularly for hydroponic applications or longer term potted crops. This can be accomplished in several ways:

- If you use a single headed injector system you can occasionally substitute either calcium nitrate or magnesium sulphate (never both together!) for your standard 'complete' feed.
- A double or triple headed injector system can be set up to dose calcium and magnesium solutions along with your commercial blend. However, since this will also provide more nitrogen than you may need, you may have to choose a different commercial fertilizer blend to compensate.
- Some companies offer a two or three part fertilizer program that requires separate mixing and concentrate injection to deliver a balanced complete feed that will supply all of the required nutrients when proportioned simultaneously.
- You can make up your own fertilizer solutions from scratch.

There are almost endless variations of liquid fertilizer recipes intended to fit the needs of special crops, conditions, or crop timing. For certain crop situations, the elemental balance, overall concentration (EC), and the effect on media pH can be adjusted by altering the choice of individual constituents, their overall concentration, and their ratios to one another.

The following is an example of a generic complete feed recipe formulated from base fertilizer compounds that are commonly used in greenhouse liquid feeding programs. If the materials are to be mixed in concentrate form for injection (above 15 x the dilute feeding level), it is necessary to separate the calcium nitrate into one concentrate tank (tank A) and the phosphate and sulphate compounds into another (tank B). A third injection tank (tank C) may be required if you need to administer pH adjusting acids or bases. You may come across other variations of this ABC concentrate tank method, but they will almost always keep the calcium nitrate separate from phosphorus and magnesium sources.

A Generic Complete Fertilizer Formula Suitable for a Hydroponic or Constant Feeding Program

Recipe for 1000 Litres of Regular Strength (Dilute) Feed Solution**

Ingredients	Grams for 1,000 Litres of Feed Solution
A Tank:	
Calcium Nitrate	947
Iron Chelate	15
Potassium Nitrate (half)	206
B Tank:	
Magnesium Sulphate	350
Monopotassium Phosphate	174
Potassium Nitrate (half)	206
Manganese Chelate	5.8
Solubor	2.4
Zinc Chelate	3.5
Copper Sulphate	2.0
Sodium Molybdate	0.13

Elements Supplied	Parts Per Million
Nitrogen	200
Phosphorus	40
Potassium	200
Calcium	180
Magnesium	35
Sulphur	46
Iron	2
Manganese	0.7
Boron	0.5
Zinc	0.5
Copper	0.5
Molybdenum	0.05

**When using an injector system you must divide the final volume desired by the proportioning ratio. For example, using a 100x injection rate, the volume of each fertilizer concentrate tank would be 1,000 litres (final volume) / 100 times dilution. Therefore you would dissolve the fertilizers required for tank A and B into 10 litres of water each.

Rules for Mixing Soluble Fertilizers:

- Buy greenhouse grade fertilizers for maximum solubility and purity.
- Wear a dust mask and gloves to avoid contact with fertilizer concentrates and dusts.
- Dissolve fertilizers individually in hot water before adding to tanks.
- To avoid the formation of insoluble precipitates, do not mix any fertilizers containing calcium (calcium nitrate) with those containing sulphates (magnesium sulphate) or phosphates (monopotassium phosphate) in their concentrated form.
- Partially fill tanks with water and then mix in the dissolved fertilizer concentrates.
- Precipitates do not normally occur when complete solutions are prepared at low concentrations. Therefore, one tank is usually sufficient for mixing all the ingredients if you plan to make up the fertilizer solution at the dilute feeding rate or at a concentration that is below 15 x. Beyond that, injector systems that proportion concentrates at up to 200 x the final dilute feed level will require 2 or 3 tanks (an A and B tank for fertilizers, and a C tank for pH adjustment) to keep reactive fertilizer materials separate and maintain the proper pH balance.

Liquid Fertilizer Calculations

To calculate the amount of fertilizer needed for any given quantity of solution:

- $$\frac{\text{ppm required / elemental content (fraction) x litres required}}{1{,}000} = \textbf{grams/litres required}$$

- **ppm (parts per million required)** - this is the feed concentration (when using blended or 'complete' fertilizers, you normally calculate the amount to dissolve based on the ppm nitrogen required).

- **elemental content of the fertilizer -** the fertilizer label lists the elemental content of each fertilizer constituent as a percentage. For "elemental content" in the calculation, put this percent in the form of a fraction, for example, 20% nitrogen = 20/100 = **0.20**. The only exceptions are for P and K. Since they are always expressed as P_20_5 (phosphoric pentoxide) and K_20 (potash), they must first be converted to their true elemental content:

  P_20_5 divided by 2.291 = P (elemental phosphorus content)

  K_20 divided by 1.205 = K (elemental potassium content)

- **litres required –** the amount of finished (dilute) fertilizer solution you plan to make up. If you plan to use a fertilizer concentrate injector you can calculate the injection ratio after you find the dilute rate (this causes the least confusion).

Examples:

- To prepare 500 litres of a 20-20-20 fertilizer at 200 ppm nitrogen concentration:

$$\frac{(200 \text{ ppm} / 0.20) \times 500}{1{,}000} = \textbf{500 grams per 500 litres}$$

- To prepare 400 litres (final solution) of calcium nitrate (15.5-0-0-19) at 140 ppm Ca concentration for injection at 200:1:

$$\frac{(140 \text{ ppm} / 0.19) \times 400)}{1{,}000} = \textbf{295 grams per 400 litres (final solution)}$$

Since you are going to inject this at 200:1, you will dissolve your 295 grams into 2 litres of water (400 litres finished solution / 200):

400 litres / 200 = 2 litres

- You plan to use diammonium phosphate (21-53-0) to supply 30 ppm of phosphorus to a bedding plant feed. Your tank holds 1,000 litres.

First convert **P_20_5** to **P** **(53% / 2.291) = 23.1% P**

$$\frac{(30 \text{ ppm} / 0.231) \times 1{,}000 \text{ litres}}{1{,}000} = \textbf{130 grams per 1,000 litres}$$

Appendix C. Light Measurement Conversions

There are many ways to measure light and most of them seem to be in use simultaneously. It's not unusual to read four articles on greenhouse lighting and see four different references to light intensity from foot candles to lux, to watts, to lumens.

The multitude of ways to express the visible radiation received by plants has hindered our understanding of practical lighting needs and supplementing illumination. Lighting engineers prefer to use illumination units such as foot candles, lumens, lux, and klux since these measurements give a good indication of the illumination intensity to the human eye.

Since plants do not 'see' light the way humans do, some photobiologists prefer to use measurements of absolute energy such as watts per square metre. Others prefer quantum measurements of photosynthetically active radiation (PAR) which is in the 400-700 nanometer wavelength range and is expressed in units of microeinsteins or micromoles.

Climate control computer systems with attached light sensors usually measure light levels in Watts/m^2 (pyranometer sensors) or in microeinsteins per square metre per second (mE$s^{-1}m^{-2}$) (PAR sensors.)

Conversion of Light Units from Various Lighting Sources*						
	Light Source Conversion Factor					
Multiply by the Conversion Factor to Convert "from → to"	**Day Light**	**Metal Halide**	**High Pressure Sodium**	**Mercury Vapour**	**Cool White Fluorescent**	**Incandescent**
Wm^{-2} (PAR) → $\mu E\ s^{-1}\ m^{-2}$ (PAR)	4.6	4.6	5.0	4.7	4.6	5.0
Wm^{-2} (PAR) → Klux	0.25	0.32	0.36	0.33	0.37	0.25
Klux → $\mu E\ s^{-1}\ m^{-2}$ (PAR)	18	14	14	14	12	20
Klux → Wm^{-2} (PAR)	4.0	3.1	2.8	3.0	2.7	4.0
Footcandles → $\mu E\ s^{-1}\ m^{-2}$ (PAR)	0.20	0.15	0.15	0.15	0.13	0.22
$\mu E\ s^{-1}\ m^{-2}$ (PAR) → Footcandles	5	6.7	6.7	6.7	7.8	4.5
* Light conversion from Li-Cor literature						

Some Lighting Definitions:

Visible Radiation: light energy in the visible portion of the spectrum having wavelengths from 400-700 nanometers (nm).

Illuminance: a measure of brightness per unit area. Illuminance units are foot-candles (fc), lumen (lu), and lux (lx) as measured by photometry.

High Intensity Discharge (HID) Lamps: refers to all mercury, metal halide, and sodium lamps which operate by exciting their various elements at high voltages.

Photosynthetically Active Radiation (PAR): radiation in the 400 - 700 nm waveband. PAR is commonly expressed in microeinsteins per square metre per second (mE $m^{-2}S^{-1}$) or in micromols per square metre per second ($m$mol $m^{-2}S^{-1}$) which are equivalent. The LI-COR quantum sensor (LI-190S) is generally used for this measurement.

Other Light Conversions:

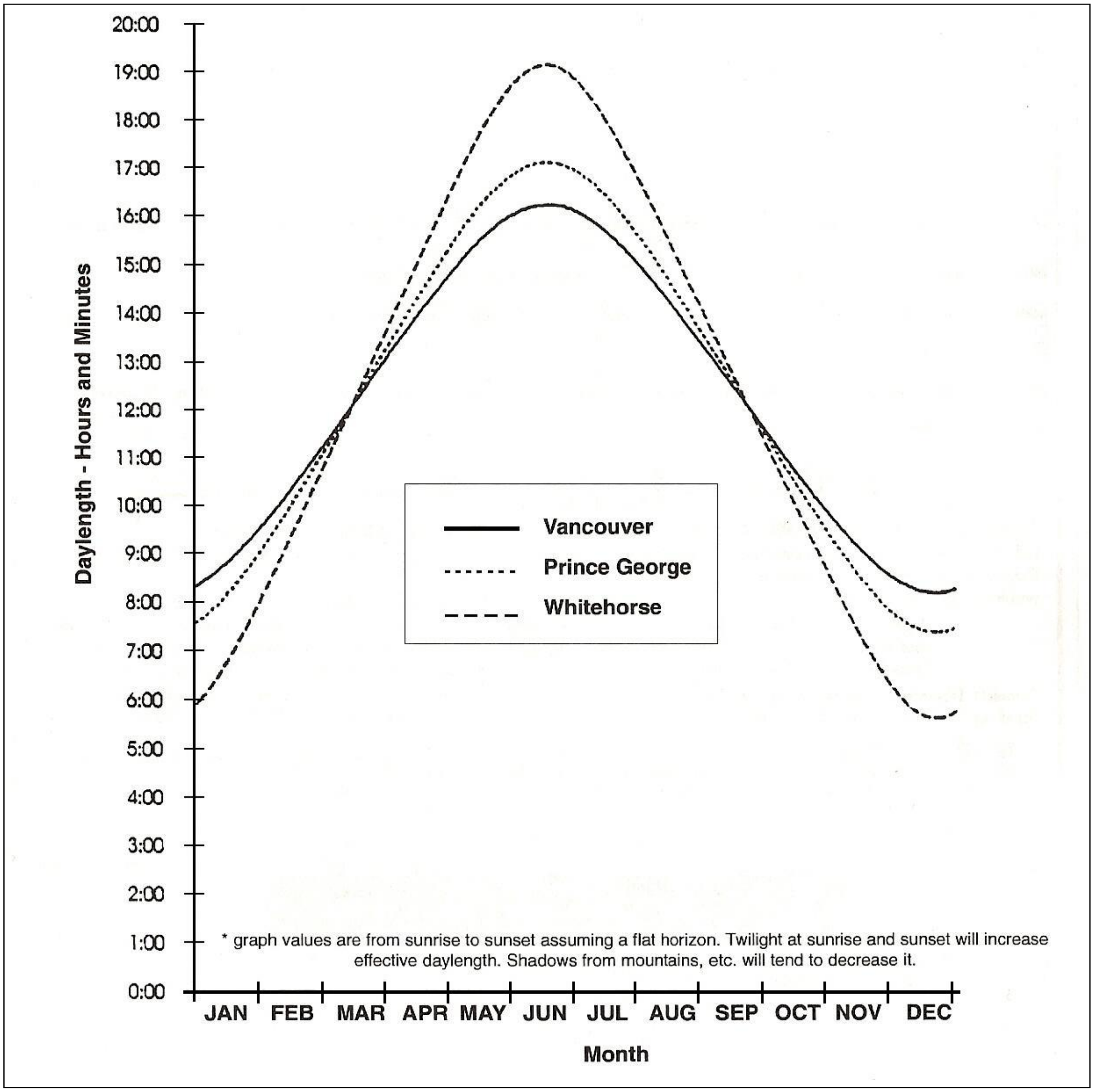
	Multiply by:
Klux to Lux	0.001
Lux to Klux	1,000
Klux to footcandles	92
Foot candles to Klux	0.011
Lux to lumens m^2	1
Lux to lumens ft^2	0.0920

Appendix D. Season Daylight Hours

Figure D.1 shows the seasonal day length for three locations. It can be used as a reference guide for photoperiod sensitive plants such as poinsettias or pot mums. Daylength can be determined at a glance to determine if extended night or day treatment is necessary.

The figures are derived from the time lapse between sunrise and sunset and assume a flat horizon. For example, nearby mountains will tend to decrease day length. The values are not the exact cut-off between darkness and light since the twilight periods before sunrise and after sunset will tend to increase the effective daylength.

Figure D.1: Seasonal Daylight Hours for Vancouver, Prince George, and Whitehorse



Appendix E. Calibration Worksheets

Measured delivery rate ________ L/ha *L/acre*

Area sprayed by a full tank ________ ha *acre*

Tractor gear ________

Throttle ________ rpm

Forward speed (if Timed Output) ________ km/h *mph*

Nozzles ________

Pressure ________ kPa(psi)

Date ________

Calibration Worksheet – Boom Sprayer

Follow this step-by-step procedure to calibrate a sprayer. All liquid volumes are in litres (L), but you can use either metric or imperial units for distance and area (don't mix them). Circle the units used such as 500 L/ha L/acre.

After you've finished calibrating your equipment, **write key data in the box at left for future reference.**

Use the Pesticide Use Calculation worksheet to find the area sprayed by a full tank, and to calculate how much of each pesticide you'll need to buy and add to each tank.

❶ Set-up

Inspection Before Sprayer Start-up ✔

- ❑ Tank size is ________ L
- ❑ Calibration strip or dipstick for tank?
- ❑ Tire pressures okay?
- ❑ Hoses in good condition?

Filler opening screen

- ❑ in place? clean? good repair?
- ❑ mesh size correct?________

Suction screen

- ❑ in place? clean? good repair?
- ❑ mesh size correct ________

Nozzle screens (check each one)

- ❑ in place? clean? good repair?
- ❑ mesh size correct?________

Nozzles

- ❑ nozzle type okay
- ❑ all same size/ID#? (record in box above)
- ❑ correct nozzle spacing of________cm *(in)*
- ❑ nozzles spaced evenly?
- ❑ aligned for crop?
- ❑ are there nozzle check valves?

Boom height

- ❑ above target?________cm *(in)*
- ❑ is boom level?

Surge tank (piston & diaphram pumps only)

- ❑ working properly?
- ❑ air pressure correct at________kPa(psi)

Inspection with Sprayer Running ✔

Fill the tank more than half full with clean water.

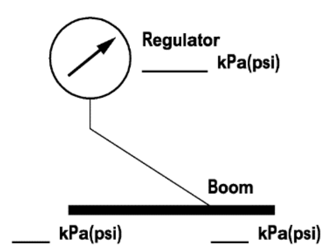
- ❑ start sprayer pump & run tractor throttle at ________ rpm. Note pump's maximum rpm is________.
- ❑ open boom valve to fill lines and begin spraying
- ❑ clean nozzles producing distorted patterns and retest
- ❑ throw out damaged nozzles and replace them

Check and fix any problems

- ❑ leaks?
- ❑ valves working?
- ❑ agitation okay?
- ❑ bypass flow okay?
- ❑ adjust pressure regulator to get right spray pressure at the nozzles

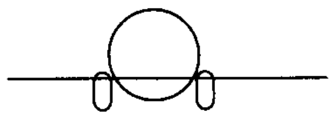
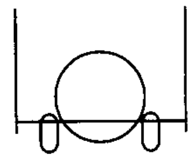
Check sprayer pressures

- ❑ measure pressure at regulator and on booms
- ❑ pressure drop less than 10%?
- ❑ pressure gauge working?



Measuring Nozzle Output

Draw nozzle locations on the diagram below and number them to identify which ones may need to be cleaned or replaced after testing. As the sprayer runs, collect and record the output for a set time eg. 1 minute, 30 sec or 15 sec. Measure in litres.

Horizontal boom (include drop pendents)	Vertical boom (include over-the-row booms
	

Nozzle Output	
Litres per ______ sec	
1. ______	Litres
2. ______	Litres
3. ______	Litres
4. ______	Litres
5. ______	Litres
6. ______	Litres
7. ______	Litres
8. ______	Litres
9. ______	Litres
10. ______	Litres
11. ______	Litres
12. ______	Litres
13. ______	Litres
14. ______	Litres
15. ______	Litres
16. ______	Litres
17. ______	Litres
18. ______	Litres
19. ______	Litres
20. ______	Litres
Total ______	Litres

1. In the box below, divide total output in L by the number of nozzles to find the average output per nozzle for collection time.

Total Output Collected ÷ # nozzles = Average Output Collected

L ÷	noz. =	L

2. For uniformity, find the maximum and minimum acceptable output (5% more or less than average). Replace if above maximum output.

Minimum Output	= 0.95	x ______	Average Output	= ______	L
Maximum Output	= 1.05	x ______	Average Output	= ______	L

3. Replace all nozzles if average output is 15% more than a new nozzle's output (from manufacturer's chart or discharge test).

Average Output per Collection ÷ Collection Time x Conversion = Average Output

L ÷	sec x 60 sec/min =	L/min

New Nozzle Output x Constant = Maximum AverageOutput

L/min x 1.15 =	L/min

4. Clean and retest all nozzles below the minimum output. Replace those still below minimum output after cleaning. If more than 20% of the nozzles need to be replaced, change all of them.

Swath Width

Do only ONE of these. You'll use the swath width for the calculation on the next page.

Broadcast swath: multiply number of nozzles by nozzle spacing; convert to metres or feet.

# nozzles	×	spacing	÷ conversion	= swath width
noz	×	cm ÷	100 cm/m	= m
noz.	×	*in* ÷	*12 in/ft*	= *ft*

Band swath: multiply number of bands by width of each band; convert to metres or feet.

# bands	× band width	÷ conversion	= swath width
bands ×	cm	÷ 100 cm/m	= m
bands ×	*in*	÷ *12 in/ft*	= *ft*

Row crop swath: multiply number of rows by width of each row. (Note: rows are stated in metres or feet, so no conversion is needed.)

# rows	x row width	= swath width
rows x	m	= m
rows x	*ft*	= *ft*

❷ Measuring Delivery Rate

You can use either of these methods to determine the actual delivery rate of the sprayer.

Test Area Method

1. Mark out a test strip at least 60 m or 200 *ft* long. Your strip was ________ m (*ft*) long.
2. Fill the tank about half full with water and start sprayer nozzles and agitation. Then set the pressure to what you want. Use the same throttle RPM you'll use in the field. Pressure ____________ kPa(psi)
3. Choose a tractor gear to get desired forward speed. Gear_____Throttle_________rpm (as in step 2)
4. Record the volume of water in the tank before the test: __________L. Mark where the sprayer is parked so you can return it to the same position to measure water sprayed (level ground is best).
5. Drive towards the first stake at the correct speed, and open the boom valve as you pass it. Check the sprayer pressure. Close the boom valve as you pass the second stake.
6. Repeat until at least 10% of a full tank is sprayed. Record the number of runs (_______runs).
7. Return to the water filling site and park in the same location as in Step 4. Measure the amount of water remaining:__________L. Number of litres discharged during the test was___________L.
8. Calculate the test area. Multiply the strip length by your swath width by the number of runs.

strip length ×	swath width ×	#runs	=	**test area**
m ×	m ×	runs	=	m^2
ft ×	*ft* ×	*runs*	=	ft^2

9. Calculate the delivery rate. Divide water sprayed (L) by test area (m^2 or ft^2).

water sprayed ÷	test area ×	conversion	=	**delivery rate**
L ÷	m^2 ×	10,000 m^2/ha	=	L/ha
L ÷	ft^2 ×	43,560 ft^2/*acre*	=	*L/acre*

(L/ha = 2.5 times *L/acre*   *L/acre* = 0.4 times L/ha)

Timed Output Method

1. Mark out a test strip at least 60 m or 200 *ft* long.
2. Fill the tank about half full with water and move to the test strip.
3. Choose a tractor gear and throttle for the forward speed you want. Gear___________ Throttle_________rpm. Use the same throttle RPM when measuring nozzle output (Step 7).
4. Measure the time in seconds required to pass through the test strip on four runs. Reach the desired speed *before* entering the test strip, and hold that speed constant throughout the test run.

   1st run______ + 2nd run ________ + 3rd run ________ + 4th run ________ = _____seconds total time.
5. Calculate total distance travelled. Multiply test strip length (Step 1) by the number of runs. Your strip was _____ m(*ft*) long x __________ runs = __________m(*ft*) total distance.
6. Calculate forward speed using the formula in the box at right.

total distance ÷	total time	×	constant	=	**forward speed**
m ÷	sec	×	3.6	=	km/h
ft ÷	*sec*	×	0.68	=	*mph*

7. Measure total nozzle output by spraying for a set time (such as 10 min) and divide volume (L) by time to find total output (L/min) OR use total nozzle output (L/min) from page 189.
8. Divide total output by forward speed and swath width and multiply by a constant to get the delivery rate.

total nozzle output ÷	forward speed ÷	swath width ×	constant	=	**delivery rate**
L/min ÷	km/h ÷	m ×	600	=	L/ha
L/min ÷	*mph* ÷	*ft* ×	*495*	=	*L/ac*

(L/ha = 2.5 times *L/acre*   *L/acre* = 0.4 times L/ha)

❸ Adjusting Delivery Rate

If the delivery rate of your sprayer is different than the rate listed on the pesticide label or recommended in the production guide, it can be adjusted in three ways:

1. **Nozzle size** should be changed if you wish to make large changes in delivery rate. Check with your nozzle supplier or agricultural advisor. Obtain a catalogue listing nozzles and nozzle outputs.

   The folowing formula can also be used to find nozzle size.

delivery rate	×	forward speed	×	nozzle spacing	÷ constant	=	**nozzle output**
L/ha	×	km/h	×	cm	÷ 60,000	=	L/min
L/acre	×	*mph*	×	*in*	÷ 5,940	=	*L/min*

2. **Forward speed** changes will adjust the delivery rate. Slower speeds increase the amount sprayed in a field, and faster speeds reduce it. If your delivery rate is 112 L/acre at 6 mph, then by halving your speed to 3 mph you'll double the delivery rate to 224 L/acre.

   Use these formulas to calculate alternative combinations of deliver rates and speeds.

present forward speed	×	present delivery rate	÷	new forward speed	=	**new delivery rate**
km/h	×	L/min	÷	km/h	=	L/min
mph	×	*L/min*	÷	*mph*	=	L/min

   Speed changes are usually made by using a different gear in order to keep tractor RPMs within the range recommended for the sprayer pump.

present forward speed	×	present delivery rate	÷	new delivery rate	=	**new forward speed**
km/h	×	L/min	÷	L/min	=	km/h
mph	×	*L/min*	÷	*L/min*	=	*mph*

3. **Spray pressure should be set for the correct droplet size.** Changing pressure is recommended only for very small changes in delivery rates. Otherwise your droplet size will change and cause drift or runoff problems. Since pressure must be increased four times to double the delivery rate, this is not a good way to adjust delivery rate.

After making the adjustments, measure the delivery rate again and fill in a new Calibration Worksheet.

When your equipment is accurately calibrated and applying the desired delivery rate, you are then ready to spray. Use the Pesticide Use Calculations ❶ to determine how much pesticide to buy and how much pesticide to add to a full or partial tank.

WHEN should I calibrate my equipment?

1. Before using new or altered equipment.
2. When making any changes that affect the delivery rate.
3. At regular intervals to see if wear is affecting output.

Why should I calibrate my equipment?

1. So the pesticide is applied accurately and uniformly at the recommended rate.
2. To prevent harm to the crop from too much, too little or uneven coverage
3. To prevent wasting money spent on pesticides.

❹a Calculating How Much Pesticide to Add to a Spray Tank – Per Area Rate

Example: pesticide label reads: "use 3 L/ha in 1000 L of water" or "use 3 L/1000 L of water/ha".

Pesticide ________________ Pest ____________________ Crop __________ Date ____________

Fill in values for only one column – hectares or acres. Use only hectares or only acres; don't mix them. Use litres (L) for all liquid volumes. Use the italicized line if you are using acres.

	Hectares	Acres
Field area	______ ha	______ *acres* (*hectares* = 0.4 x *acres*)
Spray tank capacity	______ L	______ *L* (*L* = 3.79 × US gal. L = 4.55 × Imperial gal.)
Pesticide label application rate	______ kg or L/ha	______ *kg or L/acres* (*L/acres* = 0.4 × L/ha)
Spray volume	______ L/ha	______ *L/acres* (from label or production guide)

Check your Calibration Worksheets and choose a suitable sprayer setup and Sprayer Delivery Rate

Sprayer Delivery Rate	______ L/ha	______ *L/acres*

Copy values into the formulas below where needed.

How much pesticide to buy?

field area	×	pesticide label application rate	×	# applications per year	=	**pesticide to buy**
ha	×	kg or L/ha	×		=	kg or L
acres	×	*kg or L/acres*	×		=	*kg or L*

Full tank

Area covered by a full tank?

tank capacity	÷	sprayer delivery rate	=	**area covered**
L	÷	L/ha	=	ha/tank
L	÷	*L/acre*	=	*acres/tank*

How much pesticide to add to a full tank?

pesticide label application rate	×	area covered by a full tank	=	**pesticide to add**
kg or L/ha	×	ha/tank	=	kg or L
kg or L/acre	×	*acres/tank*	=	*kg or L*

Number of tankfuls required for area?

field area	÷	area covered by a full tank	=	**tankfuls required**
ha	÷	ha/tank	=	tanks
acre	÷	*acres/tank*	=	*tanks*

Partial tank

How much spray mix to make for a partial tank?

sprayer delivery rate	×	area remaining	=	**spray mix to make in partial tank**
L/ha	×	ha	=	L
L/acre	×	*acres*	=	*L*

How much pesticide to add to a partial tank?

pesticide label application rate	×	area remaining	=	**pesticide to add in partial tank**
kg or L/ha	×	ha	=	kg or L
kg or L/acre	×	*acres*	=	*kg or L*

❹b Calculating How Much Pesticide to Add to a Spray Tank – Per Dilution Rate

Example: pesticide label reads: "use 1 L/1000 L of water and spray foliage thoroughly".

Pesticide __________ Pest __________ Crop __________ Date __________

Fill in values for only one column – hectares or acres. Use only hectares or only acres; don't mix them. Use litres (L) for all liquid volumes. Use the italicized line if you are using acres.

	Hectares	Acres
Field area	______ ha	______ *acres* (*hectares* = 0.4 x *acres*)
Spray tank capacity	______ L	______ *L* (*L* = 3.79 × US gal. L = 4.55 × Imperial gal.)
Pesticide label dilution rate	______ kg or L/1000 L of water (may be another amount of water)	
Spray volume	______ L/ha	______ *L/acres* (from label or production guide)

Check your Calibration Worksheets and choose a suitable sprayer setup and Sprayer Delivery Rate

Sprayer Delivery Rate	______ L/ha	______ *L/acres*

Copy values into the formulas below where needed.

How much pesticide to buy?

field area	×	pesticide label dilution rate	×	sprayer delivery rate	×	# applications per year	=	**pesticide to buy**
ha	×	kg or L/1000 L	×	L/ha	×		=	kg or L
acres	×	*kg or L/1000 L*	×	*L/acre*	×		=	*kg or L*

Full tank

Area covered by a full tank?

tank capacity	÷	sprayer delivery rate	=	**area covered**
L	÷	L/ha	=	ha/tank
L	÷	*L/acre*	=	*acres/tank*

How much pesticide to add to a full tank?

pesticide label dilution rate	×	tank capacity	=	**pesticide to add**
kg or L/1000 L	×	L	=	kg or L
kg or L/1000 L	×	*L*	=	*kg or L*

Number of tankfuls required for area?

field area	÷	area covered by a full tank	=	**tankfuls required**
ha	÷	ha/tank	=	tanks
acre	÷	*acres/tank*	=	*tanks*

Partial tank

How much spray mix to make for a partial tank?

sprayer delivery rate	×	area remaining	=	**spray mix to make in partial tank**
L/ha	×	ha	=	L
L/acre	×	*acres*	=	*L*

How much pesticide to add to a partial tank?

pesticide label dilution rate	×	spray mix in partial tank	=	**pesticide to add in partial tank**
kg or L/1000 L	×	L	=	kg or L
kg or L/1000 L	×	*L*	=	*kg or L*

Forward Speed Calculations

Date:_________________________

Calculate the forward speed of your tractor and sprayer in field conditions encountered during spraying. If you change tires, tire pressures, or tire lugs wear significantly, speeds will change. Also speeds will change between dry and very wet field conditions.

1. Mark out a test strip at least 60 m or 200 *ft* long.
2. Fill the tank about half full with water and move to the test strip.
3. Choose the tractor gear and throttle for the forward speed you want. Gear _________ Throttle __________ rpm. Use the same throttle RPM when measuring nozzle output (Step 7).
4. Measure the time in seconds required to pass through the test strip on four runs. Reach the desired speed *before* entering the test strip, and hold that speed constant throughout the test run.

   1st run _____ + 2nd run ____ + 3rd run ____ + 4th run ____ = _______ seconds total time.
5. Calculate total distance travelled. Multiply test strip length (Step 1) by the number of runs.
   Your strip was ______ m(*ft*) long x _______ runs = _______ m(*ft*) total distance.
6. Calculate forward speed using the formula in the box at right.

total distance	+	total time	x	constant	=	**forward speed**
m	+	sec	x	3.6	=	km/h
ft	+	sec	x	0.68	=	*mph*

Tractor #1 _______________ Tire Size ___________________ Tire Pressure ______________________

Gear						
Throttle	rpm					
Time	sec					
Total distance	in *(ft)*					
Forward speed	km/h *(mph)*					

Tractor #2 _______________ Tire Size ___________________ Tire Pressure ______________________

Gear						
Throttle	rpm					
Time	sec					
Total distance	in *(ft)*					
Forward speed	km/h *(mph)*					

Appendix F. Ministry of Agriculture Offices

AgriService BC connects farmers, food processors and new entrants to agriculture, to the services, programs and information that the BC government offers to help them succeed.

AgriService BC is available:

- online: www.gov.bc.ca/agriservicebc
- toll-free: 1 888 221-7141
- by email: AgriServiceBC@gov.bc.ca

Abbotsford
1767 Angus Campbell Road V3G 2M3
Phone: (604) 556-3001, 1 888-221-7141

Courtenay
2500 Cliffe Avenue V9N 5M6
Phone: (250) 897-7540

Cranbrook
205 Industrial Road V1C 7G5
Phone: (250) 489-8507

Creston
1243 Northwest Boulevard V0B 1G6
Phone: (250) 402-6429

Dawson Creek
1201 - 103rd Avenue V1G 4J2
Phone: (250) 784-2601, 1 877-772-2200

Duncan
5785 Duncan Street V9L 5G2
Phone: (250) 746-1210

Fort St. John
10043 - 100th Street V1J 3Y5
Phone: (250) 787-3240, 1 888-822-1345

Kamloops
162 Oriole Road V2C 4N7
Phone: (250) 371-6050, 1 888-823-3355

Kelowna
#200 - 1690 Powick Road V1X 7G5
Phone: (250) 861-7211, 1 888-332-3352

Oliver
Suite 201, 9971 - 350th Avenue V0H 1T0
Phone: (250) 498-5250, 1 888-812-8811

Prince George
815 - 299 Victoria Street V2L 5B8
Phone: (250) 565-7200, 1 800-334-3011

Smithers
3726 Alfred Avenue V0J 2N0
Phone: (250) 847-7247

Vernon
4607 - 23rd Street V1T 4K7
Phone: (250) 260-3000, 1 877-702-5585

Victoria
808 Douglas Street V8W 9B4
Phone: (250) 387-5121

Williams Lake
300 - 640 Borland Street V2G 4T1
Phone: (250) 398-4500, 1 800-474-6133

Enquiry BC - To reach any of the above offices Toll Free, calls may be routed through:
Enquiry BC: 1 800-663-7867
Vancouver: (604) 660-2421
Victoria (250) 387-6121

Agriculture Risk Management – Production Insurance:
200-1500 Hardy Street, Kelowna V1Y 8H2
Phone: (250) 712-3797, 1 888 332-3352
Fax: (250) 712-3269

Front Counter BC – Contact to access licenses, permits, registrations and other authorizations required to utilize the Province's natural resources. Phone: 1 877-855-3222, Email: FrontCounterBC@gov.bc.ca

Provincial Emergency Program – To report an emergency, Phone: 1 800-663-3456

Recycling Hot Line – Phone: (778) 588-9504 (within Vancouver) or 1 855-875-3596 (province wide)

Crown Publications – For copies of legislation and other government publications, Phone: (250) 387-6409

BC Poison Control Centre – 1-800-567-8911