Ontario

Potato Field Guide

Insects, Diseases and Defects

Publication 823

MINISTRY OF AGRICULTURE AND FOOD

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MINISTRY OF AGRICULTURE AND FOOD

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Introduction

The aim of this field guide is to help growers, scouts and crop advisors identify pests and other potato problems. The correct identification of potato pests will distinguish potentially serious problems from those of lesser importance. Identification is also the first step in effective control.

Although potato insects are relatively easy to identify, diseases are not. They are often misdiagnosed because the symptoms of different diseases are similar or because the diseases resemble genetic or physiological disorders. Symptoms such as wilting, necrotic lesions, yellowing and stunting are not sufficient for proper disease identification. The presence of fungal spores, bacterial ooze or survival structures may be essential to confirm a diagnosis.

Other factors may help to confirm the cause of the potato problem. They include:

A knowledge of weather conditions prior to the appearance of symptoms or injuries.

- Wet weather is conducive to late blight, blackleg, aerial stem rot, white mold, pink rot, etc.
- Plants die very quickly in areas of fields struck by lightning.
- Air pollution damage is most noticeable on sensitive varieties after hot and hazy days.

Distribution pattern of the problem.

- Circular patterns are typical of aphids and of nematode infestations. Wet or dry spots in fields may also cause poor growth or disease outbreaks to appear in roughly circular patterns. Late blight usually develops in low spots where the soil remains wet for longer periods after rain or irrigation.
- Some problems appear uniformly over a field. Early blight will affect nearly every plant in a field if the crop is under stress, and Colorado potato beetles are often distributed uniformly in non-rotated fields.
- Scattered distribution is usually seen in fields planted with seed that had a low percentage of viral infections, such as mosaic or leaf roll.
- Soil salinity and improper spray distribution create problems that follow the row.

Varietal differences in susceptibility to disease. Typical examples are the susceptibility of Superior to Verticillium and of Monona to blackleg.

Time of field monitoring. Time of day is also important for disease and insect identification.

- The symptoms of mosaic virus diseases are better seen on cloudy days because sunlight masks the symptoms.
- Colorado potato beetles are spotted easily on sunny warm days. If the weather is cool and windy, beetles tend to hide under leaves.
- Cutworms are not seen during the day because they feed at night, leaving characteristic holes in the leaves. To find cutworms during the day, dig the soil around the plant stems.

Laboratory analysis. A laboratory analysis must be conducted to identify the species or strain of a pathogen.

- Mosaic symptoms are caused by many viruses. Laboratory tests are necessary to identify the virus or combination of viruses that caused the mosaic symptoms.
- Laboratory analyses are required to identify the mating type and strain that is causing late blight in a field.

Field identification can be helped with some simple tools:

- Always carry a pocket knife to cut tubers to see the internal symptoms of some tuber diseases.
- A 10x hand lens is useful to confirm diagnosis.
- Plastic bags are useful for collecting samples of diseased plant parts. Plastic containers with small holes punched in the lids should be used to collect insect samples.

Keeping the samples in a cooler before taking them for laboratory examination helps to keep them fresh.

This field guide describes pests and other potato problems found in Ontario. A section on some quarantine pests not present in the province has been included to make growers, scouts and crop advisors aware of such potential problems.

Section 1

Insects

Colorado Potato Beetle (*Leptinotarsa decemlineata*)

- **Life stages:** eggs, larvae, pupae, adult beetles.

The Colorado potato beetle (CPB) is one of the most serious insect pests of potatoes. The feeding damage caused by CPB will drastically reduce yield if no effective control is applied.

Weather conditions determine the number of CPB generations per season. If cool temperatures prevail (15–16°C), CPB completes its life cycle in about 8 weeks. By contrast, at high temperatures (30–33°C), CPB populations increase rapidly because the incubation period of the eggs and the time for development of larvae and pupae is shortened. In Ontario, CPB generally completes two generations during the growing season. In warm summers, a third generation may develop.

In the fall, adult beetles burrow into the soil either in potato fields or in protected places surrounding the fields to overwinter at depths of 25–35 cm. When beetles emerge in the spring, most walk to the crop. If the weather is warm, a few beetles will fly directly to the fields.

The infestation and feeding damage of CPB is first noticed along the edges of potato fields close to overwintering sites. If spring weather is warm, beetle emergence may be very rapid; during cool springs, beetle emergence may be quite slow.

On warm, sunny days, beetles are easily observed feeding on top of the plants, but on cool days they hide under soil clods or foliage.

Mating and egg laying occur shortly after emergence. Females may lay as many as 400 eggs during their life span of 4–5 weeks. The yellow eggs are laid in clusters, usually on the underside of leaves. Frost will kill the eggs, as will sandy soil splashed by heavy rain onto the egg masses.

Eggs hatch into larvae within 4–9 days, depending on temperature. Larvae are reddish with a distinct black head, humped back and double row of black dots on each side of their bodies. The larvae pass through 4 stages (instars), reaching maturity in 7–20 days, depending on temperature. Once the fourth-instar larvae have matured, they crawl down to the ground and bury themselves in the soil to a depth of 5–10 cm to pupate. The pupal stage lasts 5–9 days. The next generation of adults then emerges.

Beetles that overwinter and emerge in the spring are usually called "first generation beetles" and die 4–5 weeks after emergence. The beetles that emerge from pupae during the season—usually in July—are called "second generation beetles." These second generation beetles feed continuously to accumulate enough energy to survive the winter buried in the soil. In southwestern Ontario, a partial third generation may develop if summer weather is unusually hot.

1 | Colorado potato beetle.

2 | Adult beetles are somewhat rounded, about 10 mm long and 7 mm wide. Males are a few millimetres smaller than females. On the wing covers, 10 black stripes run lengthwise over a yellow-cream background.

3 | Beetles feeding on an emerging plant.

4 | Mating occurs shortly after emergence.

5 | Female laying eggs. Recently laid eggs are bright yellow. In hot weather, females lay darker eggs.

6 | Eggs are yellow, elongated and cylindrical. Egg masses have 25–40 eggs and are usually laid on the underside of the leaves. Eggs turn dark orange close to hatching time.

7 | An egg mass recently laid (left), an egg mass hatching (middle) and newly hatched larvae moving away from the egg hatch site (right).

8 | **LARVAL INSTARS** Larvae are orange red and humpbacked, with two rows of black spots on each side of the body. There are four larval stages (instars).

SMALL LARVAE

First instar or newly hatched larvae are very tiny, about 1.5–2 mm long.

Second instar larvae are up to 5 mm long.

LARGE LARVAE

Third instar larvae are about 8 mm long.

Fourth instar larvae reach a maximum length of 12 mm.

9 | First instar larvae feed first on the egg shells.

10 | After feeding on egg shells, first instars migrate to feed on the tender tissues of the growing point of the potato plant.

11 | Newly hatched larvae leave a characteristic mark at the egg hatch site.

12 | Second instar larvae feeding on leaves. On sunny days, larvae and adults tend to feed on upper leaves. On cool days, they hide under the foliage.

13 | Young third instars feeding on leaves. Larvae and adults leave black droppings on the foliage.

14 | Fourth instar larvae are extremely voracious.

15 | Large larvae cause severe defoliation if left uncontrolled.

16 | Mature fourth instar larva burrowing in the soil to pupate.

17 | The pupa, found only in the soil, is an inactive stage during which the mature fourth instar larva transforms into an adult.

18 | Typical holes made by adult beetles emerging from the soil.

19 | Second generation beetles causing severe defoliation.

20 | Complete defoliation late in the season.

21 | When no leaves are left, beetles eat pieces of stems.

22 | Beetles feeding on tubers left in the field after harvest.

23 | Beetle burrowing into the soil to overwinter.

24 | Colorado potato beetles trapped in a plastic-lined trench.

25 | After being poisoned by an insecticide, Colorado potato beetles often expand their soft, red wings before dying.

26 | Excellent control provided by a systemic insecticide applied at planting.

27 | A stink bug feeding on Colorado potato beetle eggs.

Potato Flea Beetle (*Epitrix cucumeris*)

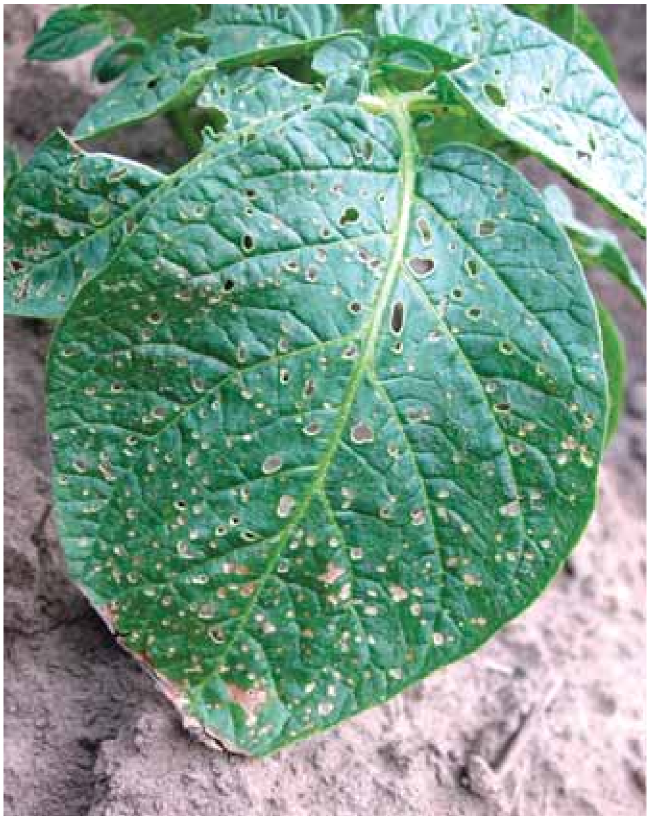
- **Life stages:** eggs, larvae, pupae, adult beetles.

Flea beetles overwinter as adults in plant litter on the soil surface. In the spring, adults move to potato fields and feed on the developing foliage. Females lay eggs in the soil around potato plants. Eggs hatch in about a week into tiny larvae that feed primarily on the fine roots of potato plants. After 4–5 weeks, the larvae reach maturity and pupate in the soil to become adults. This new generation of adults emerges from the soil, usually in late July, and feeds on potato leaves.

Flea beetle populations are higher when potatoes are grown close to crucifer crops.

28 | Adults are very small, about 1.7 mm long and 1 mm wide. Flea beetles do not fly, but jump very quickly when disturbed.

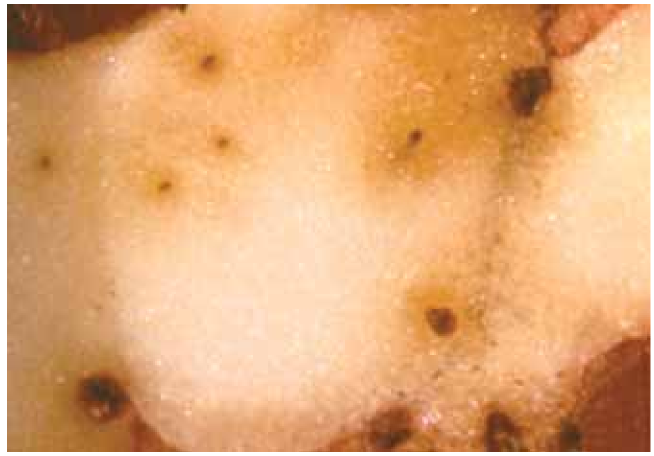
29 | Actual size of an adult flea beetle.



30 | Flea beetle feeding damage has a shot-holed appearance.

31 | Feeding holes range from 1–5 mm in diameter.

32 | Flea beetle feeding damage does not always pierce the leaflets.



33 | Occasionally, flea beetle larvae feed on tubers. This causes small, round, dark-brown lesions.

Potato Leafhopper (*Empoasca fabae*)

- **Life stages:** eggs, nymphs, adults.

The potato leafhopper does not overwinter in Ontario. It is carried by upper-level winds from the United States and can arrive in Ontario as early as May. Depending on weather conditions, 2–4 generations can develop during the season. Usually two generations develop if the season is cool. By contrast, up to 4 generations have been observed in warm years.

Although the potato leafhopper attacks many crops, alfalfa is the preferred host. Alfalfa cutting sends adults flying to infest other crops. This explains why populations of leafhopper increase so rapidly in potato fields. Potato fields adjacent to alfalfa fields are at high risk of leaf-hopper infestation.

Adults and nymphs feed by sucking sap from the leaves and stems. Initially, the feeding damage causes yellowing and browning of the tips and margins of the leaves. Later, the leaf margins roll inward, resulting in the typical hopperburn damage. Usually, hopperburn is noticeable 4 to 5 days after leafhopper feeding. **To avoid yield losses, leafhoppers must be controlled before hopperburn is visible.**

34 | Adults are small, pale green, about 3 mm long and wedge-shaped, with a broad head and thorax. The body tapers along the wings. Leafhoppers are very active and quick to fly.

35 | Actual size of a leafhopper adult. Leafhoppers inject a toxin while feeding on leaves.

36 | Nymphs pass through 5 stages, increasing in size until the adult stage is reached in about 2 weeks. When disturbed, nymphs run sideways like crabs over the edge of the leaflet to the underside.

37 | Hopperburn first appears as brown, triangular lesions at the tips of the leaflets. Later, the margins of leaflets become brown and roll upward.

38 | Severe hopperburn damage.

39 | Plants showing hopperburn damage.

Aster Leafhopper or Six-spotted Leafhopper (*Macrosteles quadrilineatus*)

- **Life stages:** eggs, nymphs and adults.

Aster leafhoppers infesting potatoes in Ontario originate from two sources: overwintering eggs laid in winter cereals and adults carried from the southern United States by upper-level winds. Because the aster leafhopper does not reproduce on potatoes, only adults infest the crop. This insect does not inject a toxin or cause hopperburn damage, but does transmit a phytoplasma that causes aster yellows and purple top (see page 111).

40 | Adults are green and have 6 black spots arranged in pairs on the front of the head. Aster leafhoppers are 3 mm long, slightly larger than potato leafhoppers.

41 | Purple top causes bunching of apical growth and upward rolling of leaflets, which develop a purple pigmentation.

Tarnished Plant Bug (*Lygus lineolaris*)

- **Life stages:** eggs, nymphs, adults.

The tarnished plant bug is a common pest of many vegetable and fruit crops.

Adults overwinter in protected areas: in debris found in fencerows, in woods, in ditches or in fields of forage legumes.

They become active as the weather warms in the spring. Tarnished plant bugs feed on leaves, stems and petioles, removing plant sap with their piercing and sucking mouthparts. While feeding, this insect introduces a toxin that causes leaves to wilt and blossoms to drop prematurely. Since nymphs feed more than adults, nymphs are more destructive.

The tarnished plant bug may spread the potato spindle tuber viroid (see page 110).

- **Adults.** They are oval, with flat bodies, and about 6 mm long. Their colour is variable, from pale yellow with a few black markings to reddish-brown to black with a few pale-yellow markings. They have a distinctive light-coloured triangular pattern on their backs. Tarnished plant bugs fly from plant to plant in short bursts.

- **Young nymphs.** They are yellowish-green and about 1 mm long. Nymphs resemble the adults except for their smaller size and the absence of fully developed wings.

- **Older nymphs.** Older nymphs are green and robust with long legs, long antennae and developing wings. Nymphs can be distinguished from aphids by their rapid movement, more robust legs and lack of cornicles.

42 | Tarnished plant bug adult.

43 | Young tarnished plant bug nymph.

44 | Older tarnished plant bug nymph.

45 | Usually the tarnished plant bug feeds on top leaves and injects a toxin that causes the leaves to wilt.

46 | Actual size of an adult.

47 | The tarnished plant bug leaves ragged holes in leaflets.

Aphids

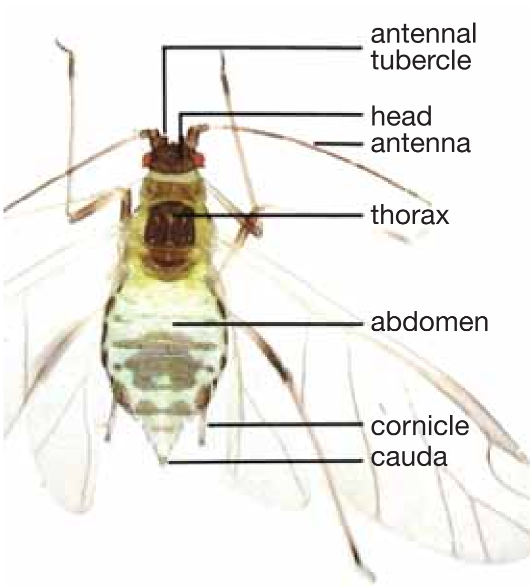
- **Life stages:** eggs, wingless forms, winged forms.

Aphids are small, soft-bodied, sucking insects 1–4 mm in length.

Aphids affect the potato crop directly by feeding and indirectly by transmitting viruses that cause important diseases. The most common species of aphids found on potatoes in Ontario are the green peach, the potato and the buckthorn aphid.

Most aphids overwinter as eggs on fruit trees. In the spring, wingless aphids hatch from the eggs and reproduce without mating by giving birth to live, wingless young. When the wingless aphid colonies become too crowded, winged individuals are produced. The winged aphids, also called "spring migrants," fly to an acceptable summer host where they feed and produce wingless offspring. Wingless aphids are by far the predominant form on potatoes during the growing season. As potato plants mature and the days become shorter, winged male and female migrants appear. They fly to overwintering hosts, where the females lay fertilized overwintering eggs.

Aphid populations may increase rapidly when temperatures are high; a mixed population of young and old aphids can increase five-fold within one week. Natural predators such as ladybeetles and lacewings are very effective in keeping aphid populations at low levels.



48 | Features used to identify aphids that infest potatoes.

49 | Green and pink aphids.

50 | Heavy aphid infestation.

51 | Circles of dead plants are a sign of large aphid populations causing severe damage to the crop.

Green Peach Aphid (*Myzus persicae*)

The green peach aphid is the most important vector of potato viruses.

Although it prefers to feed on the lower leaves of potato plants, the green peach aphid will feed on the top leaves if populations are high.

Identification

Wingless forms. They are teardrop-shaped, 1.7–2 mm long and light yellowish-green to pink. The antennal tubercles are prominent and pointed inward. The cornicles are the same shade as the body and slightly swollen on the apical half.

Winged forms. They are about 2 mm long, with a dark-brown to black head and thorax. The abdomen is green, pink or reddish with a more or less solid dark patch. The antennal tubercles point inward.

52 | Wingless green peach aphid.

53 | Winged green peach aphid.

Potato Aphid (*Macrosiphum euphorbiae*)

In Ontario, the potato aphid is the first to infest the crop in the growing season. It is also the largest aphid that infests potatoes in the province. This aphid is usually found on the middle and upper leaves of potato plants. High populations will cause wilting and will cover the upper leaves with sticky honeydew.

Identification

Wingless forms. They have elongated, wedge-shaped, yellow-green or pink bodies with long legs and long, slender cornicles. Their length ranges from 2.5–3.5 mm. The antennal tubercles slope outwards.

Winged forms. They are approximately 2.5–3.5 mm long. The antennal tubercles slope outward. The head and thorax are light yellow-brown or green-brown to dark brown. The abdomen is green or sometimes pink. The darker, pigmented legs and antennae are a distinctive feature of the potato aphid.

54 | Wingless potato aphid.

55 | Winged potato aphid.

Buckthorn Aphid (*Aphis nasturtii*)

The buckthorn aphid is the smallest aphid that infests the potato crop in Ontario. It is usually found on the lower leaves of potato plants.

Identification

Wingless forms. They are egg-shaped and about 1.2 mm long with a flat, lemon-yellow to green body. The antennal tubercles are not prominent.

Winged forms. They are approximately 1.4 mm long. The head and thorax are dark brown to black. The abdomen is yellow to yellow-green with a dark stripe behind each cornicle. The cornicles are short and light to dark brown. The antennal tubercles are not prominent.

56 | Wingless buckthorn aphid.

57 | Winged buckthorn aphid.

Foxglove Aphid (*Aulacorthum solani*)

The foxglove aphid is seldom abundant in Ontario.

Identification

Wingless forms. They have a pear-shaped body with prominent, almost parallel, straight-sided antennal tubercles. The body is light yellow-green to dark green or brownish, shiny, usually with darker areas around the bases of the cornicles. The cornicles have dark tips. Legs and antennae have dark joints.

Winged forms. The head and thorax are light yellow-brown or green-brown. The abdomen is green to yellow-brown with dark bars and spots. The legs have dark joints and the wings have characteristic dark veins. The antennal tubercles are prominent, almost parallel and straight-sided.

58 | Wingless foxglove aphid.

59 | Winged foxglove aphid.

Potato Stem Borer (*Hydraecia micacea*)

Life stages: eggs, larvae, pupae, adult moths.

Female moths lay eggs from August to September on grassy weeds in and around potato fields. These overwintering eggs begin to hatch in late April or early May, and the small larvae bore into the grasses. By late May or early June, the larvae outgrow the stems of the grasses and move on in search of larger weeds or cultivated crops such as potatoes. Larvae usually infest plants in border rows close to grasses where the larvae first fed.

60 | Potato stem borer adult moth.

61 | Mature larvae are dark to light pink and about 3.5 cm long.

62 | Larvae bore holes close to the base of the stem to penetrate young plants.

63 | Close-up view of a hole made by a potato stem borer larva.

64 | Larvae feed on stem tissue. Infested stems wilt, collapse and eventually die.

European Corn Borer (*Ostrinia nubilalis*)

- **Life stages:** eggs, larvae, pupae, adult moths.

The European corn borer is a sporadic pest of potatoes, usually attacking the crop in cool seasons when corn development is delayed. Female moths lay egg masses on the underside of the leaves of potato plants. Larvae emerge after 3–9 days, depending on temperature. They feed on the leaves for a few days and then bore into the stem of the plant, destroying the pith and the vascular tissue. Larvae complete their development in the stem. Fully grown larvae overwinter in stems left in the field after harvest. In the spring, larvae pupate and later emerge as adults.

65 | Adult females are 2–2.5 cm long and yellowish brown with dark irregular bands running in wavy lines across the wings.

66 | Adult males are smaller and darker in colour than females.

67 | European corn borer egg mass. Each egg mass can have 15–40 eggs, which are layered like fish scales.

68 | Larvae, 1.5–1.8 cm long, are easily identified by their dark heads and the paired dark spots running the length of the backs of their bodies.

69 | Stem hollowed out by a larva of the European corn borer. Damaged stems wilt and then collapse.

Wireworms (*Limonius* spp.)

- **Life stages:** eggs, larvae, pupae, adult beetles.

Wireworms are the larvae of click beetles. Female click beetles lay eggs in late spring in fields of hay, forage legumes such as red and sweet clover, or small grains. Larvae hatch in 3–7 weeks. Depending on the species, it takes 2–5 years for the larvae to reach maturity. In the spring, wireworms move upward or downward in the soil in response to moisture, temperature and the availability of food. If temperatures exceed 27°C in the summer, wireworms move downward into cooler soil.

In the spring, wireworms tunnel into seed pieces or feed on sprouts; if populations are high, the stand may be reduced. Later in the growing season, wireworms feed on developing tubers, producing tunnel-like holes that make the crop unmarketable. Wireworms generally overwinter deep in the soil to avoid freezing.

- **Adults**. Click beetles are 1–1.5 cm long with "hard-shelled" brown or black bodies. The beetles snap themselves into the air, making a clicking sound, in an attempt to right themselves after being placed or falling on their backs.
- **Larvae**. They have elongated, nearly cylindrical bodies with three pairs of short legs just behind their heads.
- **Pupae**. They are white and inactive.

70 | Adult click beetle.

71 | Larvae are yellow or light brown with a hard, shiny skin. Pupae are white.

72 | Mature wireworm larvae may reach a length of about 3 cm.

73 | Feeding holes on seed tubers.

74 | In the spring, wireworms feed on developing shoots.

75 | Later in the growing season, wireworms feed on daughter tubers, making tunnels of up to 3 cm deep.

76 | Severe wireworm feeding damage to daughter tubers.

White Grubs (*Phyllophaga* spp.)

Life stages: eggs, larvae, pupae, adult beetles.

The larvae of June beetles are the most important white grubs attacking potatoes. White grubs prefer sandy soils and are rarely pests in heavy, poorly drained soils. They are most likely to damage potatoes growing in land previously in sod.

The life cycle of this insect lasts 3 years.

First year: In the spring, the females lay eggs in grassland or in patches of grassy weeds in cultivated fields. Small, white grubs hatch in 2–3 weeks and feed mainly on fine roots. The larvae then move down into the subsoil for the winter.

Second year: As the soil warms the following spring, the small grubs move upward to feed on roots and tubers, causing severe damage. The grubs, nearly full grown, remain in the soil for the second winter.

Third year: Early in the summer of the third year, the grubs pupate. Later in the season, the adults emerge, but remain inactive buried in the soil. The adults overwinter in the ground, then emerge the following May and June.

77 | June beetle: the adult stage of white grubs.

78 | Grubs have C-shaped white bodies with red-brown heads and brown legs. When mature, grubs are about 3 cm in length.

79 | White grubs chew deep cavities in tubers, making them unmarketable.

Cutworms

Life stages: eggs, larvae, pupae, adult moths.

Cutworms are the larvae of several species of night-flying moths. Female moths lay eggs on the soil or on the foliage; the larvae then hatch and feed on plants or tubers. Most cutworms feed at night and spend the day curled up in the soil. Some species of cutworms are adapted to low temperatures, causing damage to the crop early in the season when the potato plants are still small. Cutworm problems are usually spotty in a field and concentrated in low, weedy areas. The most common species of cutworms found feeding on potatoes in Ontario are the black cutworm and the variegated or climbing cutworms.

The black cutworm (*Agrotis ipsilon*) usually feeds on stems at or below ground level, cutting off young plants at the stem base. Later in the season, the black cutworm feeds on tubers.

Variegated or climbing cutworms climb potato plants to feed on the foliage. Since there are two generations of these cutworms during the season, damage may occur when the plants are small and again in late July. Brown-black droppings are usually found on the soil surface underneath plants damaged by climbing cutworms.

80 | Male moth of the black cutworm in a pheromone trap. The markings on the wings look like cherries.

81 | Black cutworms are grey to black. When disturbed, the cutworm typically curls up into a C-shape.

82 | The black cutworm often cuts off stems at ground level. The larvae may be found by removing soil from around damaged plants to a depth of about 5 cm.

83 | Later in the season, the black cutworm may feed on the lower part of the stems.

84 | Black cutworm in potato tuber.

85 | Tubers showing severe black cutworm feeding damage that makes them unmarketable.

86 | These variegated cutworms are brown with longitudinal stripes and diamond-shaped, pale yellow markings along the back and sides of the body.

87 | Variegated cutworm feeding damage.

88 | Climbing cutworm on a leaf with feeding damage and droppings.

89 | Climbing cutworm larvae and pupa.

Minor Insect Pests

Armyworms

- **Life stages:** eggs, larvae, pupae, adult moths.

In years when armyworm populations are high, they may feed on the potato crop.

90 | Armyworm feeding damage.

Cabagge Looper (*Trichoplusia ni*)

- **Life stages:** eggs, larvae, pupae, adult moths.

The cabbage looper is a sporadic pest of potatoes. Unlike cutworms, loopers feed on potato plants during the day. They arch into a loop as they crawl.

91 | Cabagge looper larva.

92 | Feeding damage caused by the cabagge looper.

Seedcorn Maggot (*Delia platura*)

- **Life stages:** eggs, larvae, pupae, adult flies.

Occasionally, the seedcorn maggot is a pest of potatoes. Adult females lay eggs in the soil, either on decaying organic matter or seed pieces. After hatching, maggots attack the seed piece through wounds or decaying tissues. The maggot may spread bacterial soft rot. Damage is usually more severe during cool, wet springs in soils with high organic matter content.

93 | Maggots are about 6.5 mm long, yellowish-white and very tough-skinned. They are sharply pointed at the head and legless. Pupae are brown.

94 | Maggots are attracted to decaying seed pieces.

Blister Beetle (*Epicauta* spp.)

- **Life stages:** eggs, larvae, pupae, adult beetles.

Several species of blister beetles may feed on potatoes. They are slender insects, 1–2 cm long, and may be black, grey with black spots, or striped black and yellow. Blister beetles usually feed in swarms and move about a great deal.

95 | Adult blister beetle.

Red-headed Flea Beetle (*Systena frontalis*)

Life stages: Eggs, larvae, pupae, adults.

Adults are occasionally found feeding on potato foliage and may also be found on a wide variety of plant species, including grapevine. Their peak numbers usually occur by the middle of August.

Adults are black, with a dark-red spot on the head, and approximately 4 mm long. They have large hind legs, allowing them to jump very quickly. Adults chew holes in the leaves. Their abundance could depend on the proximity of corn fields and other sources of food.

Larvae may be found on the roots of a wide variety of weeds and cultivated plants, including corn.

96 | Adult red-headed flea beetle.

97 | Feeding holes made by the red-headed flea beetle.

Potato Psyllid (*Paratrioza cockerelli*)

Life stages: eggs, nymphs, adults.

Feeding by adults does not cause significant damage to potato plants. However, the nymphs inject a toxin that causes "psyllid yellows."

Adults. Adults are about 2 mm long and resemble small cicadas. Their colour goes through gradual changes from light yellow to pale green when they first emerge, brown or green 2 or 3 days later, until they become grey or black with white markings when they are 5 days old. They jump rapidly when disturbed.

Eggs. The eggs are very small, football-shaped, yellow to orange and borne singly on very fine stalks.

Nymphs. Nymphs are flattened and scale-like, with a fringe of short spines. Younger nymphs are pale brown, turning green as they get older. Nymphs are usually found on lower leaves and move readily when disturbed. They secrete a white substance resembling granulated sugar or salt that collects on leaves beneath the feeding insects.

98 | Potato psyllid adult.

99 | Eggs are usually laid along leaf margins.

100 | Potato psyllid nymphs.

101 | Symptoms of psyllid yellows. Stunted plants form rosettes and the leaves roll upwards. Affected plants turn yellow; the leaflets of red varieties turn reddish or purple. Aerial tubers may form.

Tortoise Beetle (*Plagiometriona clavata*)

- **Life stages:** eggs, larvae, pupae, adults.

The tortoise beetle is an occasional pest of potatoes; it has been detected feeding on potato leaves in wet years. Tortoise beetles are small, about half a centimetre long, with bodies that resemble miniature turtles. They have thin margins that extend out of their bodies as well as a shield-like structure that covers their head.

102 | Tortoise beetle feeding on potato leaves.

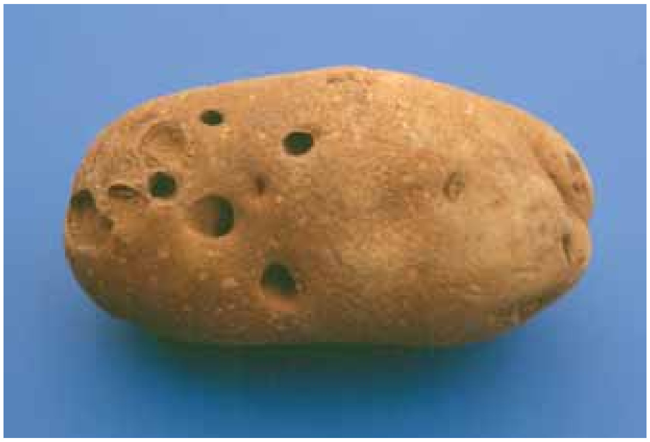
Section 2

Non-insect Pests

Slugs

103 | Slug.

Slugs are mollusks. They have soft, unsegmented, whitish-yellow to black bodies ranging from 6–25 mm long. Slugs are usually found in moist places. They come out of hiding at night to feed by rasping holes in tubers and foliage.



104 | Slug damage on tubers.

Snails

Snails may feed on tubers in wet years.

105 | Tuber damaged by snail feeding.

Millipedes

106 | Occasionally, millipedes feed on potatoes.

Mites

Occasionally, the two spotted spider mite infests potato fields. Mites are tiny, eight-legged creatures less than 1 mm long. They are difficult to see without a hand lens. Mites prefer to feed on the underside of leaves. They spin fragile webs on the leaves of plants growing along the dusty borders of a field. They damage plants by puncturing the leaf tissue with their mouth parts to extract plant juices.

Feeding injury causes mottling of leaves. As the damage increases, leaves turn brown or bronze, which results in reduced photosynthesis.

107 | The two spotted spider mite is an occasional pest of potatoes. Adults are yellowish-brown with two dark spots.

Mice

108 | Teeth marks are noticeable in damaged tubers.

109 | Severe mouse feeding damage before harvest.

Section 3

Fungal Diseases

Seed Piece Decay

Poor stands resulting from seed piece decay can be a major problem if cool, wet weather prevails immediately after planting. Several pathogens may cause seed tubers to rot before emergence.

Fusarium is the most common fungus responsible for seed piece decay. Soft rot bacteria often invade tubers infected with *Fusarium*, causing the seed to rot very quickly. The late blight fungus (see page 41) and *Pythium* spp. (see page 79) may also cause seed piece decay.

110 | Seed piece destroyed by *Fusarium*.

111 | Poor stand caused by seed piece decay.

Fusarium Seed Piece Decay and Dry Rot (*Fusarium* spp.)

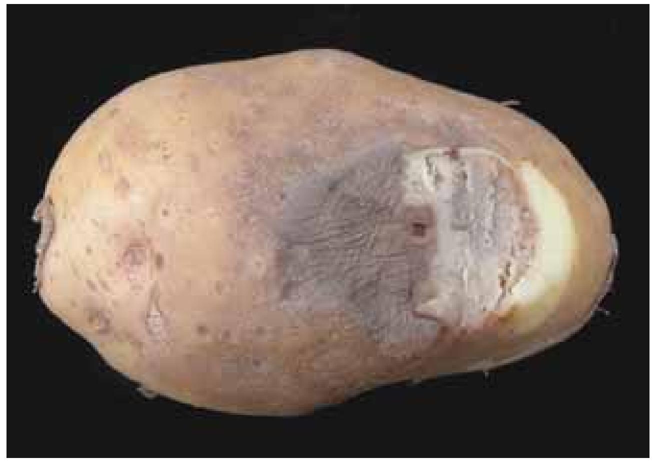
Pathogen. Several species of *Fusarium* are present in most soils. The fungus also survives in infected seed tubers. *Fusarium* causes seed piece decay, dry rot in storage and plant wilting in the field.

Disease development. Most *Fusarium* infections occur through wounds and bruises that result from rough handling during harvest, transit or storage. If potatoes are infected at harvest, symptoms are noticeable in storage about a month later. In seed storage facilities where the temperature is below 4°C, tuber lesions do not enlarge, but the fungus remains dormant. As the seed tubers are warmed up in storage or in transit before planting, the fungus will resume growth and the disease will develop rapidly.

Seed pieces infected with dry rot may be partially or completely destroyed in the soil. This results in uneven stands. Single sprouts may emerge from partially infected seed pieces, but the plants are weak and produce few marketable tubers.

Decaying seed pieces are attacked by soft rot bacteria that rot the seed pieces very quickly.

Seed-corn maggots are attracted to decaying seed pieces.



112, 113, 114 | Some *Fusarium* fungi cause a wet rot. The affected tissue has a jelly-like consistency.

115 | Infected seed pieces. Tufts of white or pink mold develop in infected areas.

116 | Older lesions are sunken and shriveled, with concentric wrinkles. Cracks often form in infected areas. The rot may involve most of the tuber, resulting in mummification of the entire tuber.

117 | Rotted tissue is brown or grey to black, dry and crumbly. There is no noticeable smell. Cavities lined with white, yellow, pink or blue mold develop in the rotted tissue.

118 | Internal tuber tissue destroyed by *Fusarium*.

Fusarium Dry Rot Lookalike

- **Phoma rot** (see page 83).

Rhizoctonia (*Rhizoctonia solani*)

Pathogen. *Rhizoctonia* is a common seed- and soil-borne fungus that survives as black resting structures called sclerotia. In the soil, the fungus can also survive as mycelium on organic debris. Planting seed potatoes infested with sclerotia increases the amount of *Rhizoctonia* inoculum in the soil.

Disease development. *Rhizoctonia* is more prevalent during cool, wet springs, when plant emergence is slower than the growth of the fungus. Infections start when sclerotia in the soil or on seed tubers germinate, producing mycelium that colonizes plant surfaces.

Symptoms. Rhizoctonia infections that pinch off sprouts before plant emergence cause severe damage. The secondary sprouts that develop from the pinched off sprouts are less vigorous and emerge much later, causing irregular, uneven stands.

119 | Rhizoctonia cankers on sprout.

Early infection of stolons often results in pruning before tuber formation or interrupted development of newly formed tubers.

Mid- and late-season infections result in long, deep, sunken cankers on the stems, the formation of aerial tubers and deformed daughter tubers.

Late in the season, the fungus produces a superficial white mycelium on the stems just above the soil line. The fungus forms black sclerotia ("black scurf") on daughter tuber surfaces before and after harvest.

Rhizoctonia may also cause skin cracks and russeting.

120 | Rhizoctonia black scurf on tuber surface. Sclerotia are hard, black structures of irregular shape and variable sizes tightly attached to the tuber skin. They are commonly called "the dirt that won't wash off."

121 | Sclerotia range from 0.1–2 cm in diameter. Delaying harvest in the fall increases the amount of sclerotia on the tubers.

122 | Seed tuber with sclerotia near the bud end.

123 | Sprouts pinched off by *Rhizoctonia*. This damage results in poor stands or weak plants.

124 | Rhizoctonia cankers on young stems.

125 | Cankers on stolons.

126 | Longitudinal cracks on older stems.

127 | White to grey mat of fungal mycelium on the stem near the soil line. The mycelium is easily rubbed off. The affected stem area remains green.

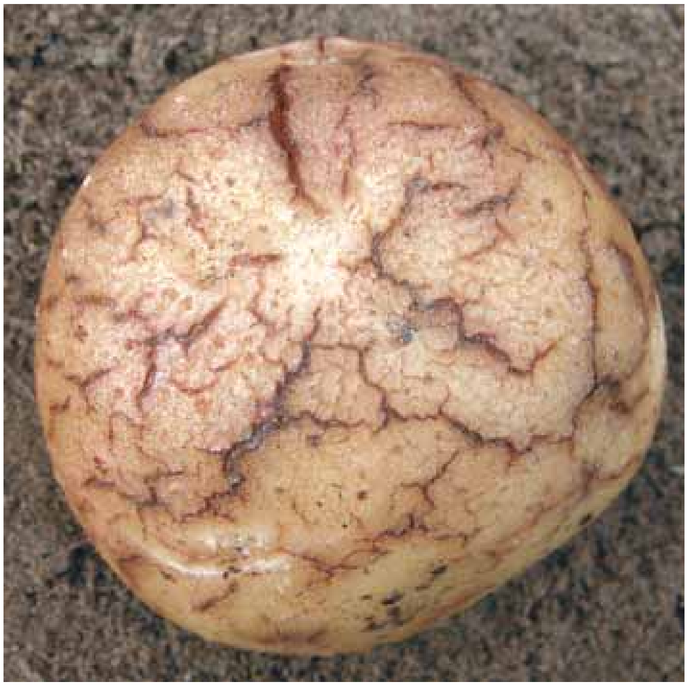
128 | Upper leaves roll upwards and turn reddish-purple. These symptoms could be confused with potato leaf roll.

129 | Aerial tubers produced on the leaf axils.

130 | Aerial tubers of a red-skin variety.

131 | Tubers form in a tight cluster close to the surface of the soil.

132 | Small, malformed tubers produced by a plant infected with *Rhizoctonia*.



133 | Cracks caused by *Rhizoctonia*.

134 | Often, sclerotia are found in sunken lesions at the stem end. The dark brown fungal threads can be seen on the tuber surface.

Rhizoctonia Lookalikes

- **Late blight:** white fungal growth at the base of the stem (see below).
- **Potato leafroll:** Reddish colour and rolling upward of top leaves (see page 101).

Late Blight (*Phytophthora infestans*)

Late blight has the potential to be an extremely destructive disease of potatoes. The fungus attacks all parts of the plant. High moisture and night temperatures of 10–15°C and day temperatures of 10–21°C are most favourable for disease development.

- **Pathogen.** The late blight fungus overwinters as mycelium in seed tubers, cull pile tubers or tubers left in the field after harvest. Potato plants originating from infected tubers are the main sources of inoculum during the growing season. Millions of spores, called "sporangia," are produced on lesions of infected plants. Sporangia are spread mainly by rain or wind to healthy plants.

The fungus has two mating types, A1 and A2. If the two mating types infect the same plant tissue and mate, sexual spores called "oospores" can be produced.

Oospores are thick-walled, survive in the soil for several years in a dormant state and can initiate late blight infections.

135 | The spores of the late blight fungus are lemon-shaped. They are called "sporangia" and may release swimming spores.

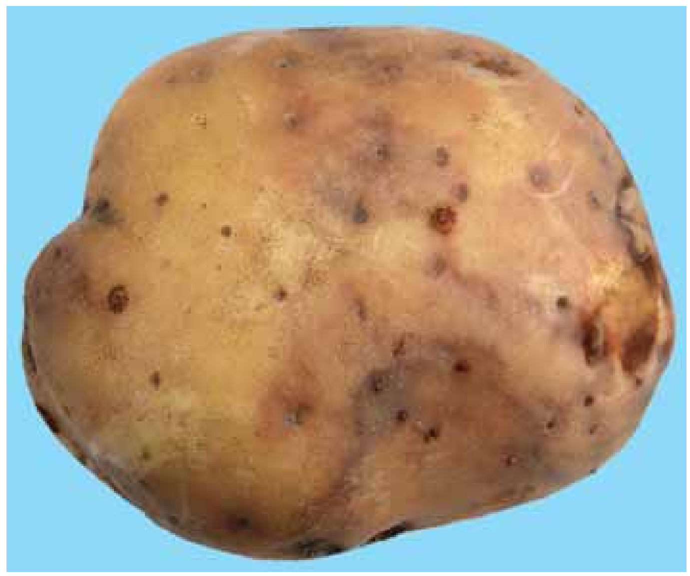
136 | Oospores are sexual spores produced when the two mating types of the fungus, A1 and A2, infect the same plant tissue and mate.

The A1 and A2 mating types have many strains. Most of the potato strains in Canada and the United States belong to the US-8 clonal lineage. Only a laboratory analysis can determine which mating type and strain is infecting a crop. Field identification is limited to "late blight."

Other hosts of the late blight fungus are tomatoes, hairy nightshade, bittersweet (*Solanum dulcamara*) and petunia (*Petunia* x *hybrida*).

Disease development. When infected seed is planted, some of the seed might rot before plant emergence or some infected plants can emerge, driving the disease up the stems. The fungus produces spores on the lesions of infected plants at any time during the growing season. The spores are splashed by rain to neighbouring healthy plants or by wind to other areas of the field. Long-distance spore dispersal is by wind. In addition, farm equipment carrying contaminated plant material can spread the fungus to healthy fields.

High humidity is necessary for spore production. Sporangia germinate under humid weather conditions or irrigation and penetrate the plants. Sporangia germinate by two different methods, depending on the temperature. Between 21° and 26°C, they germinate directly, forming a germ tube that penetrates the plant tissues. Below 18°C, each sporangium releases 8–12 zoospores. Zoospores move freely in any water film on the plant surface. Eventually, they settle down, germinate and penetrate plant tissues. Thus, disease incidence is higher when the weather is cool and wet. Under these conditions, each sporangium releases many zoospores and instead of one infection site there is the potential for 8–12 infection sites. Late blight symptoms develop 3 to 4 days after infection.



137 | Tuber infected with late blight.

Tubers are infected by spores washed by rain from infected foliage or stems into the soil.

Late blight is one of the most destructive diseases of potatoes. If wet weather prevails and the disease is left uncontrolled, it can destroy a potato field in a few days. The best disease control method for late blight is prevention: eliminating sources of infection (infected seed, cull piles, volunteer plants), following a preventative fungicide program and using resistant cultivars, whenever possible.

There are no highly effective, long-lasting methods for curing the disease once the plants are infected.

Late Blight Symptoms on Leaves

138 | Initial symptoms on leaves are light- to dark-green water-soaked spots. The spots are circular to irregular in shape.

139 | Small lesion viewed from the upper side of leaflet.

140 | Small lesion viewed from the underside of leaflet.

141 | Large lesion viewed from the upper side of leaflet.

142 | Large lesion viewed from the underside of leaflet.

143 | A lesion expanding on the leaflet. The white mycelium and spores of the fungus develop at the edge of the lesions, usually on the underside of leaflets. Entire leaves can become blighted as new infections occur and existing lesions coalesce.

144 | A lesion that started in the middle of the leaflet. Late blight lesions are not limited by veins.

145 | A lesion with a yellowish halo. When dry weather prevails, lesions dry up and no fungal growth is present on the underside of leaves. When wet weather returns, the fungus resumes growth, again producing mycelium and spores.

146 | Dry lesion at the tip of a leaflet surrounded by a light-green halo. Lesions often develop at the tips of leaflets, where dew is retained longest.

147 | Brown, dry lesions.

Late Blight Symptoms on Stems

148 | Late blight infection at the base of the stem initiated by infected seed. This symptom looks similar to blackleg (see page 87). (In humid weather, no white mycelium develops on plants infected with blackleg.)

149 | Late blight symptoms on stems are irregular, dark-brown to black lesions. Under humid conditions, fungal mycelium and spores develop on infected areas.

150 | Stem lesions expand rapidly in humid weather and can cover most of the stem.

151 | The tender growing point is an easy target for late blight because moisture persists there after a heavy dew, rain or irrigation.

152 | Growing point killed by late blight.

153 | Infected stems are brittle and break easily.

154 | Seed ball infected with late blight.

155 | The right half of the field was killed by late blight. Note the regrowth of healthy shoots after the infected plants died.

Late Blight Symptoms on Tubers

Tubers are infected in the potato hill by late blight spores washed by water from infected foliage into the soil. Tubers are also contaminated with spores of the fungus if they are dug while infected vines still have active lesions with viable spores.

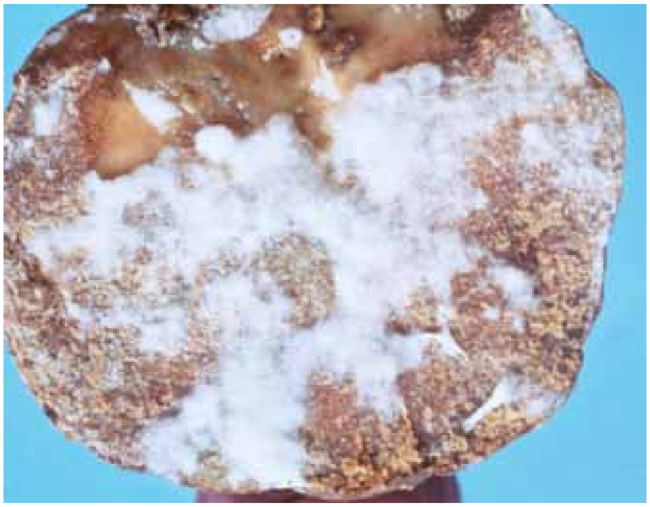
156 | External symptoms appear as slightly sunken, brown to purplish areas of variable size.

157 | The internal symptom is a tan to brown, granular dry rot. There is no clear separation between the infected and the healthy tissue.

158 | Internal rot develops rapidly.

159 | A tuber completely infected with late blight.

160 | Often, soft rot bacteria invade infected tubers. Bacterial soft rot develops rapidly under warm, humid conditions.



161 | Late blight mycelium produced on pre-cut seed.

Late Blight Lookalikes on Leaves and Stems

- **White mold on stems** (see page 66)

162 | Dense, white fungal growth develops on stems. However, affected stem areas are not dark brown to black as in late blight infections. Later, the areas infected with white mold turn whitish and break easily. Sclerotia develop in or on the stems.

Late Blight Lookalikes on Leaves and Stems *(continued)*

White mold on leaves (see page 66)

163 | Leaf infections usually start in spots where infected blossoms fell.

164 | A white, dense fungal growth on dead leaves. The late blight fungus does not survive in dead tissue.

Rhizoctonia on stems (see page 37)

165 | White fungal mycelium just above the soil line. The tissue beneath the mycelium is not damaged and the mycelium can be easily rubbed off. The stem colour of the affected area is not dark brown to black as in late blight infections.

Late Blight Lookalikes on Leaves and Stems *(continued)*

Blackleg on stems (see page 87)

166 | Black lesions starting from the infected seed tuber. Infected stems usually have a strong fishy smell caused by secondary bacteria that invade infected tissues. No white fungal growth is present as in late blight lesions.

Alternaria brown spot on stems (see page 60)

169 | Brown, sunken lesions on stem. The distribution of the lesions is spotty. The Alternaria brown spot fungus has been isolated from these lesions.

Aerial stem rot or stalk rot (see page 91)

167 | Aerial stem rot starts as a clear, soft rot on wounded stems or petioles. No white mycelium present.

Black dot on stems (see page 70)

168 | Initial symptoms could appear as brown lesions that usually develop at the base of the stem. Later, the lesions turn white and tiny, black sclerotia are formed on the lesions.

Late Blight Lookalikes on Leaves and Stems *(continued)*

Early blight on leaves and stems (see page 57)

170 | On leaves, irregular, dark-brown lesions with concentric rings. Usually, the lesions are surrounded by yellowish areas. Brown flecks develop on stems.

Grey mold on leaves (see page 68)

171 | Dark lesions with concentric rings develop on leaflets.

172 | Botrytis grey mold lesion. Masses of grey spore-bearing structures are produced on lesions in wet conditions.

Late Blight Lookalikes on Leaves and Stems *(continued)*

Water damage on lower leaves

173 | The tips of leaflets look water-soaked and are surrounded by a yellowish halo. No mycelium develops as in late blight lesions.

Hot soil damage on lower leaves
(see page 123)

174 | The tips of leaflets touching the ground become brown. The affected tissue is surrounded by a yellowish discolouration. This injury is common in sandy soils when the season is warm and dry.

Fertilizer damage (see page 140)

175 | Granules of nitrogen fertilizers burn plant tissues, particularly when the relative humidity is high.

176 | Affected areas turn grey, then black.

Late Blight Lookalikes on Leaves and Stems *(continued)*

Air pollutants (see page 115)

177 | Air pollutants cause dark lesions on leaves that resemble late blight, but no yellowish halo surrounds the lesions. No white fungal growth develops in wet weather as in late blight lesions.

178 | Acid rain lesion.

Tipburn (see page 124)

179 | The tips of leaflets turn brown.

Heat stress (see page 124)

180 | Brown areas on leaflets develop when hot weather prevails for several days.

Late Blight Lookalikes on Leaves and Stems *(continued)*

Lightning damage (see page 127)

181 | Plants look dead or wilted. The stem base has a blanched appearance.

Hydraulic liquid damage

182 | Hydraulic liquid dropped from tractors kills leaves and stems, which turn black.

Frost damage (see page 125)

183 | Leaves turn black, wilt and eventually die.

Late Blight Lookalikes on Tubers

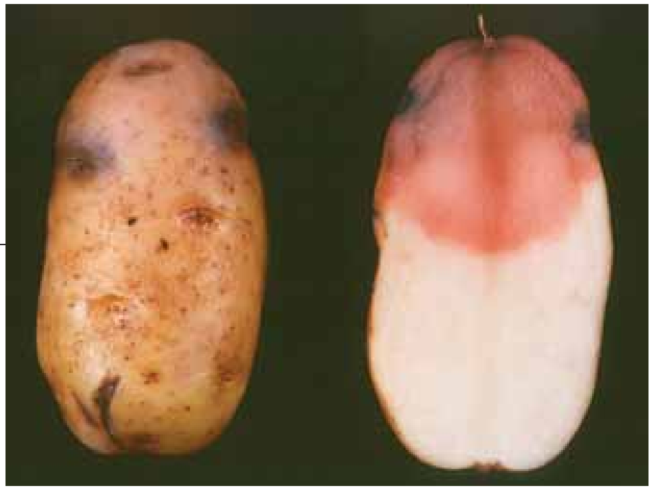
Pink Eye (see page 97)

184 | Pink patches develop around the bud end and eyes. The pink discolouration is usually skin-deep.

185 | If humidity is high, soft rot bacteria may invade affected areas.

Pink Rot (see page 75)

186 | Infected areas appear dark brown to purplish black. The margin of the decay is often limited by a dark line. Infected skin is easily rubbed off.



187 | The internal rot usually begins at the stem end and is cream to light brown. The rot has a texture similar to that of a boiled potato. When infected tubers are cut, the flesh turns pink in about 20 minutes and with time turns black.

Early Blight (*Alternaria solani*)

Pathogen. The early blight fungus is found in most soils where potatoes are grown, and the disease develops every season. The fungus overwinters in the soil on dead leaves, vines or infected tubers.

Disease development. In the spring, the fungus produces spores on the infected crop residue. Spores are spread to healthy plants by wind and rain. Usually, older leaves close to the ground are infected first. Early blight is more severe as the potato crop ages or if the crop has been stressed by poor nutrition, drought, hail, insect damage or other stress. Plants infected with *Verticillium* or expressing common mosaic symptoms are particularly susceptible to early blight.

If early blight is severe, lesions may also be found on stems and tubers. Tuber infection occurs at harvest primarily through cuts, bruises or wounds. The variety Nordonna is susceptible to tuber infection.

188 | Circular to angular dark-brown spots with concentric rings that resemble a target board occur on the leaves. Dead tissue usually collapses, leaving a hole.

189 | Early blight lesions are usually limited by large leaf veins and surrounded by a yellowish area.

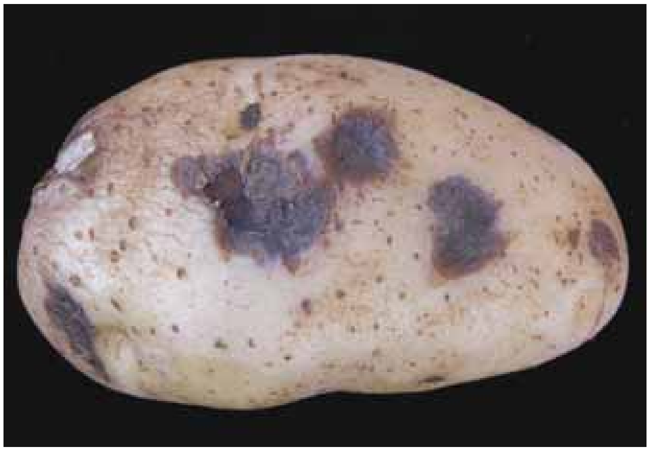
190 | Early blight lesions are not limited by small leaf veins.

191 | In severe infections, the foliage is completely covered by lesions and turns yellow.

192 | The leaf margins curl up if infection is severe.

193 | Fleck-like stem lesions may develop if foliar infection is severe.

194 | Seed ball infected with early blight.



195 | External tuber lesions are dark brown to black, slightly sunken, and round to irregular in shape. The lesions are often surrounded by a raised, violet-blue border.

196 | The internal decayed tissue is usually dark brown, dry and corky. If the infection is shallow, the rotten tissue can be easily removed. Tuber symptoms appear in storage.

Early Blight Lookalikes

- **Botrytis grey mold on leaves** (see page 68).
- **Alternaria brown spot on leaves** (see page 60).
- **Late blight on leaves and on tubers** (see pages 43 and 47).

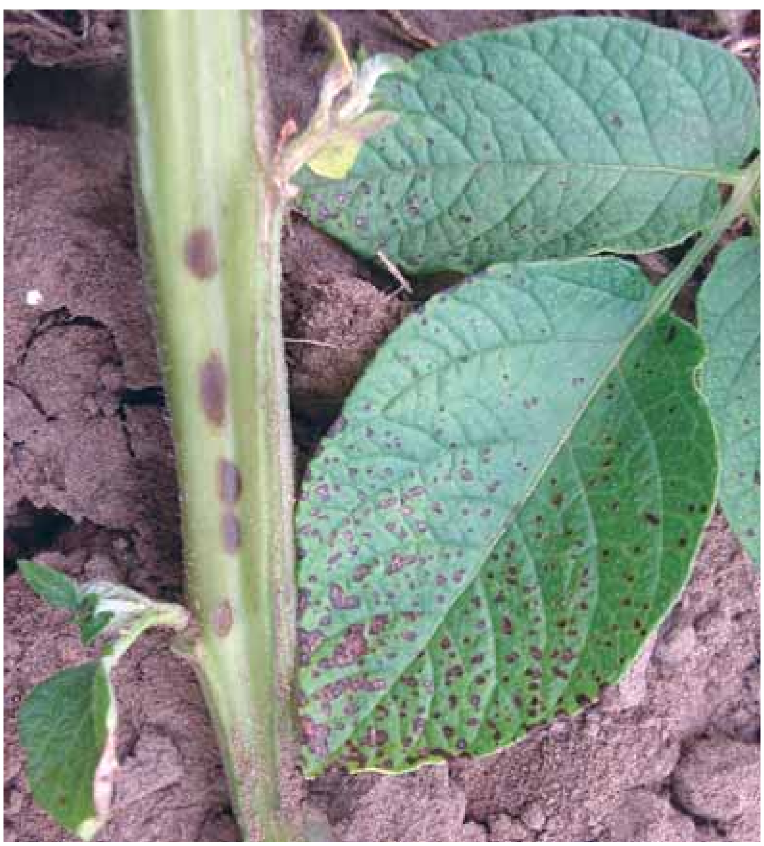
Alternaria Brown Spot (*Alternaria alternata*)

Pathogen. The fungus persists in plant refuse in the soil, on weeds and on other susceptible hosts.

Disease development. Infection occurs when wind-blown spores germinate on the foliage. Temperatures above 18°C favour disease development.

197 | Initial symptoms of brown spot are tiny brown circles or "pepper spots" on leaves.

198 | Older lesions of brown spot are round with concentric rings that are not as noticeable as the rings of early blight lesions. Brown spot lesions may coalesce to form larger necrotic areas with dark-brown margins. These necrotic areas usually form near the edges of leaflets.



199 | Brown spot lesions develop on stems when disease pressure is very high.

200 | Stem lesions.

Alternaria Brown Spot Lookalikes

- **Early blight** (see page 57).
- **Air pollution damage** (see page 115).

Fusarium Wilt, Fusarium Stem End Rot (*Fusarium* spp.)

- **Pathogens.** Several species of *Fusarium* cause this disease. These fungi are seed- and soil-borne.

- **Disease development.** Fusarium wilt usually occurs from mid- to late-season and is most common when hot, dry growing conditions place potato plants under stress. Infection is favoured by soil temperature above 20°C. The fungi penetrate roots through wounds and plug the vascular tissue.

- **Symptoms.** Wilting of plants is the most noticeable symptom. Lower leaves turn yellow and eventually dry up and hang on the plant. The disease progresses upward, stems fail to elongate and the plants die prematurely.

The wilting caused by *Fusarium* may be confused with Verticillium wilt. A laboratory test is usually needed to identify the pathogen causing the wilt.

Tuber symptoms may vary with the *Fusarium* species and the potato cultivar. In severe infections, tubers become sunken at the stem end with a brown, dry rot extending into the tuber. The lesions dry up if tubers are kept under low humidity.

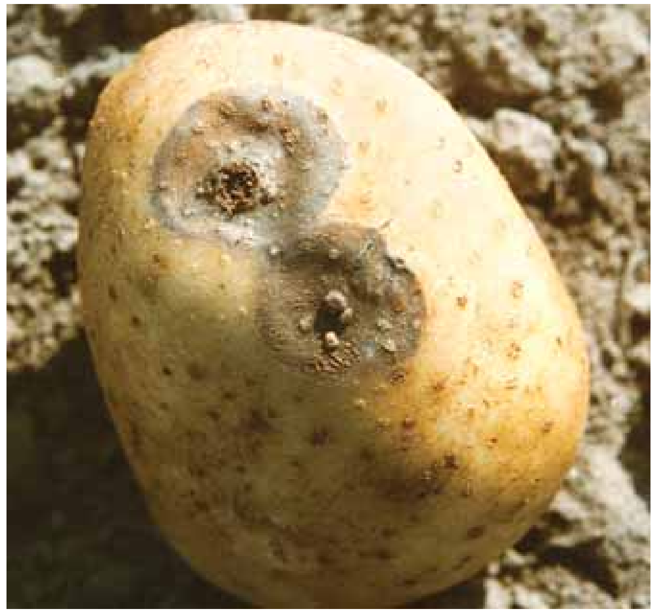
Yukon Gold seems to be very susceptible to Fusarium stem end rot.

201 | Initially, lower leaves wilt. Later, the disease moves up the stems and the plants wilt during the day but revive at night. Interveinal areas of leaflets turn yellow and brown.

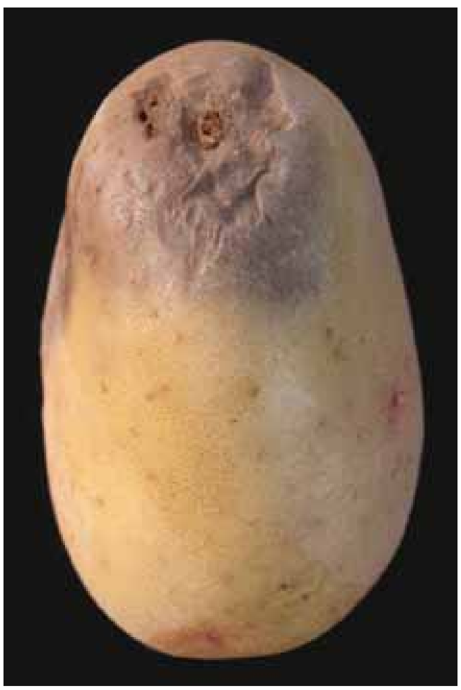
202 | Infected stem showing vascular discolouration.

203 | Vascular ring discolouration in tubers. The discolouration is more extensive than the symptom caused by Verticillium wilt.

204 | Greyish brown, sunken lesion at the stem end.



205 | More than one lesion may develop in the same tuber.



206 | This Fusarium stem end rot looks very similar to dry rot.

207 | Internal infected tissue is granular, dark brown and odourless.

208 | Older, dry lesions.

Fusarium Wilt Lookalikes

- **Verticillium wilt on tubers and on foliage** (see below).

Verticillium Wilt (*Verticillium dahliae*)

Pathogen. This fungus persists in the soil for many years as tiny propagules called microsclerotia. Short crop rotations, especially in sandy soils with susceptible varieties, tend to increase the population of *Verticillium* to damaging levels. The fungus infects many other crops and weed species. High soil temperatures (22–27°C) favour the growth of this fungus.

Disease development. Microsclerotia of *Verticillium* germinate, and the fungus penetrates the plants through the roots. Once inside the plant, the fungus plugs the vascular tissue.

Symptoms. The first symptoms usually appear in early August in the lower portions of the plant. The area between leaf veins begins to yellow. Later, the symptoms move upward to the younger leaves. Leaf yellowing is followed by browning and necrosis. In early stages of the disease, not all the stems from the same plant show symptoms. Infected plants wilt during the day but recover at night. The crop senesces early, 3–4 weeks before reaching maturity. As a consequence, tubers do not size and serious yield losses occur. The disease is favoured by crop stress induced mainly by heat, drought, nutrient deficiencies and insect damage.

The premature vine death and declining yields caused by *Verticillium* are called "potato early dying syndrome." The root lesion nematode has been associated with this syndrome because it enhances the incidence and severity of Verticillium wilt.

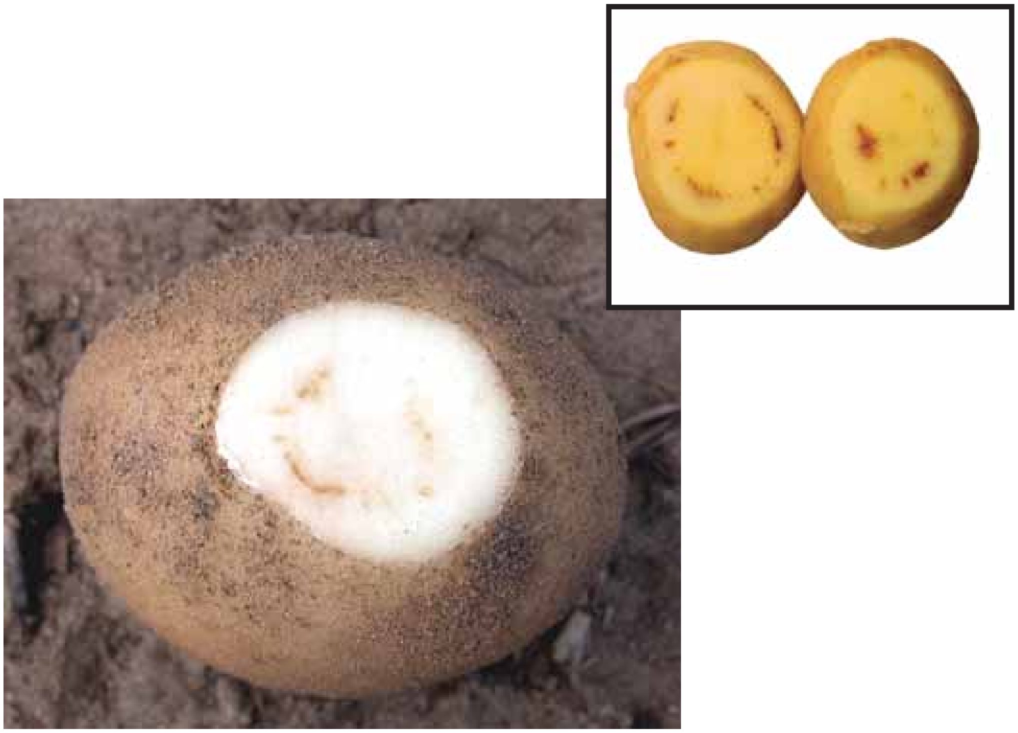
209 | Lower leaves are affected first. Initially one side of the leaves turns yellow and wilts.

210 | As the disease progresses, younger leaves also turn yellow.

211 | Infected plant.

212 | Infected and dead plants stand up higher than the other plants in the field, a condition called flagging.

213 | Brown discolouration of the vascular area or "woody tissue" of the stem. This symptom is seen easily if the stem is cut close to ground level with a long, slanting cut.



214 (215 inset) | Light-brown vascular discolouration starts at the stem end of the tuber. The discolouration does not usually extend more than halfway through the tuber.

216 | Early dying of an area of a Superior field heavily infested with *Verticillium* and the root lesion nematode.

Verticillium Wilt Lookalikes

- **Fusarium wilt and black dot on foliage** (see pages 61 and 70).
- **Fusarium wilt on tubers** (see page 61).

White Mold (*Sclerotinia sclerotiorum*)

Pathogen. The white mold fungus persists in the soil as sclerotia. Sclerotia are black, hard, irregular structures that may survive in soil for at least 3 years. They range in size from 1 mm to over 1 cm in diameter.

The fungus attacks many other vegetables, legume crops and weeds.

Disease development. Sclerotia near the soil surface germinate to form structures called apothecia that release spores.

Occasionally, sclerotia near the soil surface germinate by producing mycelium that penetrates the stems at ground level. Low to moderate temperatures and high relative humidity favour the development of white mold.

Disease incidence is higher if potatoes are planted after susceptible hosts such as beans or soybeans.

217 | Apothecia are funnel-shaped fruiting bodies that eject spores called ascospores. Ascospores infect plants if they land and germinate on potato leaves, stems or blossoms.

218 | Apothecia in a potato field. Usually, sclerotia germinate, producing apothecia when the rows close and soil moisture remains high for several days.

219 | The fungus produces a dense white mycelium on the stem surface. Lesions may girdle the stems, causing the leaves to wilt above the infected area.

220 | Infected stems appear bleached. Severely affected stems become hollow and break easily.

221 | Sclerotia are produced either inside or on infected stems.

222 | Leaf infection usually starts in spots where infected blossoms fell or at the base of the leaflets. Young lesions have a water-soaked appearance and are pale green and of irregular shape.

223 | A dense, white fungal growth on dead leaves.

224 | Sclerotia form on the surface of infected tubers.

White Mold Lookalike

- **Late blight on leaves and on stems**
  (see pages 43 and 45).

Grey Mold, Botrytis Vine Rot (*Botrytis cinerea*)

Pathogen. The grey mold fungus persists on dead or dying plant material in the soil.

Disease development. Cool, humid conditions and dense crop canopies favour infection. The fungus penetrates leaves through wounds or diseased tissues. It can infect damaged tubers at harvest, during transit or when grading.

225 | Plants showing typical grey mold symptoms.

226 | Dark-brown lesions with concentric rings usually develop on the tips or margins of leaflets.

227 | On leaves, symptoms usually develop on the tips of leaflets, where salty water drops are exuded by the leaflets and injure the tips.

228 | Infected leaf margins.

229 | Grey mold lesions can be confused with early blight. The distinctive feature is that the grey mold fungus produces a dense, grey fungal growth on the lesions.

230 | Grey mold lesions resemble those of late blight, but can be distinguished by the dense, dark mycelium and spores produced in humid weather.

231 | A grey mold lesion that resembles late blight infection.

232 | Dense, fuzzy, greyish-brown fungal growth and spores are produced on the stems when the weather is wet. Affected stems become hollow.

233 | The skin of infected areas is wrinkled. Under the skin, tissues are soft and wet, but with time will darken and develop into a dry rot.

Grey Mold Lookalikes

- **Late blight and early blight on leaves** (see pages 43 and 57).
- **Late blight on stems** (see page 45).

Black Dot (*Colletotrichum coccodes*)

Pathogen. The black dot fungus persists as tiny sclerotia on the surface of tubers or in plant debris in the soil.

Disease development. The black dot fungus needs a wound to infect potato plants. If the fungus enters underground stems, it moves upward. If infections start in injured leaves or in stems, the disease progresses downward into the stems and into the roots.

The disease is associated with sandy soils, low nitrogen, high temperatures and poor soil drainage.

234 | Yellowing and wilting of top leaves.

Symptoms. The top leaves in the canopy turn yellow and wilt in mid- to late summer. The symptoms progress down the stem to the middle and lower leaves. Wilt caused by black dot may be confused with Verticillium wilt. Black dot reduces yield by killing stems before the tubers size.

235 | Initial symptoms of black dot on stems could appear as dark-brown lesions that can be confused with late blight. Lesions often develop at the base of the stems.

236 | Older lesions have a bleached appearance.

237 | Tiny sclerotia are produced on the stem surface.

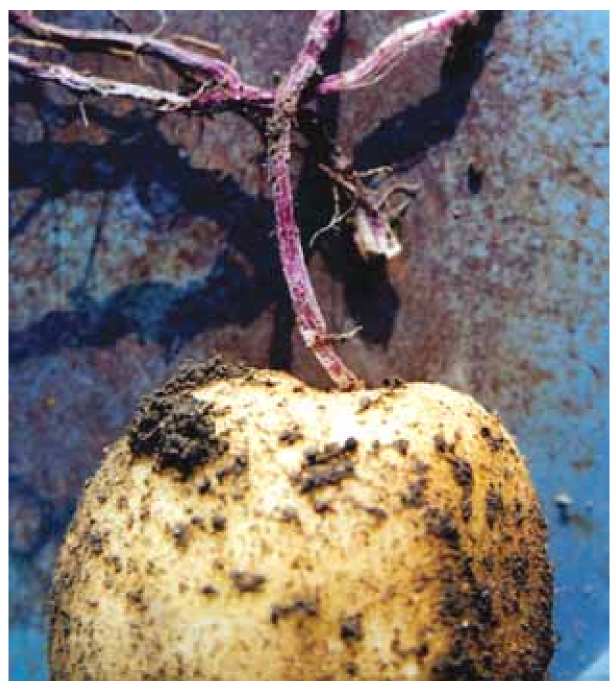
238 | As stems become dry, the internal tissue flakes away easily. The interior of the vascular ring turns purple.

239 | Sclerotia formed inside an old stem.

240 | Close-up of sclerotia produced inside a stem.

241 | Stems completely covered with sclerotia turn black.

242 | Infected roots may appear purplish.



243 | Infected stolons are purplish and may remain attached to the tubers.

244 | Black dot produces brown lesions on the skin. The lesions are usually sunken.

245 | Sclerotia are produced within the discoloured areas of the tubers.

Silver Scurf (*Helminthosporium solani*)

Pathogen. The silver scurf fungus overwinters mainly on infected seed tubers. It can also survive for at least one year on decaying organic matter in the soil, indicating that soil may be a source of inoculum.

On infected tubers, the fungus produces spores only at the edges of the lesions. Thus, seed tubers with the surface completely covered by silver scurf do not spread the disease because the fungus cannot produce spores.

Disease development. Spores produced on seed tubers wash onto new tubers. Infection takes place through lenticels and directly through the skin. The infection remains confined to the skin tissue, causing it to loosen. Air trapped under the loosened skin reflects light, resulting in the silvery sheen typical of infected potatoes.

Silver scurf lesions may be difficult to detect at harvest, particularly if the tubers are not washed. Disease incidence increases when potatoes are left in the ground after maturity and are harvested late. High humidity in the fall also increases silver scurf damage.

In storage, the tubers lose water through the lesions, so some shriveling and wrinkling may occur.

Spores produced on infected tubers spread the disease in storage. High humidity is essential for the spread of silver scurf in storage.

Primary infections or tuber infections initiated in the field usually develop at the stem end of the tuber. By contrast, secondary infections or tuber infections that develop in storage may cover a major portion of the tuber and start as dark-brown to black, circular lesions on several areas of the tuber.

246 | Small or large circular or irregular spots of silvery appearance. The silvery appearance is more noticeable when the tubers are wet.

247 | Silver scurf lesion at the stem end of the tuber.

248 | Silver scurf lesions on a red variety.

249 | Lesions that develop in storage are circular and dark brown to black. They increase in size and coalesce, rendering the tubers unmarketable.

250 | Occasionally, silver scurf (left) and black dot (right) develop on the same tuber.

251 | Close-up view of silver scurf and black dot lesions.

Silver Scurf Lookalike

- **Black dot** (see page 70).

Pink Rot (*Phytophthora erythroseptica*)

Pathogen. The pink rot fungus is soil-borne and is found in most agricultural soils.

Disease development. Infection usually occurs before or at harvest. The disease is associated with excessive soil moisture, low spots in the field, over-irrigated areas and poorly drained soils.

The fungus penetrates the tubers mainly through stolons, but infection through lenticels and eyes can occur. The fungus may also infect tubers through wounds made during harvest and handling.

Pink rot may spread slowly in storage.

Russet Norkotah, Goldrush, Snowden and Kennebec are very susceptible to pink rot.

252 | Infected areas of the tuber surface are purplish-black. The margin of the decay may be limited by a dark line.

253 | Pink rot infection started at the eye.

254 | In an advanced stage, the external symptoms of pink rot can be easily confused with late blight.

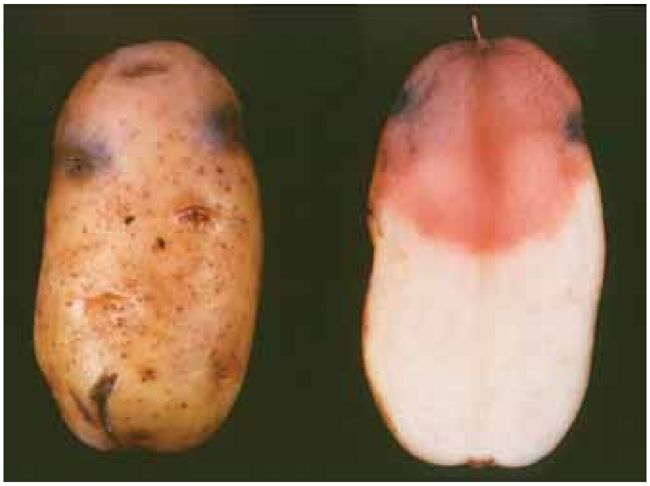
255 | Initially, the affected tissue is cream to light brown and has a rubbery consistency. When exposed to the air, the rot turns salmon-pink in about 20 minutes.

256 | Infected skin is easily rubbed off.

257 | Pink rot infection progressing with a nearly straight line.

258 | External symptoms (right) and internal salmon colour (left) after 35 minutes of exposure to air.

259 | With time, the colour changes from salmon pink to blackish.

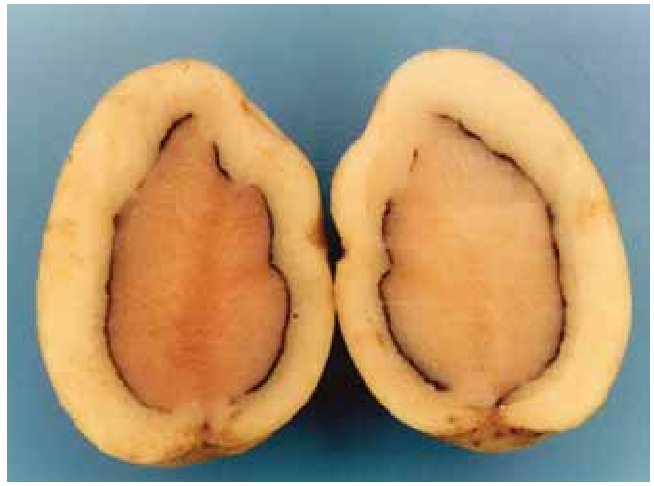


260 | Internal rot beginning at the stem end and then progressing through the tuber with a nearly straight line between healthy and diseased tissue.

261 | Tuber showing infection that started at the eye. The texture of infected tuber tissue is similar to that of a boiled potato. Rotted tissues retain some structure and firmness and give off an ammonia smell.

262 | Stored potatoes severely infected with pink rot.

263 | Cream-coloured flesh surrounded by a brownish border.



264 | The flesh turns salmon-pink after exposure to air.

265 | A black colour developed overnight.

Pink Rot Lookalikes

- **Pythium leak** (see page 79).
- **Late blight on tubers** (see page 47).

Leak (*Pythium ultimum* var. *ultimum*)

Pathogen. The leak fungus is widely distributed in soils. It also attacks the underground parts of many other crops.

Disease development. The fungus cannot penetrate tubers directly, but enters through bruises and wounds, which usually occur at harvest. Harvesting the crop in hot weather or exposing the tubers to heat for several hours after harvest creates ideal conditions for leak.

Leak development is very rapid, and can cause serious losses in storage, in transit and on the market. When infected potatoes are stored, juice from rotten tubers drips down through the pile.

Pythium may be responsible for the decay of seed tubers if conditions are warm and wet immediately after planting.

Pythium leak rot has a sweet smell.

266 | Grey to brownish lesions with a water-soaked appearance occur around wounds.

267 | Infected tissue is cream-coloured. On exposure to air, the cream rot turns brown. A dark line is present at the margin of the rot.

268 | Grey colour of leak rot.

269 | With time, the rot turns inky black. A clear, brownish liquid is readily released by the rotted tissue when the tuber is pressed.

270 | Often, the entire inside of the tuber rots, leaving a thin outer shell. This is known as "shell rot."

Pythium Leak Lookalike

- **Pink rot** (see page 75).

Powdery Scab (*Spongospora subterranea*)

Pathogen. The powdery scab fungus may survive many years in the soil as resting spores. It attacks roots, stolons, young shoots and tubers. The fungus is spread by planting infected seed tubers, by moving infested soil or by spreading contaminated cattle manure.

Disease development. Powdery scab is most common in cool, wet soils. During warm, dry weather, the disease can develop in low-lying or shaded areas of fields heavily infested with spores.

Potato roots stimulate resting spores to germinate. Resting spores release swimming spores that infect roots, root hairs, stolons, young shoots or tubers. Galls are formed in the infected tissue. A fungal mass grows inside infected tissues, then releases secondary swimming spores that spread the disease even more. Under favourable conditions, several generations of secondary spores will be produced and released.

The fungus penetrates the tubers through lenticels or wounds. Galls may be observed less than 3 weeks after infection. In infected tubers, the fungus produces resting spores.

Spores of powdery scab are the vectors of the mop top virus (see page 106).

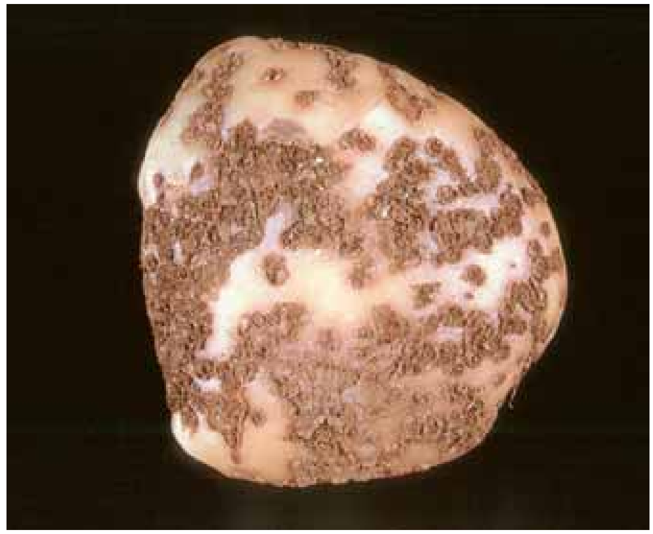
271 | Initial symptoms on tubers are purplish-brown, sunken lesions.

272 | Later, brown, raised pustules develop. They are filled with spores of the powdery scab fungus.

273 | Pustules enlarge to about 5 mm in diameter.

274 | As they mature, pustules release the spores.

275 | Ruptured pustules.



276 | Powdery scab lesions look very similar to common scab (see page 94).

277 | On roots and stolons, small necrotic spots develop into white galls 1–10 mm in diameter.

278 | Galls become dark brown when mature, then gradually break down, releasing powdery masses of spores into the soil.

Powdery Scab Look-Alike

- **Common scab** (see page 94).

Phoma Rot, Pocket Rot (*Phoma exigua* var. *exigua*)

Pathogen. The fungus persists either in the soil or on infected seed tubers.

Disease development. Infection takes place through wounds or bruises at harvest or when grading. The rot develops in storage. Disease incidence is higher when the soils are wet and cool at harvest.

279 | External lesions are circular, slightly sunken, greyish-brown and the size of a thumb print. Underneath the lesions, the tissue is black, shrunken and decayed.

280 | Severe *Phoma* infection. Often cracks form on the surface of the lesions.

281 | The black, rotten tissue can be easily scooped out from the surrounding healthy tissue.

Skin Spot (*Polyscytalum pustulans*)

Pathogen. The fungus persists mainly in infected potato tubers.

Disease development. Skin spot is favoured by low temperatures and high humidity. During the season, spores produced on infected seed tubers infect below-ground plant parts. The fungus infects the daughter tubers through lenticels, eyes and wounds.

Symptoms. The symptoms on tubers are easier to see after the potatoes have been in storage for a few weeks. Skin spot can spread in storage.

282 | Pimple-like spots develop on the tuber surface. The spots may be up to 2 mm in diameter and are either distributed at random over the tuber surface or concentrated around the eyes or stem end.

283 | The pimple-like spots are darker than the healthy areas. When wet, they appear purplish-black. The lesions may grow together to form larger diseased areas.

Section 4

Bacterial Diseases

Bacterial Ring Rot (*Clavibacter michiganensis* subsp. *sepedonicus*)

Pathogen. The ring rot bacterium is extremely infectious. It overwinters mainly in seed tubers, but can survive for up to 2 years as dried slime on cutting knives, storage bins, planting and harvesting equipment, burlap bags, paper and plastic. The bacterium is not killed by freezing.

Disease development. Ring rot spreads primarily from infected seed pieces to healthy tubers during seed cutting and planting. Contaminated seed-cutter knives and pick planters are excellent disseminators of bacterial ring rot because fresh wounds provide a means of entry for the bacteria into the tuber. Ring rot may be spread in the field by direct contact between diseased and healthy plants. The bacteria may also be carried by farm equipment or by insects such as the Colorado potato beetle (see page 3), the potato flea beetle (see page 10) or the green peach aphid (see page 17).

Symptoms. One of the characteristics of this disease is that the expression of foliar symptoms and the type of symptoms expressed vary depending on the variety. In addition, infected plants may not show symptoms if the weather is cool and wet. Thus, all potato cultivars are potential symptomless carriers and may spread the disease extensively as latent infections. Latent infections in tubers may be secondarily infected by Erwinia soft rot.

In hot, dry seasons, ring rot develops rapidly. The first symptoms in the field usually appear on the lower leaves about mid-season.

Zero tolerance control measures are in place against this disease. The seed potato regulations in Canada indicate that upon finding bacterial ring rot, all lots under cultivation by the grower are rejected for certification.

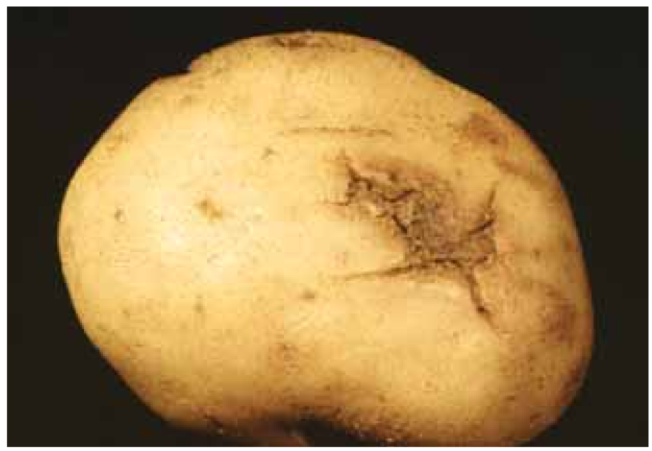
284 | The yellowing of interveinal areas and curling and browning of leaf edges are distinct symptoms of ring rot. Eventually, necrosis kills the leaflets.

285 | Interveinal yellowing on lower and upper leaves.

287 | Russet Burbank may develop the dwarf rosette symptom early in the season.

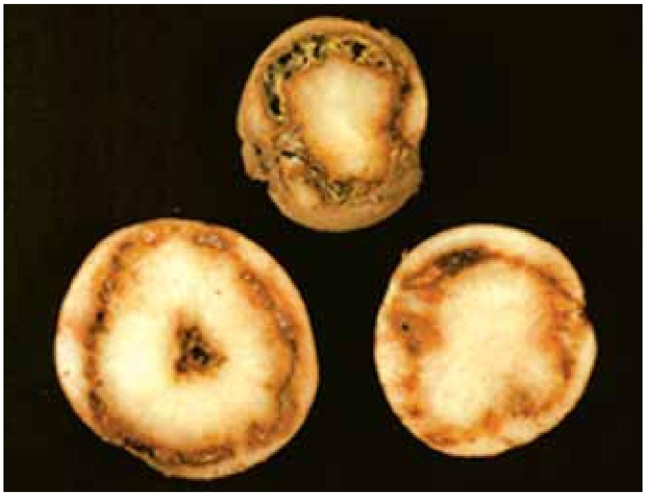
289 | Severe tuber cracking caused by ring rot.

286 | Lower leaves usually wilt first. Interveinal areas turn yellowish.



288 | Infected tubers usually develop star-shaped cracks in the skin.

290 | A creamy, yellow-brown, cheesy, odourless rot develops in the vascular ring.



291 | Corky tissue surrounds hollows in the vascular ring. When secondary bacteria enter, a foul-smelling rot may occur, and infected tubers may be completely destroyed.

292 | Typical ring rot symptoms on tubers.

Blackleg, Aerial Stem Rot and Tuber Soft Rot

These diseases, caused by *Erwinia* spp. bacteria, are closely related. They are found wherever potatoes are grown.

Blackleg (*Erwinia carotovora* subsp. *atroseptica*)

Pathogen. The blackleg bacterium is primarily seed-borne. Contaminated handling equipment such as seed cutters and picker planters contribute to the spread of the bacterium to healthy seed tubers. Wind-blown rain may be a source of inoculum.

Disease development. If the spring is wet and cool, infected seed and sprouts usually rot before or early after emergence, resulting in uneven stands. If spring weather favours rapid emergence, infected seed will produce weak plants with stems showing an inky black decay extending up from the infected seed piece.

During the season, bacteria from decaying seed pieces and stems are spread by water in the soil and contaminate new tubers. Wind-blown rain spreads the bacteria to healthy plants.

The disease can spread in storage, particularly after wet harvests. Some varieties, such as Monona and Chieftain, are very susceptible to blackleg.

Symptoms. Blackleg symptoms may develop at any time during the season. New tubers infected from the mother plant have lesions that start at the stem end.

293 | Stem end lesions are sunken, circular and black.

294 | Soft rot develops in the pith, extending into the tuber from the stem end.

295 | The infected flesh first appears cream-coloured.

296 | With time, the rot turns darker. In an advanced stage, the infected tissue turns greyish-black and mushy.

297 | Infected plants are stunted and look stiff and erect, especially early in the season. The foliage becomes chlorotic, and leaflets tend to roll upward at the margins.

298 | Older plant with leaves rolled upward due to blackleg infection.

299 | Stems show an inky-black decay that starts from the seed. The decay extends a variable distance up the stem, anywhere from a few centimetres to the top of the stem.

300 | Infected plant with the rot extending from the seed piece up the stem. Often, infected tissue is invaded by secondary bacteria that produce a fishy odour.

301 | Severe blackleg has caused the stem to break. In wet weather, the decay is soft and slimy. Under dry conditions, infected tissues may become dry and shriveled.

302 | Older plant wilted and dying as a result of blackleg.

Blackleg Lookalikes

- **Late blight on stems** (see page 45).
- **Ring rot in tubers** (see page 85).

303 | Blackleg (left) and ring rot (right).

Aerial Stem Rot, Aerial Blackleg (*Erwinia carotovora* subsp. *carotovora*)

Pathogen. The aerial stem rot bacterium is soil-borne. Contaminated surface water is an important source of infection.

Disease development. Incidence of this disease is high in wet seasons. Stems, petioles and leaves become infected through natural openings, such as leaf scars or wounds, caused by hail, wind-blown sand or farm equipment. The infection extends up and down the stem from the point of infection. Infection can spread through the stems and stolons to daughter tubers, causing symptoms similar to blackleg. These infected daughter tubers begin to rot either in the field or later during storage.

304 | Initial lesions on stems first appear as a clear rot.

305 | Eventually, the rotten tissue acquires the typical blackleg colour.

306 | Aerial rot may spread to most of the plant.

307 | Infection has moved down the stem and probably into daughter tubers.

Tuber Soft Rot (*Erwinia carotovora* subsp. *carotovora*)

Pathogen. The soft rot bacterium is common in all agricultural soils and in surface water.

Disease development. The bacterium invades tubers mainly through wounds and enlarged lenticels. Excessively wet soils favour soft rot development in the field. Tubers infected with other diseases, such as late blight and dry rot, are often invaded by the soft rot bacterium. Also, potatoes dug, hauled, graded, washed and bagged while hot are much more likely to become infected than potatoes handled at cooler temperatures. Wet conditions in storage allow soft rot to spread from one tuber to another.

Erwinia soft rot is odourless, but the presence of secondary bacteria causes it to turn slimy and take on a foul smell.

308 | The rotted tissues are wet, cream to tan, and have a soft, granular consistency. Rotted tissues are sharply delineated from healthy ones by a black border. Infected tissue can be easily washed away.

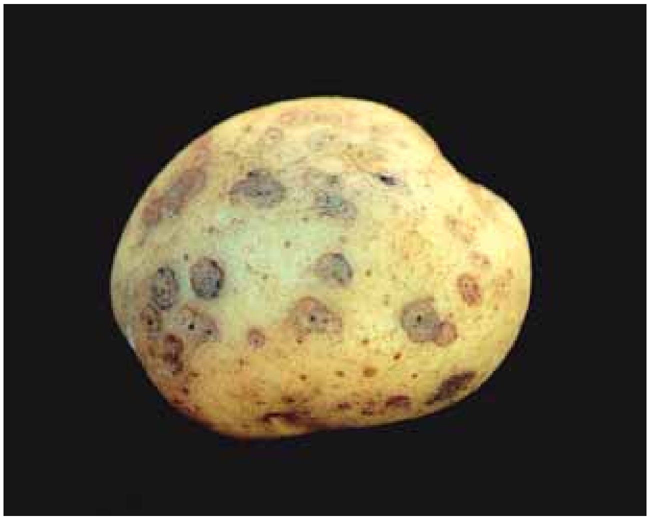
309 | External symptom of bacterial soft rot.

310 | Secondary bacterial infection has destroyed the tubers.

311 | Immature tubers harvested under hot, humid conditions are prone to soft rot.

312 | In hot and humid weather, immature tubers will rot in 24 hours.

313 | Infected lenticels appear as circular, water-soaked areas that are slightly sunken and tan to brown in colour.



314 | Under dry conditions, these lenticel infections may dry up, leaving a sunken spot.

Clostridium Soft Rot (*Clostridium* spp.)

Pathogen. Clostridium bacteria are present in most soils.

Disease development. The bacteria probably infects tubers at harvest. The disease is favoured by the presence of a film of water on the tuber surface, which decreases the oxygen concentration in the internal tissues. Usually, in tubers infected with clostridium soft rot, the decay is caused by more than one bacterial species.

315 | Clostridium rot is slimy and smelly.

Common Scab (*Streptomyces scabies, Streptomyces acidiscabies*)

Pathogen. The scab bacterium is a common soil inhabitant that survives for long periods of time, even in the absence of potatoes. The strains of the bacterium that cause common scab produce a toxin called thaxtomin that enables the bacterium to cause lesions on tubers.

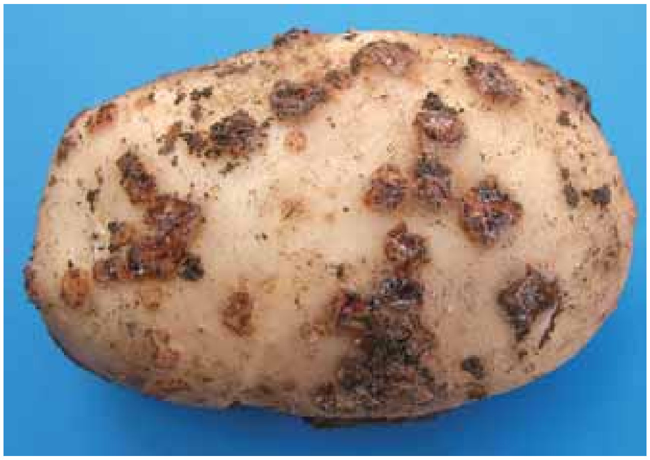
Planting scab-infected seed or spreading contaminated cattle manure will introduce the bacterium to scab-free fields. Tubers that look healthy may carry the bacterium on their skin. A soil pH from 5.5 to 7.5 is favourable for common scab development. The acid-tolerant scab species (*S. acidiscabies*) can infect tubers in soils with pH as low as 5.

Disease development. Most scab infections take place at tuber initiation. The bacterium enters newly forming tubers through immature lenticels. As tubers increase in size, lesions expand and scab severity increases.

Scab lesions are quite variable. The type of lesion—superficial, pitted or erumpent—is probably determined by variety tolerance, aggressiveness of the bacterium strain, time of infection and environmental conditions. The incidence and severity of scab varies from year to year and from field to field. Warm, dry soils favour scab development.

316 | Initial scab lesions. The infection of the skin and underlying superficial tissue is followed by the formation of a corky layer.

317 | Superficial corky lesion (Russet scab).



318 | Severe scab.

319 | If tubers are dug when the soil is wet, a thin, whitish layer of spores may be present on scab lesions.

320 | Severe scab lesions may result in cavities as deep as 1 cm. This is called pitted scab. The tissue around the interior of the pith is corky.

321 | Pitted scab lesions covering most of the tuber.

322 | Raised areas of rough, corky tissue are often called erumpent scab. Lesions are of variable size and shape. The spots may be few and scattered or may cover most of the surface.

323 | Scab incidence is high in dry years.

324 | Net-like scab lesions.

325 | Severe net-like scab lesions.

Scab Lookalike

- **Powdery scab.**

Section 5

Physiological Diseases

Pink Eye

For many years, the cause of pink eye was thought to be a bacterium. However, recent scientific reports suggest that pink eye is a physiological disorder.

Disease development. Pink eye occurs sporadically. Disease incidence has been correlated with warm and wet soils at harvest, lack of crop rotation and Verticillium wilt. Tubers infected with Verticillium seem to be more susceptible to pink eye. The incidence and severity of pink eye may be high in very susceptible varieties such as Kennebec or Superior.

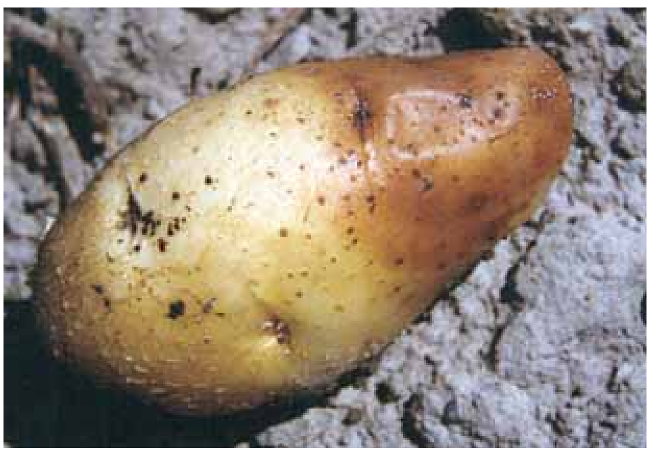
Symptoms. The typical pink discoloured areas on affected tubers are easy to see on moist, freshly dug tubers, but difficult to notice on dry, unwashed potatoes. Diseased tubers usually fluoresce under ultra-violet light.

326 | A puffy and pink discolouration usually occurs around the eyes and at the tuber stem end. Pink eye closely resembles early symptoms of late blight.

327 | Small pink eye lesions.

328 | Eye lesion. Lesions dry up if humidity is low.

329 | Often soft rot develops if humidity is high.



330 | Pink eye lesion at the stem end. A secondary bacterial infection is causing the tuber to rot.

331 | In storage, the affected skin dries out under cool temperatures and low humidity. Underlying tissue appears healthy.

332 | The lesions on this Shepody tuber have dried up in storage.

333 | After 3–4 months in storage, the skin of severely affected tubers often becomes raised and corky, with an appearance like bull hide.

Pink Eye Lookalike

- Late blight on tubers (see page 47).

Toxic Seed Piece Syndrome

Toxic seed piece syndrome (TSPS) develops when the potato plant absorbs the breakdown juices from its rotting seed piece. Often, if an extended dry period is followed by very wet weather, seed pieces undergo a watery breakdown. The breakdown products are toxic to the plant.

334 | The initial symptom on leaves is interveinal yellowing. Later, the leaves roll up and the margins of the leaves die.

335 | Plant showing toxic seed piece syndrome. Plants exhibiting these symptoms almost invariably have a seed piece with a watery breakdown.

336 | Plant dying as a result of TSPS.

337 | Leaves have died as a result of TSPS but the stems are still green.

338 | The breakdown juices of rotten seed pieces are absorbed by the plants.

339 | Field showing toxic seed piece syndrome damage.

Toxic Seed Piece Syndrome Lookalikes

- **Verticillium wilt on foliage** (see page 63).
- **Ring rot on foliage** (see page 85).

Section 6

Viral Diseases

The main potato viruses attacking the crop in Ontario are potato leafroll virus (PLRV), potato virus Y (PVY) and potato virus X (PVX).

Viruses spread easily in crops, such as potatoes, that are vegetatively propagated. To prevent this, there are strict requirements for seed potato production.

Aphids play an important role in transmitting viruses to healthy potato plants. There are two types of aphid transmission: persistent and non-persistent.

- **Persistent transmission.** The aphid must feed on an infected plant for 10–60 minutes to acquire the virus. Once the aphid has absorbed the virus, there is a latent period of at least 12 hours while the virus migrates within the aphid's system. Once the aphid has become infectious, it can continue to transmit the virus for at least a week, but sometimes much longer. PLRV is transmitted in a persistent manner.
- **Non-persistent transmission.** The aphid becomes infectious when it probes or feeds on infected plants. The virus can be carried in the mouth parts and in the gut of the aphid and it can be transmitted immediately to one or only a few healthy plants. The virus is transferred from the mouth parts during feeding. Aphids lose their ability to transmit the viruses very quickly. PVY is transmitted in a non-persistent manner.

Leafroll and Net Necrosis (Potato Leafroll Virus)

The potato leafroll virus (PLRV) is introduced into a potato field either by planting infected seed tubers or by aphid transmission. Several species of aphids can transmit PLRV, but the green peach aphid seems to be the most efficient vector of this virus. Winged aphids spread the virus over long distances.

Infected seed, sprouted cull potatoes and volunteers are the main sources of PLRV. Aphids acquire the virus while feeding on infected plants and transmit the virus to potato plants in a persistent manner.

PLRV is restricted to the phloem vascular tissue. In some varieties, notably Russet Burbank, the virus causes discolouration of the phloem in the tubers, or net necrosis.

Leafroll Symptoms

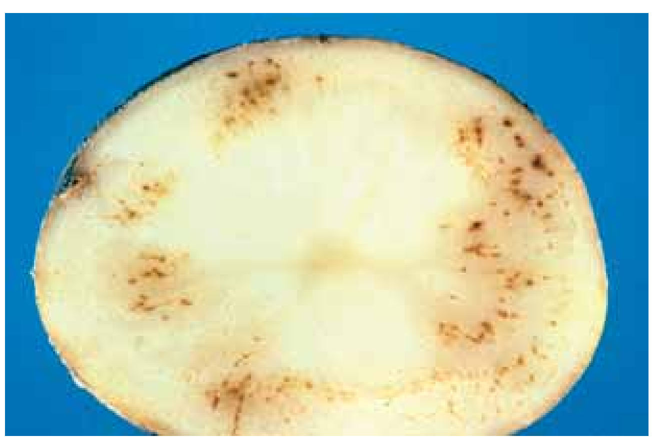
SEED INFECTION Infected seed is the source of infection	**FIELD INFECTION** The virus is transmitted by aphids during the current season
Symptoms are more severe • Plants are stunted, with an upright growth habit. • Lower leaves are rolled up, pale green and leathery. • Eventually lower leaves die and upper leaves turn yellowish.	**Symptoms are milder** EARLY SEASON INFECTION • Plants are stunted. • Upper leaves are rolled up. • Rolled-up leaves may be yellowed or pinkish. LATE SEASON INFECTION • Plants may show little or no foliar symptoms. • The virus can still move down into the tubers.
• Often daughter tubers do not develop net necrosis symptoms.	• Usually, daughter tubers develop net necrosis that renders tubers unmarketable. Net necrosis may not be apparent at harvest, but develops in storage.
• Yield is reduced both in tuber numbers and in tuber size.	• Yield reduction is not significant unless infection occurs very early in the season.

340 | Plant showing seed-borne infection. The rolled lower leaves have a leathery texture.

341 | Current season leafroll symptoms. The top leaves roll upward and may stand upright.

342 | Rolled up young leaves showing a reddish colour (current season leafroll).

343 | Net necrosis symptoms first appear as light- to dark-brown strands of discolouration in the flesh at the stem end of the tuber.



344 | These dead tissue strands can continue to progress the length of the tuber either in the field or after months in storage.

Mosaic Viruses

PVY, PVA and PVX all cause leaf symptoms called mosaic. Symptoms range from slight mottling to severe crinkling of leaves and stunting of plants. Symptoms are usually mild when only a single virus is present. The presence of two or more viruses often induces rugose mosaic. The symptoms of mosaic are easier to see on cloudy days. The decrease in yield and reduction in quality depend on the severity of mosaic. Laboratory tests should be conducted to determine the virus, or mix of viruses, causing the mosaic.

PVY, Potato Common Mosaic (Potato Virus Y)

PVY is the common strain of the PVY complex and is the most important virus infecting potatoes in Ontario. PVY persists in infected seed potatoes, volunteer potato plants and some weed hosts.

Other crops attacked by this virus are tobacco, tomatoes and peppers. Nightshade and groundcherry are the most important weed hosts.

The virus is transmitted by aphids in a non-persistent manner. The green peach aphid is an efficient vector of PVY. Some mechanical transmission of PVY can also occur.

Symptoms. Symptom expression depends on the potato variety and the virus strain.

Shepody is very susceptible to PVY, although the symptoms may disappear in a few days. In Russet Norkotah the symptoms are not noticeable.

345 | Darkening of veins caused by PVY infection. This symptom is called "vein banding."

346 | Yellowish or light green coloured mottling. Mottles are variable in size and are not delineated by leaf veins.

347 | Often, the infected leaves develop necrotic spots. The necrosis is considered to be a plant reaction to the virus infection.

348 | PVY causes leaves to crinkle and curl (right). The leaf on the left is healthy.

349 | Plants are stunted, lower petioles and leaves turn yellow, and dead leaves cling to the stem. This symptom is called "leaf drop." PVY-infected plants usually die early.

350 | PVY reduces yield. Infected plants (left) produce fewer and smaller tubers than healthy plants (right).

PVA, Potato Mosaic (Potato Virus A)

PVA persists in infected seed potatoes, volunteer potato plants and some weed hosts. Several aphid species transmit PVA in a non-persistent manner. The green peach aphid and the potato aphid are considered to be efficient vectors. Some mechanical transmission may also occur.

Symptoms. PVA causes milder symptoms than PVY. The extent of leaf mottling or mosaic depends on the virus strain, the potato variety and weather conditions. Many potato varieties are symptomless even though infected with PVA (latent infections).

PVX, Potato Latent Mosaic (Potato Virus X)

PVX persists in infected seed potatoes or volunteer potato plants. This virus is transmitted mechanically and by plant-to-plant contact.

Symptoms. PVX is usually symptomless, but may cause a mild mosaic symptom. Mixed infection with PVY may or may not cause more severe mosaic symptoms (rugose mosaic). Plants expressing rugose mosaic symptoms are stunted and lack vigour. Yields are reduced drastically.

351 | Mild mosaic caused by PVX (right). The plant on left is healthy.

352 | Severe symptoms caused by the simultaneous infection of PVX and PVY.

353 | Leaflet showing severe puckering of leaf surfaces and leaf mottling (rugose mosaic).

Calico (Alfalfa mosaic virus)

Alfalfa mosaic virus is transmitted by aphids. Aphids acquire the virus from infected alfalfa or clover plants or from infected volunteer potato plants.

354 | Yellow mottling or blotching of leaves. This symptom may be confused with the foliar symptoms of potato mop top (see below). Symptoms usually appear before flowering.

Potato Mop Top (Potato Mop Top Virus)

Potato mop top is a regulated, non-quarantine disease.

Potato mop top is caused by the potato mop top virus (PMTV).

PMTV is transmitted to potatoes by the powdery scab fungus (see page 80). The virus survives inside the resting spores of the fungus, which can remain viable in the soil for as long as 18 years.

Spores germinate in cool, wet soil, releasing swimming spores called zoospores. Zoospores carrying the virus infect healthy plants through the roots, root hairs, stolons or young tubers.

Because zoospores need water to swim and infect potatoes, the incidence of powdery scab and mop top is greatly reduced in warm, dry seasons.

Potato mop top is thought to be a self-curing disease. That is, in the absence of powdery scab, plants may become free of the virus after three generations.

Potato Mop Top Symptoms on Leaves and Stems

Foliar and stem symptoms develop only on plants growing from infected seed. Because infected seed does not transmit the disease to all of the plant stems, only the leaves from infected stems will show potato mop top symptoms. The systemic infection of the virus is erratic: infected stems may have some healthy leaves, or infected leaves may have some healthy leaflets.

Foliar symptoms are highly variable and may appear as yellow blotches (aucuba pattern), V-shaped yellow chevrons, "thistle leaf" patterns around the veins, deformed leaves, wavy or rolled margins, and bunching of foliage.

Infected stems are shortened at the internodes, resulting in stunted plants with bunched foliage.

The overall effect is a dwarfed and bunched growth habit. **The name mop top refers to this growth habit**.

355 | Leaves showing V-shaped yellowish chevrons.

356 | Stunting of plants and bunching of foliage caused by potato mop top.

357 | Bunching of growing point.

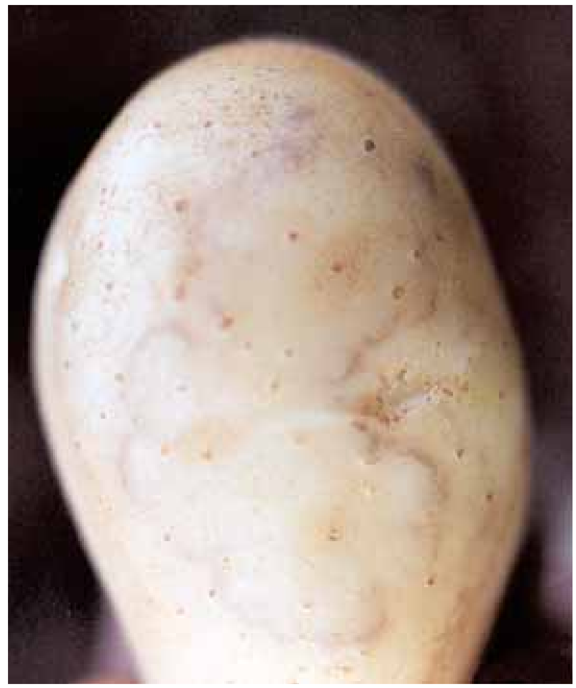
Potato Mop Top Symptoms in Tubers

Seed tubers infected with PMTV transmit the disease to roughly half of their daughter tubers. The other half remains healthy. Not all daughter tubers infected in the field show symptoms at harvest. Infected tubers that appear healthy at harvest develop symptoms in storage.

Rust-brown, necrotic arcs or rings and flecks form in the flesh of infected tubers that show symptoms. There may be single or multiple concentric arcs. These symptoms are called "spraing." On very susceptible varieties, raised concentric rings of 1–5 cm in diameter develop on the tuber surface.

Laboratory and greenhouse tests are required for correct identification of the potato mop top virus.

358 | Spraing symptoms in tubers.



359 | Potato mop top external symptom on a very susceptible variety.

360 | Internal symptom of potato mop top.

Potato Mop Top Lookalike

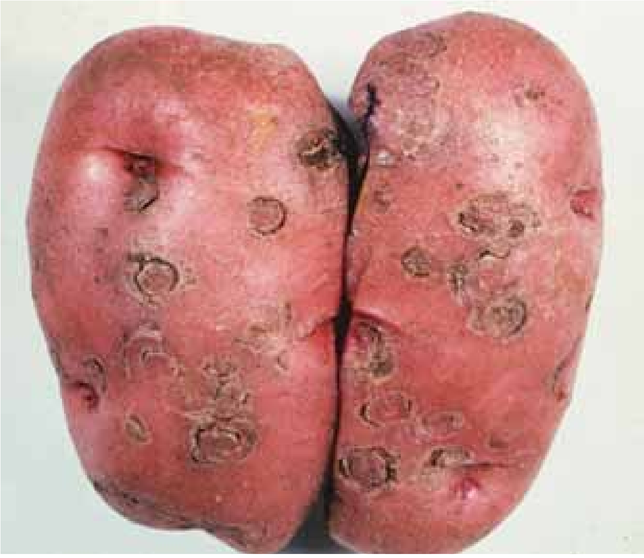
Corky Ring Spot

Potato mop top symptoms may be confused with other viral diseases, particularly corky ring spot, which is caused by the tobacco rattle virus. The virus is transmitted by stubby-root nematodes.

Corky ring spot has not been found in Ontario.

Corky ring spot symptoms vary with the potato variety and the virus isolate.

361 | Internal tuber necrosis caused by corky ring spot.



362 | Necrotic rings on the surface of tubers.

363 | Necrotic rings and arcs on a tuber.

364 | Early season infection may result in growth cracks and other tuber malformations.

365 | Dwarfing, mottling and deformation of leaves.

Section 7

Viroid

Viroids are minute infectious agents, smaller than viruses, that infect higher plants and cause stunting or distorted growth.

PSTVd (Potato spindle tuber viroid)

Pathogen. The viroid persists in infected seed tubers. It is transmitted by direct contact and by any mechanical operation that involves the release of plant sap, such as seed cutting, seed handling and crop cultivation.

Symptoms. High temperatures early in the growing season promote the development of symptoms.

This disease has been eliminated from Canadian potato stocks.

366 | Plants are stunted and are more upright and have fewer stems than healthy plants. Leaves are smaller than normal and are folded upward with wavy margins. Leaves are attached to the stem at acute angles.

367 | Infected tubers tend to be cylindrical and more pointed at the stem end than normal. The eyes are more numerous and may protrude or be shallower than those of healthy tubers.

Section 8

Phytoplasmas

Phytoplasmas are similar to bacteria, but they lack cell walls. They reproduce like bacteria and usually remain in the food-conducting vessels (phloem) of infected plants.

Leafhoppers transmit phytoplasmas.

Phytoplasmas cause a wide range of foliar symptoms:

- yellowing, purpling or reddening of leaves
- simple leaves rather than compound
- upward rolling of top leaves
- wilting
- aerial tubers
- excessive proliferation of shoots
- dwarfed and bushy plants
- vascular discolouration of stems

Tubers are often small or malformed. Infected tubers may not sprout, may break dormancy early or may produce long, spindly sprouts.

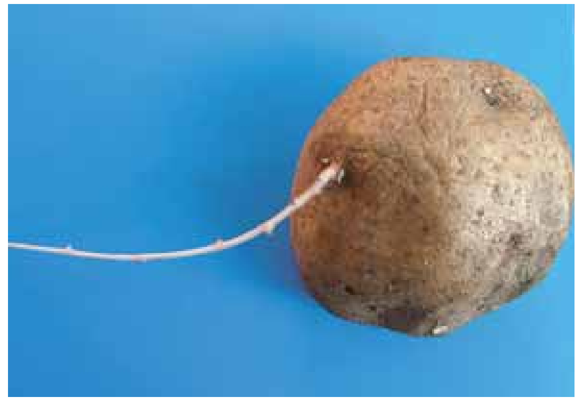
Purple Top or Aster Yellows (Aster yellows phytoplasma)

The aster yellows phytoplasma is transmitted by the aster leafhopper. Aerial tubers may form on affected plants and affected stems usually die prematurely.

368 | Early symptoms of purple top.

369 | Terminal growth appears bunched and the leaflets roll up at the margins and develop a purplish colour. The leaves may be rigid at first, but later they wilt.

370 | Terminal growth may appear yellowish in some varieties.



371 | Daughter tubers of affected plants may produce hair sprouts.

Witches' Broom

Leafhoppers acquire the witches' broom phytoplasma from infected legume hosts. Later, they migrate to potato fields and transmit the pathogen. Usually, infections occur too late in the season for symptoms to develop. Symptoms are usually visible on plants that emerged from infected seed tubers.

372 | Plants are dwarfed. An excessive number of shoots proliferate at the base of the stems. Leaves are yellowish, round and simple. Tubers produced by infected plants lack dormancy.

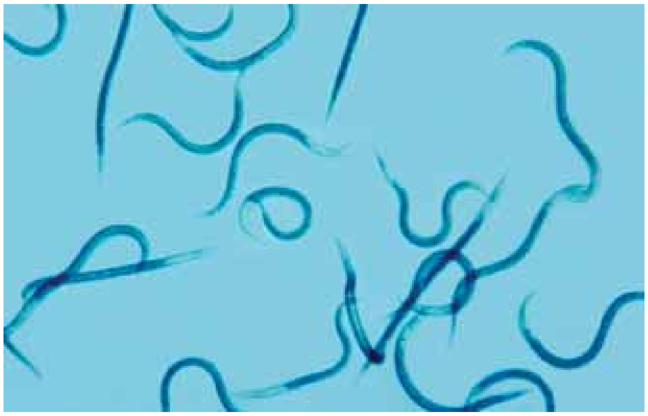
373 | Numerous small plants with simple leaves develop from infected seed tubers.

Section 9

Nematodes

More than 40 nematode species parasitize potatoes, but only a few are of economic importance. Nematodes parasitizing potatoes have either worm-like or sack-like bodies and range in size from 0.5–4 mm in length. Their bodies are colourless and appear more or less transparent; only the sack-like species (root-knot and cyst nematodes) can be seen with a hand lens in the field. The main distinctive characteristic of plant-parasitic nematodes is a stylet in the mouth that is used for feeding. They do not have circulatory or respiratory systems. Because nematodes are basically aquatic organisms, a film of moisture around them is necessary for survival.

The life cycle of potato-parasitic nematodes is simple. Females lay eggs that hatch into young nematodes (called "juveniles") that are much like adults in appearance. During their growth and development, juveniles undergo a series of molts before becoming adults. Nematodes that attack potatoes feed on roots and/or tubers. Roots of infected plants and soil samples taken close to infected plants are usually sent to diagnostic laboratories to identify the nematode species.



374 | Nematodes.

Northern Root-knot Nematode (*Meloidogyne hapla*)

Pathogen. The only root-knot nematode that has been detected on potatoes in Ontario is the northern root-knot nematode. Males are worm-like, and females are pear-shaped.

375 | Root galls and proliferation of roots caused by the northern root-knot nematode.

This nematode causes small galls to develop on the roots, and lateral roots to proliferate around the galls. Brown spots form in the tuber flesh close to the tuber surface. The spots are visible if a thin layer of tuber is peeled off.

The Northern root-knot nematode causes a general swelling of tubers but no warty galls. Penetration of lenticels results in scab-like lesions.

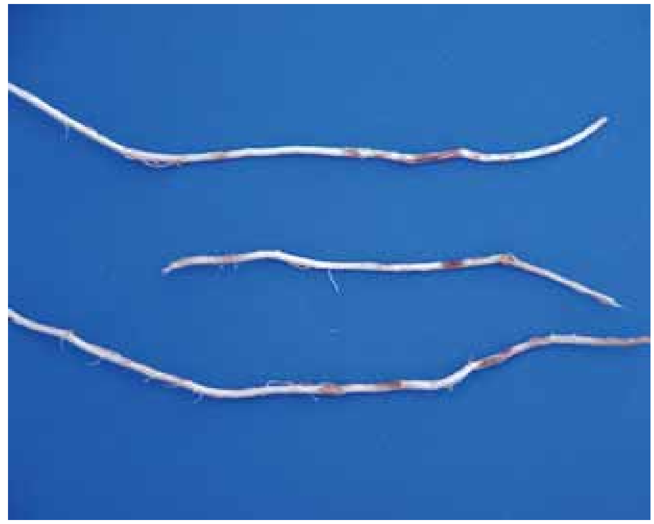
376 Brown spots under the tuber skin.

Root Lesion Nematode (*Pratylenchus penetrans*)

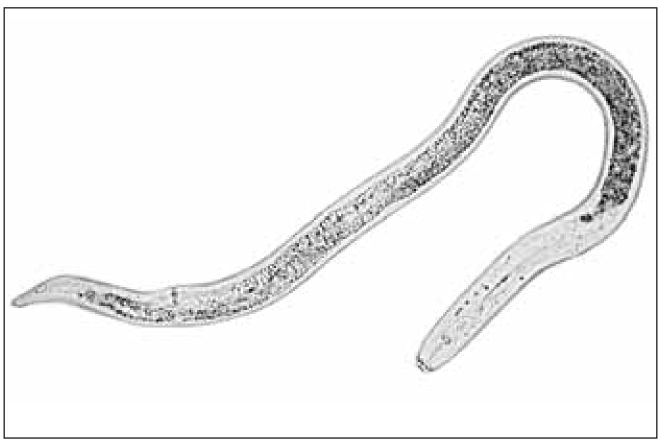
Pathogen. The root lesion nematode is a tiny, threadlike worm about 0.5 mm long when mature. It is mainly a root pathogen and is often associated with the Verticillium wilt fungus (see page 63), causing early dying. This nematode affects potato yields directly by reducing the size and weight of tubers and also indirectly by weakening the plants and making them more susceptible to Verticillium wilt.

High populations cause extensive damage to young feeder roots, which are then invaded and damaged by other soil microorganisms.

Higher infestations of the root lesion nematode are usually found in sandy fields with short rotations out of potatoes.



377 | Brown lesions on roots caused by root lesion nematode feeding damage.



378 | Root lesion nematode.

379 | Field areas of poor growth with stunted, yellowish, weak plants usually have a large root lesion nematode population.

Section 10

Physiological Disorders and Injuries

Air Pollution

Potato plants may be injured when exposed to high concentrations of various air pollutants. Injury can range from leaf damage to death of the plant. Severity of the injury depends on environmental conditions, the concentration of the pollutants, the stage of development of the plant, the susceptibility of the variety and the overall health of the plant.

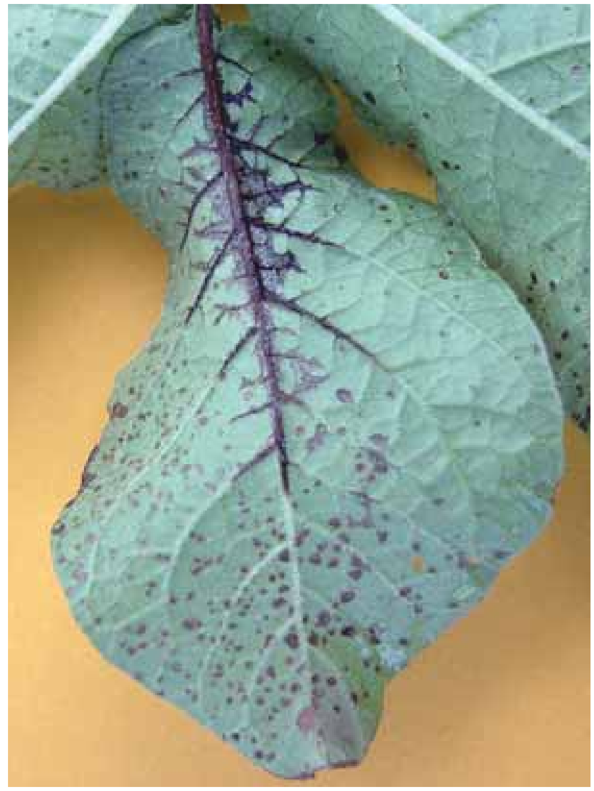
The following environmental conditions will result in injurious levels of pollutants:

- Atmospheric ozone levels over 80 parts per billion (ppb) for 4 or 5 consecutive hours, or 70 ppb for a day or two are usually sufficient to injure plants at a susceptible stage of growth.
- High levels of vehicle exhaust. Crop injury is often visible on fields in proximity to busy highways after heavy weekend traffic.
- Cloudy, hazy, overcast days and high humidity and little breeze result in a high concentration of pollutants at ground level and in hollows.
- Foggy conditions and heavy dew often cause air pollution damage.

Crop stress due to disease or environmental factors predisposes plants to air pollution injury.

380 | Pepper spotting on leaves caused by ozone injury.

381 | Yellowing and pepper spotting on Yukon Gold leaves caused by air pollution.



382 | Pepper spots on Norland leaves. The reddish vein discolouration could be the result of herbicide damage.

383 | Air pollution on Yukon Gold.

384 | One side of the leaves may be more severely affected by air pollution than the other.

385 | Browning on the underside of leaves caused by peroxyacetyl nitrate (PAN).

386 | Glassy PAN damage.

387 | Early PAN damage.

388 | Purplish discolouration on the upper side of leaves.

389 | Speckling caused by high levels of ozone.


390 | Acid rain damage on leaves.


391 | Acid rain has burned large areas of the leaflets.


392 | Air pollution injury. Large veins remain green.


393 | Areas burned by acid rain turn black.


394 | Interveinal necrosis.


395 | Acid rain damage.


396 | White or bleached spots caused by sulphur dioxide (SO_2) injury.


397 | Acid rain injury.


398 | Acid rain damage on leaves.


399 | Air pollution injury. This injury could be confused with leaf necrosis induced by PVY (see page 103).


400 | Air pollution damage to Andover leaves.


401 | Acid rain.


402 | Air pollution damage to Norland leaves.

Physiological Leafroll

This symptom is associated with crop stress. Drought, temporary water logging and nutrient imbalances may cause leaves to roll upward.

The leaves of the varieties Superior and Andover often roll when the plants are under stress.

403 | Stress-related leafroll. The texture of the leaves is not leathery as in the leafroll symptom caused by the potato leafroll virus.

404 | Plants showing stress-induced leafrolling.

Edema

Edema is a physiological disorder that develops when plants absorb water faster than it can be lost from leaf surfaces. This causes swellings that appear initially as pale-green or water-soaked blisters or bumps. Older leaves are more affected than younger ones. This disorder is more common in potatoes grown in greenhouses.

405 | Bumps on leaflets caused by edema.

Distorted Growth

Long periods of either cool or hot weather cause distorted growth.

406 | The leaf on the left shows puckering caused by hot weather. The leaf on the right shows normal growth.

407 | Growth distortion caused by cool weather.

408 | Cool-weather symptoms may be confused with phenoxy herbicide damage.

Hot Soil Damage

409 | Tips of emerging sprouts are burned by hot, sandy soil.

410 | Tip of leaflet burned by hot soil.

Tipburn

This disorder develops when water transpires from leaves more rapidly than it can be absorbed from the soil. This usually occurs under hot, dry, windy conditions.

411 | The tips of leaflets turn brown and become brittle. *Botrytis* often infects the damaged tissue.

Heat Stress

Necrotic spots often develop on leaflets when temperatures remain high for several days.

412 | Leaflets roll inward, and affected areas turn brown and die.

Sunscald on Stems

413 | Strong sun during hot weather may bleach the base of exposed stems. Stems are most likely to be exposed when the canopy opens in August.

Frost Damage

414 | Frost kills emerging shoot tips. New sprouts emerge at a 90° angle to the injured shoot.

415 | Frost kills the foliage. The affected plant parts wilt, turn black and die very quickly.

Coiled Sprout

Sprout coiling has been associated with physiologically old seed, low soil temperatures, soil compaction and exposure of emerging sprouts to some herbicides.

416 | Sprouts do not grow straight, but coil with the curved portion of the stem often swollen and sometimes split.

Elongated Stolons

Some varieties develop extremely long stolons during warm, dry seasons.

417 | This plant of the variety Snowden has stolons about 0.6 m long.

418 | Leaves developing from an elongated stolon.

419 | Stolons protruding from hills form new plants (Snowden variety).

Lightning Damage

Lightning damage to potato plants and tubers may occur during severe thunderstorms. Usually, the areas struck by lightning are circular or elliptical. Because lightning damage is influenced by soil moisture and plant hydration, affected areas are often low spots in fields.

Injury to plants is evident soon after the electrical discharge. Different plant injury patterns may be found in fields:

- Well-defined areas with dead plants.
- Areas with dead plants at the center and progressively reduced injury toward the edges.
- Poorly defined areas. Plants with varying degree of injury are scattered among dead and healthy plants.
- Several small areas with injured plants.

420 | Lightning damage in a field. Collapsed stems and wilted tops are typical of lightning strikes. Stems show longitudinal depressions on the surface.

421 | Stems are most severely damaged at or near soil level. Leaves remain green for some time following injury to the stems.

422 | The pith in affected stems collapses, forming horizontal plates that appear ladder-like when the stems are split lengthwise.

423 | Lightning damage to tubers. The texture of the affected flesh is similar to that of a boiled potato.

424 | Lesion on tuber caused by lightning.

425 | A lightning injury that dried up.

Wind Damage

426 | Holes caused by strong winds.

427 | Strong winds cause leaves to rub against each other. This friction causes bronzing of the leaves and tearing of the leaf margins.

Hail Damage

Hail damage varies from holes through leaves and impact lesions on stems to partial defoliation or vine kill.

428 | Whitish-grey spots on stems and petioles occur at the points of impact.

429 | Severe hail damage breaks the stems.

430 | Hail often tears or perforates leaves.

Chemical Damage

431 | Spots with bleached appearance on leaves caused by a mixture of pesticides and nutrients applied in hot and humid weather.

432 | Top-dressed nitrogen fertilizers often burn foliage if applied when the weather is hot and humid. This is most likely to affect the growing point or newly developing leaves, where granules of nitrogen may be trapped.

Salt Injury

High salt content in the soil injures the root tips of potato plants. Plants cannot take up nutrients, and growth is stunted. If heavy rains wash the salts from the root zone, the plants may resume growth, but yield is reduced.

433 | Stunted plants as a result of a high content of sodium in the soil. Affected plants do not wilt and the foliage is usually dark green.

Unusual Pigmentation of Leaves

434 | The leaf margins of some red varieties turn reddish.

435 | Uneven green colour.

436 | Plant with yellow leaves. This may be a genetic problem.

437 | The margin of leaflets or entire leaflets are yellow. This is a genetic disorder.

Section 11

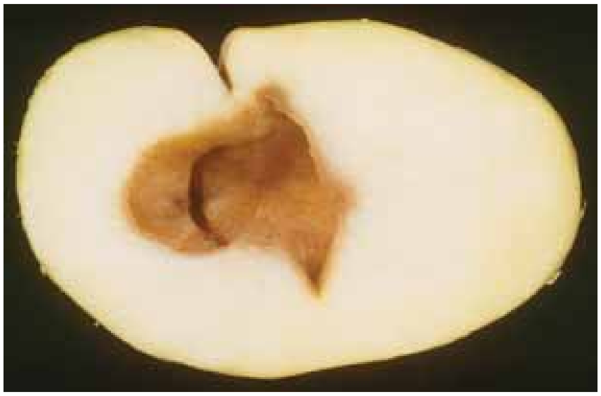
Internal Defects of Tubers

Brown Center and Hollow Heart

Brown center is associated with cool, wet soil conditions during early tuber development.

Brown centers in small tubers may disappear if tuber growth is uniform during maturation.

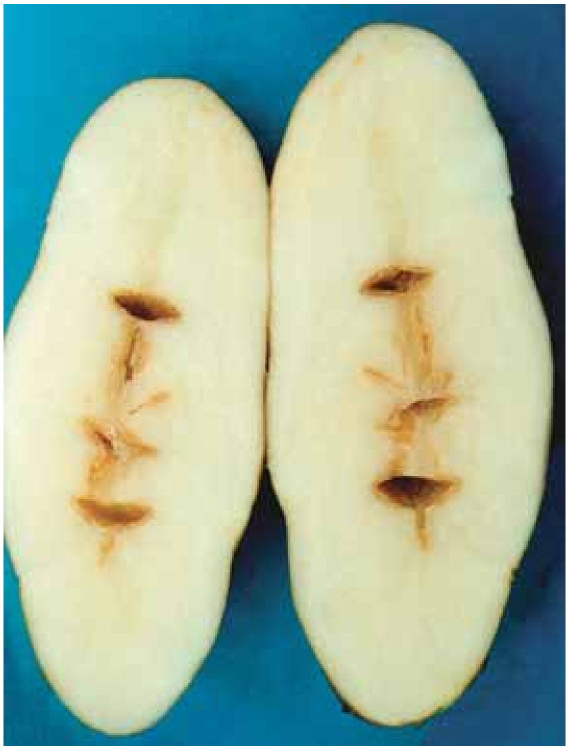
438 | Pith tissues near the center of the tuber become light to dark brown.



439 | The size and shape of the discoloured area are variable. The affected cells eventually die.

The internal cavity formed when tubers grow too rapidly is called **hollow heart**. Hollow heart is common in oversized or rapidly growing tubers. It is more severe under conditions that favour rapid tuber enlargement, such as dry soil conditions followed by high moisture levels. Wide plant spacing can increase the incidence of hollow heart. Calcium deficiency has been implicated in this disorder. The varieties Atlantic and Yukon Gold are very susceptible to hollow heart.

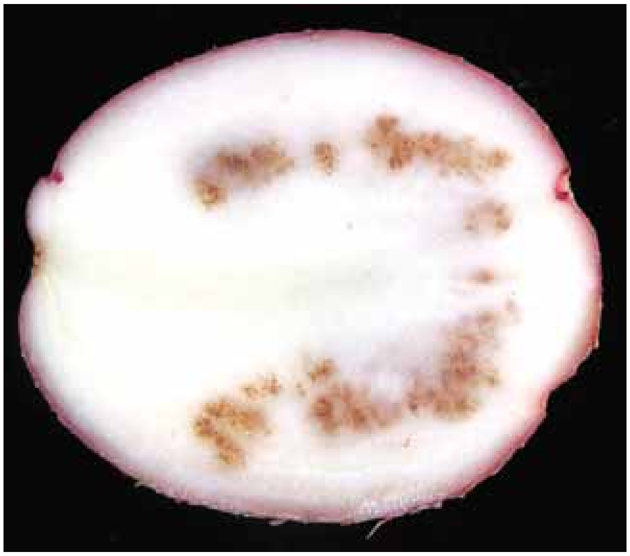
440 | A cavity forms, usually in the center of the tuber or near the stem or bud end. The cavity is either irregular or star-shaped. Cavity size can range from less than 1 cm to a large area that includes the whole pith tissue.



441 | In many cases, instead of a single large cavity several smaller cavities are found. There are no external symptoms of hollow heart.

Heat Necrosis

High soil and tuber temperatures cause heat necrosis. It occurs when a period of slow tuber growth is followed by active tuber growth at high temperatures. Light to dark brown necrotic spots or blotches form in the vascular tissue of the tubers. Cortical tissue between the vascular ring and tuber skin is seldom affected. There are no external tuber symptoms of heat necrosis. The varieties Atlantic and Chieftain are very susceptible to heat necrosis.



442 | Heat necrosis.

Internal Brown Spot

This disorder has been associated with calcium deficiency, low soil moisture and periods of uneven growth.

443 | Round or irregularly shaped, light-brown necrotic spots can be located anywhere in the tuber.

444 | Numerous brown spots can develop in a tuber.

445 | Internal brown spots in seed pieces.

Stem-end Browning, Vascular Necrosis

The vascular tissue turns brown near the stem end of the tuber. In severely affected tubers, vascular discolouration will extend throughout the tuber to the bud end. This disorder develops either in the field or during the first few months in storage. Vascular necrosis is frequently associated with rapid vine death caused by vine desiccants. The symptoms are always more severe when vine killers are applied to a crop under drought or heat stress. Rapid vine death caused by frost or by mechanical removal may also cause stem-end browning.

446 | The discolouration near the stem end varies from light tan or reddish-brown to dark brown. In mild cases, the discolouration is shallow and speckled in appearance.

447 | Vascular ring discolouration caused by the sudden death of the plant.

Blackheart

Blackheart is caused by a deficiency of oxygen that impairs tuber respiration. Freshly harvested tubers are especially vulnerable to blackheart if held in a low-oxygen environment. In storage, tubers become prone to blackheart if stored in closed bins with poor ventilation. Under these conditions, oxygen levels drop and CO_2 levels may increase above 1000 ppm for an extended period of time, inducing the development of blackheart. Also, blackheart may develop in the field under waterlogged conditions.

448 | A black, irregularly shaped spot usually develops in the center of the tuber. The black tissue is firm. The black discolouration often extends to the edges and diffuses into healthy tissue without a distinct margin.

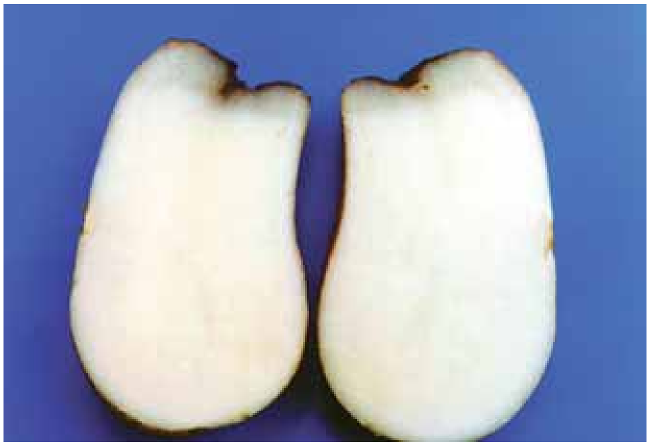
449 | As tubers dry out, the affected tissues shrink and cavities form.

450 | Tubers severely affected by blackheart.

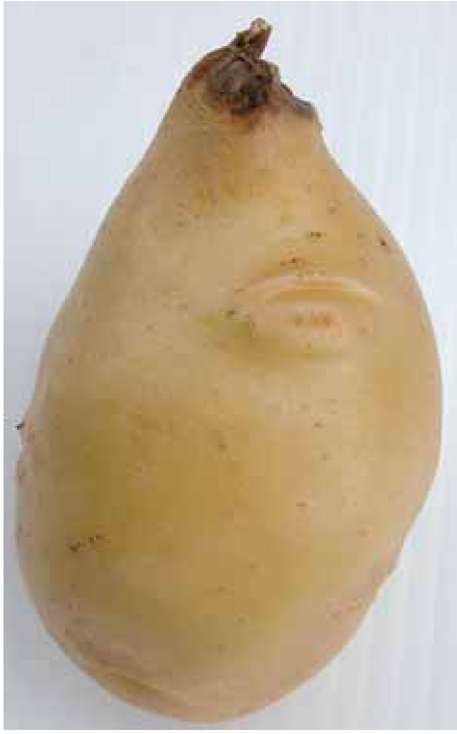
Translucent End and Jelly End Rot

Translucent End (Sugar End). High temperature or moisture stress during the early stages of tuber growth may interfere with starch deposition at the stem end of the tuber.

Jelly End Rot. Often, the tissue of tubers affected with translucent end breaks down. This breakdown is called jelly end rot. In hot seasons, heavy losses occur in varieties susceptible to jelly end rot.



451 | The tuber tissue in the affected stem end is usually translucent or glassy in appearance as a result of the low content of starch and high content of sugar.



452 | Affected tubers often have pointed ends.

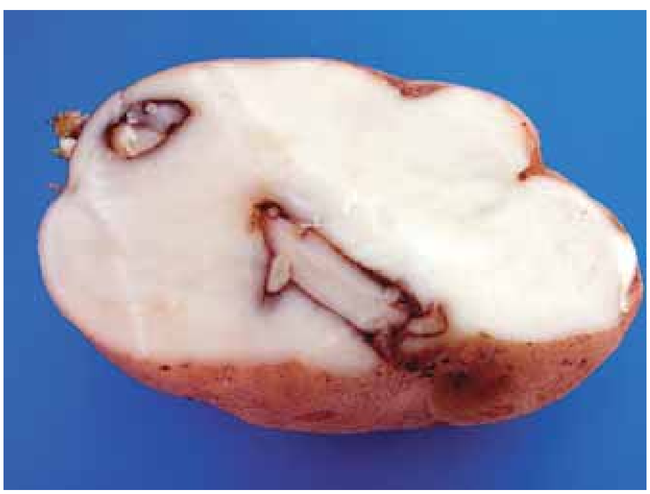
453 | The stem end of tubers are soft, jelly-like and slightly watery. The affected area may extend up to 3 cm from the stem end.

454 | As the tubers age or dry out, the affected tissue dehydrates, shrivels, turns light brown and papery.

Internal Sprouts

This disorder is more frequent in physiologically aged tubers and in those stored at 12°C. Pile pressure also causes sprouts to grow internally.

Applying the sprout inhibitor CIPC (chlorpropham) below the recommended rate or when tubers are beginning to sprout will promote internal sprouting.



455 | Tuber showing internal sprouting.

456 | Internal sprouting caused by pressure bruise on a tuber eye.

457 | A new tuber has formed inside the mother tuber.

Chilling Injury

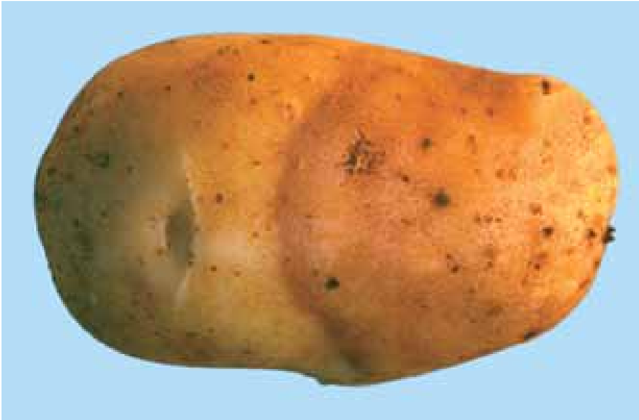
Potatoes are sensitive not only to freezing but also to chilling. Chilling injury occurs if tubers are exposed to temperatures between 0° and 3°C. Chilled tissue will discolour, turning grey or black, even though ice crystals have not formed. If the tissue turns reddish-brown after chilling, the injury is called mahogany browning.

458 | Affected tissues appear as diffuse, grey to black areas.

459 | Chilling injury on tubers.

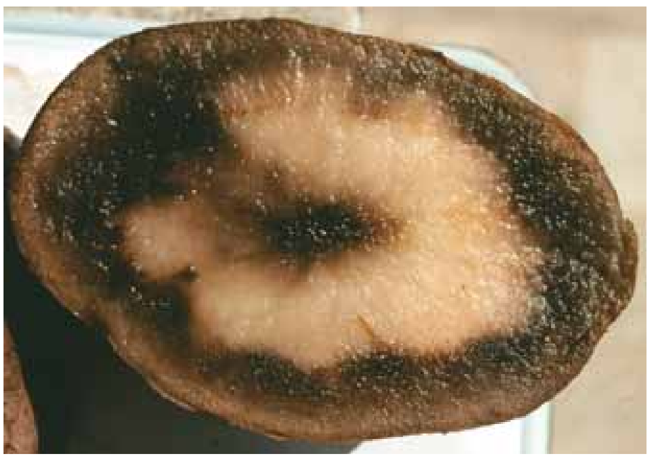
460 | The vascular tissue is very susceptible to chilling injury.

Freezing Injury

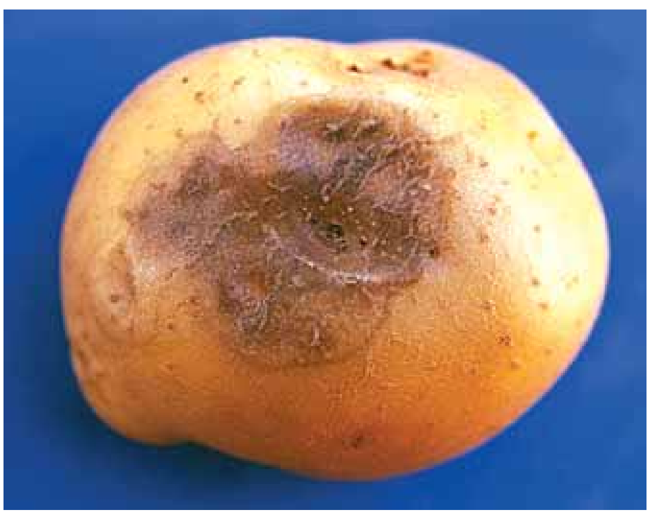


461 | Freezing injury results when ice crystals form in the cells. Externally, tubers or affected areas of the tubers appear flabby and of a darker colour.

462 | Tissues that have been frozen are soft and watery after thawing. A dark line separates the affected area from healthy tissues.



463 | The vascular tissue is very susceptible to low temperature injury. It often turns black when affected by freezing temperatures.



464 | Usually, a short period of frost that penetrates the soil will injure tubers that are close to the soil surface, causing superficial lesions.

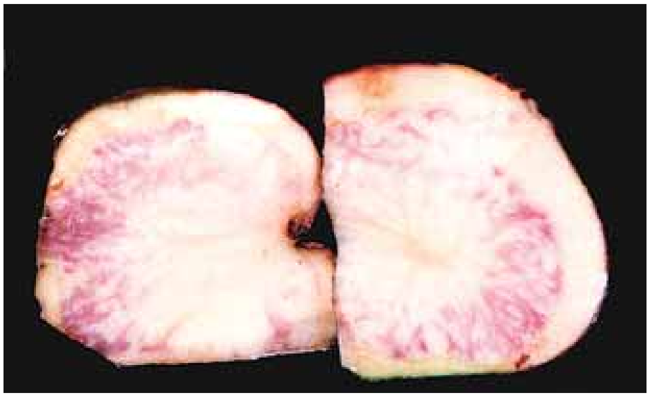
465 | Eventually, the lesions dry up in storage.

Internal Anthocyanin Discolouration

Anthocyanin is the pigment responsible for the red, pink, purple and blue colours in flowers, fruits and leaves.

Affected tubers show purplish red stripes and flame-shaped discolouration of the flesh, the result of anthocyanin formation in the cell sap. Light seems to play a role in the development of this defect because the production of anthocyanin in tuber flesh has been associated with tuber greening in the field. Proper hilling reduces this problem.

This defect is rare and usually affects only certain cultivars. The varieties Mainestay and Frontier Russet are susceptible to anthocyanin discolouration.



466 | Tubers showing internal discolouration due to anthocyanin formation in sap.

Purplish-red Pigmentation

467 | Tuber showing purple pigmentation under the skin.

Section 12

External Defects of Tubers

Tuber Greening

Greening results from the exposure of tubers to light. In the field, light reaches the tubers through soil cracks or when the tubers protrude from the hill. Light induces the formation of chlorophyll and increases the levels of glycoalkaloids such as solanine. Chlorophyll is harmless, but glycoalkaloids are toxic and give the tubers a bitter taste.

468 | Green spots on the surface of the tubers are caused by exposure to light.

Fertilizer Burn

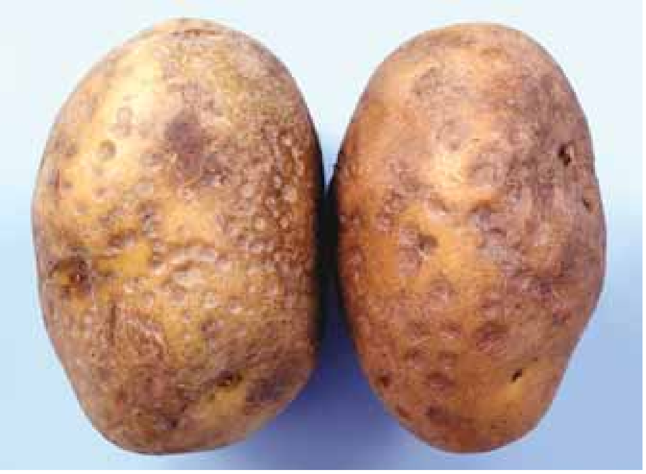
469 | Tuber showing blemishes caused by fertilizer burn (see "Elephant Hide," page 149).

Brownish Skin of Red Varieties

The skin of many red varieties becomes brown and thicker than normal. This problem is common in red potatoes grown in sandy soils. The brown colour becomes more noticeable in storage.

470 | Red tubers at harvest (right) turn brownish after a month in storage (left).

Ammonia Damage



471 | Potato tubers injured by ammonia gas.

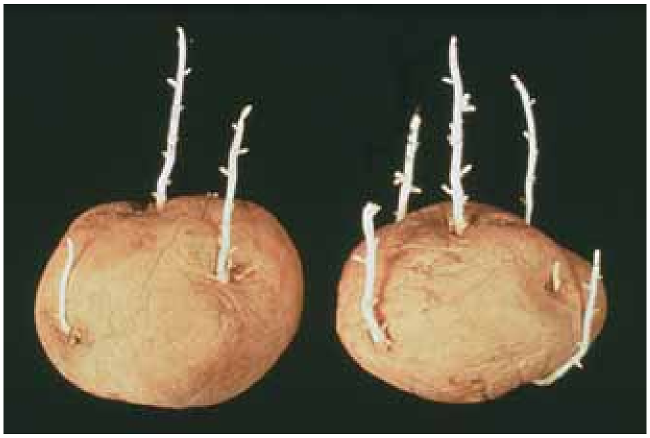
Enlarged Lenticels

Lenticels swell and enlarge when tubers are in saturated soils. This disorder may also develop on freshly harvested tubers that remain wet for some time after washing.

472 | White, corky bumps protruding from the tuber surface. When the soil dries out, lenticels become light brown and close up.

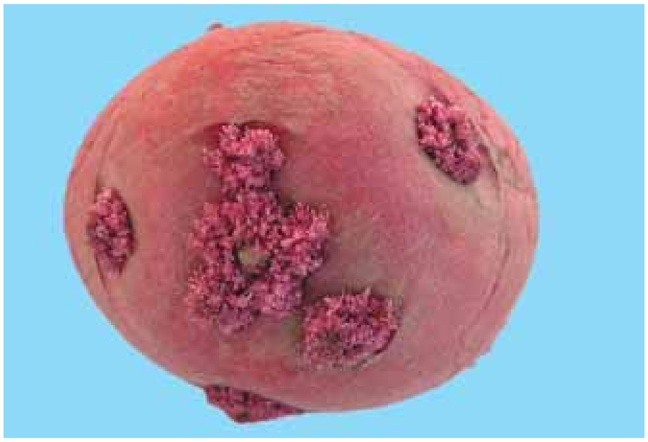
Hair Sprout, Spindle Sprout

Tubers germinate early, even before harvest, producing very thin sprouts. This disorder has been associated with hot, dry conditions late in the season, with physiologically aged seed tubers, and with aster yellows or psyllid yellows.



473 | Very thin hair sprouts emerging from tubers.

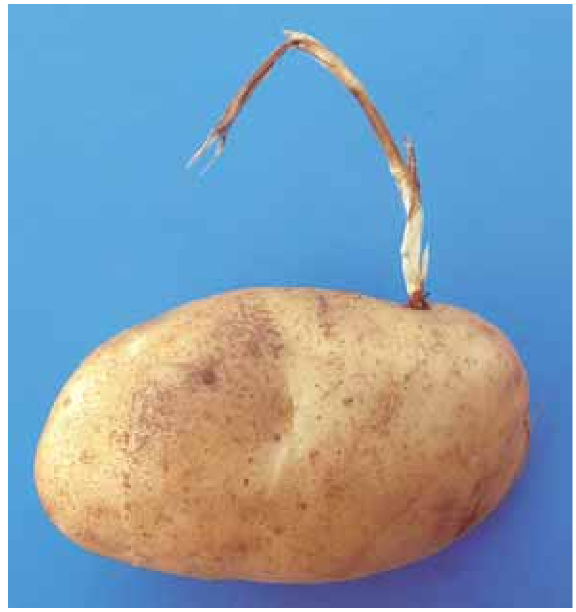
Rosette Sprouting



474 | This type of sprouting is often observed on tubers produced by a crop treated with a sprout inhibitor.

Unusual Tuber Problems

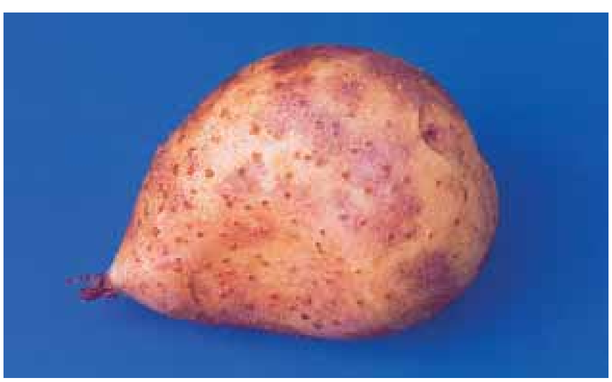
475 | Scar on tuber skin caused by quackgrass.



476 | Quackgrass grew inside the tuber.

477 | Tubers showing the stitched end defect. This abnormality, considered to be genetic, affects both the foliage and the tubers. The plants have broad, flat stems. The tubers are usually flat, especially the bud end, which looks like a wound that has been stitched. Affected tubers sprout early.

478 | A dark liquid that looks like molasses often leaks from tubers with internal problems.



479 | Purplish spots on the tuber skin. The skin is not damaged. The purplish spots fade rapidly under dry conditions.

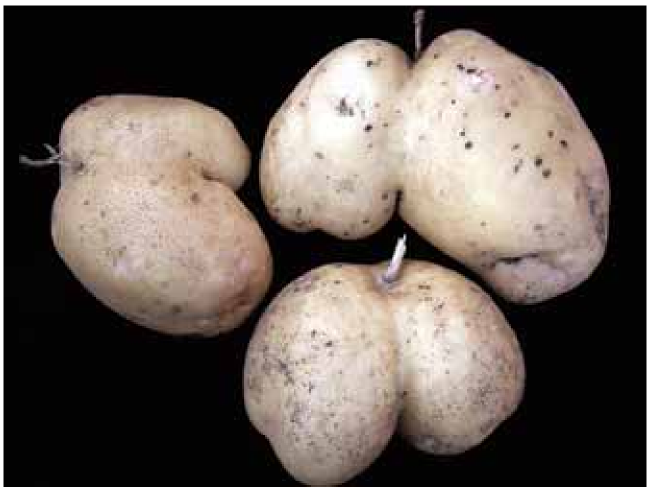
480 | Severe tuber lesions. *Alternaria alternata* was isolated from these lesions.

Section 13

Rough or Misshapen Tubers

Several types of tuber malformations are caused by either environmental or cultural stress.

Drought, wide fluctuation in soil and air temperature, and defoliation resulting from hail or pests often cause the development of malformed tubers.



481 | Misshapen tubers of an oblong variety.

482 | Misshapen tubers of a long, specialty variety.

Knobby Tubers

Water stress can trigger the loss of apical dominance in some varieties, notably Russet Burbank. The abnormal growth of lateral buds results in knobby tubers.

Rhizoctonia cankers on the stems increase the incidence of knobby tubers.

483 | Knobs or protuberances develop from one or more eyes.

484 | The knobs vary considerably in size and shape.

Pointed Stem End and Pointed Bud End

485 | Tubers showing the pointed stem end defect. The pointed stem end defect is the result of growth disruption during the early stages of tuber development. The pointed bud end defect develops when tuber growth is restricted late in the season.

Dumbbells

486 | Dumbbell tubers have a constriction between the stem end and the bud end. Growth disruption at the mid-bulking stage causes irregular radial growth of tubers.

Section 14

Bruise Damage

If potatoes are treated roughly during harvest, storage or handling, the tubers may suffer varying degrees of damage.

Blackspot Bruising

Blackspot bruising is an internal discolouration caused by an impact that injures the tissue beneath the skin. Discolouration of the damaged tissue is observed 6-8 hr after bruising occurs. Black spot is more common in tubers that have reduced water content and in tubers harvested cold.

Bruised areas vary in size and shape but usually do not break the skin or penetrate deeper than 5 mm into the tuber. The stem end is more susceptible to black spot than is the bud end.

487 | A peeled tuber showing blackspot bruises. There are no external symptoms.

White Knot Bruise

White knot bruise has been detected in chipping potatoes. The damage is similar to blackspot bruise but is white-coloured.

White knot forms a hard spot when the tubers are processed.

488 | White knot bruise.

Shatter Bruise

Shatter bruising is caused by a mechanical impact that splits or cracks the tuber. Well-hydrated or turgid potatoes are more susceptible to shatter bruise. Cool pulp temperature during harvest or handling increases the incidence of shatter bruising.

489 | Shatter bruising first appears as small cracks or splits in the tubers. The fissures may not be visible until the tubers have dehydrated slightly.

Pressure Bruise

Pressure bruises occur in stored tubers because of the weight of the overlying potato pile. Potatoes are most susceptible to pressure bruising when the storage humidity drops below 90% and the tubers lose moisture. Tissue below the pressure bruise is susceptible to blackspot bruising.

490 | The affected area is flattened or depressed as a result of continuous pressure.

Skinning, Feathering

Skinning damage usually occurs when tubers are harvested immature.

491 | Skinned areas turn dark when exposed to sunlight, wind or dry air.

Section 15

Tuber Cracking

Growth Cracks

Growth cracks develop when the tuber's internal tissue grows faster than its surface tissue. This problem is associated with conditions that cause rapid internal growth, such as drought followed by a rainy period. Also, growth cracks may develop when an excessive amount of fertilizer is available to the plant.

Growth cracks are also characteristic of some viral diseases and herbicide damage.

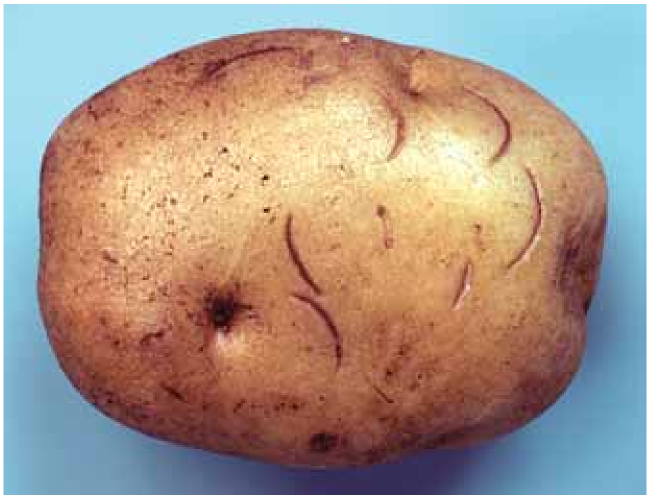
492 | Growth cracks are shallow or deep fissures that usually follow the long axis of the tuber.

493 | Growth crack at the stem end of the tuber.

494 | A branched growth crack (left) and a transverse crack (right).

Thumbnail Cracks

Thumbnail cracks are shallow splits in the tuber skin of well-hydrated tubers that have been exposed to drying conditions.



495 | Thumbnail cracks resemble cracks made with a thumbnail. They are usually shallow, 1–2 mm deep and randomly distributed on the tuber surface.

Mechanical Cracking

496 | Hairline mechanical cracks enlarge as tubers dry out.

497 | Mechanical cracking. These cracks facilitate *Fusarium* and soft rot infection.

Elephant Hide

Elephant hide or alligator hide refers to thick, coarse russetting and cracking of the tuber skin. It has been associated with soils that contain undecomposed organic matter, salts or certain agricultural chemicals.

498 | Cracking of the coarse, thickened skin gives the tubers the appearance of an elephant's hide.

499 | Cracking of the skin often associated with agricultural chemicals.

Rhizoctonia Cracks

500 | Cracks caused by *Rhizoctonia*.

501 | The cracks enlarge as tubers dehydrate.

502 | Cracks on a Nordonna tuber.

Herbicide Cracks

503 | Herbicide damage.

Section 16

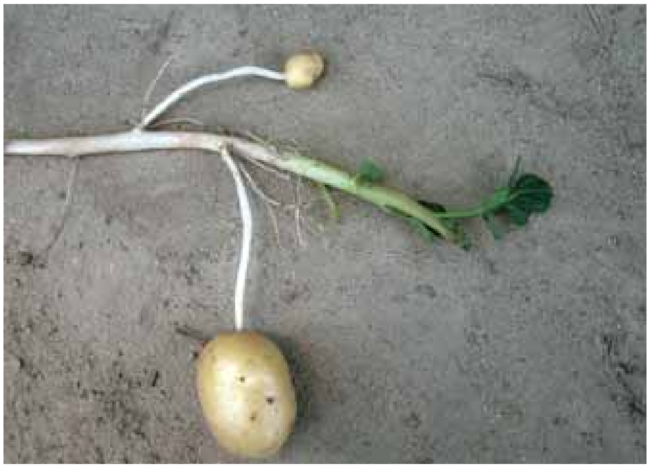
Second Growth

Potato tubers develop best when they grow at a constant rate. High temperatures, drought and other stresses that cause growth to slow and then speed up when favourable conditions return result in second growth.

Tuber chaining and heat sprouts are caused by renewed tuber growth after exposure to extended periods of warm soil temperatures.

Tuber Chaining

504 | A series of several tubers form on a single stolon.



505 | New tubers developed from a stolon with leafy growth at the tip.

506 | New tubers developed from stolons of daughter tubers.

507 | New tubers formed on thick stolons emerging from daughter tubers.

Heat Sprouts

Heat sprouts are produced from tubers or stolons, and grow as new sprouts or develop into leafy above-ground stems.

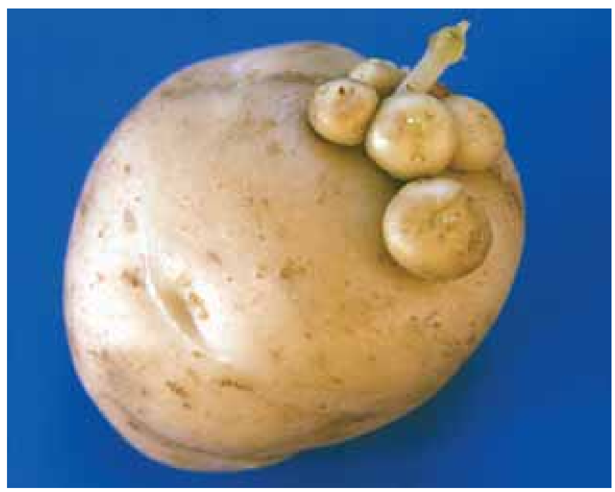
508 | Daughter tubers showing leafy growth.

509 | Long stolons that protrude from the hill produce new plants.

Little Tuber, Secondary Tuber

Tubers sprout either in storage or in the field, producing new marble-size tubers without forming a normal plant. The little tuber disorder is associated with physiologically aged tubers, warm seed tubers planted in cool soil, and the transfer of sprouted tubers from warm to cold storage.

510 | New marble-size tubers formed directly on the tuber.



511 | Little tubers formed at the stem end.

512 | A physiologically aged tuber with the little tuber disorder.

Section 17

Herbicide Damage

The foliage of potato plants can be damaged by herbicides applied to the crop, herbicides drifting over from neighbouring fields or herbicide residues that carry over from a previous crop. Distorted plant growth and yellowing are typical symptoms of herbicide injury.

Laboratory analyses of soil, water, tubers or foliage are necessary to confirm herbicide damage.

513 | Herbicide damage to tubers causes cracks and malformations.

Glyphosate

The drift of glyphosate onto potato foliage injures the crop. Tubers develop folds or clefts.

514 | Glyphosate causes the youngest leaves of plants to turn yellow. Later, the affected leaves wilt.

Phenoxy Herbicides

2,4 D and Dicamba injuries are caused by spray drift. Picloram injury results from residue in the soil carried over from a previous crop.

515 | Young stems are curled and leaves are severely distorted or absent. This symptom is called fiddleneck.

516 | Severely distorted leaves.

517 | Plants exposed to a phenoxy herbicide at tuber initiation produce malformed tubers with raised circles around the eyes.

Metribuzin

518 | Yellowing along the veins (Atlantic variety).

Metribuzin injury is more likely when the herbicide is applied after emergence. Metribuzin may injure potato plants when high rates are used, when it is applied to sensitive varieties (e.g., Atlantic, CalWhite), or when the weather is cloudy, cool and wet before or soon after application.

Leaves turn yellow either along or between the veins, depending on the variety. If the injury is slight, the yellow tissue eventually becomes green.

519 | Severe yellowing of veins.

520 | Interveinal yellowing caused by metribuzin. The variety Atlantic often develops this symptom.

Atrazine

521 | Atrazine residue carried over from the previous crop causes yellowing of older leaves, especially at the leaf margins.

EPTC

Potato foliage may be injured if applications of EPTC exceed recommended rates or if applications overlap during soil preparation before planting.

522 | Stems appear twisted and leaves become cupped, curled or bent over. This symptom can be confused with a viral infection.

Linuron

523 | Tips of leaflets turn yellow as a result of linuron damage.

524 | Yellowing of foliage.

525 | A field of Shepody with some rows showing severe linuron damage.

526 | Yellowing of Shepody leaves due to linuron damage.

527 | Yellowing and distortion of leaves.

Imazethapyr

528 | Imazethapyr drift at tuber initiation causes the leaves to roll upward and the plants to appear wilted.

529 | Tubers with multiple deep cracks and thick, coarse skin due to imazethapyr drift at tuber bulking.

Section 18

Nutrient Deficiencies

Symptoms of nutritional deficiencies may be confused with physiological disorders or infectious diseases.

Excessive rain or irrigation can leach mobile nutrients from the root zone, reducing the availability of nutrients for the normal development of the crop.

Nitrogen Deficiency

530 | Plant exhibiting nitrogen deficiency symptoms. Plants grow more slowly and leaves turn light green, then yellow. Severe deficiency causes the leaflets to cup upward. Eventually, older leaves dry up.

Phosphorus Deficiency

531 | Plant exhibiting phosphorus deficiency symptoms. Plants appear stunted. The leaves are of a darker green than the leaves of healthy plants. If the deficiency is severe, the leaves turn purplish and curl upward.

Potassium Deficiency

532 | Young leaves have a glossy sheen and bluish colour.

533 | If the deficiency is severe, bronzing of leaves, marginal leaf scorching and leaf curling occur. Eventually, the leaves dry up.

Magnesium Deficiency

534 | Older leaves show interveinal yellowing and brown spots. Young leaves near the growing point remain green.

Manganese Deficiency

535 | Manganese deficiency. Dark to black spotting develops between the veins, especially along the mid-rib and larger veins of the leaflets. Younger leaves turn yellow and roll upward.

Boron Deficiency

Leaflets are crinkled and rolled upward; the leaf margins are dry and light brown. The growing point dies and the immature centre leaves are deformed.

536 | Boron deficiency.

537 | Boron toxicity: tipburn, arching of leaflet midribs and yellowing.

Zinc Deficiency

Affected plants are stunted; young leaves turn yellow and roll up. Terminal leaves are vertical and may show tip-burn injury. The petioles become easily detached from the stems, giving the plants a "palm tree" appearance.

538 | Leaflets showing varying degrees of zinc deficiency: mild symptoms (left), yellowing and greyish-brown spots on leaflets (middle), and severely deficient (right).

Iron Deficiency

539 | The growing point and young leaves become yellow to nearly white without necrosis.

Section 19

Quarantine Pests

Quarantine pests are regulated to avoid their introduction to areas where the pests are not present.

The Canadian Food Inspection Agency (CFIA) has the authority to take action on any of the pests considered to be quarantine pests to Canada.

Some important quarantine pests of potatoes are:

- **Potato wart fungus**
- **Brown rot bacterium (race 3, biovar 2)**
- **PVY^{n} and PVY^{ntn} viruses**
- **Columbia root-knot nematode**
- **Golden and Pale cyst nematode**

LABORATORY ANALYSES ARE REQUIRED FOR THE POSITIVE IDENTIFICATION OF A QUARANTINE PEST.

Potato Wart (*Synchytrium endobioticum*)

Pathogen. The potato wart fungus persists in the soil for up to 30 years as resting spores (sporangia). The spores may be introduced to healthy fields by infected seed and by farm equipment carrying infested soil. Manure from animals fed with infested potatoes will also spread the resting spores.

Disease development. Cool, rainy weather favours disease development. In the spring, the resting spores release zoospores, which are able to move in soil water to reach and infect tubers, stolons and stems. After infection, the fungus produces a structure that releases more zoospores. These zoospores infect neighbouring healthy cells. This cycle of infection and zoospore release may repeat several times during the season. Infected and surrounding cells enlarge or undergo rapid division, forming galls. Under stress conditions, zoospores may fuse in pairs and infect potatoes to form winter sporangia. Winter sporangia contaminate the soil as galls decay.

Symptoms. Wart galls form on tuber eyes, on the stolon bud and on stem tissue, including the base of the stem. Occasionally, warts may develop on leaves, flowers and the upper sections of stems. There may be a reduction in plant vigour.

540 | Below-ground galls are white. As they grow older, they darken and decay. They range from 1–8 cm or more in diameter.

541 | Above-ground warts turn green, as tubers do, when they are exposed to light.

542 | Tuber severely infected with potato wart. The entire tuber often becomes warty. Warts are not solid, but have a soft and pulpy texture.

PVY^n, Tobacco Veinal Necrosis Strain of Potato Virus Y

Pathogen. The virus persists in potato tubers. Volunteer plants produced from infected tubers left in the field after harvest are a source of the virus as well. Potatoes, tobacco and ground cherry weed are the main hosts.

PVY^n is identified in the laboratory using serological tests and in the greenhouse by symptoms on inoculated tobacco plants.

Disease development. Several aphids can spread PVY^n on potato fields, but the green peach aphid is the main vector.

Symptoms. Although symptoms are rare, yield reductions of up to 30% may occur. PVY^n is very destructive to tobacco.

543 | Symptoms of PVY^n on potato plants are rare. Some varieties develop symptoms similar to mosaic. This symptom has also been associated with PVY^{ntn}.

544 | Foliar symptoms of PVY^n on tobacco leaf.

PVY^{ntn}, Potato Tuber Necrotic Ringspot Strain of PVY^{n}

Pathogen. The virus persists in seed potato tubers and is spread by aphids.

Symptoms. On tubers, PVY^{ntn} causes superficial necrotic rings that protrude slightly from the skin. Symptoms appear around harvest and the disease develops rapidly in storage for the next three to eight weeks.

The development of symptoms requires warm temperatures in the latter stages of growth in the field and in storage. Infected tubers may be symptomless if temperatures are low. PVY^{ntn} may also cause severe chlorotic mosaic in leaves.

PVY^{ntn} can sometimes overcome resistance on varieties that are resistant to potato virus Y.

545 | PVY^{ntn} necrotic lesion.

546 | Tubers with more than one necrotic ring on their surface.

Brown Rot, Bacterial Wilt (*Ralstonia solanacearum*, race 3-biovar 2)

Pathogen. *Ralstonia solanacearum* (Rs) is a bacterial plant pathogen that has a very wide host range. Rs has been classified into various races and biovars. Most races of the bacterium, and their associated diseases, appear to be limited to tropical, sub-tropical and warm temperate climates, and thus would pose no long-term threat to agriculture in cool temperate climates.

However, one particular race of the bacterium, termed race 3-biovar 2, or the "potato race," is not known to occur in the United States or Canada. In recent years, it has been found in some temperate areas of Europe, mainly on potatoes but also on tomatoes and a few weed species. This race of the bacterium is now considered a quarantine pest in Europe, Canada and the United States.

The potato race has a narrow host range. It infects potatoes, geraniums, tomatoes, eggplants, peppers and nightshade weeds. Bittersweet nightshade has latent infections.

The bacterium can be soil- and seed-borne. It survives poorly in the absence of water. Contaminated irrigation water may also be a significant source of infection.

Disease development. Although high temperatures and high soil moisture favour the development of Rs, race 3-biovar 2 is more pathogenic at lower temperatures. It invades a plant mainly through injured roots. Once inside the plant, the bacteria multiply and move to the vascular tissues. Infection eventually leads to wilting of the plant as the xylem vessels get blocked by the bacterium. The end result is plant death.

Bacteria can move from the roots of infected plants to the roots of nearby healthy plants.

Symptoms. Brown rot causes foliage to wilt rapidly. A stem cross-section usually reveals vascular browning. The eyes and the vascular tissue of infected tubers appear greyish-brown.

Glistening beads of bacterial slime ooze freely from the vascular tissue of freshly cut stems and tubers. A sticky exudate may form at tuber eyes or at the stem end of the tuber. Soil sticks to the tuber where bacterial slime has emerged.

Brown rot and ring rot have similar symptoms, and a laboratory test is necessary for a definitive identification.

547 | Upper leaves wilt during the heat of the day, but recover at night. This is usually followed by permanent wilting and the death of the plant.

548 | The vascular ring shows a grey-brown discolouration. A pale bacterial slime oozes freely from the diseased tissue.

549 | In severely infected tubers, the rot extends beyond the vascular tissue.

550 | External appearance of a tuber severely infected with brown rot. Often, bacterial ooze exudes from the eyes and stem end.

Brown Rot Lookalike

- **Bacterial ring rot** (see page 85).

Some Differences Between Ring Rot and Brown Rot Symptoms

RING ROT	BROWN ROT
Bacterial slime is cream-coloured	Bacterial slime is greyish-white
Bacterial slime oozes when tuber is pressed	Bacterial slime oozes more freely
Cracks on tuber surface	Soil sticks to bacterial ooze at the eyes

Golden Nematode (*Globodera rostochiensis*)

551 | Golden-yellow cysts on potato roots.

Potato Rot Nematode (*Ditylenchus destructor*)

552 | Tubers showing symptoms caused by the potato rot nematode.

Columbia Root-knot Nematode (*Meloidogyne chitwoodi*)

553 | Galls produced in tubers give the skin a rough appearance.

554 | Females are visible just below the tuber surface.

Appendix A—Photo Credits

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Appendix B—Metric Conversions

Metric Units

Linear Measures (length)

10 millimetres (mm)	=	1 centimetre (cm)
100 centimetres (cm)	=	1 metre (m)
1000 metres	=	1 kilometre (km)

Square Measures (area)

100 m × 100 m = 10,000 m^2	=	1 hectare (ha)
100 ha	=	1 square kilometre (km^2)

Cubic Measures (volume)

Dry Measure

1000 cubic millimetres (mm^3)	=	1 cubic centimetre (cm^3)
1,000,000 cm^3	=	1 cubic metre (m^3)

Liquid Measures

1000 millilitres (mL)	=	1 litre (L)
100 L	=	1 hectolitre (hL)

Weight-Volume Equivalents (for water)

(1.00 kg) 1000 grams	=	1 litre (1.00 L)
(0.50 kg) 500 g	=	500 mL (0.50 L)
(0.10 kg) 100 g	=	100 mL (0.10 L)
(0.01 kg) 10 g	=	10 mL (0.01 L)
(0.001 kg) 1 g	=	1 mL (0.001 L)

Weight Measures

1000 milligrams (mg)	=	1 gram (g)
1000 g	=	1 kilogram (kg)
1000 kg	=	1 tonne (t)
1 mg/kg	=	1 part per million (ppm)

Dry-Liquid Equivalents

1 cm^3	=	1 mL
1 m^3	=	1000 L

Application Rate Conversions

Metric to Imperial (Approximate)

litres per hectare × 0.09	=	gallons per acre
litres per hectare × 0.36	=	quarts per acre
litres per hectare × 0.71	=	pints per acre
millilitres per hectare × 0.015	=	fluid ounces per acre
grams per hectare × 0.015	=	ounces per acre
kilograms per hectare × 0.89	=	pounds per acre
tonnes per hectare × 0.45	=	tons per acre

Imperial to Metric (Approximate)

gallons per acre × 11.23	=	litres per hectare (L/ha)
quarts per acre × 2.8	=	litres per hectare (L/ha)
pints per acre × 1.4	=	litres per hectare (L/ha)
fluid ounces per acre × 70	=	millitres per hectare (mL/ha)
tons per acre × 2.24	=	tonnes per hectare (t/ha)
pounds per acre × 1.12	=	kilograms per hectare (kg/ha)
ounces per acre × 70	=	grams per hectare (g/ha)

Calculating Parts per Million (ppm)

1 ppm	=	1 g active ingredient per 1000 L water

Liquid Equivalents

Litres/Hectare		*Approximate Gallons/Acre*
50	=	5
100	=	10
150	=	15
200	=	20
250	=	25
300	=	30

Dry Weight Equivalents

Grams or Kilograms per Hectare		*Ounces or Pounds per Acre*
100 grams	=	1 1/2 ounces
200 grams	=	3 ounces
300 grams	=	4 1/4 ounces
500 grams	=	7 ounces
700 grams	=	10 ounces
1.10 kilograms	=	1 pound
1.50 kilograms	=	1 1/4 pounds
2.00 kilograms	=	1 3/4 pounds
2.50 kilograms	=	2 1/4 pounds
3.25 kilograms	=	3 pounds
4.00 kilograms	=	3 1/2 pounds
5.00 kilograms	=	4 1/2 pounds
6.00 kilograms	=	5 1/4 pounds
7.50 kilograms	=	6 3/4 pounds
9.00 kilograms	=	8 pounds
11.00 kilograms	=	10 pounds
13.00 kilograms	=	11 1/2 pounds
kilograms	=	13 1/2 pounds

Metric Conversions

5 mL	=	1 tsp
15 mL	=	1 tbsp
28.5 mL	=	1 fl. oz.

Handy Metric Conversion Factor

Litres per Hectare x 0.4 = Litres per Acre

Kilograms per Hectare x 0.4 = Kilograms per Acre

Conversion Tables—Metric to Imperial

Length		
1 millimetre (mm)	=	0.04 inch
1 centimetre (cm)	=	0.40 inch
1 metre (m)	=	39.40 inches
1 metre (m)	=	3.28 feet
1 metre (m)	=	1.09 yards
1 kilometre (km)	=	0.62 mile
Volume (liquid)		
1 millilitre (mL)	=	0.035 fluid ounce
1 litre (L)	=	1.76 pints
1 litre (L)	=	0.88 quart
1 litre (L)	=	0.22 gallon (Imp.)
1 litre (L)	=	0.26 gallon (U.S.)
Weight		
1 gram (g)	=	0.035 ounce
1 kilogram (kg)	=	2.21 pounds
1 tonne (t)	=	1.10 short tons
1 tonne (t)	=	2205 pounds
Pressure		
1 kilopascal (kPa)	=	0.15 pounds/in^2
Area		
1 square centimetre (cm^2)	=	0.16 square inch
1 square metre (m^2)	=	10.77 square feet
1 square metre (m^2)	=	1.20 square yards
1 square kilometre (km^2)	=	0.39 square mile
1 hectare (ha)	=	107,636 square feet
1 hectare (ha)	=	2.5 acres
Volume (dry)		
1 cubic centimetre (cm^3)	=	0.061 cubic inch
1 cubic metre (m^3)	=	1.31 cubic yards
1 cubic metre (m^3)	=	35.31 cubic feet
1000 cubic metres (m^3)	=	0.81 acre-foot
1 hectolitre (hL)	=	2.8 bushels
Speed		
1 metre per second	=	3.28 feet per second
1 metre per second	=	2.24 miles per hour
1 kilometre per hour	=	0.62 mile per hour
Temperature		
°F	=	(°C × 9/5) + 32

Conversion Tables—Imperial to Metric		
Length		
inch	=	2.54 cm
foot	=	0.30 m
yard	=	0.91 m
mile	=	1.61 km
Area		
square foot	=	0.09 m^2
square yard	=	0.84 m^2
acre	=	0.40 ha
Weight		
ounce	=	28.35 g
pound	=	453.6 g
ton	=	0.91 tonne
Volume (dry)		
cubic yard	=	0.76 m^3
bushel	=	36.37 L
Volume (liquid)		
fluid ounce (Imp.)	=	28.41 mL
pint (Imp.)	=	0.57 L
gallon (Imp.)	=	4.55 L
gallon (U.S.)	=	3.79 L
Pressure		
pound per square inch	=	6.90 kPa
Temperature		
°C	=	(°F - 32) × 5/9

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