CHAPTER 2 Crop losses and their causes

Tables

2.1 Types of crop losses

Production losses - Diseases, insects, weeds and other pests annually cause substantial losses in the yield and quality of vegetables produced in Canada. Reliable estimates of these losses are not available, but they probably are proportional to losses in the USA. Even with the extensive application of pesticides, the estimated reductions in the farm-gate value of selected vegetable crops in the United States caused by diseases range from 8 to 23%, by insects 4 to 21 %, and by weeds 8 to 13%. If it is accepted that the average losses caused by diseases, insects and weeds in Canada are 15.5, 12.5 and 10.5%, respectively, they would have reduced returns to the vegetable industry by $172.7, $138.2 and $115.2 million, respectively, in 1990. If the costs of crop protection practices were factored in, these figures would be even higher. In the United States in 1987, crop losses caused by diseases and insects in specific vegetables were, respectively: cole crops 9 and 13%, lettuce 12 and 7%, potato 20 and 6%, tomato 21 and 7%, sweet corn 8 and

19%, onion 21 and 4%, cucumber 15 and 21%, pea 23 and 4%, and pepper 14 and 7%. Losses in greenhouse lettuce, cucumber and tomato are similar, but pest damage may necessitate replanting the whole crop. Until resistant cultivars of tomato became available, this was regularly the case with fusarium crown and root rot.

Post-harvest losses - Reduced yield and quality from pest damage in the field may be equalled or exceeded by losses in storage. This is especially the case where freshly harvested produce is not rapidly cooled or where it is not transported and stored under controlled conditions. For example, it is not unusual to see truckloads of perishable vegetables parked on farms, at roadside truck-stops and at food terminals rapidly deteriorating in the full summer sun. Similarly, attempts to dry onions in primitive storages with humid air frequently result in wetter, not drier, onions in production areas of the Great Lakes region. Such crops are often destroyed by diseases, such as neck rot and sour skin. Poorly stored carrot, potato and cabbage crops also are subject to substantial losses.

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2.2 Causes of crop losses

Direct crop losses caused by diseases and pests may be measured as the proportion of crop not sold. In addition to losses in yield and quality in the field and later during storage and transport, there are many, less tangible ways in which diseases and pests exact an economic toll. For example, the fungus *Botrytis cinerea* may cause multiple but almost imperceptible ghost spot lesions on tomato fruit, which, depending on the rigor of official or consumer inspection, may result in little or no financial loss to the grower. However, the same fungus causing a single, girdling lesion on the stem of an indeterminate tomato cultivar will result in the total loss in yield from that plant, as often happens in the greenhouse.

Bacterial spot on processing tomatoes makes the skin very difficult to peel by standard factory procedures, so the skins have to be removed by hand, which is very expensive. On the other hand, buyers of fresh-market tomatoes at roadside stands may scarcely notice a few lesions of bacterial spot. Similarly, when cabbage is fermented to produce sauerkraut, or cooked, the lesions caused by thrips are very pronounced and unacceptable, whereas thrips damage may be of little consequence if the cabbage is finely chopped and used fresh in coleslaw.

Nematode damage to roots may be mechanical or chemical, thereby reducing root capacity to absorb and translocate water and nutrients, even when soil moisture is adequate. Some vegetable crops are tolerant of nematode damage, while others are highly sensitive. Seedlings and young transplants usually are especially susceptible. The distribution of nematodes in the soil, whether in the field or in the greenhouse, normally is uneven. Plant-parasitic nematodes may reduce crop yield and quality but other biotic and abiotic stresses on plants make it difficult to predict the impact of nematode damage. Losses may increase significantly if nematodes interact with other pathogens, such as fungi and viruses. In Canada, yield-loss data, where available, are generally restricted to a few crops within a limited geographical area.

Insects and mites may damage vegetable plants directly or indirectly. For example, larvae and adults of the Colorado potato beetle may extensively defoliate a potato plant, substantially reducing its photosynthetic capacity and resulting in significant reduction in yield of tubers or even death of the plant; however, infestations that occur late in the growing season may have little effect on yield. Direct damage also may be caused by wireworms that feed or burrow into tubers, and this damage may be augmented by rot caused by bacteria and fungi. Aphids and leafhoppers suck on the foliage of the plant, reducing its vigor, but these insects also may damage a crop indirectly by transmitting plant viruses. Reduction in the yield of greenhouse-grown tomato, resulting from extensive (piercing and sucking) feeding by adults and nymphs of the greenhouse whitefly and the two-spotted spider mite, is a less direct form of damage to the crop than is the feeding on the fruit of field grown tomato by horn worms and cutworms. Consumption of foliage of cabbage plants by larvae of the cabbage looper or the imported cabbage worm reduces the vigor of the plant, resulting in a smaller head; these insects also may feed directly in the head, rendering it unmarketable, or on the outer wrapper leaves of fresh-market cabbage and cauliflower, downgrading marketability. Similarly, the presence of insects in a marketed product, such as heads of broccoli, may render the product unmarketable without visible evidence of feeding by the insect.

The economic significance of damage and the action threshold applied in deciding on measures to manage populations of pests depend on the severity of damage, the value of the crop, and the proposed end use of the crop. For example, the threshold approaches zero for species that cause damage directly to the part of the crop to be used by the consumer; these include the carrot rust fly in carrot and the corn borer in pepper and sweet corn. On the other hand, low populations of pests that cause foliar damage but do not feed on or damage marketable parts of the plant may be tolerated, and thus the action threshold for implementation of control procedures is higher; examples include the Colorado potato beetle on potato and the cabbage maggot on cabbage. Similarly, relatively high numbers of the two-spotted spider mite and of the greenhouse whitefly can be tolerated on greenhouse-grown cucumber and tomato without affecting the yield of marketed product significantly. Action thresholds also may vary with the stage of development of the vegetable plant when attacked. For example, low populations of the imported cabbageworm and cabbage looper can be tolerated when they feed on the foliage of young plants of cabbage, cauliflower and Brussels sprouts. Later, however, the tolerance for these pests is greatly reduced when they feed on the head or wrapper leaves of cabbage or cauliflower or in the head of broccoli. Likewise, thresholds for pests that cause indirect damage is very low if the pest can disseminate plant pathogens. For example, low populations of aphids do not cause significant loss of yield in potato, but the potential for spread of aphid-vectored viruses is so high that control measures must be considered whenever aphids appear, particularly in seed-potato crops.

Crop losses caused by competition from weeds can be assessed quite readily, but weeds also contribute to overall crop losses by acting as alternative hosts for pathogens and insects. For example, wild cucumber (*Echinocystis lobata* (Michx.) Torr. & Gray) harbors the fungus *Didymella bryoniae*, which causes gummy stem blight in melon and cucumber (see Greenhouse cucumber, *22.11*). The universal pathogens *Botrytis cinerea, Sclerotinia sclerotiorum* and *S. minor* are found on many weed species, *B. cinerea* in particular having hundreds of hosts.

Weeds also may act as a reservoir for many vegetable viruses and mycoplasma-like organisms, and of their insect and nematode vectors. The passage of workers and machinery through weed-infested crops can transmit viruses from weeds to crop plants; weed canopies provide the humid and cool microclimate in which fungi and bacteria infect their vegetable hosts; and finally, weeds provide shelter for pest insects and other types of animals, such as rabbits and rodents. Weed control, therefore, is an important part of a pest management program for vegetable crops.

2.3 Pathogens and other pests

Identification Correctly identifying both the host plant and the causal agent of a disease or pest damage will enable a vegetable grower to choose effective management practices that will prevent further damage to crop plants without affecting harmless or beneficial organisms. In the crop chapters of this book, the scientific or Latin names of pathogenic microorganisms and pests follow their common names; the italicized scientific name usually is followed by the name (often abbreviated) of the scientist(s) who described and named the organism. Using the scientific name for organisms avoids confusion over differences in language and in the selection of common names. For example, in some regions of Canada, the rutabaga is known as a swede or even as a winter turnip, but it is universally recognized by its scientific name *Brassica napus* var. *napobrassica* (L.) Reichb. The recommended common and scientific names of the major and minor vegetable crops grown in Canada are listed in Table 1.3. Classifying and naming plants and animals, including insects and microorganisms, follows a system of binomial nomenclature that is based chiefly on characteristics of vegetative and reproductive structures. Within species, populations also may be described at the functional or molecular level. Characteristics of the chief groups of organisms causing injury and disease in plants are described briefly in this chapter. More detailed descriptions of causal organisms are included in the discussion of specific disease and pest problems in the crops chapters.

Bacteria and actinomycetes

Bacteria are tiny, one-celled microorganisms (prokaryotes) that, like fungi, require an external food supply for their energy. They, too, are facultative parasites of plants and are capable also of independent existence in plant residues, water or soil. Bacteria differ in certain fundamental ways from fungi in their cell structure, but they have very few morphological features that distinguish them from one another. Thus, a diagnostician has to rely on laboratory tests to identify them. Bacteria gain entry into plants through the stomata or through wounds caused by abrasion, insects or pruning. Bacterial diseases are highly infectious and are particularly difficult to control. Bacteria are spread easily by splashing water, particularly wind-blown rain and overhead irrigation. Some bacteria are carried from plant to plant by insect vectors, and they are all spread by hands, machinery and tools. Many also are carried on or in seed. Some pathogenic bacteria are capable of infecting one or a few host species or cultivars, whereas others, such as *Erwinia carotovora* subsp. *carotovora*, a soft-rotting bacterium, have a very wide host range.

Actinomycetes are classified with bacteria because nuclear fusion does not occur and they have cell wall biochemical characteristics more closely resembling those of bacteria than of fungi. They do resemble fungi in their filamentous morphology, but differ notably in the small diameter (usually about 1 μm) of their vegetative filaments. The most important actinomycete pathogen of vegetables is *Streptomyces scabies*, the cause of scab on such crops as potato, radish, carrot, rutabaga, parsnip and beet.

Fungi *[The classification of several sections within this group of pathogens has changed substantially since the book was written, but details of reproduction are unchanged]*

Fungi are microscopic plants with a basic, threadlike structure collectively called the mycelium. They have no chlorophyll and thus are unable to utilize carbon dioxide from the air for their nutrition. Instead, they utilize previously formed carbon compounds as a source of energy. They obtain these materials while growing saprophytically on the products or remains of plants and animals, or by parasitizing living plants and animals. In living, green plants, fungi usually degrade the host, producing visible damage, which, in vegetable crops, causes losses in yield and quality. As saprophytes, fungi are responsible for much of the natural breakdown of organic material and hence the recycling of essential elements and compounds in the environment. Mushrooms and toadstools are larger fungi that can be saprophytic, parasitic or, in many cases, symbiotic with green plants (mycorrhiza), living in plant roots to the mutual benefit of both fungus and host.

Parasitic fungi fall into two broad groups: obligate parasites, which depend entirely on a living host for their nutrition and reproduction, and facultative parasites, which can do considerable damage to crop plants as parasites, but can also live indefinitely as saprophytes on plant remains. Obligate plant parasites include the rusts, powdery mildews and downy mildews, whose names broadly describe the symptoms of the diseases they cause. The ubiquitous gray mold fungus *Botrytis cinerea* is a facultative parasite. Virtually all fungi that cause plant diseases form microscopic spores that serve two basic functions: to act as dispersal and infective propagules to spread the disease, and to act as resistant structures permitting the pathogen to survive adverse environmental conditions. In addition, many fungi also form compact, hard structures called sclerotia. These, like spores, are capable of resuming growth under favorable conditions to infect the host plant, sometimes after months or years.

Spores are dispersed in various ways, for example by air, in water through the soil or irrigation systems, by insects, or on hands, clothing and tools. Spores are the principal agents of plant infection. They germinate under suitable conditions, almost invariably in a water droplet or film or on a moist wound, to form a thread-like germ tube that can penetrate through the plant epidermis directly or through a stomatal pore. Once inside the plant tissue, the mycelium permeates the host tissues, sometimes blocking the water-conducting system, as in the wilt diseases. As the food supply for the fungus diminishes, more spores are formed to spread the pathogen through the crop. By this time the host is either severely damaged or dead.

Spores can be produced by a sexual process, which imparts genetic variability to the fungus and can give rise to pesticide resistance or overcome host resistance, or they can be produced in huge numbers by an asexual, vegetative process. Some fungi form two or more types of spores that often do not much resemble each other in the same fungus. The sexual state is called the teleomorph and gives the fungus its proper, scientific (Latin) name, while asexual states are called anamorphs and frequently have a different Latin name. For example, the gray mold fungus *Botryotinia fuckeliana* is the teleomorph name for a rare, tiny, toadstool-like fungus. However, it is better known as *Botrytis cinerea*, the name that describes its asexual, dispersive and infective spores (conidia), which are arranged in a grape-like cluster. *Botrytis cinerea* is derived from the Greek, meaning an ashy-colored bunch of grapes. The fungus also has anamorphic microconidia, which are not infectious but have a sexual function, and chlamydospores. The latter are durable, long-lived spores in nature.

Viruses and viroids

Viruses are submicroscopic particles consisting of a nucleic acid, either ribose nucleic acid (RNA) or deoxyribose nucleic acid (DNA). They multiply by inducing host cells to form more virus particles at the expense of host metabolism. The nucleic acid can be single- or double-stranded. Virus particles are rod-like, straight or flexuous, bacillus-like (rhabdoviruses), or isometric (polyhedral). Some small viruses are dependent on another virus for multiplication; these are called satellite viruses and require a helper virus for infection. Gemini viruses are paired, isometric particles with single-stranded RNA; an example is maize streak virus. Viroids are small units of single-stranded RNA arranged in a circle, devoid of protein, yet still capable of causing plant diseases; potato spindle tuber is a notable example.

The criteria for identifying and classifying a virus depends on certain physical, chemical and biological properties, including whether the nucleic acid is DNA or RNA, whether it is single- or double-stranded, and whether it has a membrane around the protein coat. In practical terms, indicator plants, often tobacco or *Chenopodium* species, are inoculated with sap from a diseased plant, and they produce symptoms characteristic of a particular virus. Since viruses have a protein coat, specific antibodies can be induced in animal serum, which can be made to react chemically and specifically in various diagnostic tests, such as precipitin or enzyme-linked immunosorbent assay (ELISA) tests.

Most viruses can be transmitted from plant to plant by infected sap introduced by injury, on hands, machinery or clothing, or by grafting. Many viruses are transmitted by insects, especially aphids; others are transmitted by mites, nematodes, fungi, or the parasitic plant dodder *(Cuscuta* spp.). Some viruses are seed- and pollen-borne.

Virus-like pathogens (wall-less prokaryotes) *[The classification of this group of pathogens has changed substantially since the book was written]*

Lying somewhere between viruses and bacteria in characteristics are a group of microorganisms known as wall-less prokaryotes; in the crops sections of this book they are referred to as virus-like pathogens. They have genetic material but no nucleus or cytoplasmic organelles, in contrast to the more complex eukaryotes that include the fungi. Bacteria are also prokaryotes, but they have a cell wall. Wall-less prokaryotes have been linked with some 200 plant diseases. There are three main groups that cause plant diseases, 1) mycoplasma-like organisms (MLOs) of indefinite form that are more or less restricted to sieve tubes of plant vascular systems; 2) spiroplasma-like organisms, which are helical in form and restricted to sieve tubes; and 3) rickettsia-like organisms that resemble in form the typhus-causing *Rickettsia*, which has a rippled, trilaminate outer membrane. MLOs cause yellows diseases, (e.g. aster yellows) of lettuce, celery, potato, carrot and about 180 other plants, as well as leaf mottling, flower virescence, dwarfing and witches'-brooms. Typically, MLOs are transmitted from plant to plant by leafhoppers and can be controlled by the antibiotic tetracycline. Spiroplasmas cause such vegetable diseases as corn stunt.

Nematodes

Plant parasitic nematodes or eel worms are small (usually less than 1 mm long), worm-like animals that live in soil. They are broadly divided into two groups: ectoparasitic nematodes that attack the plant externally, and endoparasitic nematodes that live, at least for part of their life cycle, inside the host tissues. All parasitic nematodes have mouth spears through which saliva is injected into the host tissues; it is the saliva that induces most of the damage in plants, for example tissue necrosis or the proliferation of giant cells, which can produce galls. Some nematodes, while causing little direct damage to plants, transmit viruses; such nematodes include species of *Xiphinema, Longidorus* and *Trichodorus*.

Worldwide, several hundred nematode species are plant parasites, most of which live in the soil. Many thousands of other species are free-living in the soil, feeding on fungi, bacteria and other microbes. Others are associated with animals, including man; some are naturally occurring biocontrol agents of insects. Most plant-parasitic nematodes feed on a relatively narrow spectrum of hosts, and only a few species are considered agricultural pests. Canada has relatively few nematodes that are of major economic importance in field and greenhouse vegetable crops (see Table 2.3a), mainly because of unfavorable climatic conditions.

Endoparasitic nematodes - These nematodes usually penetrate the roots, and feed and multiply within root tissues; some also invade bulbs, leaves and stems. They include the northern root-knot nematode *Meloidogyne hapla* Chitwood, which attacks almost all types of vegetable crops commonly grown in gardens, fields and greenhouses in Canada (see Carrot, *6.20*). The southern rootknot nematodes *Meloidogyne incognita* (Kofoid & White) Chitwood, *M. javanica* (Treub) Chitwood, and *M. arenaria* (Neal) Chitwood do not occur in the field in Canada, but they can persist in greenhouses when imported from warmer climates. The pale cyst nematode *Globodera pallida* (Stone) Behrens and the golden nematode *G. rostochiensis* (Wollenweb.) Behrens have been introduced into Canada (see Introduced diseases and pests, *3.11*). Both species occur in Newfoundland, and the golden nematode also occurs on Vancouver Island (see Potato, *16.36*). The root-lesion nematode *Pratylenchus penetrans* (Cobb) Filip. & Stek. affects most of the major vegetable crops grown in Canada (see Potato, *16.38*). The stem and bulb nematode *Ditylenchus dipsaci* (Kuhn) Filip. attacks mainly onion and allied crops. It has been confirmed from Newfoundland, Ontario, Saskatchewan and British Columbia (see Onion, *13.24*). The sugarbeet cyst nematode *Heterodera schachtii* Schmidt occurs at scattered locations across Canada. It can affect beet, spinach, rhubarb and cruciferous crops (see Beet, *5.14*).

Ectoparasitic nematodes - These nematodes feed on root tissues, such as the epidermis and cortex and, if their stylet is long enough, the vascular tissue. They rarely enter the roots of plants. They include the stubby-root nematodes *Paratrichodorus allii* (Jensen) Siddiqi, *P. pachydermus* (Seinhorst) Siddiqi, other *Paratrichodorus* spp., and *Trichodorus* spp. These nematodes have caused only minor damage to a few gardens in southern Alberta (see Potato). Other ectoparasitic nematodes include the dagger nematodes *Xiphinema* spp., the needle nematodes *Longidorus* spp., the pin nematodes *Paratylenchus* spp., the spiral nematodes *Rotylenchus* spp. and *Helicotylenchus* spp., and the stunt nematodes *Tylenchorhynchus* spp., *Merlinius* spp., *Amplimerlinius* spp., and *Gracilacus* spp. These nematodes are prevalent in some Canadian vegetable fields and often are identified from soil samples, but they are rarely a serious problem. At numbers as high as 5000 or more per kilogram of soil, pin nematodes have reduced yields of rhubarb in Ontario. Dagger and needle nematodes prefer hosts with woody roots and are more frequently associated with strawberry, raspberry, grapes and roses than with vegetable crops, which tend to be more soft-rooted.

Damage caused by plant-parasitic nematodes is often difficult to distinguish from that caused by other pathogens or by abiotic factors. Stunting, chlorosis and early senescence also can indicate a problem with soil nutrition, watering, or a soil-borne pathogen; these conditions need not necessarily be nematode-related. Proliferation of secondary roots, a symptom of attack by some nematodes, also may result from the branching of the tips of young roots of some vegetables in the presence of such unfavorable soil conditions as soil compaction, insufficient decomposition of organic plant residues, extremes in moisture content, poor fertility, and frost heaving. Some nematode problems can be assessed by visual examination of plant tissue. In many cases, however, nematode problems can only be determined after soil sampling and extraction; both procedures are time-consuming and expensive. Nematodes do not spread very rapidly, and a minor infestation may not result in visible symptoms or reduced productivity.

Table 2.3a. Host ranges of economically important nematode pests on vegetable crops in Canada

Crop	RKN*	RLN	PCN	SBN	SRN	SCN
Bean	X	X			X	
Beet, chard and spinach	X	X				X
Carrot	X	X				
Celery and celeriac	X	X				
Crucifers	X	X			X	X
Cucurbits	X	X				
Ginseng	X	X[t]				
Greenhouse cucumber	X	X				
Greenhouse lettuce	X	X				
Greenhouse pepper	X	X				
Greenhouse tomato	X	X				
Lettuce, chicory and endive	X	X				
Maize (sweet corn)		X			X	
Onion and other allium crops	X	X		X		
Parsnip	X					
Pea	X	X		X		
Potato	X	X	X		X	
Rhubarb	X	X				X
Tomato, eggplant and pepper	X	X	X		X	

*RKN = Root-knot nematode (*Meloidogyne hapla* Chitwood); RLN = Root-lesion nematode (*Pratylenchus penetrans* (Cobb) Filip. & Stek.); PCN = Potato cyst nematodes (*Globodera* spp.); SBN = Stem and bulb nematode (*Ditylenchus dipsaci* (Kuhn) Filip.); SRN = Stubby-root nematodes (*Paratrichodorus* and *Trichodorus* spp.) SCN = Sugarbeet cyst nematode (*Heterodera schachtii* Schmidt).

[t] The root-lesion nematode is regarded as a potentially serious pest of ginseng in British Columbia.

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Insects

Many species of insects, mites, spiders, millipedes, centipedes and like animals, collectively known as arthropods, are present in the plant ecosystem. Only a relatively small proportion of insect species feed or have a detrimental effect on vegetable plants, and only a few of those that feed on vegetable plants are economically important pests; a large proportion occur in small numbers, feed very sporadically, or cause only minor, indirect damage. Nevertheless, the relatively few insect species that are economically important pests, often only one, two or three on a plant species, can destroy a crop or cause sufficient damage to render it unmarketable or unprofitable to grow unless the pest populations are regulated. A list of the major groups of insects associated with vegetable crops in Canada is given in Table 2.3b.

Insects are a diverse group of six-legged invertebrates that undergo complete, gradual or no change of form (metamorphosis) during development. Insects and their close relatives, spiders and mites, are animals that have jointed legs. Adult insects have three body regions (head, thorax and abdomen), three pairs of legs, one pair of antennae, complex mouthparts, and frequently two pairs of wings. The skin of an insect is the external skeleton, which covers the whole body. This exoskeleton must be shed from time to time (molting) as the insect grows.

Life cycle - All insects have an egg and an adult stage. A few, such as springtails, do not undergo metamorphosis; the juveniles resemble adults but are smaller. Juveniles that resemble the adult stage except that they lack wings or have underdeveloped wings are called nymphs; insects that have egg, nymph and adult stages are said to undergo gradual metamorphosis; examples include earwigs, aphids, plant bugs and whiteflies. Juvenile forms that do not resemble the adult stage are called larvae; in some larvae, the thoracic legs are underdeveloped, while others have legs in the abdominal region, and some have no legs at all. Certain types of larvae have distinctive names; larvae of moths and butterflies are called caterpillars, while caterpillars in which some of the abdominal legs are missing are termed loopers; larvae of beetles are known as grubs, and the legless larvae of flies are called maggots. Insects that have egg, larval, pupal and adult stages are said to undergo complete metamorphosis. The juvenile forms (larva or nymph) grow in steps called instars; at the end of each instar they molt, then swell to the new size; the new outer skin hardens and remains unchanged until the next molt. The number of molts varies with the species. The last instar typically spins a cocoon or forms a puparium from which the insect emerges in its adult form. Insects may overwinter in the egg, larval, pupal or adult stage. Juvenile stages usually do the most serious damage to plants, but many adult insects also can inflict damage. It is important in devising appropriate pest management strategies to be able to recognize the different stages of insect development.

The most common, foliage-eating insect pests are larvae of moths and butterflies (Lepidoptera) and larvae and adults of beetles (Coleoptera); nymphs and adults of grasshoppers and other related species (Orthoptera) also may consume foliage. Aphids and leafhoppers (Homoptera), plant bugs (Heteroptera) and thrips (Thysanoptera) have piercing or piercing-and-sucking mouthparts in the nymphal and adult stages and may cause extensive damage to vegetable crops; many of these insects have a major role in transmission of pathogens, especially viruses. Larvae of flies (Diptera) feed and burrow into roots, bulbs and stems of plants and are important pests of root crops, such as carrot, onion and rutabaga, and of several other crops, including cabbage and cauliflower, on which they feed on the roots and stems, and bean and corn, where they feed on the germinating seeds and seedlings. A great many insects also are beneficial, feeding on other pest species of insects as predators or as parasites (see Beneficial insects, mites and pathogens, *3.7*). A key to the principal orders of insects associated with vegetable crops in Canada is given in Table 2.3c.

Mites and spiders

Adult mites and spiders characteristically have four pairs of jointed legs; exceptions include the rust mites and the blister mites, which have only two pairs of legs. Unlike insects, they lack antennae and have only two body regions, the cephalothorax and abdomen. Spiders are predators, chiefly of insects. The spider-like daddy longlegs, or harvestman, which is related to mites and spiders, is commonly seen around home gardens. It also is a beneficial predator of small organisms, including insects.

Female mites deposit eggs, which hatch into six-legged larvae. The larvae feed and molt to form eight-legged nymphs, of which there are several forms, before the adult stage is reached. In some species the females give birth to live young. Because of their small size, mites often are not noticed. Many are scavengers and some are predators. Many species have rasping and sucking mouthparts and may damage vegetable crops, not only by weakening the plant by sucking out sap, but also by destroying cells and by aiding entry and transmission of pathogenic microorganisms. The two-spotted spider mite is the most important species on vegetable crops in

Canada, both in the field and in greenhouses. Some mites are predatory and are being used to control pest mites and thrips in greenhouses (see Beneficial insects, mites and pathogens, *3.7*).

Centipedes and millipedes

These animals, sometimes confused with insects, are encountered in the garden or compost. Centipedes are somewhat flattened, have 15 or more pairs of legs, with one pair per body segment, and their antennae (one pair) are long and have 14 or more sub-divisions. Millipedes (*12.21T1*) are cylindrical, have two pairs of legs on each segment except the first several segments following the head, which have only a single pair, and their antennae (one pair) are short, usually with seven sub-divisions. Centipedes are poisonous predators of insects and are usually faster moving than millipedes, which feed primarily on dead plant remains and tend to coil when disturbed.

Table 2.3b. Characteristics of major groups of insects associated with vegetable crops in Canada

Order	Common Name	Mouthparts	Metamorphosis
Collembola	springtails	chewing	none
Orthoptera	grasshoppers, crickets	chewing	gradual
Dermaptera	earwigs	chewing	gradual
Thysanoptera	thrips	piercing	gradual
Homoptera	aphids, leafhoppers	piercing-sucking	gradual
Heteroptera	stink bugs, plant bugs	piercing-sucking	gradual
Coleoptera	beetles, weevils	chewing	complete
Lepidoptera	butterflies, moths	chewing (larvae)	complete
Hymenoptera	ants, bees, wasps	chewing	complete
Diptera	flies	rasping (larvae)	complete

Symphylans

Symphylans are small, flattened, white animals that resemble centipedes. They are less than 8 mm long. The adults have 10 to 12 pairs of legs (centipedes have 15 or more pairs), a pair of unbranched antennae, and a pair of hair-like appendages on the last segment. They feed chiefly on microorganisms and plant material in the soil, but they also may feed on the roots of plants, especially in moist soils that are high in organic matter. Damage to root hairs and roots may facilitate the entry of plant pathogens.

Slugs and snails

All land snails and most slugs have a calcareous shell. In snails the shell is external and twisted in a continually increasing spiral, usually clockwise. The shell takes many forms among different species. The shell aperture ("mouth") in all land snails in Canada lacks a cover (operculum). In some snail groups, identification is based on characteristics of soft anatomy. In slugs, the shell is internal, and characteristics of the fleshy body are used in identification; these include the position of the breathing pore, the presence of a groove in the mantle, the ridge (keel) on the back, the caudal mucal pore, the color and pigmentation of the body, and the color of the mucus.

Both slugs and snails may be plant pests in damp situations. They both glide on a slime trail of secreted mucus. Mouthparts are rasping, and most damage is done at night or on cloudy days. Under dry conditions, eggs of slugs may remain unhatched for long periods. Young snails remain close to the area in which they were hatched for several months and may take many months to mature. The brown garden snail, which was introduced into British Columbia, is edible but is regarded as a pest in Canada (see Introduced diseases and pests, *3.11*).

Sowbugs and pillbugs These are crustaceans adapted to living out of water but in damp environments. They are oval, with a small head, two pairs of antennae, seven pairs of jointed, similar (isopod) legs and a dorsoventrally flattened body that is composed of hard, overlapping plates. They can be distinguished by the ability of the pillbug to curl into a ball, and by the two tail-like appendages on the sowbug. Both are active decomposers of rotting vegetation. They may cause problems in certain situations where vegetables, such as cucurbits, rest on moist ground or where young seedlings are slow to develop in cool, moist weather. These crustaceans have not been implicated in transmission of diseases in vegetable crops.

Table 2.3c. Key to the principal orders of insects associated with vegetable crops in Canada

This key should be applicable to adults and most nymphs and larvae of the groups indicated

1.	Winged Wings entirely or partly membranous with veins	2
la.	Winged or wingless If winged, forewing (FW) thickened throughout	7
2.	Wings with scales Mouthparts coiled	butterflies and moths
2a.	Wings lacking scales Mouthparts not coiled	3
3.	FW only, hind wing (HW) greatly reduced	flies
3a.	FW and HW same size or HW only slightly smaller	4
4.	Wings narrow, fringed around the margin Body less than 5 mm in length Legs (tarsi) without claws	thrips
4a.	Wings broad, without fringe around margin Body more than 5 mm in length	

Legs (tarsi) with a pair of claws 5

5. Tarsi with 5 sub-segments (tarsomeres)
Mouthparts for chewing
HW with tiny hooks (hamuli) along leading edge .... winged ants, bees and wasps

5a. Tarsi with only 2 or 3 tarsomeres
Mouthparts for sucking
HW without hamuli along leading edge 6

6. Mouthparts arising at front of head
Immatures with wing buds
Adult FW membranous over outer half, ... plant bugs, stink bugs
and thickened over inner half.

6a. Mouthparts arising beneath head
Immatures with wing buds (as above)
Adult FW membranous or thickened throughout .... aphids, leafhoppers
Adult FW membranous with a waxy coating .... whiteflies

7. FW hard or leathery, covering HW 8

7a. Entirely wingless 11

8. Abdomen with forceps-like appendages (cerci) .... earwigs

8a. Abdomen lacking cerci or cerci not forceps-like 9

9. Mouthparts adapted for piercing-sucking .... true bugs (go back to 6)

9a. Mouthparts adapted for chewing 10

10. FW thickened or leathery with veins
Wings held roof-like over abdomen or overlapping with HW folded lengthwise fan-like
Cerci present, straight
Antennae short .... grasshoppers
Antennae long, filamentous .... crickets and katydids

10a. FW hardened (elytron) and without obvious venation
Wings held flat over abdomen FW's meeting in a straight line HW folded crosswise,
not fan-like
Cerci absent .... beetles

11. Body narrow-waisted
Antennae elbowed .... wingless ants and wasps

11a. Body broad-waisted
Antennae not elbowed 12

11b. Body fleshy and larva-like, lacking division into thorax and abdomen by a waist
Antennae inconspicuous or absent 16

12. Abdomen with a spring (furcula) .... springtails

12a. Abdomen lacking furcula 13

Abdomen with a pair of dorsal projections (cornicles)
Body plump, not narrow
Adults and nymphs may be present .... wingless aphids (go back to 6)

13a. Abdomen lacking cornicles
Body narrow, not plump and less than 5 mm in length 14

14. Tarsi lacking claws .... thrips (go back to 4)

14a. Tarsi with claws 15

15. Antennae 4- or 5-segmented
Mouthparts for piercing-sucking (from front of head)
Cerci absent .... plant bug, young nymph (go back to 6)

15a. Antennae with many more than 5 segments (filamentous)
Mouthparts for chewing
Cerci present cricket, young nymph .... (go back to 10)

16. Body with a capsule-like head and legs
Head lacking compound eyes
Mouthparts for chewing, moveably attached to head 17

16a. Body lacking a head capsule and legs
Mouthparts in form of mouthhooks, retractable .... fly larvae (maggots)

17. Head with 1-6 simple eyes (ocelli) on each side
Body with segmented legs (3 pairs) anteriorly
Body with fleshy legs (2-5 pairs) posteriorly ...... butterfly and moth larvae (caterpillars)

Note: sawfly larvae, which have I simple eye on each side of the head and may be mistaken for caterpillars, do not have representatives on vegetable crops in Canada.

17a. Head lacking simple eyes
Body with segmented legs (3 pairs) anteriorly
Body lacking fleshy legs posteriorly .... beetle larvae (wireworms, white grubs and other beetle grubs)

(Original by J.A. Garland)

Weeds (*Figs. 2.3a–q*)

Weeds generally are considered to be plants growing where they are not desired. They sometimes can be as serious a threat to vegetable crops as diseases and other pests, and they occur wherever vegetable crops are grown in Canada. Successful vegetable production often depends upon the integration of weed management (see *3.13*) with other pest management strategies.

Vegetable crops vary widely in their response to weed competition, ranging from non-competitive crops, such as onion, to moderately competitive crops, such as potato and transplanted cabbage. Studies in Canada have shown that direct-seeded onion does not produce marketable bulbs if weeds are not controlled. In southern Alberta, the time from seeding to the two-leaf stage in onion averages 46 days; during that time, wild mustard can emerge, complete its vegetative growth, and flower.

The critical period of weed competition in vegetable crops is the minimum time that weeds must be suppressed to prevent yield losses. In a southern Ontario study, cucumber yields were reduced if the crop was not kept weed-free for up to four weeks after seeding, or if it was weedy for more than three to four weeks. In another trial, the critical period for pickling cucumber ranged from two to five weeks after seeding. In Prince Edward Island, the critical period for rutabaga is two to four weeks after crop emergence when barnyard grass (*2.3a*) and lamb's-quarters (*2.3f,q*) are present. Similarly in Quebec, the critical period for carrot crops grown on organic soils was found to be between three and six weeks after crop emergence. Although the concept of a critical weed period has practical limitations because crops and weeds grow at different rates from year to year, early removal of weeds is clearly important in reducing losses from competition. In addition to their direct competition in crop growth, weeds are important reservoirs of most crop viruses and their insect and nematode vectors, and of pathogenic fungi and bacteria. Because of their density and proximity to crop plants, weeds also provide microclimates conducive to infection by fungi and bacteria.

Chemical weed control treatments have been developed mainly for field crops in which the soil becomes shaded early in their development. Many vegetable crops, on the other hand, do not provide rapid shading of the soil around them and weeds continue to germinate over a longer period of time. The continued emergence of weeds necessitates additional tillage, which disturbs the soil and stimulates more weed seeds to germinate, perpetuating the problem.

The weeds most commonly encountered in vegetable fields in Canada are listed in Table 2.3d. Weed problems in vegetable crops are often regional. In the Prairie provinces, for instance, vegetables occasionally follow cereals and, hence, volunteer barley or wheat can be a problem, especially after a dry autumn. In eastern Canada, cereals are sometimes used as cover crops or form part of a stale-seedbed treatment for weed control. Other examples of regional weed problems include: eastern black nightshade, hairy galinsoga, velvetleaf (*Abutilon theophrasti* Medik.) and large crabgrass (*Digitaria sanguinalis* (L.) Scop.) in southern Ontario; kochia (*Kochia scoparia* L.) (*2.3e*) in southern Alberta and hemp nettle (*Galeopsis tetrahit* L.) in central Alberta; barnyard grass (*2.3a*) in New Brunswick; common groundsel (*Senecio vulgaris* L.) (*2.3d*) in Newfoundland; and creeping yellow cress (*Rorippa sylvestris* (L.) Besser) in the Fraser Valley of British Columbia.

Table 2.3d. Weeds commonly occurring in vegetable crops in Canada

Common Name	Scientific Name
Annual grasses	
Barley, volunteer	*Hordeum vulgare* L.
Barnyard grass	*Echinochloa crusgalli* (L.) Beauv.
Crabgrass	*Digitaria* spp.
Foxtail, green	*Setaria viridis* (L.) Beauv.
Foxtail, yellow	*Setaria glauca* (L.) Beauv.
Wheat, volunteer	*Triticum aestivum* L.
Broadleaved annual weeds	
Buckwheat, wild	*Polygonum convolvulus* L.
Chickweed	*Stellaria media* (L.) Cyrill
Cudweed, low	*Gnaphaliu muliginosum* L.
Flower-of-an-hour	*Hibiscus trionum* L.
Galinsoga, hairy	*Galinsoga ciliata* (Raf.) Blake
Groundsel, common	*Senecio vulgaris* L.
Lamb's-quarters	*Chenopodium album* L.
Mallow, round-leaved	*Malva rotundifolia* L.
Mustard, wormseed	*Erysimum cheiranthwoides* L.
Mustard, wild	*Brassica kaber* (DC.) Wheeler
Nightshade, black	*Solanum nigrum* L.
Nightshade, eastern black	*Solanum ptycanthum* Dun.
Nightshade, hairy	*Solanum sarrachoides* Sendt.
Pigweed, red root	*Amaranthus retroflexus* L.
Pigweed, prostrate	*Amaranthus graecizans* L.
Purslane, common	*Portulaca oleracea* L.
Radish, wild	*Raphanus raphanistrum* L.
Ragweed, common	*Ambrosia artemisiifolia* L.
Shepherd's-purse	*Capsella bursa-pastoris* (L.)
Smartweeds, annual	*Polygonum* spp.
Spurry, corn	*Spergula arvensis* L.
Perennial weeds	
Bindweed, field	*Convolvulus arvensis* L.
Milkweed, common	*Asclepias syriaca* L.
Mint, field	*Mentha arvensis* L.
Quack grass	*Agropyron repens* (L.) Beauv.
Thistle, Canada	*Cirsium arvense* L.
Thistle, sow	*Sonchus arvensis* L.

Parasitic higher plants

More than 2500 species of higher plants are known to live parasitically on other plants. These parasitic plants belong to several different botanical families and vary greatly in their dependence on their host plants. Relatively few of the known higher parasitic plants cause diseases on agricultural crops. In Canada, only dodder (*Cuscuta* sp.) has been observed as a pest in field-grown crops, and only very rarely has it been found in vegetables. In the United States, dodder has been reported to occasionally cause economic losses in carrot, onion, tomato, sugar beet, potato, hops, peppermint and pepper. Dodder forms dense tangles of leafless strands on and through the crowns of host plants (*2.3T1*). It reduces the growth and yield of affected plants.

2.4 Climate and environment

Pest distribution

The plant pathogens, insects, mites and other pests that attack and damage vegetable crops in Canada often are the same as those found on the same crops grown in similar climates in other countries. However, the climatic tolerances and other characteristics of pathogens may be altered as they adapt to climate, soil and other factors in Canadian production areas. Similarly, insect and other pests are influenced by climate, often resulting in pest complexes that are substantially different from those in other production areas. Indeed, because Canadian production areas are near the northern limit of distribution of some pest species, their population fluctuations and numbers differ from those nearer the main area of distribution, partly because parasitic and predaceous species, themselves, may not be as functional in Canada. It is apparent, therefore, that some species of pathogens and pests that are common elsewhere may be of minor importance on the crops grown in Canada; they may be secondary or occasional, or they may not be noticed at all. Others, however, may be devastating.

Environment-related disorders

All crop plants have an optimum total environment for productivity; any environmental factors departing markedly from that optimum will decrease yield and, by causing stress to the plants, may make them more susceptible to diseases and pests. Heavy yields also may stress plants by diverting photosynthetic products and other nutrients to the harvested organs (fruit, tubers, roots, leaves) at the expense of other parts of the plant. Many vegetables are raised from transplants, often started in greenhouses or distant geographical areas, and sometimes they are poorly acclimatized, so that they, too, are severely stressed at transplanting, being more susceptible, for example, to late spring frosts or heat damage, particularly on sandy soils.

Other environmental factors that can have minor or disastrous effects on crops include: too much or too little water, poor soil structure and compaction from machinery, poor drainage, heat, cold (including frost), wind, hail, lightning, and industrial pollutants in air, soil and water.

Chemical injury

Experienced extension personnel know that a high proportion of crop damage can be attributed to chemical injury; for example, too much or the wrong fertilizer, or too much or the wrong pesticide. Often, these situations result from simple, arithmetical errors in calculating rates of application, or by applying pesticides on the assumption that twice as much might be twice as good. Indeed, all materials with a '-cide' suffix can damage non-target organisms and, even at the recommended rates, may reduce yield to an extent that is scarcely compensated for by the control of weeds, insects or pathogens. Not infrequently, herbicide damage occurs simply because various pesticides have been applied from the same sprayer without thoroughly cleaning it after each use.

All fertilizers and pesticides should be applied strictly in accordance with the manufacturer's directions and local expert advice, and with appropriate care to avoid exposure of non-target organisms, including workers and the public. To avoid environmental contamination, precautions about spraying in windy conditions, disposing of pesticide containers, and avoiding contamination of ground water and reservoirs should be observed.

Nutritional disorders

In addition to the gross effects of nitrogen-phosphate-potassium (NPK) fertilizers, there are many disorders of vegetable crops that are caused by excesses or deficiencies of the so-called minor or trace elements. The availability of the essential elements to plants depends largely on soil type and environmental conditions. For example, phosphorus is less available to plants in heavy than in light soils; magnesium becomes deficient in sandy soils leached by heavy rains and irrigation; boron is less available in limed and dry soils; and iron and manganese both become more available in acidic soils. Indeed, manganese toxicity can occur in very acidic soils. Various elements can affect the availability of others; for example, iron availability is depressed by an excess of phosphate. Some of these effects are magnified in greenhouse soils, which are heavily amended with organic materials and may be steam-sterilized. Steaming releases toxic amounts of manganese and ammonia, and steamed soils generally have to be leached before use for those reasons. It is strongly recommended that vegetable soils be sampled regularly for chemical analysis in order to determine exact fertilizer requirements. It is particularly important to provide the proper amounts of calcium and potassium because they enhance the natural resistance of plants to some diseases.

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