3 Disease and pest management

▶ 3.1 Integrated pest management

For many years, Canadian vegetable producers relied heavily on protective applications of pesticides to reduce the impact of diseases and pests on their crops. In some cases, excessive amounts of chemicals were applied with little or no regard to effects on non-target organisms or contamination of the produce, soil and water. In the late 1950s, however, scientists, particularly those dealing with control of arthropod pests, began to develop alternative procedures for crop protection, using a minimum of broad-spectrum chemical insecticides in combination with selective chemicals, biological agents, and modified cultural practices. This work stimulated interest in regulation of plant pathogens by biocontrol agents. In addition, by monitoring population levels of pests and pathogens in relation to crop damage, action thresholds were established for use in crop protection programs as a guide to the timing of control measures. Thus, the present holistic approach to disease and pest control, termed integrated pest management, is evolving and is being widely implemented. Predictive programs, such as BOTCAST for onion botrytis leaf blight, TOM-CAST for tomato early blight, and BLITE- CAST for potato late blight, are resulting in a more precise approach to disease and pest control and are within the spirit of sustainable agriculture. Similarly, action thresholds for application of chemical insecticides to regulate insect pests on such crops as carrot, celery, crucifers, onion, potato, sweet corn and tomato have been or are being developed.

The effective integration of cultural practices and other methods of disease control is illustrated by the development of a system for the control of pea root rot. This system takes into account four pathogenic fungi and their disease cycles, tillage practices, drainage, soil compaction, cultivar susceptibility, green manure crops, and the predisposition of pea to these fungal pathogens by herbicides. A more limited program for the control of potato late blight has been developed, and an integrated system for the control of cucumber powdery mildew in the greenhouse has been described, along with several ways of manipulating the greenhouse crop and its environment to escape diseases. Thus far, none of these systems considers the simultaneous control of insect and other pests, so the term “integrated” is only partially valid, but it is encouraging to note that many greenhouse tomato growers have not used chemical pesticides for several years.

These integrated programs can be improved by the development and use of selective pesticides to minimize the environmental impact of crop protection practices, particularly on indigenous and introduced agents for biological control. Undoubtedly, the most successful selective pesticides developed to date are formulations of the bacterium *Bacillus thuringiensis* Berliner. Applications of these formulations will control most foliage-feeding lepidopterous larvae, including those on cruciferous crops, lettuce and celery, and some coleopterous larvae, notably the Colorado potato beetle on potato and tomato. Such applications have no direct effects on non-target, parasitic or predaceous arthropods and do not contribute to pollution of the soil, water or crop. Furthermore, residues on the crop are not hazardous to humans and other animals. The potential for using viruses, protozoa, fungi and nematodes that kill insects and mites also is promising. Introduced parasitic or predaceous insects and mites are especially successful for control of pests of greenhouse-grown vegetables. Introductions of beneficial insects and mites, in combination with environmental manipulation and hydroponic systems to minimize the occurrence of diseases, have permitted pesticide-free production of greenhouse vegetables, particularly tomato and lettuce, by many growers. Unfortunately, introductions of beneficial insects and mites, and manipulation of those that occur naturally have been exploited very little for control of insect pests of vegetable crops under commercial field conditions.

Other methods to control pest insects and mites, such as introduction of attractant and repellant materials, application of growth-regulating chemicals, or mass release of pheromones to cause mating disruption, which have been tested or applied to other crop systems, have not appeared promising or have not been assessed for controlling pests on vegetable crops. Similarly, the release of sterilized males to reduce development of pest species has not proven economically practical for control of insects on vegetables.

In greenhouse vegetable crops, the high degree of environmental control available to growers enables fully integrated programs to be devised that give good productivity as well as control of insects, mites and diseases. Biological control, using natural and introduced parasites and predators of pathogens and pests, plays a major role in greenhouse crop protection, but it is more difficult to realize in field vegetable crops because of the lack of control over the environment.

Management of viral diseases depends largely on vector control, crop hygiene, resistant cultivars, and regulatory systems of quarantine, inspection and certification. Crop protection strategies for nematode and weed pests are discussed later in this chapter.

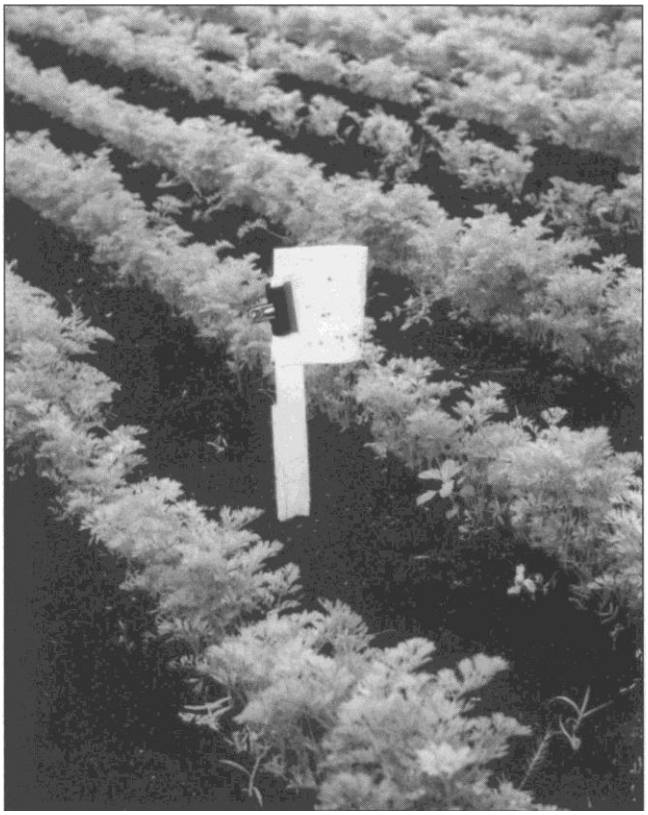
(Original by W.R. Jarvis and R.P. Jaques)

▶ 3.2 Monitoring *Figs. 3.2T1, 3.2T2*

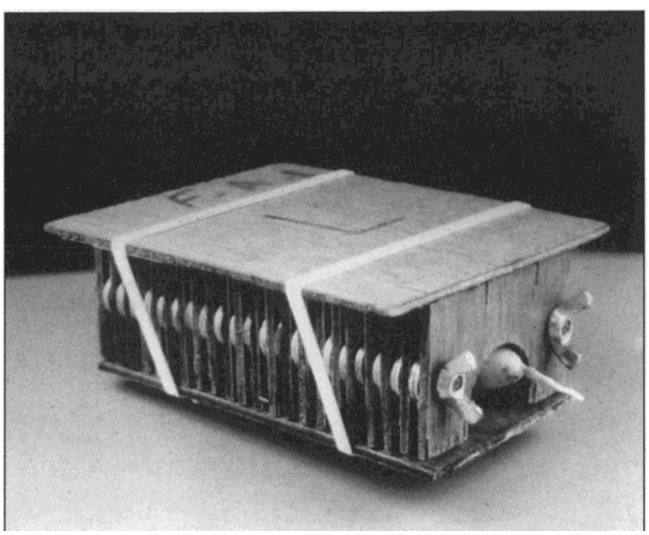
Monitoring involves some form of surveillance to detect the presence of a disease or pest before economic damage has occurred and in time to economically apply eradicative or protective measures. Two such methods involve visual inspection and trapping.

Visual inspection is the simplest method of monitoring and is used for insect and mite pests and for certain diseases, especially in combination with weather data and epidemiological information concerning sporulation, spore dispersal, infection periods and host plant growth stages. Surveillance is done on a regular basis, beginning soon after seeding or planting out, and includes watching for signs of feeding or irregularities of plant growth.

Trapping is necessary for monitoring certain pests; traps may be purchased for certain pests or some may be constructed at home. The type of trap and its location must be suitable for the target species. Sticky strips or glass slides smeared with petrolatum or other adhesive are used for trapping fungal spores, aphids and thrips; colored pans with water in the bottom are used for aphids; colored sticky strips or ribbon-like tapes are available commercially for whiteflies in greenhouses; a variety of lights and light traps are used for moths of many types; and a pheromone in a rubber septum is available for such insects as the European corn borer. Determining the density in soil of nematode pests before planting is important for some crops. Threshold levels have been established for a number of vegetable crops with regard to the root-lesion and root-knot nematodes.



3.2T1 Monitoring; sticky traps, such as the yellow one shown here in a carrot field, are used to trap insects such as the carrot rust fly, aphids, leafhoppers and thrips; in the greenhouse, blue traps are more attractive than yellow ones to the western flower thrips and may be less attractive, and therefore less harmful, to beneficial insects.



3.2T2 Monitoring; carrot weevil adults may be monitored with traps made of wooden plates spaced 3 mm apart and containing a carrot as bait at the base.

▶ 3.3 Cultural practices

Escape and prevention

After genetic resistance, the most important strategy for managing plant diseases and pests is best thought of as escape or prevention rather than cure. Such measures are aimed at avoiding the conditions that predispose the crop to infection or infestation; for example, selection of healthy seed of high germinability from a reputable source; treating seed if necessary to eradicate pathogens; checking the health of transplants at their source; practicing adequate crop rotation; sowing and transplanting only when soil conditions (temperature, moisture, nutrients, tilth) are adequate; maintaining adequate spacing and row orientation parallel to prevailing winds to permit good crop ventilation; avoiding overhead irrigation when the crop is in a vulnerable stage (e.g. at flowering in bean and pea); avoiding working in fields when the foliage is wet with dew or rain; roguing infected plants from seed crops; picking fruit before it is overripe; avoiding mechanical damage and removing field heat as quickly as possible at harvest; controlling weeds that may harbor pathogens and arthropod pests and contribute to humid microclimates in the crop; and controlling insects that may cause infectible wounds and transmit viruses.

Crop hygiene is a major factor in disease escape because it removes many sources of pathogens. Trash piles, contaminated seed trays, pots and stakes, and infected weeds are important sources of wind- and water-borne fungi and bacteria. Personal hygiene and equipment sanitation are also very important. Bacteria and viruses are easily transmitted on hands, clothing, tools and machinery. Tomato mosaic virus, for example, can persist for several months or years on sap-drenched overalls if they are hung dry in a dark closet. In bean fields, bacterial diseases often follow the tracks of workers walking among wet plants.

In nature, populations of insects and mites are regulated primarily by climate-related factors; by predation and parasitism by other arthropods and by other animals, such as birds; by diseases; by preference for food source; by competition with other plant feeders; and by numerous other factors. Because of the significant mortality of insects and mites by predation, parasitism and diseases, the best control practice for many insects and mites is to do nothing that could reduce the impact of these naturally occurring beneficial organisms and other beneficial agents in the environment.

Cultural practices usually influence the impact of pests indirectly. Tillage, crop nutrition, crop rotation, timing of planting and other management practices affect the vigor of the crop plant. A vigorous, healthy plant is more likely to withstand damage from feeding by sap-sucking insects and mites. Attack by a pest sometimes can be circumvented or damage reduced by tillage, by timing of planting and by selection of field conditions. For example, planting cruciferous crops in well-drained soils and delaying planting to reduce exposure of young plants to cold, damp soil conditions will reduce damage by root maggots. The removal of crop residue from the field and other sanitation procedures may reduce infestations of some pests, such as the European corn borer, in the following crop.

(Original by W.R. Jarvis and R.P. Jaques)

▶ 3.4 Resistant cultivars

Pathogen resistance

The primary management technique for most plant diseases is to develop cultivars that possess genetic resistance or tolerance to infection; tolerance is the ability of the plant to be productive despite being infected.

Of course, not every cultivar is resistant to every disease, but the prevalence of a disease in a particular locality often will determine the choice of a cultivar. Even when using a resistant cultivar, producers should be vigilant in watching for disease. Microorganisms, particularly those with genetic diversity derived from sexual reproduction, which occurs in many fungi, can quickly overcome resistance with a new form or race. For example, the fungus *Bremia lactucae,* which causes downy mildew of lettuce, exists in a number of pathogenic races, so lettuce growers must be aware of the races that are prevalent in their area and choose a cultivar accordingly. Recently, a new race of the tomato wilt pathogen *Fusarium oxysporum* f. sp. *lycopersici* appeared in Florida, and it is perhaps just a matter of time before it shows up in Canada and elsewhere. It is known as race 3 and it overcomes resistance to the two previously known races 1 and 2. Plant breeders work continually to produce cultivars resistant to new races of pathogens.

Insect and mite resistance

The development and use of resistant or tolerant cultivars has been less successful for arthropod pests than for diseases. Some cultivars of vegetable crops are less attractive to pest insects and mites, and a few cultivars and hybrids are resistant to some insect and mite pests by virtue of chemical or physical characteristics. For example, there is a substantial difference in the frequency of tunneling by the European corn borer among cultivars of sweet com. On the other hand, no apparent difference in feeding of the imported cabbageworm is found among cultivars of cabbage.

Future possibilities

The development of pest-resistant cultivars of vegetable plants will be enhanced by the use of genetic manipulation techniques. These advanced biotechnological procedures permit more precise and faster addition and removal of specific factors or characters than do conventional plant breeding techniques.

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(Original by W.R. Jarvis and R.P. Jaques)

▶ 3.5 Biological control

Concepts and practices

Effective biological control of vegetable diseases is rarely achieved, even on an experimental scale. Unlike predatory and parasitic insects and mites, a disease-controlling organism is almost invariably a fungus or bacterium and has to be registered in the same manner as the microbial insecticide *Bacillus thuringiensis* Berliner or a chemical pesticide. The registration process entails tests to ensure that the biological pesticide is environmentally safe, not harmful to operators or crop handlers, and safe for humans and livestock to consume with food. These tests, combined with the need to demonstrate that the biological pesticide is at least as effective as the best alternatives, as well as being economical and non-phytotoxic, require several years of research and testing, which leads in the end to a very expensive product.

At present, Dygall (*Agrobacterium radiobacter* (Beij. & Van Delden) Conn) is the only biological pesticide available commercially in Canada for control of a bacterial disease, in this case crown gall in nursery stock. However, organisms to control white mold in bean and powdery mildew in greenhouse cucumber offer considerable commercial promise, and a number of patents of biological fungicides are pending. A yeast-like fungus is being developed commercially to control powdery mildew of cucumber in greenhouses, and fungi in the genera *Trichoderma* and *Gliocladium* show promise for control of root-infecting fungi. These agents actively parasitize the pathogen, produce enzymes that degrade the cell wall, or produce antibiotics. Examples are *Coniothyrium minitans* W.A. Campbell, which is a parasite of the white mold *(.Sclerotinia* spp.) and gray mold (*Botrytis* spp.) pathogens, and *Sporidesmium sclerotiovorum* Uecker *et al.*, which parasitizes sclerotia of *Sclerotium cepivorum* (see Onion, white rot, 13.12) and *S. minor* (see Lettuce, drop, 11.9).

A wide variety of indigenous or naturally occurring biological agents affect populations of pest insects and mites, in most cases limiting populations to densities well below economic significance. These indigenous, beneficial organisms include predaceous and parasitic species of invertebrates, principally arthropods, in soil and on plants, and a variety of small animals, such as birds, rodents and toads, that feed on insects and mites, and microorganisms (fungi, bacteria, protozoa and viruses) that infect pest species.

The impact of indigenous beneficial organisms is enhanced by procedures that sustain or promote their activity. It is apparent that the application of a broad-spectrum toxic chemical to the crop will kill not only the target insect or mite but also the beneficial arthropods in a field. In addition, use of the chemical may repel birds but also may discourage their feeding because of the sparse numbers of surviving insects. The use of pesticides that are selective for the target pest species and that have minimum effect on non-target species is desirable in a pest management system. Also, the activity of indigenous organisms may be encouraged by such management practices as provision of hedgerows, cover crops, interplanted crops and field borders that can provide a habitat not only for birds but also for parasitic and predaceous insects and mites.

Beneficial arthropods that occur naturally in small numbers may be augmented by introduction of mass-produced colonies. Releases of ladybird beetles have been found effective in controlling aphids on some field-grown crops. Also, the greenhouse whitefly on cucumber and tomato is controlled in a majority of greenhouses in Canada by release of the parasite *Encarsia formosa* Gahan propagated commercially for this purpose. The release of exotic, predaceous and parasitic arthropods has considerable potential for control of pests, particularly introduced pests, for which indigenous parasitic or predaceous species are not present or are not effective.

The augmentation of naturally occurring pathogenic microorganisms for pest insects has potential for a major role in management of pests of vegetable crops. Applications of the bacterium *Bacillus thuringiensis* Berliner represent the most widespread distribution of a mass-propagated, indigenous biological agent. For example, formulations of *B. thuringiensis* are commonly used as alternatives to chemical insecticides to protect cruciferous crops against the cabbage looper, the imported cabbage- worm and the diamondback moth. More recently, formulations of strains of the bacterium have been developed to control the Colorado potato beetle on potato. Applications of *B. thuringiensis* have little or no direct effect on parasitic and predaceous arthropods and other non-target animals in the field habitat and are not considered to be hazardous to humans, domestic animals or crop plants.

Several species of pest insects are susceptible to viruses. These agents, which are usually specific for one species of insect, occur naturally in the field habitat and cause high mortality of some pests. For example, a granulosis virus is a major factor in natural regulation of the imported cabbageworm, and other naturally occurring viruses cause high mortality in populations of several species of cutworms and armyworms. Some entomoviruses have been found to be very effective bio-insecticides when applied to vegetable crops; for example, applications of viruses are effective alternatives to chemical insecticides to control the cabbage looper and imported cabbageworm on cruciferous crops. These viruses are specific for the target insect, have no direct effect on beneficial species, and are not considered hazardous to higher animals and man.

Several species of naturally occurring entomopathogenic fungi cause substantial mortality of some species of pests, but fungi introduced into the field habitat to augment the natural populations generally have not caused significant predictable mortality of pests on vegetables. An exception is the effectiveness of applications of *Verticillium lecanii* (A. Zimmerm.) Viégas and *Aschersonia aleyrodis* Web. to control the greenhouse whitefly on greenhouse-grown tomato and cucumber.

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(Original by W.R. Jarvis and R.P. Jaques)

3.6 Beneficial plants (allelopathy)

Some higher plants exhibit biological activity against other plants, a phenomenon known as allelopathy. For example, tomato will not grow under walnut trees or on land that has recently been cleared of walnut because of the phytotoxin juglone, which is secreted by walnut roots. Some higher plants exert a similar influence over soil microorganisms that cause disease. In addition, residues of allelopathic plants act, as do many green manures, to enhance the populations of soil microorganisms, many of which compete with or are antagonistic to pathogens. The use of allelopathic plants for disease control does not require registration. Several examples of allelopathy are associated with lettuce, crucifers, marigold and onion.

Lettuce and allied plants — Fusarium crown and root rot of tomato (see Greenhouse tomato, 25.10) can be controlled by growing lettuce between two successive tomato crops in the greenhouse or by planting dandelion beside tomato. Chemicals in lettuce, dandelion and allied plants, such as endive and chicory, interfere with the growth of the fungus *Fusarium oxysporum* f. sp. *radicis-lycopersici* in the soil. The active chemicals in this case are phenolic materials, which retard the growth of *F. oxysporum* f. sp. *radicis- lycopersici.* Some of these compounds, for example cichor- ic acid, also bind strongly to iron, which is required by the fungus.

Cabbage and other brassicas — Residues of cabbage and other brassicas decompose in the soil, releasing volatile, sulfur-containing isothiocyanates and ammonia. These chemicals are toxic to several pathogens, including: *Aphanomyces euteiches*, the root rot fungus of pea and bean; *Rhizoctonia solani*, a widespread root pathogen; and *Fusarium oxysporum* f. sp. *conglutinans*, the causal agent of cabbage yellows. The toxic effects are enhanced when these metabolites are confined by a plastic tarp, as during soil solarization.

The isothiocyanates released by *Brassica* residues are chemically related to methyl-isothiocyanate, the active ingredient of some commercial soil fumigants. A recent study suggested that the release of isothiocyanates from chopped rapeseed tissue incorporated into root-knot nematode-infested soil also suppressed nematode populations; however, other researchers failed to confirm this and suggested that success may vary with cultivar, nematode species, geographic location and climate.

Marigolds — The African marigold (*Tagetes erecta* L.) and the French marigold (*Tagetes patula* L.) are inhibitory to the nematodes *Pratylenchus*, *Tylenchorhynchus* and *Rotylenchus* spp., and their use with certain vegetable crops may reduce root lesioning and virus transmission. The toxic compounds secreted by marigolds are sulfur-containing polythienyls.

Onion — White rot caused by the fungus *Sclerotium cepivorum* is one of the most difficult diseases of onion to control. Its sclerotia are very long lived in soil and germinate only in the presence of the host, stimulated by various oils (disulfides and polysulfides) secreted by onion. Synthetic onion oils have been found to stimulate the germination of sclerotia of *S. cepivorum* in the absence of the host. The resulting mycelium is very susceptible to a variety of natural biocontrol mechanisms operated by soil organisms, and the population of *S. cepivorum* is considerably reduced. Unfortunately, synthetic onion oils are too expensive to be used on a field scale.

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(Original by W.R. Jarvis and J.W. Potter)

▶ 3.7 Beneficial insects, mites and pathogens *Figs. 3.7a-z*

Besides allelopathic plants, beneficial organisms include parasitic or predaceous insects, mites, spiders, daddy long- legs, centipedes, nematodes, protozoa, bacteria, viruses, and fungi. Indigenous populations of these organisms are considered to have a major role in the natural regulation of many species of pest insects, mites, slugs and snails, and some nematodes and weeds. Unfortunately, their role in natural regulation of pests in commercial production of vegetables has not been assessed or exploited to a significant extent, and the impact of chemical and other control practices on their effectiveness is seldom considered in present management systems. Although there has been extensive research on the introduction of beneficial organisms for control of insects on vegetables, their use in commercial production has been limited to the control of insects and mites on greenhouse crops, and to the application of formulations of the bacterium *Bacillus thuringiensis* Berliner to control insects in various field-grown crops. Some indigenous and introduced species also are beneficial as pollinators (see 1.4).

The major groups of predatory insects and mites, as well as parasites of pest insects, are discussed here, starting with the predators.

Predators

Beetles (Coleoptera; several families) — The adult and larval stages of many beetles are predatory. For instance, ground beetles (family Carabidae) *(3.7a)* are found in or on the surface of the soil and on low plants and under stones. The larvae of certain ground beetles are beneficial, but the adults may be injurious if they feed upon small fruits. Rove beetles (family Staphylinidae) attack all types of insects and some prey on slugs and snails. Their larvae live in the soil or in damp places.

Lady beetles (family Coccinellidae) — The Vedalia lady beetle, introduced from Australia to California in the late 1800s to control an introduced scale insect on citrus trees, is a classic example of pest management by introduction of a biological control agent. In less than two years, the scale was under control. Most lady beetles *(3.7b,c),* or ladybird beetles, are entirely beneficial because both the adult and larva are predaceous. The two-spotted, seven-spotted, and convergent lady beetles are common in Canada. Aphids are their main food source but the eggs and nymphs of other insects also are accepted. Lady beetles overwinter as adults in any sheltered location, becoming active in spring. The females deposit yellow, cigar-shaped eggs in small groups in the midst of aphid colonies. Lady beetle larvae *(12.16b)* start to feed on the prey as soon as they hatch. Usually one generation and sometimes a partial second generation occur per year. During summer, all stages from egg to adult may be present simultaneously. Imported lady beetles show promise for use in greenhouses and may be available commercially. However, when released outdoors they usually disperse beyond the target crop and become ineffective.

Lacewings (Neuroptera; several families) — Lace wings are fragile-looking insects with four lace-patterned wings and a green or brown body. Both the adult and larva of many species feed chiefly upon aphids, though they also attack other insects and mites. Lacewing eggs are deposited singly or in groups of three or four on leaves and stems, often near a colony of aphids. The green lacewings (family Chrysopidae) *(3.7d,e)* may suspend their eggs on long, thread-like stalks. Lacewing larvae are active and voracious. Their jaws are designed for probing crevices, piercing prey, and sucking body fluids. Some lacewings hibernate as adults. Others overwinter as mature larvae in small cocoons of dense, white silk. Lacewings tend to be habitat-specific, and certain species are more common than others in horticultural crops.

Hover flies (family Syrphidae) — Hover flies, sometimes called flower or syrphid flies, *(3.7f)* have the ability to remain stationary while in flight. The eggs are pale yellow and cylindrical, with small, spine-like projections; they are laid on leaves and shoots where there are colonies of aphids. The legless, slug-like maggot (*3.7g,h*) is pale green or red-green and creeps over the plant. Aphids are its primary food source. Hover flies overwinter among dead leaves either as a maggot or pupa. They can be very abundant in some seasons.

Other predatory flies — The midge *Aphidoletes aphidimyza* (Rondani) (family Cecidomyiidae) *(3.7i; 24.12d)* shows promise as a biocontrol agent for use against the melon aphid in greenhouses (see Greenhouse cucumber, 22.33).

True bugs (Heteroptera; several families) — Many true bugs are predaceous *(3.7k,m),* although some, such as the tarnished plant bug (see Celery, 7.21), are pests. The nymphs and adults of true bugs are very active and have a varied diet. The immature and adult stages occur together throughout the season. Some species hibernate as adults under loose bark, among dead leaves or in other sheltered situations, becoming active again in the spring. Predaceous true bugs eat young caterpillars, aphids and spider mites. The minute pirate bug *Orius tristicolor* (White) (*22.34i)* is an example of a predatory bug (family Anthocoridae) that shows promise for use against the western flower thrips in greenhouses (see Greenhouse cucumber, 22.34).

Mantids (Dictyoptera) — The introduced European praying mantis *Mantis religiosa* L. (3.*7j*) is a non-discriminating predator that now may be found in parts of eastern Canada and in the southern interior of British Columbia, particularly around home gardens where its egg masses are left undisturbed.

Ants (family Formicidae) and social wasps (families Sphecidae and Vespidae) — Most ants are opportunistic predators and scavengers on other arthropods. Ants and social wasps may greatly reduce populations of caterpillars and other insects, and they can be found almost everywhere. Sphecid wasps include species that are solitary and others that occur in nesting aggregations. Adult sphecids consume plant nectar and fluids from their prey, using the bodies of their prey to provision a nest for their larvae. In contrast, all hornets and yellow jacket wasps (Vespidae) (*3.7n*) feed their larvae the masticated remains of their prey, which may be insects or other animals.

Predatory mites — Predaceous mites occur naturally, often in large numbers, and some species are available commercially for biological control of small insects and phytophagous mites in greenhouses. One such mite, *Phytoseiulus persimilis* Athias-Henriot (family Phytoseiidae) (*22.36g*), has been used effectively in greenhouses against the two-spotted spider mite (see Greenhouse cucumber). Other predatory mites mentioned in this book are *Amblyseius* (syn. *Neoseiulus) cucumeris* Oudemans (*22.34h*), *Amblyseius* (syn. *Neoseiulus) barkeri* Schuster & Pritchard, and *Metaseiulus* (syn. *Typhlodromus) occidentalis* (Nesbitt). These predatory, foliage-dwelling mites are being used against thrips in greenhouses (see Greenhouse cucumber, western flower thrips). A soil-dwelling mite, *Hypoaspis* (syn. *Geolaelaps*) sp. *(22.31c),* also is being used in greenhouses (see Greenhouse cucumber, fungus gnats, 22.31).

Parasites

Parasitic wasps (Hymenoptera; several families) — More than three quarters of all Hymenoptera are parasitic. They are important in the natural regulation of many insect populations, and species of several wasp families have been introduced into Canada to control crop pests. The ichneumonids, braconids (3.*7r),* chalcids (*3.7p*), eulophids, pteromalids and scelionids include the major, naturally occurring biocontrol agents. Their bodies are long and slender, and in females often end in an ovipositor. Parasitic wasps attack the immature stages of other insects; some are host specific, whereas others attack a wide range of insects. The female parasite lays an egg in or near the host's body and the parasite larva feeds on the body fluids of the host, slowly killing it. Only one parasite larva is associated with a host in the Ichneumonidae. Braconids lay many eggs on a single host (*3.7u*). The parasitic wasps that are available commercially for use in greenhouses are *Encarsia formosa* Gahan (*3.7q)* against the greenhouse whitefly (see Greenhouse cucumber, 22.32, and Greenhouse tomato, 25.27), and *Aphidius matricariae* Haliday *(3.7s,t)* against aphids (see Greenhouse pepper, 24.12).

Parasitic flies (notably the family Tachinidae) — Tachinid flies parasitize moths, butterflies, sawflies, leaf beetles, and some land slugs and snails. Their host range includes many pests of horticultural crops. The larval stages of tachinid flies are parasitic, usually on other insects (3.7v). Some tachinid females lay their eggs on their hosts, but the majority of them retain their eggs and deposit them fully developed with an active maggot ready to hatch. The females of some tachinids pierce the host and inject their eggs. Others broadcast their eggs, or lay them separately on a plant for the host to swallow. The larval stage passes inside a single host, which is killed in the process. When mature, the larva usually abandons the carcass of its host, pupating and overwintering in the soil. Adult tachinid flies are active, fast-flying insects that feed on nectar or honey- dew and search erratically for suitable hosts. Tachinids figure prominently in importations and releases for biological control programs in Canada.

Pathogens and other parasites of insects — Naturally occurring pathogenic bacteria, viruses, fungi, protozoa and nematodes contribute substantially to regulation of many species of insects on vegetables. For example, several species of naturally occurring bacteria kill insect pests of vegetable crops; however, factors that influence their pathogenicity and procedures required to increase their effectiveness in reducing populations of insect pests are not well understood. The bacterium *Bacillus thuringiensis* Berliner is the only pathogen that is used commercially in Canada to protect vegetable crops from insect pests. Crystals formed in the sporangium of the bacterium contain an endotoxin which, upon ingestion by a susceptible insect, causes paralysis and death. Strains of *B. thuringiensis* are used quite extensively to control the larvae of several foliage-eating butterfly and moth pests of vegetables, particularly on cruciferous crops (*3.7y,z*) and, more recently, to control the Colorado potato beetle on potato and tomato.

Insect pests of vegetables are killed by various species of indigenous fungi, notably species of *Beauveria, Entomophthora* and *Metarhizium.* Under favorable conditions, these and other fungi may decimate insect populations. *Beauveria bassiana* (Bals.) Vuill., for example, kills substantial numbers of adult Colorado potato beetles in some years, and species of *Entomophthora* kill various species of bugs and flies, such as root maggot adults (see Onion, onion maggot, 13.26). The green muscardine fungus *Metarhizium anisopliae* (Metsch.) Sorokin shows promise for control of white grubs in the soil. Other entomopatho- genic fungi include *Aschersonia aleyrodis* Web. (3.7w) and *Verticillium lecanii* (A. Zimmerm.) Viégas; both infect pupae of the greenhouse whitefly.

Viruses kill several species of insects on vegetable crops, in some cases causing high mortality. The most common are the Baculoviruses, that is, the polyhedrosis viruses and the granulosis viruses, which kill larvae of several species of butterflies and moths (order Lepidoptera). For example, a naturally occurring granulosis virus is considered to be instrumental in regulation of the imported cabbageworm, and polyhedrosis viruses contribute substantially to suppression of the cabbage looper and to the oscillations in populations of the fall armyworm. Applications of these viruses are very effective in controlling the cabbage looper and the imported cabbageworm on cruciferous crops (*3.7x*). However, the viruses are not registered for use at this time.

Several species of protozoa (order Microsporidia) are parasitic on insect pests of vegetables, particularly Lepidoptera. Parasitism by microsporidia may suppress populations of susceptible insects by reducing vigor and fecundity, often without killing the host. Several species have potential for use in pest management; *Nosema locustae* Canning, a parasite of grasshoppers, is of particular interest in Canada.

Many species of pest insects are susceptible to parasitism by nematodes, principally of the families Steinernematidae and Heterorhabditidae. There is particular interest in these insect-parasitic nematodes for control of soil-inhabiting pest insects. One possible disadvantage in using these nematodes is that they are readily killed by desiccation, thus limiting their usefulness.

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(Original by R.P. Jaques and J.A. Garland)

▶ 3.8 Chemical control

Pesticides

Pesticides are regarded by many as controls of last resort because they add considerably to the cost of production and their misuse creates high-profile environmental problems. Nevertheless, in well-planned, integrated pest management programs, pesticides have a valuable role if used judiciously. A major problem with many pesticides is the rapid development of pathogen races or insect and mite populations that are resistant to them. When that happens, their continued use is pointless; not only do they have little or no efficacy, but they can aggravate the situation by killing other organisms that contribute to the natural biological control of pathogens and other pests. Blanket, season-long pesticide programs used as insurance in anticipation of pest outbreaks are seldom justified if other precautions have been taken.

The application of crop protection chemicals to vegetable crops or to the soil is a widely used method of controlling diseases, insects, weeds and many other pests. Because of the environmental impact of the use of chemical pesticides and because of their toxicity to humans, management procedures to minimize their use and their effects on non-target species are being developed and implemented. Accordingly, applications of effective pesticidal chemicals should be made in response to indications that populations of the pest have developed or will develop to economically significant densities. The threshold at which action is taken is dependent on the type of damage inflicted on the crop, especially the marketed portion of the crop. Populations of pests on crop plants are monitored to determine the timing and necessity for applications. This procedure of pest management minimizes the amount of chemical applied throughout the season. Unfortunately, many growers prefer to apply pesticides indiscriminately to crops according to a predetermined schedule as insurance against damage by pests. This practice increases the detrimental environmental impact of adding pesticide chemicals to the field habitat and increases the cost of crop production. Also, the application of some chemicals causes stress to crop plants and may make them more susceptible to disease and other pests. On the other hand, scheduled applications of pesticides may be necessary to prevent development of economically damaging populations of pests, such as root maggots and other pests within roots or stems, that cannot readily be killed when crop damage is occurring, or pests for which populations cannot be predicted with acceptable accuracy.

Environmental impact

The unnecessary use of pesticides is discouraged because of their direct and indirect effects on the field habitat and environment, on the consumer and the grower, and on the cost and efficiency of production. Most insecticidal and acaricidal chemicals kill or are harmful to several species of non-target arthropods, including parasitic and predaceous species that contribute to regulation of primary or potential pests. There are cases where additional applications of pesticides were required to control pests whose populations increased to a damaging level following application of a pesticide to control a different species. Applications of chemicals may affect populations of birds and other animals that feed on pest species, and residues of some chemicals in soil and on plant debris may affect microbial activity in soil, thus influencing the availability of plant nutrients. In addition, there is concern for the possible harmful effects of residues of chemical pesticides in food and for the effects on growers of excessive exposure to chemicals. Also, the tendency for pest species to become resistant or tolerant to a pesticide is enhanced by repeated use of the chemical, necessitating the use of higher concentrations or the use of other chemicals, often resulting in greater crop loss and increased cost of production.

(Original by W.R. Jarvis and R.P. Jaques)

▶ 3.9 Management by exclusion and regulation

Legislative control measures

Federal legislation administered by Agriculture Canada and complemented by provincial legislation is the means by which certain diseases and pests are regulated in Canada. Such regulations are aimed at preventing the introduction of new diseases and pests and their movement within Canada. The Canada Seeds Act and the Plant Protection Act provide for field surveys; inspection of produce, premises, containers and packages; destruction or treatment; restriction on movement; and other safeguards and requirements as specified in regulations under these Acts. Treatment of infested commodities, short of destruction, consists of fumigation, cleaning in a manner that is satisfactory to an inspector, or diversion to an approved industrial process.

There are substantial reasons for concern about pests that may be associated with vegetable commodities at the time of harvest. For instance, pests may be disseminated to other production regions within the country, a possibility that is greatly enhanced by modem, rapid transportation facilities. Pests also have resting stages that may survive cleaning and packaging operations and storage. The harvested, unprocessed commodity itself may serve as a pathway for the spread of pests. Apart from cold storage, which may affect the survival of some pests, Canada does not yet have the necessary facilities for bulk treatment and disinfestation of commercially produced quantities of vegetable commodities. Research into such alternative pest control technologies has only just begun.

Further information about the current status of federally regulated pests can be obtained from Agriculture Canada.

(Original by W.P. Campbell, P.M.D. Martin and J.A. Garland)

▶ 3.10 Foreign diseases and pests

Exclusion from Canada of the following diseases and pests is of particular importance for vegetable crops.

Potato gangrene

Phoma exigua var.***foveata*** (Foister) Boerema

Potato gangrene is caused by a soil- and tuber-borne fungus not known to occur in North America. Gangrene manifests on the tuber surface as extensive, dark brown or purplish, sharp-edged lesions, with variously shaped hard rots and cavities developing beneath the lesions.

(Original by A.R. McKenzie)

Potato viruses

Andean potato latent virus
Andean potato mottle virus
Arracacha virus B
Tobacco ringspot virus, potato calico strain
Potato deforming mosaic virus
Potato mop top virus
Potato virus T

Potato virus V
Potato virus X, resistance breaking strain

These and other viruses that occur in other countries are of concern to Canada because of their potential effects on crop yield and impact on trade. Their importation into Canada poses a threat to the potato industry in Canada, and thus they are cause for regulatory concern. To protect Canadian producers from potentially harmful viruses, the importation of potatoes from all countries other than the USA is prohibited. However, germplasm for research or commercial evaluation can be imported through Agriculture Canada's post-entry quarantine program.

(Original by I.A. MacLatchy and J.G. McDonald)

Columbia root-knot nematode *Figs. 3.10a,b*

Meloidogyne chitwoodi Golden *et al.*

The Columbia root-knot nematode has not been reported in Canada, but it is widely distributed in the western United States. It was described as a distinct species in 1980 after years of confusion with the northern root-knot nematode, which is widespread in Canada (see Carrot).

The Columbia root-knot nematode is a pathogen of bean, carrot, corn, pea and potato. It also affects canola, sugar beet and cereals, such as wheat, barley and oat. On potato, it induces galls *(3.10a)* on the surface of the tubers, greatly downgrading them. When tubers are sliced, the body of the female nematode can be seen as a tiny, water-soaked dot, and masses of eggs appear as small brown spots *(3.10b).*

(Original by I.R. Evans and T.C. Vrain)

Potato-rot nematode *Fig. 16.37*

Ditylenchus destructor Thorne

The potato-rot nematode is a widespread and serious pest of potato in Europe; it also occurs in many Asian countries and has been reported from New Zealand and Peru. In South Africa it is an important pest of peanut. In the United States, it has been found in Arizona, California, Hawaii, Idaho, Indiana, New Jersey, Oregon, Washington and Wisconsin, and it is subject to quarantine regulations in some of those states. In Canada, the nematode was detected in potato in 1945 in three small areas of Prince Edward Island, and in 1952 in a small potato planting on Vancouver Island, British Columbia. Following eradication procedures and provincial legislation, the infested fields in P.E.I. have been kept out of potato production, and the nematode has not been detected in surveys conducted since the early 1960s. The potato-rot nematode also attacks bulbous iris and over 80 other hosts, including such vegetables as beet, carrot, celery, crucifers, cucurbits, eggplant, onion, pepper, rhubarb and tomato. Information on host range, diagnostic techniques, feeding habits, ecology and persistence of *D. destructor* in the field is incomplete; most infestations are detected only when found in mature potato tubers.

The potato-rot nematode feeds chiefly on fungi and can survive in weed hosts and in fallow soil for several years, but it seldom survives in rotted tubers in storage or in the field. Infestations are spread mainly by seed tubers. The nematode feeds first on the roots and later invades the tubers, in which it feeds just under the skin. Initial symptoms include small (0.3 mm diameter) pits surrounded by snow-white rings that are visible when the tuber is peeled. Continued feeding results in a depressed area in the skin, which becomes necrotic and dries out, resulting in characteristic irregular, triangular cracks. Severely affected tubers have large, sunken areas covered by dried-out skin *(16.37).* The cracks in the skin provide ready access to bacteria and fungi, and affected tubers usually rot in storage or in the soil.

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(Original by W.L. Seaman and R.J. Howard)

Pepper weevil *Figs. 24.13a-e*

***Anthonomus eugenii* Cano**

The pepper weevil was found in Canada for the first time in 1992 in greenhouse pepper. See Greenhouse pepper (24.13) for further information.

Potato tuberworm *Fig. 3.10c*

Phthorimaea operculella (Zeller)
(syn. *Gnorimoschema operculella* (Zeller))

The potato tuberworm, a moth (family Gelechiidae), has a worldwide distribution in tropical and subtropical latitudes. In North America, it occurs in the southern United States and Mexico but not in Canada. Larvae of this moth feed on Solanaceae and may be encountered on potato and tomato imports as a post-harvest pest. The most recent importation into Canada occurred during 1989-90, when larvae were found in or on tomatoes originating from Australia. Interceptions on potatoes imported into Canada have been recorded but not for many years, the last time being 1972- 73 in chipping potatoes originating from the United States.

The only confirmed case of this insect as a field pest in Canada was in 1958 at Duncan on Vancouver Island, British Columbia. That infestation did not survive and it is thought to have been eliminated by exposure to the elements, leaving open to question the potential for survival in warehouses in Canada. (See Mackay, 1972, for a warehouse find.)

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(Original by J.A. Garland)

Sweetpotato whitefly *Figs. 3.10d-g*

Bemisia tabaci (Gennadius)

The sweetpotato whitefly (family Aleyrodidae) is widespread elsewhere in North America, especially at more southern latitudes. It was imported into Canada on cuttings of ornamental plants from the southern United States in 1987, 1988 and 1989. Field infestations were detected in 1988 on tomato plants around an ornamental greenhouse in Leamington, Ontario, but these did not survive the winter. Sweetpotato whitefly occurred at damaging levels in several greenhouse tomato crops in British Columbia in 1988 and 1989; a ripening disorder, similar to blotchy ripening (25.25), was associated with the presence of adults and immatures of this whitefly and resulted in severe losses in those crops.

The sweetpotato whitefly will not survive the winter outdoors in Canada, although infestations could be carried over in ornamental greenhouses and on houseplants. It is considerably more difficult to control both chemically and biologically than the greenhouse whitefly (see Greenhouse cucumber, 22.32, and Greenhouse tomato, 25.27).

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(Original by J.L. Shipp and D.R. Gillespie)

Tomato pinworm *Fig. 3.10h*

Keiferia lycopersicella (Walsingham)

The tomato pinworm (family Gelechiidae) occurs in Mexico, the southern United States, the Caribbean, and Hawaii. Larvae of this moth feed in developing tomato fruits and may be encountered on post-harvest tomatoes as an imported pest. The most recent importation into Canada occurred during 1988-89, when larvae were found in or on tomatoes originating from California. This moth was unknown in Canada prior to 1946, when larvae were confirmed in field tomato crops and in greenhouses in southwestern Ontario; however, these infestations did not survive. There since have been two isolated infestations in Canada: in 1970 in a greenhouse on Vancouver Island, and in 1975 in a greenhouse and surrounding home gardens at Kamloops, British Columbia. Eradication at both locations was accomplished by exposure to the elements and by planting cucumber, which is a non-host crop. These occurrences probably had their origin in post-harvest tomatoes that then were being imported during the off-season from Mexico and the southern and western United States.

These experiences show that the tomato pinworm cannot survive the winter outdoors in Canada. Temporary greenhouse infestations can be avoided by destroying used shipping containers and by screening greenhouse openings, and they can be managed by including cucumber or other non- solanaceous plants in the greenhouse cropping cycle.

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(Original by J.A. Garland)

▶ 3.11 Introduced diseases and pests

The following diseases and pests have been introduced from foreign countries and have become endemic in certain regions of Canada. Regulations have been established to prevent their spread to non-infested areas.

Bacterial ring rot *Figs. 16.1a-e*

Clavibacter michiganensis subsp. *sepedonicus* (Spieckermann & Kotthoff) Davis *et al.*
(syn. *Corynebacterium sepedonicum* (Spieckermann & Kotthoff) Skapston & Burkholder)

In Canada, widespread infections of bacterial ring rot no longer occur in potato fields, although there are still sporadic outbreaks in various regions (see Potato, 16.1). The Canada Seeds Act sets a zero tolerance for this disease, and regulates seed potatoes for domestic and export purposes. There also are provincial restrictions in Alberta, British Columbia, New Brunswick and Prince Edward Island. The combined effect of these programs has been to eradicate the disease in most areas, and there have been relatively few occurrences of ring rot in the last few years in these provinces.

Potato wart *Figs. 16.21a-d*

Synchytrium endobioticum (Schilbersky) Percival

In Canada, this disease occurs only in Newfoundland and parts of Labrador. The French islands of St. Pierre and Miquelon also are considered to be infested. (See the following discussion on cyst nematodes and see also Potato, wart, 16.21.)

Potato spindle tuber *Figs. 16.28a,b*

Potato spindle tuber viroid

Potato spindle tuber viroid has been reported in Canada and the United States, but it has been eradicated from two of the largest seed-producing provinces. It is transmitted mechanically by contact and by chewing insects, and it is dispersed in potato seed and pollen as well as in tubers. In Canada, the effect of a zero tolerance in federal and provincial programs has been to eradicate the disease from potato seed- producing fields. Prince Edward Island and New Brunswick have been declared free of this viroid after official surveys were conducted.

Potato virus Y^N *Figs. 3.1 la-c; 16.27b*

PVY^N (tobacco veinal necrosis strain)

The tobacco veinal necrosis strain of potato virus Y (PVY^N) has been present in Europe for many years, but it seldom has been detected in North America. In 1989, it was diagnosed in tobacco and potato in southern Ontario, and between 1990 and 1992, it was found in potato crops in parts of Prince Edward Island, New Brunswick, Nova Scotia, Quebec, Florida and California.

Most strains of this virus are almost symptomless in potato and cause minimal, if any, yield loss in this host, which at most displays only slight mottling of the leaves. In tobacco, however, the virus causes leaf-yellowing and darkening of the veins, which are conspicuous symptoms, and yield losses may be considerable. In the field, PVY^N is spread non-persistently by aphids. It overwinters principally in potato tubers. (See also Potato, potato virus Y, 16.27.)

Potato cyst nematodes *Fig. 16.36*

Golden nematode *Globodera rostochiensis* (Wollenweb.) Behrens
Pale cyst nematode *Globodera pallida* (Stone) Behrens

These two species of *Globodera* affect potato; both occur in Newfoundland, and the golden nematode also has been found on Vancouver Island. Most countries require freedom from potato wart and from the two potato cyst nematodes. These pests are regulated in Canada from Newfoundland; the golden nematode also is regulated from Central Saanich, British Columbia, and all three pests are regulated from any country in which they occur to all other areas of Canada. Plants or any object that may be contaminated with soil, such as used bags, containers, sacks, covers and vehicles, are regulated. Potato tubers are the most likely vegetable commodity to be affected by and possibly harbor stages of these pests, even after washing. Other commodities, such as vegetable transplants or nursery stock grown in infested soil, are suspect if soil adheres to their roots, fruits, or vegetative parts. For this reason, field- grown tomato and eggplant fruits are regulated from infested areas; they cannot be moved out of an infested area if soil adheres to them. Potatoes in storage must be treated with a sprout inhibitor, and a domestic movement certificate is required.

The use of potato cultivars, such as Cupids, which is resistant to wart and to the potato cyst nematodes, may diminish the risk of dispersing these pests. In the meantime, federal legislation in Canada prevents the spread of these pests by prohibiting or controlling the movement from Newfoundland and Labrador of soil, plants, equipment, and other materials to which resting spores or cysts may be attached. Potato production in the affected area of Central Saanich in British Columbia has been prohibited since 1982.

Colorado potato beetle *Figs. 16.44a-d*

Leptinotarsa decemlineata (Say)

The Colorado potato beetle (see Potato, 16.44) now occurs in most areas of Canada but is regulated on potato plants and plant parts, except true seed, destined for Newfoundland. This regulation is intended primarily for potatoes that are bagged in the field, where the overwintering summer adults may gain access to bags before they are closed. However, deregulation has been proposed because field bagging is no longer practiced commercially.

European corn borer *Figs. 12.16a-h*

Ostrinia nubilalis (Hübner)

The European corn borer (see Maize) is regulated on certain commodities destined for British Columbia. Plants or plant parts of maize (corn) and sorghum are the most likely vegetable commodities to be affected by and possibly harbor the larva, which may tunnel into the shanks and ears of fresh-market sweet corn or be inside pepper fruit. The tops of bunching beets are a potential pathway for larval dispersal.

Japanese beetle *Fig. 3.11d*

Popillia japonica Newman

The Japanese beetle (family Scarabaeidae) occurs in parts of Ontario, Quebec and generally throughout the northeastern United States. It is regulated on plants from areas of the world where it occurs. Proposed regulations between Canada and the United States would ensure a harmonized North American approach to regulating Japanese beetle.

Brown garden snail *Fig. 3.11e*

Helix aspersa Müller

The brown garden snail is present in many localities in southwestern British Columbia, including Vancouver Island. It is regulated on plants destined for areas of Canada where it does not occur.

(Information on introduced diseases and pests courtesy of Agriculture Canada, Food Production & Inspection Branch)

▶ 3.12 Management of nematode pests *Fig. 3.12*

Successful management of plant-parasitic nematodes in vegetable crops requires the integration of cultural practices, resistant cultivars, and chemical nematicides to reduce nematode populations at planting. Pesticide use may be economically feasible when other management strategies prove too costly or inadequate. For information on the major nematode pests of vegetable crops in Canada and their management, see Carrot, root-knot nematode; Onion, stem and bulb nematode; Potato, root-lesion nematode, potato cyst nematode, and stubby-root nematodes; and Beet, sugarbeet cyst nematode.

Monitoring

There is a direct relationship between population density of plant-parasitic nematodes in the soil at planting and crop damage, and theoretically a damage threshold can be established for each parasitic nematode on its respective vegetable host. When nematode density in the soil exceeds this level at planting, losses in yield, quality or both become noticeable. Determining such thresholds is time consuming. Relatively little information of this type is available for Canadian vegetable crops. In practice, nematode numbers in the soil are used to predict nematode damage; this is also the first step in diagnosis. After determining the density of nematodes in a soil sample, the number is often extrapolated to estimate the population in the entire field; however, caution is advised if using this procedure. An average count above a certain threshold could mean only that some areas of the field will show crop injury.

Cultural practices

It is almost impossible to design effective and economical rotation schemes for farms that grow vegetables exclusively. Destruction of infested crop residue, clean fallowing between crops, and rotation with non-host crops are effective measures for nematode species that attack only a few crops. Useful rotations against the sugarbeet cyst nematode are alfalfa, cereals, and bean and potato, which are non-host vegetable crops. The root-lesion and root-knot nematodes have very wide host ranges and are more difficult to manage. Some grasses and cereals, such as wheat, barley, oat and rye, which are non-hosts of the northern root-knot nematode, are used extensively. An ideal practice for reducing numbers of root-knot and root-lesion nematodes in small vegetable plantings is to interplant with French marigold, *Tagetes patula* L., or African marigold, *T. erecta* L. The use of these plants is more effective than fallowing or other cultural practices. The nematodes are attracted to and penetrate *Tagetes* roots but are unable to feed and multiply. Consequently, the density of nematode pests in the soil is lowered. Marigolds are not effective against *Heterodera, Ditylenchus,* or most ectoparasitic species.

Solarization is practical for small gardens. Intense summer sunlight can raise the soil temperature above 40°C beneath a transparent plastic tarp, killing many nematodes to depths of 5 to 10 cm. The soil must be well worked and moistened so that the heat will penetrate evenly. The soil should be covered for 3 to 6 weeks. Control is complete at the surface but less so at greater depths.

Despite the extra cost, the use of certified, nematode-free seed and transplants is usually worth the expense. Transplants should be vigorous and free of root galls or lesions caused by nematodes. The use of soil-free media, or pasteurized and fumigated soil, is suggested for cucumber, tomato and other susceptible crops. To eliminate plant-parasitic nematodes from small quantities of soil to be used to germinate seeds and grow transplants, growers should moisten the soil for several hours, then heat it to 80°C for one hour. In heavily infested greenhouse soils, annual or even semi-annual pasteurization may be required to avoid severe damage to greenhouse cucumber and tomato crops, as well as to some ornamentals sometimes found in vegetable greenhouses.

Resistant cultivars

A few vegetable cultivars are resistant to species of nematodes. In most cases, there is some degree of resistance to some but not all root-knot species or other plant-parasitic nematodes. There are no vegetable cultivars with specific resistance against the root-lesion nematode or the northern root-knot nematode, but some are more tolerant; for instance, some carrot cultivars have been shown to be more tolerant than others to root-knot nematode infection, and nematode-resistant rootstocks of tomato are available for grafting.

Biological control

Microbial nematicides are not yet commercially available. However, some soil microorganisms are natural enemies of nematodes and there are ways to enhance their activity. Nematode-trapping fungi, for instance, can be stimulated by heavy applications of manure or other types of organic matter.

Chemical control

Several fumigant nematicides were developed in the 1950s. Non-fumigant, non-phytotoxic nematicides that can be applied at planting have been developed, but lack of registration for use on vegetable crops prevents their use. A successful fumigation *(3.12)* under optimal conditions and at the recommended rate should eliminate 80 to 90% of nematodes to a depth of 25 cm. Activity depends on the presence of water and air in the pore spaces of the soil. Fumigant gas dissolves in water, killing the nematodes. Some of the gas adheres to organic matter and plant residues. The gas moves approximately 1000 times further in air than in water, and faster in warm than in cold soil. In wet soil in which pore spaces are filled with water, the gas dissolves but cannot diffuse; consequently, most of the spaces in the medium are not reached and not all nematodes are killed.

All fumigant nematicides are phytotoxic. It is essential to allow enough time for the gas to disperse from the medium being treated before seeding or transplanting. The aeration process usually requires cultivating or turning the medium once a week for two to three weeks between the time of fumigation and planting. A further disadvantage of fumigants is that they kill beneficial organisms, such as mycorrhizal fungi, *Rhizobium* bacteria, predatory nematodes, and fungi and bacteria that compete with or prey upon the plant-pathogenic nematodes.

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(Original by T.C. Vrain)

▶ 3.13 Management of weed pests *Fig. 3.13*

By managing weeds in headlands and other non-productive areas, and by preventing them from setting seed on crop land, growers can gradually decrease the reservoir of weed seeds in vegetable fields (see also Weeds, 2.3).

Monitoring

Scouting vegetable fields, particularly in the early stages of crop emergence, is essential for making decisions on the management of weeds. Although information on the economic threshold levels for specific weeds in vegetable crops grown in Canada is generally not available, some assessment of the weed population is required to decide whether a herbicide application or cultivation is necessary. Similarly, regular monitoring is required to properly time management operations when weeds are at a susceptible stage (*2.3a-q*). In a field where weeds are uniformly distributed, a zig-zag pattern for scouting is recommended.

A map of the field showing dense weed patches or areas requiring special management should be prepared for immediate as well as future use. Because most weeds originate from the soil seed-bank, there usually is some consistency in weed problems from one year to the next.

Cultural practices

Weeds can be managed mechanically by cultivation, mulching and mowing. Cultivation and hand hoeing have been relied upon for centuries to control small weeds in row-cropped vegetables and for improving soil aeration. However, if cultivation is too frequent or if the soil is too moist, compaction occurs and can adversely affect crop growth. Frequent rototilling can destroy soil aggregates and structure.

Mulching with plastic has been a common practice in recent years for heat-responsive crops, such as cucumber, melon, pepper, sweet corn and tomato. Although clear plastic mulch provides the highest soil temperature, it also permits weed growth. Black plastic, which blocks sunlight, will inhibit weed growth. A newly developed plastic permits the transmission of infrared radiation and is being studied for its effectiveness in preventing weed emergence. Recent research also has focused on the use of living mulches or surface crop residues for reducing or suppressing early weed emergence. Other strategies, such as rotation and altering row widths and seeding rates, have an important role in integrated weed management.

Biological control

BioMal, the first commercial mycoherbicide in Canada, was registered in 1992 for the control of round-leaved mallow in certain field crops. The active ingredient is the pathogenic fungus *Colletotrichum gloeosporioides* f. sp. *malvae* Mortensen. In the future, this product also may be registered for use in some vegetable crops. Results from research are expected to provide new mycoherbicides for controlling other species of weeds. In contrast to most chemical herbicides, biocontrol agents (insects or plant pathogens) are very specific for individual weed species. Biological control methods for weeds in vegetable crops will require the application of an organism to the weed to be controlled, a practice called inundative biocontrol. Classical biocontrol of weeds involves the establishment in an area of organisms from another region to provide ongoing control. This latter method is suitable for rangeland and other non- cultivated areas, but not for annual vegetable crops.

Chemical control

Herbicides are commonly used along with cultivation to provide overall weed control. Chemical companies rarely develop herbicides specifically for vegetable crops because of the limited market. Scientists, therefore, have had to adapt existing herbicides for vegetable production. In many instances, federal and provincial researchers in Canada provide the data on efficacy and crop tolerance required for the registration of herbicides through the “User Requested Minor Use Label Expansion” (URMULE) program.

The recent development of sethoxydim and fluazifop-p- butyl has contributed significantly to the control of annual grasses and quack grass in dicotyledonous vegetable crops. These products are applied after emergence. Because they do not have significant soil residual activity, later weed flushes may reinfest vegetable crops and interfere with harvesting. These products are used in vegetable production, on both mineral and organic soils, to destroy cereal windbreaks before they compete with vegetable crops.

The status of chemical weed control for broadleaved weeds in vegetable crops ranges from excellent for carrot, potato, sweet com, and tomato to unsatisfactory in cucurbits and most low-hectarage vegetable crops. Other modes of weed control need to be employed for these crops. In situations where only pre-plant incorporated or pre-emergence herbicides are specified, growers must rely on hand weeding and cultivation to remove weeds that emerge later.

Crop injury from herbicide drift or soil residues

Herbicides, such as 2,4-D and dicamba, which act as plant growth hormones, often injure susceptible vegetable crops by accidental drift or through the use of contaminated sprayers or watering cans. Typical symptoms are stem or petiole bending, leaf curling and cupping, and abnormal leaf- vein development. Picloram residues in manure from cattle fed with a treated crop often have caused problems in home gardens, and occasionally in commercial fields.

Sulphonylurea (chlorsulfuron, metsulfuron methyl) and imidazolinone (imazethapyr, imazamethabenz) herbicides can be injurious to most vegetable crops, even at very low concentrations. Soil residues of these herbicides can produce stunted, chlorotic growth and cause plant mortality. Trifluralin products are widely used for weed control in vegetable crops. However, in the following year, carry-over in soil can seriously damage beet, sweet corn and, to a lesser extent, cucurbit crops. Close monitoring is necessary to ensure that only tolerant crops are grown after triazine and urea herbicides are used.

In greenhouse crops, damage may result from the use of cereal straw or other mulches and amendments that have been contaminated with herbicides. Occasional cases of direct injury to crops from careless spraying of alleys, walkways or areas beneath benches also have been reported.

Future trends in weed management

Alternative methods of weed control will become increasingly important to vegetable growers in the future. Although these techniques will likely reduce the reliance on chemical herbicides, they will be only a partial substitute.

Reducing the use of herbicides — Methods by which herbicide use can be reduced include banding applications; using new, low-rate herbicides; timing of post-emergence herbicides to maximize effectiveness; placing fertilizer below the seed to target the crop instead of weeds; using new herbicide combinations, adjuvants, and application equipment; monitoring and determining weed thresholds as a basis for applying herbicides.

Alternatives to chemical herbicides — Alternative strategies for weed management are becoming increasingly important to vegetable growers. Reliance on chemical herbicides may be reduced but not eliminated. Methods under study and development include: biological control by weed-specific mycoherbicides; weed suppression by cover crops; rotation; the use of allelopathic plants (see Beneficial plants, 3.6) as green-manure crops; and the use of liquid- nitrogen fertilizer to control certain weeds in cruciferous crops. Chemical herbicides will likely remain the major method of weed control for some time, although specific products can be expected to change. The general trend to use less herbicide will continue, with greater reliance on cultural practices, including cover crops for weed suppression and soil conservation.

Genetically engineered crops — Biotechnology may have an impact on weed management through the development of vegetable cultivars with resistance to low rates of "environmentally friendly" herbicides and by the incorporation of allelopathic properties into vegetable crops.

Herbicide-resistant weeds — The first occurrence of a herbicide-resistant weed in North America was documented in 1970 in a commercial nursery in Washington State, where common groundsel, which originally was susceptible to simazine, had become resistant. This herbicide had been used for many years at this location. With prolonged use, in some cases for as few as five years, resistance to most of the herbicide groups with similar modes of action has developed in a number of weed species, although some of these resistant biotypes have only recently been detected. Methods used to delay or prevent the development and establishment of herbicide-resistant weeds include: rotating crops; rotating herbicides (using herbicides with different modes of action); using short-term or non-residual herbicides; using the lowest possible effective rate; using herbicide mixtures; and practicing cultural/mechanical control where possible.

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(Original by R. Esau)

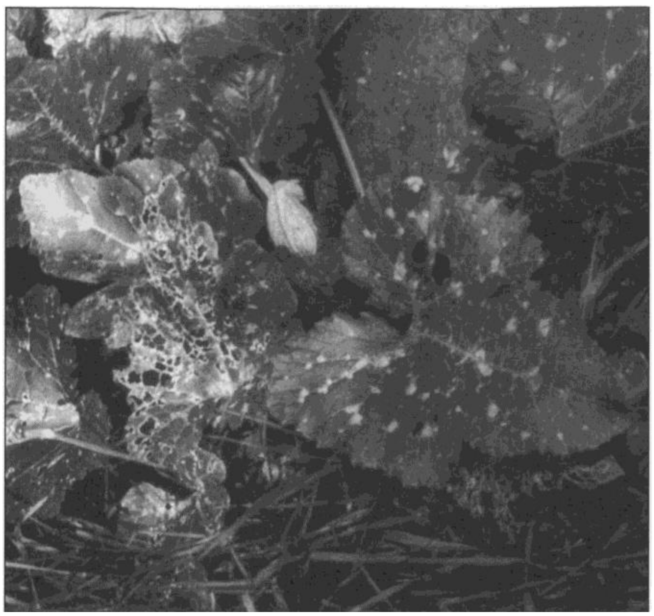
▶ 3.14 Managing diseases and pests in home vegetable gardens *Fig. 3.14T1*

Vegetable gardening is a rewarding and enjoyable hobby that provides a supply of fresh produce in season and that also can help to reduce a family's food costs. Vegetable crops are threatened by various disease, insect and weed problems that may reduce the yield and quality of the produce and even destroy the plants. Diseases and pests can damage vegetables from the time seeds are planted until after the crops are harvested, and gardeners who fail to follow good growing practices that minimize damage from diseases and pests in their gardens will suffer many disappointments.

The impact of plant diseases on vegetables often appears less direct than that of insects and weeds. Insects usually can be seen with the naked eye, and their activities quickly noted, while weeds are conspicuous, competing directly with vegetable plants for space, nutrients and moisture. Diseases, on the other hand, may make their presence known only when plant growth begins to slow down or when productivity is less than expected. No causal agent may be visible, only symptoms indicating that something is wrong.

Based on general cause, there are two kinds of diseases: biotic and abiotic. Biotic diseases are caused by an identifiable microorganism or infectious agent, for example, bacteria, fungi and viruses. Abiotic diseases result from unfavorable growing conditions or environmental stresses, such as extreme temperatures, too much or too little water, and nutrient imbalances. Both kinds of diseases exist widely in vegetable gardens across Canada.

Plant-feeding insects, mites and nematodes become pests if they injure crop plants sufficiently to interfere with the capacity of the plant to produce food. Some species of insects also transmit plant pathogens. Aphids, for example, transmit several viruses, and cucumber beetles can spread bacterial wilt and squash mosaic virus. The presence of some plant-feeding pests can be tolerated, but control may be necessary if the pests begin to cause significant damage. Home gardeners usually tolerate more pest injury, especially cosmetic injury, to their vegetables than do commercial producers. Many pest species are kept at a low level by natural enemies, such as predators and parasites, and additional control measures may not be required. It is important to realize that the population build-up of natural parasites and predators lags behind that of the pests, so some damage usually is evident. Special practices may have to be employed to keep the pest population at a level where damage will not be serious.



3.14T1 European earwig feeding injury to squash; in many urban areas of Canada, the European earwig has become one of the most annoying and difficult to control pests in home gardens. For more information, see Crucifers, 8.43, and color figures ***8.43a-d.***

The most effective pest control strategy for the home gardener utilizes a combination of practices; these include planting resistant cultivars, providing optimum soil conditions, fertility and moisture supply, selecting pest-free seed and transplants, employing crop rotations, monitoring carefully for pests, destroying plant residue, cultivating, mulching, and using pesticides only when necessary. Such practices often keep the populations of garden pests at tolerable levels. The role of these and other techniques in helping to minimize disease, insect and weed problems in home vegetable gardens is discussed here.

Monitoring

Traps and lures — Baits and lures using light, color, sex attractants (pheromones) or food to draw a pest to a trap may be effective for some pests. Wireworms can be trapped by burying pieces of potato or carrot in the soil, then checking the bait every few days for the insect. Infested baits can be collected and destroyed. Slugs can be drawn to reservoir traps of beer or to a mixture of molasses, water and yeast. Boards laid out in the garden can be used to trap slugs because they look for a cool, damp spot to hide during the day. These pests can then be collected and destroyed daily. Earwigs can be trapped in wooden traps or in containers filled with water containing a small amount of detergent. Growing an insect pest's favorite plant as a trap crop to lure it from the garden also works. However, the pests must be controlled on the trap crop or they will migrate back to the garden.

Cultural practices

Healthy seeds and transplants — Many disease-causing organisms are capable of living in and on vegetable seeds; therefore, it generally is unwise for a person to save seed produced in the home garden. Rather, it should be purchased from dealers who have a reputation for producing or selling high quality, disease-free seed. When growing transplants, gardeners should use high quality seed and a pasteurized growth medium. If transplants or rootstocks are purchased from a supplier, they should be carefully checked for signs of pests and diseases, and any found to be infested should be destroyed.

Crop rotation — Moving the preferred host plant of an insect or disease organism hampers that pest's ability to feed and reproduce. Many disease-causing organisms do not survive long in the soil in which a different crop is planted. Exceptions include fungi that cause such diseases as fusarium wilt on cabbage, potato or tomato, and clubroot of cruciferous crops; once the soil is infested with these pathogens, it can remain so for several years.

Many insects and mites hibernate or lay their overwintering eggs in the soil near their preferred hosts. Moving the garden to a different location, or even switching the host crops from one to another part of the garden, has the effect that, upon emergence in the spring, the pest may find a non-host plant on which it is unable to feed and reproduce. This practice also may help to control weeds, especially if part of the garden is summerfallowed for at least one growing season. Crop rotation has the added advantage of allowing the soil to rejuvenate itself. Cabbage, turnip and potato use large amounts of nitrogen and should be preceded with legumes, for example, pea or bean, followed by fallow and the incorporation of compost or manure.

It is advisable to rotate among vegetable families because different members of a plant family often are susceptible to many of the same pest problems. For example, tomato, potato, eggplant and pepper are in the potato family and share many common diseases and insect pests, as do members of the cucurbit family (cucumber, melon and squash) and the crucifer family (cabbage, broccoli, Brussels sprouts, cauliflower, kohlrabi, turnip and radish). It is desirable to leave as much time as possible between related crops; three to six years is ideal. If rotation is not practical, gardeners should at least alternate the cultivars of vegetables that they are growing, choosing pest-resistant ones whenever possible.

Manual and mechanical methods — Hand-picking large, slow-moving pests, such as caterpillars, Colorado potato beetles and slugs, and dropping them into a container of soapy water or a *5%* isopropyl (rubbing) alcohol solution is effective. Shaking the plants or hosing them off with a spray of water dislodges some insects and mites. Barriers are meant to keep a pest away from the crop that it may harm. Some examples are floating row covers, copper strips, abrasive materials and mulches. Used cans or frozen- juice containers opened at both ends and placed around transplants will protect them from subterranean cutworms. Copper strips repel slugs because their slimy coating interacts chemically with the copper. Applying bands of abrasive materials, such as diatomaceous earth, stone dust or crushed egg shells, around the perimeter or between rows in a garden helps to deter slugs and crawling insects. Diatomaceous earth is an insecticide made up of the ground shells of tiny sea creatures called diatoms. The silica daggers pierce the skin of the insect, causing dehydration. Soap solutions smother the pests to which they are applied. Tar paper collars placed on the soil around individual crucifer seedlings will prevent root maggot flies from depositing their eggs at the base of the plants.

Mulches provide an effective means of weed control in vegetable gardens. Organic materials, such as weed-free straw or grass clippings 7 to 10 cm thick, will inhibit germination of weed seeds brought to the surface by cultivation, retard development of weed seedlings, conserve moisture, and help to maintain a uniform soil temperature. After the crop is removed, the mulch can be incorporated into the soil to enhance its organic matter content. Plastic mulches increase the soil temperature and also conserve moisture. Black plastic mulches, with openings for the crop, will prevent weed growth, except at the opening. Clear and white plastic mulches, however, permit weed growth, as some light can penetrate through the plastic. Plastic mulches are best suited for warm-season vegetables. Mulches also may prevent soil from being splashed onto plants, thereby keeping the produce clean and reducing the risk of spreading some diseases. Weed mats made of woven fabric allow water and air to reach the soil but screen out light and act as a barrier to emerging weeds, thereby providing effective, long-term control.

Removal of infested plant material — Many fungal diseases can build up and spread rapidly through the production of millions of spores. Prompt removal or destruction of diseased plant residues retards the spread of disease-causing organisms. This is an effective practice with such diseases as gray mold, powdery mildew, and various leaf spots and fruit rots. Removing diseased plant material from the garden at the end of the season eliminates an important source of inoculum for the following spring. The remaining residues should be rototilled or spaded into the soil to destroy disease organisms and to expose overwintering pests to the elements and to predators. Composting diseased plant material is not recommended because it may not destroy all of the disease organisms, even if the compost heats properly and is turned frequently. In some cases, leaving the remains of insect-infested plants in the garden may help to increase the population of beneficial parasites.

Good growing practices — When watering vegetable gardens, allow the soil surface to dry before another watering. Avoid frequent, light waterings as they tend to promote disease development and favor the germination of weed seeds. Watering with soaker hoses or in-ground furrows may reduce disease incidence because the foliage stays dry. When using overhead sprinklers, gardeners should be sure that the water is applied during the late morning or early afternoon. This allows for rapid drying of the foliage. Prolonged leaf wetness favors the development of most foliar diseases. Wide row-spacing ensures rapid leaf drying and reduces the spread of certain pests and diseases by direct contact. However, wide spacing also reduces shading of the soil, thus enhancing the loss of soil moisture and favoring the growth of weeds.

Keeping plants as healthy as possible is an important strategy in managing insect and disease problems. Planting into a warm, moist, well-prepared, well-drained seedbed, maintaining a high organic matter content, applying fertilizers correctly, and not cultivating when either the plants or the soil is wet, are recommended practices. Monitoring the crop through the growing season may help to keep pest problems small by facilitating prompt control. Accurate record keeping is suggested to ensure success from year to year.

Companion planting — Many insects prefer to feed on plants belonging to specific families and reject others. For example, the imported cabbageworm feeds on cabbage, radish, kohlrabi and other cole crops; therefore, interplanting unrelated plants, such as onion, with cole crops will help to deter feeding and limit damage by this pest. Furthermore, garlic, onion and other aromatic plants inter-planted among other garden crops are believed to repel certain insect pests. Alternating vegetable cultivars or species also reduces the chances of disease spread. Where root- knot and root-lesion nematodes are a problem, interplanting with French marigold or African marigold may help to reduce the populations of these pests (see Management of nematode pests, 3.12).

Altered planting times — Seeding dates of vegetables can be altered to allow the plants to grow at times when they are less likely to be injured by certain pests. This requires knowing the life cycles of the common pest species in the area. In some cases, it may be feasible to plant certain vegetables before or after the pests have passed through their most active feeding period. For example, in Ontario, onion maggot eggs are laid near onion plants in May, and maggots soon attack plants and may cause them to die. However, onion sets planted after June 1 will escape most first-generation maggots.

Resistant cultivars

Some vegetable cultivars are resistant or tolerant to certain pests and diseases, and growing resistant plants is an excellent way to decrease the risk of damage. Certain disease-causing fungi can survive for many years in the soil and may not be managed by routine cultural practices; therefore, planting resistant cultivars is the best means of controlling them. Packages of tomato seed marked VFN produce plants that are resistant to the *Verticillium* and *Fusarium* fungi that cause wilt diseases, and to root-knot nematodes that may attack and cause galls on the roots. Other diseases best controlled by planting resistant cultivars include cabbage yellows, potato scab and cucumber mosaic. Certain vegetable cultivars also are less vulnerable to insect damage than others. For example, Red Pontiac potato is more resistant than other potato cultivars to tuber flea beetle, and Champion radish seems to be somewhat resistant to the crucifer flea beetle.

Biological control

Beneficial insects can be attracted to the garden by planting some of their favorite nectar- and pollen-producing plants in the garden or nearby. Members of the carrot (dill, caraway, fennel and parsley), mint (catnip, hyssop and lemon balm), and daisy (yarrow and coneflowers) families are known to attract such insects. Providing a source of water and shelter also helps to keep beneficial insects around. Birds and toads also aid in the control of insect pests. Care must be taken when applying pesticides because beneficial insects can be killed as well as the target pest.

The bacterium *Bacillus thuringiensis,* or Bt, is a pathogen of certain insects and must be ingested by the larva of the insect to be effective. Only butterfly and moth larvae are susceptible to this product, although a strain of Bt has recently been developed that will kill the Colorado potato beetle. Various formulations of this microbial pestcontrol product are available for controlling larvae of certain moths and butterflies on home garden vegetables. This and other treatments must be applied when the pest is most susceptible.

Chemical control

Seed treatment — Planting fungicide- or hot-water-treated seed helps to ensure good stands and may avoid the need to replant. Seed treatments kill disease- causing organisms on the seed and help to protect the vulnerable seed and young seedlings from certain soil-borne disease organisms. Treated seed is available to the home gardener and is marked “treated” on the package. Fungicide-treated seed is usually red or some other easily identifiable color. If untreated seed is used, it should be certified disease-free or be hot-water treated (see Crucifers, black rot, 8.2). Seed can be treated by the gardener, using recommended chemicals according to the manufacturer’s directions. Small packets of seed can be treated by tearing off one comer and putting about twice as much chemical in the packet as can be picked up on the first centimetre of the flat end of a toothpick. The packet should be shaken until the seed is thinly coated.

Foliar treatment — Most foliar diseases can be controlled by spraying or dusting plants with an effective fungicide as a preventative treatment. Protectant fungicides work on the plant surface to protect against infection, but they cannot cure established infections. If a considerable amount of disease is present, it is usually too late to apply a fungicide treatment, except to protect newly emerging leaves. Fungicides should be applied at 7- to 10-day intervals, or as directed by the manufacturer, with reapplication after rain or watering has washed the material away. A thorough covering of the plants is necessary for proper disease prevention. Early detection, timely fungicide applications and removal of diseased leaves are necessary for effective control of many foliar fungal diseases. Gardeners can choose from a wide variety of organic and inorganic fungicides for use in combatting vegetable diseases in home gardens.

The home gardener also has a number of insecticides and miticides to choose from. Most botanical insecticides are derived from plant parts and will break down quickly into harmless substances. Botanical insecticides include pyrethrin and rotenone. Insecticidal soaps are effective against aphids, but they also are non-selective and may upset the natural balance of beneficial insects and their prey.

Chemical control of weeds usually is not practical for small home gardens but can be employed for larger gardens and for market gardens. If the decision is made to use a herbicide, extreme care should be taken to avoid accidental drift onto non-target species. In addition, residual soil herbicides should not be used where residues may carry over and affect succeeding crops.

Growers who apply pesticides in their home gardens should use only products that are registered and recommended for the crops being grown and for the specific diseases or pests that are prevalent in the area. It is very important to carefully follow the manufacturer's directions to ensure maximum effectiveness of a pesticide and to minimize potential adverse effects, such as poor control, crop injury and unacceptable chemical residues on the edible produce. Spot treatment is preferable to a general application because it lessens the risk of harming beneficial organisms, humans and pets.

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