4. Integrated Pest Management and Crop Health

This chapter discusses the tools of integrated pest management (IPM) and plant health for insects, mites and diseases. IPM is a pest control approach that uses all available control strategies to maintain pest populations below an economic injury level. Historically, the routine spraying of pesticides for insurance purposes has led to a number of problems, including:

- pest resistance (which is discussed later in this chapter under the section *Chemical Control*).
- environmental concerns regarding pollution and groundwater contamination that make it important to reduce use and misapplication of pesticides, and to focus on pesticides with a more environmentally friendly profile.
- personal health and safety concerns relating to potential exposure of applicators and workers to pesticides, as well as pesticide residues in greenhouses. Refer to Chapter 1, *Using Pesticides in Ontario* on page 1, and Chapter 2, *Safe Use of Pesticides* on page 11 for more information on working safely with pesticides.

IPM promotes an integrated program rather than reliance on a purely pesticide-based program to eradicate pests and prevent pest problems. IPM is built on the following principles:

- a well-structured and routine pest monitoring program that drives the decision-making process
- cultural controls such as sanitation, environmental management and cultivar resistance
- physical controls including the exclusion of pests through strategies such as the use of disease-free plant stock, screening for flying insect pests and mass trapping
- biological controls
- chemical control strategies

The basic objectives of any IPM program should be to:

- reduce the possibility of introducing pests into the crop.
- avoid creating conditions suitable for pest establishment and spread.
- develop management strategies for controlling pests if they do become established.

Monitoring

Careful monitoring provides reliable information to guide an IPM program. Monitoring techniques can be quite different for insect/mites compared with diseases, but it is important that a monitoring program focus on all pests (insects, mites, diseases, weeds).

To be successful, monitor on a regular basis. Record information so growers can make use of it in the future. Monitoring records can be used for anticipating patterns of future pest problems including their timing, location and crops affected, providing continuity of information for new employees and to assist in the process of crop export. It is also beneficial when attempting to identify a crop problem or when completing a post-crop production review. Include information such as:

- date
- pests identified
- location in the greenhouse – compartment or section
- number of insects trapped
- stage of development (e.g., adults, pupae)
- diseases present or suspected and percentage of crop affected
- crop species and cultivar
- stage of plant development
- control action initiated (pesticide used, rate, area treated, date and time, etc.)
- greenhouse environmental conditions (temperature, relative humidity (RH), electrical conductivity (EC), pH, light levels, shading used etc.)

Insects and mites

The most common greenhouse monitoring technique is the use of yellow sticky traps (cards or tape) to collect many species of flying insects. These are especially effective for whitefly, thrips, leafminer, fungus gnats, shoreflies and winged aphids. Note that blue sticky traps have proven to be especially attractive to western flower thrips. However, if a variety of pests is present, yellow traps are a better choice.

Use one sticky card every 100–200 m^2 and change the traps regularly. In spring and summer, this usually means changing the cards every week when recording pest numbers. In winter, when pest numbers are lower, it may be possible to change sticky cards less frequently. However, pest numbers should still be recorded weekly.

Another important, and often overlooked, monitoring technique is a routine and structured crop inspection program. It is essential for monitoring the presence of mites, wingless aphids or the immature stages of whitefly and leafminer. Detecting non-flying pests early makes control easier and may mean containing a problem with only a spot spray or other localized action.

Adopt a regular sampling pattern that provides good coverage of the whole greenhouse, including entry points and areas of concern. Concentrate on known susceptible crops or areas within the greenhouse that are known hot spots. Keep weekly records.

Diseases

A sound disease management program integrates a few universal principles and concepts into the overall production system for that particular crop. It is important to understand the concepts of disease control and the strategies developed from them, and to make modifications appropriate for a particular greenhouse or crop situation. A disease control program involves more than a fungicide application, which too often addresses the symptoms but not the problem.

Successful disease management begins prior to the start of each crop. Knowing the diseases most likely to infect the crop is helpful in anticipating the potential problems that may arise. However, with so many new plant introductions each year, the susceptibility to disease is not always known. Experience has shown that most new plant material is susceptible to many of the same diseases that have frustrated growers for decades.

> Becoming familiar with the typical symptoms of the most common economically important diseases is important in quickly recognizing and identifying a disease in its early stages.

Regular crop monitoring and record-keeping provides reliable information to guide disease management if the crop inspection is routine and structured. It is essential to monitor for the presence of plant diseases, just as it is in reviewing crops for plant growth regulator (PGR) application or for irrigation. It must be considered part of the production process. Concentrating on known susceptible crops or areas within the greenhouse that are typical locations for certain problems (e.g., powdery mildew near door entrances) can save time when growing a range of crops.

To monitor effectively for disease incidence and development, it is important to inspect foliage and flowers (if present) weekly. Roots should also be checked at least bi-weekly, which is practical for potted crops although not for soil-grown cut flowers. Check EC and pH at least biweekly for each crop grown as these two factors often predispose plant roots to attack by various root rot pathogens. Monitoring greenhouse RH and temperature for dramatic fluctuations by reviewing graphs produced by environmental computers provides early warning of the potential for foliar disease problems. Detecting diseases early makes control easier and may mean containing a problem with only a spot spray or other localized action.

Cultural Controls

Cultural controls include a number of strategies such as sanitation, environmental management and cultivar resistance. They are important for both insects/mites and diseases, although how they are used can be different for these two groups of pests.

Sanitation

Sanitation is the first step in any pest control program. If a source of infection or infestation persists due to poor hygiene, pest control programs will be expensive and frustrating. Practise proper sanitation in the greenhouse and adjoining structures (boiler rooms, etc.) in the immediate vicinity of the greenhouse and during every stage of crop production. A good sanitation program will include a number of approaches.

Basic hygiene

Proper greenhouse hygiene is a continual, year-round process. Cleanliness on its own may not control pest problems, but it is a basic component of any control program and an essential adjunct to other pest management strategies. It is important to:

- Use footbaths between greenhouse compartments, particularly between propagation and stock plant areas. Proper maintenance of these footbaths is essential. Follow the label of the product being used. Household bleach is not recommended for this purpose.
- Remove dead and dying plants, leaves and flowers as detected. In geraniums, removing and disposing of all flowers away from the greenhouse plays a significant role in reducing the incidence of *Botrytis*. Do not leave diseased plants under benches. In roses, remove all flowers (including those that will not be sold) and dispose of them away from the greenhouse. This can play a significant role in control of thrips.
- Place rogued plants with difficult-to-control diseases in commercial garbage containers and dispose of them in a landfill to reduce potential sources of inoculum.
- Dedicate wheelbarrows or soil carts used to discard diseased material strictly for disposal purposes. If this is not possible, disinfect after every use.
- Have employees wear disposable gloves when handling diseased or infested plant material. Otherwise, employees should wash their hands thoroughly with soap or bactericidal hand lotion before performing another function. They should also wash their hands or change disposable gloves between cultivars when taking cuttings.
- Store normal crop residues well away and downwind from the greenhouse to prevent particles of media or plant tissue being blown or sucked into the greenhouse. It is preferable to cover plant residues. Alternatively, move residues offsite on a routine basis.
- Keep walks and the surfaces of benches clean. Sanitize between crops.
- Avoid overwintering garden or "pet" houseplants in the greenhouse, as they may act as a source of disease or insect pests.
- Maintain proper drainage to eliminate puddles and wet surfaces, as these provide ideal breeding sites for fungus gnats and shoreflies. These insect pests are a common vector of infection for root diseases such as *Pythium* and *Fusarium*.
- Keep the greenhouse free of weeds that may harbour diseases like impatiens necrotic spot virus/ tomato spotted wilt virus (INSV/TSWV) and other common viruses. Weeds can also act as a refuge for insects that can be an ongoing source of new infestations or vectors of disease.
- For soil-grown crops, steam soil before planting winter crops to minimize the carryover of root and crown rot pathogens. See *Steam* on page 51.
- Steam traditional propagating benches regularly.
- Disinfect propagating benches and trays before use and between each round of rooting to eliminate bacteria, fungi and insects/mites.
- Use clean containers and porous, well-draining media to minimize the potential for pathogens such as *Pythium* and *Phytophthora*.
- Use expanded metal benches rather than wooden benches for easy cleaning and sanitizing, and to minimize the spread and survival of pathogens during propagation.
- Sweep or vacuum bench surfaces before sanitizing to ensure the best possible effectiveness of the sanitizer. Peat and other organic matter left on the bench prior to sanitizing reduce the effectiveness of most sanitizing agents. If necessary, wash down benches and walls with horticultural detergents to remove algae and other organic material before sanitizing.

- Empty and sanitize tanks used to hold recirculated nutrient solution (if root rot diseases have been a problem or there is no routine pasteurization of the recirculated water) at the same time as concrete floors or troughs are being sanitized to prevent recontamination of the production areas.
- Dip cutting knives in 70% alcohol between cultivars to prevent the spread of disease. Milk is effective as a dip for knives for control of tobacco mosaic virus.
- Between crops, perform a general disinfection of the greenhouse structure (walls), heating pipes, walks, benches or equipment if possible.

Disinfectants and cleaners of greenhouse surfaces

Disinfectants and cleaners play an important role in the prevention and control of fungal and viral pathogens and algae within the greenhouse. They should routinely be used as a pre-crop clean-up and during the cropping cycle to sanitize greenhouse structural surfaces and equipment.

There are two categories of products – cleaners and disinfectants/sanitizers. The following are cleaners:

- *Horti-Klor* – a chlorinated cleaner or detergent that can be used initially to remove algae and plant residue from packing equipment, planting lines, plug trays and coolers. Follow manufacturer's directions.
- *Strip*-It – an acid-based formulation that removes algae, biofilm and fertilizer build-up for end-of-crop cleaning of greenhouse structures and irrigation systems.

Disinfectants are oxidizing agents that are fast-acting, broad spectrum and considered low-toxicity biocides. Disinfectants can be categorized into the following types; sodium hypochlorite, quarternary ammonium compounds or hydrogen peroxide based. Use the appropriate safety equipment when loading, mixing and applying disinfectants as recommended on the label. The following products are available as of June 2014:

- Household bleach (5% sodium hypochlorite) – most household bleach solutions contain 5% sodium hypochlorite (50,000 ppm available chlorine). Dilute 5% sodium hypochlorite in a ratio of 1:100 to create a 0.05% solution. This is the usual dilution for disinfection of surfaces. Use a higher strength solution (up to 1.0%) in cases of serious disease outbreaks or when disinfecting wooden benches or surfaces with considerable organic matter remaining on surfaces. A final solution of 0.5% of sodium hypochlorite bleach is made by mixing 1 part household bleach with 10 parts water. For a 1% solution, mix 1 part bleach to 5 parts water. When there is significant amount of organic matter, free chlorine readily reacts to form less efficacious chloramines. Bleach will produce a toxic gas when mixed with acidic detergents or when undiluted bleach is exposed to sunlight. Chlorine is very effective but rapidly volatilizes when mixed in water. The strength will be reduced by 50% in two hours. Chlorine fumes can be harmful to plants. If plants are present in adjacent areas, ensure adequate ventilation. Organic matter very quickly inactivates the free chlorine. Residual chlorine can be released from surfaces when rewetted if rapid drying has occurred.
- Hydrogen peroxide – 35% regular hydrogen peroxide is an effective disinfectant through the process of oxidation for cleaning and sanitizing greenhouse surfaces and irrigation systems, but has less residual activity than the following two disinfectants, which are acidifed with peroxyacetic acid.
- ZeroTol – 27% hydrogen peroxide acidified with peroxyacetic acid is an effective disinfectant through the process of oxidation for cleaning and sanitizing greenhouse non-porous hard surfaces and irrigation systems including flood floors and benches used for non-food crops.
- SaniDate 5.0 – 23% hydrogen peroxide acidified with peroxyacetic acid has similar activity as ZeroTol and is registered for the sanitation and disinfection of hard, non-porous surfaces for use on farm/harvesting and packing equipment.
- KleenGrow – a quaternary ammonium chloride compound with broad fungicidal and bactericidal activity, for general hard-surface disinfection of packing lines, plug trays and foot baths.
- Virkon – potassium monoperoxysulphate, a non-corrosive disinfectant with broad fungicidal, bactericidal and virucidal activity for use in greenhouses and other agricultural buildings.

- Quaternary ammonium chloride compounds are quite stable because the chlorine is not volatile, but they disinfect in a way similar to chlorine bleach. As with bleach, contact with any type of organic matter will inactivate the disinfectant. Therefore, it is very important to remove as much organic matter as possible prior to application.

Soil pasteurization

Greenhouse media containing field soil (unless guaranteed sterile or pasteurized by the manufacturer) and cut flower soil-based ground beds typically contain weed seeds, insects, bacteria and fungi that may be harmful to the plants being grown. Pasteurization of media containing soil is important to eliminate these harmful organisms. Ideally, this is accomplished without injuring beneficial soil organisms.

Steam

Steam is the most common heat source for pasteurization. The most common use of steam for soil pasteurization is in ground beds used for some cut flower crops. The beds are covered with a tarpaulin and the steam is injected directly under the tarpaulin through a canvas hose or a perforated, flexible plastic field tile to ensure even distribution. Soil should be in fine tilth and free from clods and undecomposed crop remains, to allow rapid and uniform penetration of the steam.

Table 4-1. *Time-Temperature Relationships to Destroy Undesirable Organisms* on this page shows the time necessary to destroy insects, weeds and various diseases at specific temperatures. It shows that most organisms of concern to growers can be eliminated under ideal conditions of 60°C for 30 minutes.

Table 4-1. Time-Temperature Relationships to Destroy Undesirable Organisms

Weeds (most)	70–80°C for 15 min.
Insects and mites	60–71°C for 20 min.
Bacteria (most)	60°C for 10 min.
Fusarium	57°C for 30 min.
Botrytis	55°C for 15 min.
Nematodes	55°C for 30 min.
Rhizoctonia	52°C for 30 min.
Sclerotinia	50°C for 5 min.
Pythium	46°C for 40 min.

When temperatures rise above 82°C, beneficial soil organisms begin to be destroyed. If the soil is heated to a temperature that is too high for too long a time, it becomes sterile. It is then subject to a greater degree of infection, as all beneficial organisms have now been destroyed. There are many other undesirable effects of over-steaming, such as:

- excessive ammonia release
- manganese toxicity
- higher total salt levels
- destruction of organic matter

Chemical fumigants

Chemical fumigants such as Basamid Granular and Vapam Liquid can be used to pasteurize soil for preplanting treatments for potting or in greenhouse beds or benches. Each of these fumigants has a specific rate and activity against soil-borne insects, diseases, nematodes and weeds. Always read the manufacturer's label – some formulations may be less effective against certain types of pests. Do not use when plants are in other areas of the greenhouse.

Weed control

Methods

Control of weeds inside and outside the greenhouse is an important part of any pest management program. Weeds can provide a refuge for insect and mite pests and can act as a reservoir for diseases. A 3-metre vegetation-free or carefully maintained strip of lawn around and between greenhouses will decrease the danger of invasion by insects and diseases from outside. Fescue grasses have been shown as one of the least preferred grasses of western flower thrips, which makes it useful for lawn plantings around greenhouses. For some regulated pests such as Japanese beetle, there are specific requirements for the outside perimeter of greenhouses. See Chapter 6, *Occasional Pests* on page 77 or contact the Canadian Food Inspection Agency (see Appendix D. *Other Contacts* on page 155).

Steam

Steam used to pasteurize soil will kill non-rhizomatous annual weeds and most weed seeds if the soil temperature can be held at 70–80°C for 15 minutes. Weed seeds with hard seed coats, those along the periphery of the steam tarpaulin and those in the transition layer between soil reaching the appropriate temperature and cooler soil below, may not be killed.

Soil fumigation

Metam sodium (Vapam) and dazomet (Basamid) are useful in treating seedbeds and potting soil. They break down in the soil to produce a gas that kills many weed seeds, nematodes and fungi that cause damping-off and other plant diseases. Do not use when plants are in other areas of the greenhouse.

Herbicides

OMAFRA Publication 75, *Guide to Weed Control* is available from OMAFRA Resource Centres and ServiceOntario Publications, and contains information on herbicides registered for use in Ontario. Treatments listed in the publication are subject to extensive field trials and observation on farms. Herbicides (e.g., those containing glyphosate) may be particularly useful for weed control outside, but there is currently only one product (EcoClear with acetic acid as the active ingredient) for use inside the greenhouse. Inside the greenhouse, remove weeds when young to prevent seed production from occurring. For bedding plant production facilities growing on the ground, cover the surface of the soil with black nursery mesh to minimize weed growth. Other methods such as cultivation, hand weeding and flaming can also be useful inside the greenhouse.

There is potential for crop damage if any herbicide is used incorrectly. Always turn off ventilation fans and close wall vents to avoid drawing herbicides into the greenhouse when applying herbicide outside adjacent to the greenhouse. Do not use any phenoxy-type herbicides adjacent to the vent side of the greenhouse because of the volatility of these herbicides. Carefully follow instructions in OMAFRA Publication *75 Guide to Weed Control* regarding chemicals, safety precautions, calibration, and care and use of sprayers. Where crop damage from herbicide drift from neighbouring sources is suspected, contact an office of Ministry of the Environment and Climate Change (see Appendix B. *Ontario Ministry of* the *Environment and Climate Change – Regional Offices Contact Information* on page 153).

Where unwanted herbicide residues remain in the soil, applying activated charcoal can reduce the problem. The rate varies depending on the type of chemical contaminant and its concentration. A typical range is 0.5–1.5 kg/100 m².

Managing the greenhouse environment

Environmental factors such as light, air temperature, plant temperature, RH, air circulation, media composition, pH and EC, as well as the nutritional status of the crop, impact both the health of the plants and the pests that attack them. The use of environmental controls to manage diseases is complex because of the simultaneous effect on crop production. Look at each case carefully – every one is different.

It is important to understand the cultural and environmental requirements of the crops being produced. Chronically stressing plants, for example, by growing them under conditions that are too dry or too wet can make them more susceptible to attack by disease pathogens. Plants become stressed when unsuitable root and/or shoot environments for a specific crop are provided by the grower.

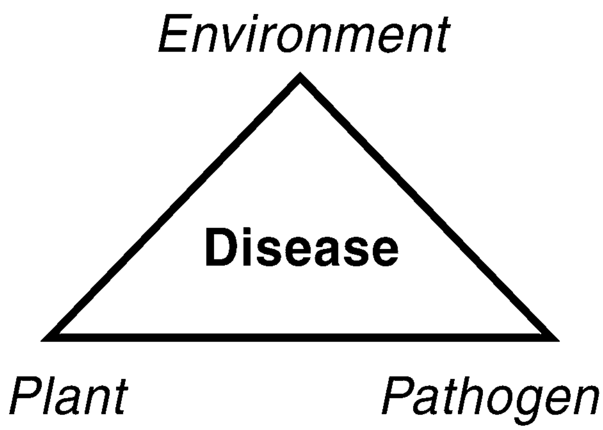
The Disease Triangle

Environmental management and its impact on the crop have particular relevance for disease control. Figure 4-1. *The Disease Triangle* on page 53 shows the importance of the three factors necessary for disease development:

- a pathogen or disease-causing organism (e.g., a fungus, virus or a bacterium)
- a susceptible plant for the pathogen to infect
- a suitable environment in which the first two will interact

Disease cannot occur if any one of these three factors is absent. In some circumstances, however, there is a fourth factor to consider. Some diseases, especially viruses and viroids, are primarily spread by insects. For example, aphids spread aster yellows in chrysanthemum, while impatiens necrotic spot virus/tomato spotted wilt virus (INSV/TSWV) is transmitted by western flower thrips. Fungus gnats can spread the spores of *Pythium*. The larvae damage young roots through feeding activity. *Pythium* oospores (thick-walled sexual spores) are routinely transmitted through the gut of fungus gnat larvae. In addition, the adult can transfer the pathogen with its legs and mouthparts. Controlling algae growth through judicious watering practices and providing adequate drainage under benches helps control fungus gnat and shorefly populations, and minimizes the spread of disease pathogens. In such cases, control of the insect vector will remove the means by which a plant is infected. For vector control, consider the full range of IPM strategies discussed in this chapter.

Figure 4-1. The Disease Triangle



Not all crops will tolerate the same growing conditions or water management practices. For example, Easter lily and primula require very different root management. Lily roots cannot tolerate being overly wet and starved for oxygen, while primula cannot tolerate having the media drying out.

Thielaviopsis basicola will attack the bedding plant Vinca when air and media temperatures are cool (15–17°C), but rarely at temperatures above 21–22°C. However, this pathogen will attack pansy when the temperature is above 25–26°C, the media pH is high (above 6.5), and the sanitation is generally poor.

Reduce the rate of fertilization when soluble salts (EC) are high. The definition of high salts varies with the crop and its stage of development (see Chapter 3, *Water, Growing Media and Crop Nutrition* on page 21). High salts damage root hairs and young roots by desiccation. These wound sites become entry points for disease pathogens like *Pythium* and *Fusarium*.

If foliar diseases are an ongoing problem, review temperature, RH, air circulation patterns, and watering practices. Often, by maintaining higher night temperatures, higher minimum overhead pipe temperatures, lowering under-bench heating pipe temperatures, or ensuring that air exchange occurs regularly throughout the night through gapping of blackout or energy curtains, the incidence of foliar diseases can be lessened.

The plant environment includes the soil or growing media in which the roots grow, and the above-ground environment or air where the shoots, leaves and flowers are produced and developed.

Soil or media environment characteristics that must be considered include:

- pH of the growing media. pH strongly influences the availability of micronutrients such as iron and manganese and can influence the development of the root system in the growing media.
- nutrient levels and their balance. These affect the plant tissue content and can trigger toxicity or deficiency symptoms. This tissue is typically more susceptible to attack by pathogens.
- EC (electrical conductivity created by soluble salts). High EC can damage root hairs, creating a wound site for attack by root disease pathogens.
- moisture-holding capacity. The media must hold sufficient available water to prevent desiccation of the roots once the root system becomes pot-bound.
- media texture to allow good drainage. Adequate coarse-fibred peat is required to ensure sufficient aeration when the growing media is at full water-holding capacity to prevent water logging and oxygen deprivation of the roots.
- oxygen content. Adequate media aeration is critical to healthy root growth and nutrient uptake and to prevent temporary exposure of roots to anaerobic conditions.
- media temperature. Roots develop best at temperatures somewhat lower than those required for shoot growth. High media temperature causes significant root death in most crops when media temperatures are above 26–28°C. This is of significant concern in sub-irrigation systems when plants are grown on metal troughs or concrete floors during the heat of the summer.

Aerial environment characteristics that must be considered include:

- light levels which should be suitable for the crop. Exposure of high-light requiring plants to low-light levels or heavy shading often triggers soft, weak growth that is more susceptible to leaf rot pathogens.
- air temperature. Growing the crop above or below the optimal temperature for the specific crop often results in higher incidence of root and foliar disease problems. For example, crops typically considered cool crops, are usually more susceptible to crown and root rot pathogens when grown during high temperature periods of the year.
- air movement. Airflow patterns within the greenhouse influence the severity of powdery mildew and Botrytis. Open doors causing drafts and fluctuating leaf and air temperature, or horizontal air fans that are improperly positioned that cause air turbulence or down drafts in front of the fan unit will increase the severity of foliar diseases. Insufficient air movement can also increase the incidence of foliar diseases because of the high RH levels developing within the plant canopy.
- relative humidity (RH). High RH at night (above 90%) fluctuating with low daytime RH increases the incidence of foliar diseases.
- air quality. Chronic low-level air pollution often associated with hydrocarbons such as propylene, propane or natural gas as a result of leaks or incomplete combustion in heaters, can cause plant responses similar to those caused by ethylene – triggering premature senescence of older leaves and flowers whose tissue is more prone to opportunistic fungi like *Botrytis.*

Know and understand the conditions required for both the optimal growth of the crop and the common diseases of that crop. For example:

- Avoid extremes or, more importantly, rapid changes in RH. This minimizes the time period and conditions suitable for *Botrytis* or powdery/downy mildew to develop. Humidity can also play an important role in development of infestations of pests such as spider mites.
- Be aware that temperatures of leaf surfaces are lower in plastic houses than in glass houses particularly at night, because of greater heat loss due to far-red radiation.
- Avoid poor air circulation (too little/too much) within individual greenhouse zones. This causes uneven temperatures throughout the crop. It can also lead to free moisture forming on the plants, particularly at night, which creates ideal conditions for powdery mildew and *Botrytis* infections.
- Avoid extremes, as much as possible, for the crops. For example, the combination of high temperature and over-fertilization promotes Fusarium crown and root rot in cyclamen, while the combination of high temperature and high RH is favourable to *Rhizoctonia* attacking cuttings during or just after propagation. Avoid low temperatures to prevent outbreaks of *Pythium* in warm-temperature crops.

Know and understand the conditions required for both the optimal growth of the crop and the common insect and mite pests of that crop. For example:

- During the winter months, developmental time and immature mortality increase for insect pests such as thrips. They also appear to be less mobile, so yellow sticky cards may not catch as many thrips, even when they are present and actively feeding in the crop.
- If the greenhouse is empty between crops, heat treatment can be an effective way to remove infestations of insects and mites. If temperatures are maintained at 40–42°C and humidity at <50% for 3–4 days, insect and mite pests will be effectively controlled. This is particularly suitable during the warmer months of the year when these temperatures can be achieved by simply closing the vents. Note: At higher temperatures, plastic fittings will warp or split.

Resistant cultivars

Many plant species display varietal differences in their susceptibility to insect and disease attack. Breeding of crops can provide growers with cultivars resistant to one or more insects or diseases. For example, greenhouse tomato growers seldom experience problems with Fusarium crown and root rot because resistant varieties have been developed. Greenhouse cucumber growers are increasingly using powdery mildew-tolerant cucumber varieties. However, although ornamental plant breeders have not taken the same advantage of host plant resistance, it offers potential for future advancements in pest management.

In the meantime, growers with pest problems can improve their pest management program by examining the varieties grown and how pests affect these varieties. Use susceptible varieties as indicators for pests and diseases (e.g., the colour of the flower might attract more thrips). Spot-spray the susceptible variety when pests or diseases occur to provide effective control and reduce the amount of pesticide applied. Alternatively, use susceptible varieties as an intensive focus of biological control programs. Although market demands ultimately determine the varieties grown, consider whether it is possible to eliminate or reduce the amount of a susceptible variety and replace it with a more resistant one.

Physical Control

Physical control of insects, mites and diseases can be accomplished in a number of ways:

- Pay careful attention to new plant material.
- Restrict entry to outdoor populations of pests.
- Control pest populations once they have become established in the greenhouse.

Biosecurity

Biosecurity is a process to protect a geographic area or individual facility from pests and diseases. It includes reducing the risk of the introduction of new pests and diseases, and eradicating or effectively managing the spread of those that have already arrived. Taking common sense precautions to prevent pests and diseases from entering the farm is a worthwhile investment. In the context of greenhouse floriculture, this should entail proper sanitation of the production facility between and during cropping cycles, including properly maintained foot baths, thorough inspection of incoming cuttings, and the other integrated disease strategies described in this chapter. The implementation of a biosecurity protocol for visitors entering the facility also plays an important role in reducing the potential for the introduction and establishment of both new and common pests and diseases.

Clean plant material

Purchasing cuttings from specialized propagators or plant breeders may minimize the chance of introducing diseases or insects into a greenhouse operation. If possible, isolate new plant material to reduce the potential for contamination.

Change stock plants regularly. This should occur quarterly or every six months, depending on the crop. Do not carry stock of any bedding plants from one season to the next.

Do not bring young clean stock into a production zone until the old has been moved out and the area is thoroughly sanitized.

Screening

Screening greatly reduces the entrance of common greenhouse pests such as thrips, aphids and whiteflies, as well as some less common pests such as tarnished plant bugs and European corn borers, which can become major pest problems when pesticide use is reduced as in biological control programs. Benefits of using insect screening have been demonstrated in Israel and California. In Ontario, growers who have installed screens have reported that pest levels and pesticide use are reduced and effectiveness of pest control measures, especially biological control, improved.

The most important consideration for a grower wishing to screen a greenhouse is to determine which pests are to be excluded. The size of the pest determines the mesh size of the screen that is needed. Large-mesh sizes of the style normally found in household screens are inadequate for excluding most major greenhouse pests. However, they can be useful in keeping out occasional larger pests such as tarnished plant bugs and lepidopteran (moth) pests. For smaller insects such as thrips, screens must be made of a very fine mesh for total exclusion. In cases with multiple pests of concern, mesh size should exclude the smallest of these pests.

Reduction of airflow as a result of installing screening is a major concern of growers. It can lead to the greenhouse overheating and stress on the fan motors (in the case of fan-ventilated greenhouses), which may be overtaxed if they are required to pull the same amount of air through the vents that are, in effect, partially blocked. Reduced ventilation is a valid concern, but it can be addressed by increasing the surface area of the vent. In many situations this has been completed successfully by building a screened framework around the vent opening. The goal is to ensure that the final surface area of the vents provides sufficient air exchange to allow adequate cooling of the greenhouse. There are several methods available to determine the required increase in surface area of the vents for any given greenhouse, but factors such as screen mesh size, fan capacity, and static pressure drop (the difference in air pressure between inside and outside the greenhouse when the fans are running) are important. Although there are software programs available to assist with these calculations, they can be complicated and are generally best left to screening manufacturers.

The small-mesh size means that the screens are very prone to blockage with dust and other deposits, especially in the summer. Clean the screens regularly as blockage reduces airflow through the screens and may contribute to excessively high temperatures in the greenhouse. It is also important to incorporate easy access in the design of the screens to facilitate their cleaning. Wash screens from the inside with a high-pressure hose. Do not do this when the fans are operating, because the water will block the pore openings and completely stop airflow, leading to overheating of the greenhouse.

The effectiveness of the screen depends on its ability to exclude flying insects. Repair tears or holes as soon as possible to avoid pest entry. Small tears can be simply repaired by gluing a piece of screening over the hole.

The cost of screening will depend on several factors: the final screening design, the increase in surface area needed to maintain adequate ventilation, the cost of the screening material, whether roof vents or side vents are to be screened, frequency of replacement, frequency of cleaning, etc. The biggest variable is the difference in cost between installing screens in a fan-ventilated, side-vented greenhouse or a passively vented greenhouse with roof vents. Nevertheless, reports from growers who have installed screens over side vents in fan-ventilated greenhouses suggest a rapid payback from reduced pesticide costs and improved pest management.

For more information, see OMAFRA Factsheet, *Screening Greenhouses for Insect Exclusion*.

Other physical controls

Physical controls of established pests include the roguing of diseased or infested plants as already discussed above. However, for flying insect pests it can also include the use of yellow sticky tape or large numbers of yellow sticky cards. It works on the same principle as the sticky cards used for monitoring. String tape along beds or benches or hang it vertically within the crop to provide significant supplementary control in conjunction with other control methods.

Biological Control

Biological control is the use of living organisms such as insects, mites, nematodes, fungi and bacteria to control pests such as insects, mites and diseases. Biological control requires very different approaches for insects and mites compared to diseases.

Biocontrol of insects and mites

While biocontrol of insect and mite pests has been widely used in greenhouse vegetable crops for many years, it is only since the early 2000s that it has become the predominant control strategy in ornamentals. Predatory and parasitic insects and predatory mites comprise the primary biocontrol agents (BCAs) used, however, there is an increasing number of microbial BCAs (e.g., fungi, bacteria) becoming available as well. Table 4-2. *Biocontrol Agents for Principal Greenhouse Pests* on page 58 lists the commercially available natural enemies used for insect and mite management in greenhouse floriculture.

Biocontrol involves more than just the release of parasites or predators. To be successful, plan at least several months in advance. Follow these steps when considering the use of biological control:

1. Develop a list of resources to help with the program. This may include producers and/or suppliers of biocontrol agents, other growers, extension specialists, researchers or consultants. Attend courses, seminars and workshops, read magazines

and newsletters, and use the Internet to find out as much as possible about biocontrol. Determine which pests to control and which are the most appropriate natural enemies.

2. If possible, start in a small, isolated part of the greenhouse to focus more closely on the area being used, and to gain experience with biocontrol before applying the concepts on a larger area. After reaching a level of comfort, expand the use of natural enemies to include other areas of the operation.

3. If possible, screen the area to be used. Movement into the greenhouse of pests from outside is unpredictable from year to year. Large numbers can swamp a biocontrol program and make it difficult for the natural enemies to maintain control. With screening, growers need only be concerned about the pests inside the greenhouse. See *Screening* on page 55.

4. Ensure that all staff are aware of the biological control program and why it is being used. They are in the greenhouse every day performing routine crop management tasks, and with proper training can recognize problems at a very early stage.

5. Many registered pesticides can have long-term (2–3 months) residual impact and can prevent establishment of natural enemies. Check pesticide spray records for the previous several months. If such pesticides have been used, wait the appropriate length of time before introducing BCAs. Use products with less residual impact to control pests and diseases during this period. Side effects of many pesticides on different BCAs are available from Biobest *(www.biobest.be)* or Koppert *(www.koppert.com)*.

6. Work with the supplier to learn how to check incoming BCAs and determine if they are alive and well. The quality of natural enemies produced by the major insectaries is excellent, but problems can occasionally arise in shipping. Suppliers need to know about any problems so the causes can be identified and corrected.

7. Follow instructions in storing and releasing the natural enemies. Many can be stored for only a short period of time under fairly specific conditions.

8. Monitor the populations of natural enemies and the progress of the biocontrol program. This is as important as monitoring the pest populations.

Use sticky cards to monitor flying insects, especially the parasitic wasps. Be aware, however, that some natural enemies (e.g., *Eretmocerus* for whitefly control) are highly attracted to yellow, and too many sticky cards may be detrimental to the program.

Check the impact of the natural enemy on the pest. For example, parasitism of whitefly by *Encarsia* and aphids by *Aphidius* parasitic wasps is easily checked.

Visually inspect the crop for natural enemies such as predatory mites, which do not fly. Inspect the crop especially in areas of highest pest numbers.

Regularly monitor pests to determine if populations are decreasing.

9. Use compatible pesticides if necessary. Identify them prior to starting a program so they are available if needed. Contact your biocontrol suppliers for more information on pesticide compatibility.

10. Be patient. It takes time and experience to understand and implement an effective system of biocontrol. Ask others with experience if the program is not progressing as expected.

For more details about the implementation of biological control or about supplies of parasites/predators, consult a greenhouse floriculture specialist or an industry consultant.

Use caution when using pesticides with biocontrols, since most pesticides are harmful to natural enemies. Application of just one harmful pesticide can prevent any further use of biocontrol agents for an extended period of time. Contact your biocontrol supplier for more information, or refer to the information on the Biobest website (*www.biobest.be*) or the Koppert website *(www.koppert.com)*.

Table 4-2. Biocontrol Agents for Principal Greenhouse Pests

Pest	Biocontrol Agent
Whitefly (*Trialeurodes vaporariorum* and/ or *Bemisia argentifolii, Bemisia tabaci*)	*Encarsia formosa*[1] *Eretmocerus eremicus*[1] *Eretmocerus mundus*[1] *Amblyseius swirskii*[2] *Amblydromalus limonicus*[2] *Delphastus catalinae*[2] *Dicyphus hesperus*[2] *Beauveria bassiana*[3] *Paecilomyces fumosoroseus*[3]
Spider mite *(Tetranychus urticae)*	*Phytoseiulus persimilis*[2] *Amblyseius fallacis*[2] *Amblyseius californicus*[2] *Amblyseius andersoni*[2] *Feltiella acarisuga*[2] *Stethorus punctillum*[2]
Western flower thrips *(Frankliniella occidentalis)*	*Neoseiulus cucumeris*[2] *Amblyseius swirskii*[2] *Amblydromalus limonicus*[2] *Iphesius degenerans*[2] *Orius* spp.[2] *Hypoaspis spp.*[2] *Dalotia (Atheta) coriaria*[2] Nematodes – *Steinernema feltiae* *Beauveria bassiana*[3] *Paecilomyces fumosoroseus*[3] *Metarhizium anisopliae*[3]
Aphids, including: green peach aphid *(Myzus persicae)*, melon aphid *(Aphis gossypii)*, foxglove aphid *(Aulacorthum solani)*, potato aphid *(Macrosiphum euphorbiae)*	*Aphidius spp.*[1] *Aphelinus abdominalis*[1] *Aphidoletes aphidimyza*[2] Lady beetles *(Harmonia and Hippodamia)*[2] Lacewings[2] *Beauveria bassiana*[3]
Fungus gnat (*Bradysia and Corynoptera* spp.)	*Stratiolaelaps (Hypoaspis)* spp.[2] *Gaeolaelaps (Hypoaspis)* spp.[2] Nematodes — *Steinernema* spp. *Dalotia (Atheta) coriaria*[2]
Leafminer *(Liriomyza trifolii)*	*Diglyphus isaea*[1] *Dacnusa sibirica*[1]

[1] Parasitoid: Usually requires only one host for completion of development, often killing it by living on or in its body.
[2] Predator: Feeds on its prey (pest) by catching it, but otherwise lives independently of it. It must consume more than one individual to reach maturity.
[3] Microbial agent

Biocontrol of diseases

Biological control of diseases involves the use of naturally occurring fungi and bacteria that strongly suppress disease-causing organisms without harming the crop. Mechanisms of action include competition, antibiosis, parasitism or induced resistance. Most biocontrol products should be considered preventative or suppressive and their use should start with the planting of a crop. Note that most labels indicate suppression of disease, not control of disease.

Microbial or bio-rational fungicides having received Canadian registrations for use on greenhouse-grown ornamental crops are listed below.

For root diseases:

- Actinovate SP consisting of the bacterium *Streptomyces lydicus* Strain WYEC 108, is registered for the suppression of Rhizoctonia crown and root rot of geranium, Pythium root rot of petunia and Fusarium wilt of cyclamen. It should be applied either when sticking cuttings or at transplanting and repeated every 4–12 weeks based on disease pressure.

- Mycostop is registered as a bio-fungicide for the suppression of damping-off caused by *Pythium,* root and crown rot caused by *Phytophthora,* and wilt caused by *Fusarium* on greenhouse ornamentals. The soil bacterium *Streptomyces griseoviridis* K61 is the active ingredient. Its mode of action includes hyperparasitism (microbe deprives pathogen fungi of nourishment by colonizing plant roots in advance of the fungi) and antibiotic production, which inhibits pathogen growth. Because the effect is preventative, drench Mycostop immediately after potting and repeat the treatment every 3–6 weeks, depending on disease pressure.

- Rootshield is registered as a bio-fungicide for suppression of *Fusarium, Pythium* and *Rhizoctonia* on all ornamental crops. The naturally occurring fungus *Trichoderma harzianum KRL-AG2* Strain provides protection by colonizing the surface of the roots and root rhizosphere through the utilization of waste products produced during normal root growth. It also parasitizes disease-causing fungi through the release of enzymes that cause breakdown of their cell walls. This bio-fungicide should be applied soon after germination, rooting or sticking of vegetative cuttings.

Two formulations are available: a granular formulation that can be incorporated into the growing media, and a drench to be applied to newly transplanted seedlings or cuttings at regular intervals.

- PreStop WP is registered as a contact bio-fungicide applied as incorporation into the media or as a drench application during propagation for the suppression of damping-off caused by *Pythium spp. and Rhizoctonia* on a variety of ornamental, vegetable and herb bedding plants During the growing-on stage, apply as a drench application to suppress *Pythium* spp. on many vegetable transplants and root and crown rots caused by *Phytophthora cryptogea* on many greenhouse ornamentals. The active ingredient is the fungus *Gliocladium catenulatum* Strain J1446, which works by competing with plant pathogens for colonization of plant root surfaces, depriving the pathogen of nutrients. Additionally, it produces enzymes that break down the cell walls of pathogens, an action known as hyperparasitism. It can be applied as a growing medium treatment or soil drench for root diseases, or as a foliar spray for *Botrytis*.

- Subtilex and BioTak both contain *Bacillus subtilis* MBI 600, a naturally occurring bacterium that has been shown to rapidly colonise the roots of growing plants, producing an antibiotic protein that suppresses the ability of *Pythium* spp., *Fusarium* spp. and *Rhizoctonia solani* to grow and become pathogenic through antibiosis and competition. Subtilex Biological Fungicide is registered for commercial incorporation into Promix soilless media manufactured by Premier Peatmoss. BioTak is another end use product registered for incorporation by commercial growers into their peat-based growing media prior to planting.

- Cease and Rhapsody ASO both contain *Bacillus subtilis* Strain QST 713, a widespread, naturally occurring bacterium with similar mode of action to *Bacillus subtilis* MBI 600. These two products are registered for the suppression of *Rhizoctonia solani, Pythium ultimum* and Phytophthora crown and root rots when applied as a soil drench to greenhouse and outdoor-grown ornamentals.

- Taegro containing *Bacillus subtilis* var *amyloliquefaciens* Strain FZB24 is registered for the partial suppression of Fusarium wilt of cyclamen when applied at the beginning of the seedling stage.

- Contans containing the fungal strain *Coniothyrium minitans* Strain Con/m/91-08 is registered for the control of sclerotia activity of *Sclerotinia sclerotorum* in soil-grown greenhouse cut flowers and for suppression in outdoor-grown cut flowers. The bio-fungicide should be applied to the soil three months prior to anticipated *Sclerotinia* outbreak in a susceptible flower crop.

For foliar diseases:

- Actinovate SP is registered as a contact biological fungicide for suppression of powdery mildew on greenhouse and field-grown gerbera daisy, greenhouse-grown verbena and peppers; for suppression of Botrytis on greenhouse and field-grown strawberries; and suppression of powdery mildew of greenhouse and field cucurbit vegetables and tomatoes. The active ingredient, *Streptomyces lydicus* Strain WYEC 108, is a bacterium that colonizes the leaf surface and competes against foliar pathogens. Its mode of action is a combination of parasitism and competition. For effective suppression of powdery mildew, it should be applied as a foliar spray at 7–14-day intervals.

- PreStop WP is registered as a contact bio-fungicide applied as a foliar spray for suppression of Botrytis. For mode of action, see description of PreStop WP for root diseases on this page.

- Rhapsody ASO and Cease bio-fungicides containing the bacterium *Bacillus subtilis* Strain QST 713 are registered for suppression of powdery mildew, Botrytis and several leaf spots on a number of greenhouse and outdoor ornamental crops. *Bacillus subtilis* produces chemicals that break down the cell membrane of disease organisms through parasitism and competition. The bacterium must contact the disease pathogen. It also inhibits pathogens from colonizing the plant. There is a range of rates depending on the disease pressure. It should be applied at 7–day intervals.

- Regalia Maxx contains an extract from *Reynoutria sachalinensis* that, when applied to plants, improves their natural defense mechanisms against certain fungal diseases and is registered for the suppression of *Oidium* spp., a powdery mildew of greenhouse and greenhouse and outdoor-grown ornamental crops.

- Cyclone, containing fermentation products of *Lactobacillus caseii* Strain LPT-111 is registered for the suppression of powdery mildew and blackspot on greenhouse roses when applied as a foliar spray.

As with pesticides, biocontrol using microbial or bio-rational fungicides is not a panacea for disease control. Biocontrol agents will not replace proper crop management strategies, nor will they eradicate a disease pathogen.

Chemical Control

Pesticides will remain an important component of greenhouse pest management programs. However, growers should carefully monitor their use for the reasons previously noted with regard to biocontrol, and as part of a resistance management program.

Resistance

Resistance is the evolutionary adaptation of a population to survive a pesticide dose that is lethal to most of its individuals. It is an inherited trait that is passed on to future generations. While resistance does not develop within an individual during its lifetime, it usually exists naturally in some individuals in a population, but at very low frequencies (too low to be measured or noticeable). The frequency of resistance increases when pesticide exposure kills susceptible individuals, while allowing successively greater numbers of resistant individuals to survive and reproduce, passing on their resistance to their offspring.

Pests can develop resistance to any pesticide if it is used incorrectly or too often. Although there are benefits from new product registrations, do not simply wait for the latest advance in pesticide chemistry. The long-term problems presented by pesticide resistance far outweigh the short-term gains of a new product if it is used incorrectly.

Resistance management programs aim to reduce the pressure applied to pest populations by pesticides. Use diverse control methods to reduce the need for pesticides. There are several ways to do this, mirroring the approach of IPM programs. Growers who use an IPM program, including good monitoring techniques and cultural, biological, and physical controls, are practising resistance management at the same time.

Insects and mites

When insecticides/miticides are used in an IPM program, the rate at which resistance develops increases if one class of pesticides (e.g., organophosphorus, synthetic pyrethroid, carbamate) is used for a prolonged period. The speed at which resistance develops depends on a number of factors. It may be as short as 1–2 years or could take place over a period of 10 years or more depending on:

- the pest being controlled
- the pesticide being used
- the pesticide history of the greenhouse
- how often the pesticide is applied
- the introduction of pests from other facilities
- the resistance management strategies that are in place

To slow the rate of resistance development, rotate pesticide classes every few weeks or for a period equal to the generation time of the pest being controlled. See Chapter 8, *Pesticide Application, Toxicity and Activity* on page 101 for pesticide classes. Most importantly, reduce the use of pesticides by implementing a well-rounded IPM program.

Diseases

Fungicides have been the conventional approach to disease control. The role of fungicides can vary from protecting healthy plants to treating infected plants and eradicating diseases. It is necessary to rotate fungicides with different modes of action to reduce the likelihood of resistance development. Rotation of fungicides has become increasingly important as most newer fungicides have a single-site mode of action and are more prone to resistance development. Never use fungicides with the same grouping number back-to-back. The grouping/class number is printed on the front of the label and can be found in Chapter 10, Table 10-2. *Pesticide Registrations by Pest* on page 133. Reducing the use of and reliance on fungicides is also critical in resistance management. An important aspect of reducing fungicide use is developing a better understanding and appreciation of the role of cultural practices in disease management.

Pesticides must be used responsibly and as part of a broader resistance management program. For more information on pesticide application, see Chapter 8, *Pesticide Application, Toxicity and Activity* on page 101.

Achieving Successful Pest Management

Successful pest management can be achieved if the measures below are followed:

- Monitor crops weekly with a formal monitoring program for insects, mites and diseases. However, the monitoring program should be supported by daily (or at least two times per week) informal inspections, by walking the crop(s) to achieve early detection. This involves checking the crop foliage and root systems and equally importantly, manual and automated computer-controlled environment settings.
- The employee responsible for monitoring must work closely with the person responsible for overall crop scheduling and growing. Ideally, the individual in charge of growing is the same one who monitors for pests and manages the environmental controls. In many operations, this should be done by an employee dedicated to the task because the owner/grower often has other issues on which he/she is focused.
- Correct diagnosis of pathogen, insect or mite is crucial. Without correctly identifying the pest, control using cultural or chemical strategies is impossible. Soil-borne fungi are the most difficult pathogens for growers to identify. Send samples to the Pest Diagnostic Clinic, University of Guelph for an accurate diagnosis. See Appendix E. *Diagnostic Service* on page 156 for further details. For some bacterial, fungal and virus diseases, ELISA disease diagnostic kits for grower use are available from Agdia Inc.
- Develop a thorough understanding of the pests that affect the crops being grown. Correct use and timing of management strategies then become part of an ongoing process.
- As a grower/manager, keep detailed records that enable merging of cultural, environmental, and insect and disease data for review when a production problem arises or for doing post-season crop summary reviews.
- Monitor the weather to help anticipate potential problems. For example, from a disease perspective, a cool, cloudy and wet summer with the central heating system off creates ideal conditions for downy mildew development. Poinsettia propagators can anticipate slow, uneven rooting and increased Botrytis rot without supplementary heating. For insects and mites, a hot dry summer will likely result in an increase in spider mite problems, and an unusually warm spell in early spring can lead to a sudden increase in pests such as thrips a couple of weeks later.
- Emphasize disease prevention rather than cure. This is critical in any production system, but is especially true when crops are being grown in closed sub-irrigation systems. Additionally, because disease pathogens are microscopic, learn to anticipate when possible pathogen infection periods are likely to occur. By the time the problem is visible, the pathogen has usually been present for some time and is more difficult to control.