3.6 Pest Management

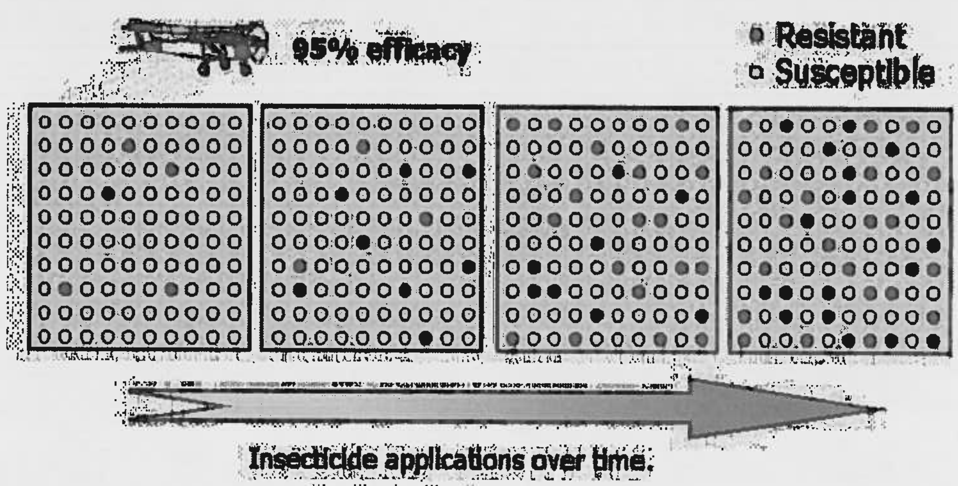
Apply only pesticides, which are registered for use in Canada and where there is a defined maximum residue limit (MRL) in the country of export. Countries, such as the United States, will not accept food with pesticide residues that are not approved by the Environmental Protection Agency. Consult with the potato processor or packer for a list of approved pesticides.

Apply only pesticides, which are registered for use in Canada and where there is a defined maximum residue limit (MRL) in the country of export.

3.6.1 Pesticide Resistance Management (Mark S. Goettel, Robert E. Blackshaw)

Selective breeding is an important tool in agriculture. Through selection of important traits, breeders have been able to produce the diversity of high yielding, high quality crops used in food production. Unfortunately, another form of selective breeding is detrimental. Through repeated application of pesticides, producers are inadvertently selecting resistant "breeds" of insects, weeds and diseases (Figure 3.6-1).

Figure 3.6-1 How Resistance Developments



All natural populations have a wide variety of genetic traits. Within a population, there may be a few individuals that are naturally resistant to a particular pesticide. Pesticide resistance develops when a pest population is constantly being selected through repeated use of pesticides with a similar mode of action. The few surviving individuals multiply and eventually replace the susceptible population. The rate of increase of the resistant individuals within the population depends on the frequency of application and the reproductive potential of the pest in question.

Once resistance is established, pesticides within that chemical group are no longer effective. Weed resistance to herbicides is becoming more prevalent on the prairies and may affect weed management in potatoes. Populations of wild oats and green foxtail are known to be resistant to Group 1 herbicides (Poast Ultra, Select, Hoegrass 284). The Colorado potato beetle is notorious for its ability to have resistant populations selected, sometimes within two years after the introduction of a chemical with a new mode of action. Populations of the Colorado potato beetle in eastern Canada and most of the United States are resistant to many chemicals (Carbamates, Organophosphates, Organochlorines and Pyrethroids), forcing producers to rely on new chemical groups. Within the last several years, populations of the beetle resistant to most conventional insecticides have surfaced in Manitoba. To date, no insecticide resistance has been detected in Saskatchewan and Alberta.

The first signs of resistance are incomplete control of the pest after pesticide application. With weeds, this often appears as a healthy weed patch within a field where most weeds have been well controlled. However, before assuming resistance, other factors that could be responsible for pesticide failure must first be ruled out. Such factors include improper application (clogged nozzles, drift etc.), unfavourable weather (rain following application, wind, drought, etc.), and emergence of new pests (egg hatches, weed germination, etc.). If you suspect resistance, then you are strongly encouraged to contact your provincial potato extension officer.

Managing to prevent resistance to pesticides.
Prevention is the key strategy in resistance management. Once resistance has established, there is no "cure". If available, alternative pesticides must be used. The development of pesticide resistance can be delayed by rotating between different groups (classes or families) of the pesticide, as each group tends to have a different mode of action. Pests or their offspring that survive an application would be killed by a pesticide from a different group in the following application. The rotation between pesticide groups could occur within the same or following season Pesticide resistance management through rotation of pesticide groups is only possible in situations where totally resistant populations are not yet present. Adequate record keeping of pesticide use is critical when rotating pesticides over years to minimize resistance development.

Prevention is the key strategy in resistance management. The development of pesticide resistance can be delayed by rotating between different groups (classes or families) of the pesticide.

Continued dependence on chemicals as the sole method of pest control is a sure recipe for the development of pesticide resistance.
Agronomic practices can play an important role in managing pests and the development of pesticide resistance. For instance, a cereal crop planted after potato harvest to protect soil from erosion may also aid in controlling weeds. Crop residues shade weeds that require light to germinate and physically impede growth of young seedlings. Additionally, rye is known to contain allel chemicals that inhibit weed germination and growth. To manage Colorado potato beetle, plant the potato crop at least 650 feet (200 m) from last year's crop. A significant number of beetles will over-winter in the previous field. The further the distance between the current potato crop and the source of over-wintering adults, the less chance the beetles will survive the journey to the new field. Refer to the sections on weed, insect and disease control below for more alternative pest control strategies that reduce dependence on chemical applications.

By implementing the following pesticide resistance management practices today, growers will ensure that there are more pesticides to choose from in the future.

1. Monitor your fields and apply pesticides only when necessary. Pest populations below an economic threshold can be beneficial, as they provide food for natural enemy populations and also serve to ensure genetic diversity within the population (i.e. they interbreed with resistant individuals, thereby diluting the resistance trait).
2. Employ agronomic practices that play a role in managing pest populations. For example, maintaining at least 650 feet (200m) between the previous and present year's potato fields will reduce the survival of over-wintering Colorado potato beetle adults.
3. Apply pesticides only to areas of the field where the pest is a problem.
4. Alternate between different groups of pesticides. Remember to take into account the pesticides you may wish to apply to control other pests later in the season. For example, if you expect to use an insecticide to control aphids later in the season, then choose an insecticide from a different family to control Colorado potato beetles early in the season. Alternate pesticide groups within and between years. Refer to your provincial crop protection manual for a listing of the different chemical groups.
5. Never repeat a treatment because adequate control was not obtained. This is the first sign that resistance is high. Always change chemical groups if repeated treatments are necessary.
6. Contact your provincial potato crop specialist if you suspect resistance is present. The sooner resistance is detected; the earlier alternatives can be implemented.

For more information regarding pesticide resistance management and grouping of chemicals, consult your provincial crop protection guide.

Monitor your fields and apply pesticides only when necessary. Pest populations below an economic threshold serve to ensure genetic diversity within the population (i.e. they interbreed with resistant individuals, thereby diluting the resistance trait).

3.6.2 Insect management (B. Elliott)

Chewing insects can cause serious yield and quality losses in potatoes by feeding on the leaves, stems or tubers. Sucking insects such as aphids and leafhoppers cause indirect losses by transmitting viral diseases.

Effective insect control depends on a combination of cultural and chemical practices. Good control of weeds and volunteer potatoes in and around potato fields removes alternative food sources for many of the pest insects, particularly early in the spring before the crops have emerged from the ground. Field rotation will reduce the numbers of many pest insects, particularly Colorado potato beetles. Insecticides can reduce wireworm populations, however, regardless of an insecticide application, growers can expect reduced potato quality if they plant potatoes immediately following pasture or perennial grasses. Potato plants are more severely affected by insect pests when they are also suffering other stresses, so adequate moisture and fertility, as well as effective disease and weed management will minimize losses due to insects. Despite the effectiveness of cultural practices in reducing insect populations, insecticides are still required in most potato insect control programs.

Colorado Potato Beetle

Adult Colorado potato beetles are orange and black striped insects about 1/4" (0.6 cm) long (Plate 3). Adult beetles over-winter in the soil and in response to warmer temperatures in late May or early June they emerge and migrate by walking or flying to potato plants. Beetles cannot fly except when the temperature exceeds approximately 77°F (25°C) for several hours, so the majority of beetles walk to potato fields.

Once in the potato field, beetles feed; mate and the females lay orange eggs in groups of approximately 30 on the underside of potato leaflets (Plate 4). Eggs are laid over a period of several weeks in June, and usually hatch within 5 - 10 days. Because of the length of the egg laying period, some larvae may have completed development before others have hatched. Unless controlled, larvae are present in the field in late June and throughout July (Plate 5).

The young larvae are brick red with black spots; older larvae are orange with black spots. Larvae are slow moving, soft-bodied, hump-backed and feed on the leaves of the potato plant. Larvae are generally found near the top of the plant and they seldom move far from the plant on which they hatch, unless all the leaves are eaten. There are four larval stages, which differ mainly in size; newly hatched, first-stage larvae are about 1/10" (2.5 mm) long; fully-grown larvae of the fourth stage are about 2/5" (10-12 mm) long. From hatching to completion of the larval stage takes 2-3 weeks, and larvae feed almost continuously, except when moulting from one stage to the next. The third and fourth stage larvae (over 1/5" or 5-6 mm long) cause the most damage to the potato plant as they consume about seven times as much food as the previous two stages. In addition to the damage caused by feeding, the Colorado potato beetle is capable of transmitting spindle tuber virus and bacterial ring rot.

When the larvae have completed their development, they enter an inactive pupal stage in the soil. After 1 - 2 weeks, adults emerge from the pupae and begin to feed on the potato plants. Some years, the new adults may lay eggs that hatch into larvae in August or September. These larvae frequently die of starvation or cold, and do not contribute to future populations of Colorado potato beetles. Defoliation by larvae just before harvesting has negligible effect on yield. In late summer, the adults respond to senescence of potato foliage, shorter days and cooler temperatures by burrowing deep in, or close to, the potato fields in which they were feeding.

Using cultural control methods and augmenting them with insecticides only when necessary to prevent loss can reduce the development of insecticide resistance. The single most important cultural control method for Colorado potato beetle is field rotation where there is a 650 ft. (200m) separation between last season's and this season's potato fields. Colorado potato beetles usually over-winter close to last season's potato fields and are very vulnerable when they emerge in the spring if no food plants are close at hand. A 650 ft. (200m) separation between consecutive years' crops will reduce the survival rate of migrating adult Colorado potato beetles.

The single most important cultural control method for Colorado potato beetle is field rotation where there is a 650 ft. (200m) separation between last season's and this season's potato fields. Colorado potato beetles usually over-winter close to last season's potato fields and are very vulnerable when they emerge in the spring if no food plants are close at hand. Separation between consecutive years' crops will reduce the survival rate of migrating adult Colorado potato beetles.

Migrating Colorado potato beetles will often be concentrated at the edge of the potato crop. This phenomenon is called the edge effect. The edge effect occurs because under normal spring climactic conditions the adult beetles walk into new potato fields in the spring, and tend to stop after encountering the first plants. In this case, the density of females laying eggs, and of the resulting larvae, is much higher at the edge than in the middle of the field. There may be no Colorado potato beetles in the middle of extremely large fields. The pattern of higher densities at the edge is less distinct when spring temperatures are abnormally warm, allowing adult beetles to fly into the field. The pattern may also change if the plants emerge unevenly. The first plants to emerge may attract more beetles.

The edge effect provides an opportunity to reduce the area where Colorado potato beetle densities are high and where insecticide application is required. The proportion of edge effect is reduced in larger relative to smaller fields. Increasing the size of field increases the proportion of the field where Colorado potato beetle densities are lower, and where insecticide treatments may not be required.

Insecticides should be applied only when they are justified economically; that is, when the cost of control is exceeded by the benefits of increased marketable yield. Applying insecticides when they are not economically justified reduces net return and promotes development of resistance. The level of insect population above which control is economically justified is called the economic threshold. Economic thresholds have been determined for Russet Burbank and Norland for the normal control situation in which spray applications are applied against larval populations in early summer.

The economic thresholds for Russet Burbank and Norland are quite low, because if the larvae are not controlled they will mature into adults that will also feed on the potato plants. Continuous defoliation throughout the season has a marked effect on yield. However, plants are quite tolerant of defoliation early in the season, so large numbers of larvae can be allowed to feed for a short time.

Insecticides should be applied only when they are justified economically; that is, when the cost of control is exceeded by the benefits of increased marketable yield.

The decision to make an insecticide application is not based entirely on the number of feeding larvae exceeding the economic threshold. The degree to which hatching is complete and the extent of defoliation must also be considered. Hatching takes place over a 5 - 10 day period, depending upon environmental conditions. The larvae are protected from an insecticide application while inside the egg. If a spray is applied during the early stages of hatching, the unhatched larvae will not be controlled and a second application may be required later in the season. Knowing that the plant is tolerant to defoliation early in the season allows for the insecticide application to be delayed until a greater portion of the larvae have hatched.

Larvae that have matured and are pupating in the soil will not be controlled by an insecticide application. If a spray is applied too late in the season while some larvae are pupating, a second application may be required when the pupating larvae emerge as adults.

The information contained in the box below shows how to calculate the economic threshold for Russet Burbank and Norland potato varieties.

<u>Calculation of the economic threshold.</u>

Calculate the economic threshold for each field or group of fields <u>before</u> sampling for Colorado potato beetle, using the following formula:

$$\text{Economic threshold} = \frac{\text{(Control Cost \$/ac or \$/ha) x 1800 (Russet Burbank) or 600(Norland)}}{\text{Expected Gross Revenue (\$/ac or \$/ha)}}$$

Note: The same units must be used for Control Cost and Expected Gross Revenue.

The economic threshold is expressed in terms of the <u>total number of large larvae (longer than 1/5" or 5 mm) and adults</u> on a 20-plant sample.

<u>Example</u>: Control costs are $15 per acre and the expected gross revenue is $1500 per acre; economic threshold is 18 larvae per 20-plant sample.

Scouting for Colorado potato beetle larvae should begin 2 weeks after crop emerges. Twice weekly sample along field edges as this is where beetles will first appear, providing proper crop rotations are employed. Edge sampling consists of walking around the edge of the field and at corners and the midpoint of each side, counting the total number of the specified stages on 20 plants. Do not sample plants less than 1 yard (1 metre) from the field edge. Do not sample immediately neighbouring plants, skip a plant in between or move to the next row over. Record the number of beetles and perform the economic threshold calculation. Note also the percent defoliation. If the result of sampling indicates that the economic threshold has not been reached, repeat the sampling at the next scheduled interval. If the economic threshold has been exceeded and 10% or more of the foliage has been consumed, sample the field intensively to determine which parts of the field require treatment and apply insecticide immediately to areas where defoliation exceeds 10%. Sample again about 3 days after insecticide application (observe re-entry precautions on insecticide label) to determine whether application gave effective kill. If the insecticide was effective, sample intensively twice weekly until 6 weeks after plant emergence. If the total numbers of all larval stages and adults again exceed the economic threshold, apply the insecticide as soon as the largest larvae reach third stage more than 1/5" (5 mm).

Flea Beetles

Both the potato and tuber flea beetle species exist on the Prairies. Both types produce "shot holes" in the leaves (Figure 3.6-2), but only the tuber flea beetle causes tuber injury. The potato flea beetle sometimes reaches economic threshold levels in Manitoba, but it is not a problem pest in Saskatchewan and Alberta. The tuber flea beetle was first reported in Alberta in 1974, but has not yet become a significant pest. There is no evidence that it has expanded its range eastward.

Figure 3.6-2 "Shot holes" caused by a potato flea beetle

Potato flea beetle adults are black beetles about 1/10" (2 mm) long; their legs and antennae are brown (Plate 6). The beetles jump actively, particularly when disturbed, but they seldom, if ever, fly. The potato flea beetle over winters as an adult among litter or undergrowth either in, or close to, the potato fields in which it fed the previous summer. In spring, the adults move to potatoes, where they feed on the foliage of newly emerged potato plants. If potatoes have not yet emerged, the adults feed on weeds or volunteer plants. In Manitoba, the spring adults are generally present in relatively small numbers. They feed on potato foliage making small round holes "shot holes" or scars in the leaf tissue. The eggs are laid in the soil. The larva, which is a slender white grub with a brown head and tiny legs, feeds on rootlets, and occasionally penetrates into developing potato tubers. When larvae are mature, they are about 1/5" (5 mm) in length. They moult into pupae, which are found in cells close to plant roots. Adults emerge from pupae and feed on potato foliage in late July and August. Populations of adults at this time may be high, and considerable "shot-holing" of potato foliage can result.

Potato flea beetle adults damage the potato plant by defoliation "shot holes", which can cause yield loss.

Direct damage from potato flea beetle is mainly attributable to defoliation "shot holes" of plants during late summer. Occasionally, larval feeding may cause tubers to be pimply or to have short tunnels bored into the tuber to a depth of 1/10" (3 mm) or less. Most of this injury can be removed by peeling. Fungal diseases, such as Verticillium wilt, Fusarium dry rot, rhizoctonia and common scab have been reported to be associated with potato flea beetles. Transmission of bacterial diseases and spindle tuber viroid may also occur.

Cultural control measures for potato flea beetles include crop rotation, field rotation where there is a separation of this year's potato fields from last year's potato crops and control of weeds in the nightshade family. It has been noted that beetles are more abundant where potato crops are adjacent to uncultivated areas.

Insecticides should be applied to the late summer generation of flea beetle adults if feeding damage is severe. Early maturing potato varieties are more susceptible to feeding damage than late maturing varieties. Emergence of flea beetles from pupation occurs over several weeks, so applications should be delayed as long as possible after the beginning of emergence, as insects in the soil will be unaffected by the insecticide. At the time of this application, Colorado potato beetle adults may also be on the plants, so it is important that the insecticide used to control flea beetles not be from the same group that was used to control of Colorado potato beetle larvae earlier in the season.

Late summer populations of potato flea beetles below 65 per plant for Norland and 300 per plant for Russet Burbank do not cause economic yield loss in unstressed potato plants. However, plants, which have previously experienced defoliation from other insects are very sensitive to potato flea beetle injury, and may suffer economic loss with late summer populations of as few as 22 flea beetles per Russet Burbank plant. Economic injury can also be estimated by assessing the percent defoliation. Early in the season, healthy plants can withstand 10% defoliation (regardless of the insect causing defoliation) without an economic loss. Later in the season (August), healthy potato plants can withstand up to 25% defoliation without suffering a serious yield loss.

Aphids

Aphids are small, soft-bodied insects that originate mostly from local populations, but some arise as migrants blowing in from the United States (Plates 7 & 8). After appearing in fields in mid-June to early July the population can increase rapidly to peak in the second or third week of August then decrease by early September. Although aphids are normally wingless, winged forms may appear when environmental conditions in the field deteriorate or as a response to overpopulation.

Aphids transmit viruses and in rare circumstances reduce marketable yield. Identification and control of aphids is important in potato seed production, where the tolerance for total virus levels is extremely low (Table 6.5-1). Aphids control is less important in processing and table production where only the potato leaf roll virus (PLRV) causes an economic loss (Plates 26 and 27). PLRV, which is transmitted by the green peach aphid, causes net necrosis in the tuber and reduces market quality. In rare circumstances, high populations of feeding aphids will remove enough plant sap to damage the crop and reduce yield. The plant damage resulting from feeding aphids occurs in small-localized areas of the field referred to as "aphid holes".

Potato Aphids (PA)

The potato aphid is the largest and most numerous of the aphid species found in potato fields. Potato aphids are up to 1/10th of an inch (3.5 mm) long, and are usually green; however individuals may be red, brown, yellow, orange, or even purple. The body of the potato aphid is elongate and pointed at the hind end. These aphids are found on the underside of potato leaves. Potato aphids over-winter on the Canadian Prairies in the egg stage on rose bushes. Wingless females hatch from these and produce live young females, some of which develop wings and fly to new hosts. There are several generations of winged and wingless forms during the summer. Winged males and females fly to rose bushes during late summer and early fall where the females give birth to wingless females that mate with the winged males and produce the winter eggs.

Aphids are small, hard bodied insects that transmit viruses and in rare circumstances reduce marketable yield.

Potato aphids are efficient vectors of mild and rugose mosaic (PVY) viruses. The potato aphid is a poor vector of potato leaf roll virus when compared to the green peach aphid (discussed below). In spite of being a poor vector of PLRV, extremely high populations of potato aphids may be as much of a factor in PLRV transmission as a small population of green peach aphids. In addition to virus spread, a toxin produced by the potato aphid is injected during the feeding process and may cause mottling, curling or premature death of the leaflets. Large quantities of honeydew excreted by the insects may cause the tops of the plants to become sticky if populations are extreme.

Green Peach Aphids (GPA)

Green peach aphids are smaller than the potato aphid (not more than 1/8" or 2.3 mm long), and the body is egg-shaped and lacks a pointed hind end. GPA varies in colour from creamy white to peach and even pinkish, but is most often pale green. In the green peach aphid, the antennal tubercles are prominent and inward pointing (appearing like a bottle cap opener). The GPA does not over winter outdoors in Manitoba. Populations may be maintained from year-to-year by over wintering in greenhouses, but it is likely that many populations migrate from the southern United States. In the spring, winged females are carried outside with bedding plants and then fly to weeds. They multiply rapidly for several weeks and by July they move to potatoes and fly from field to field, transmitting viruses to healthy plants. Winged females usually appear in the fall and some of these are successful in becoming established in greenhouses or root cellars.

Green peach aphids are highly efficient vectors of the potato leaf roll and rugose mosaic (PVY) viruses. Like potato aphids, they inject a toxin during the feeding, which causes leaf deformities, streaking, and even leaflet death.

Buckthorn Aphid (BA)

The buckthorn aphid is smaller than the potato aphid (1/16-1/8" or 1.2 – 2.0 mm) and the same shape as the green peach aphid. They are relatively easy to tell apart based on the antennal tubercles, which are small and hardly noticeable in the buckthorn aphid. In the green peach aphid, the antennal tubercles are prominent and inward pointing (appearing like a bottle cap opener). BA over-winter as eggs on buckthorn plants. In the spring, the eggs hatch and the larvae move from host plant to weeds, and by mid-July to potato plants. Late in the summer, the winged males and females give birth to wingless forms that mate and lay eggs for over-wintering. Summer populations are usually localized but, in those fields, this may be the most abundant species of aphid and, in a dry year, it can spread throughout the field. Buckthorn aphids are not as efficient at vectoring PLRV, but are a very effective vector of PVY.

Scouting and Control of Aphids

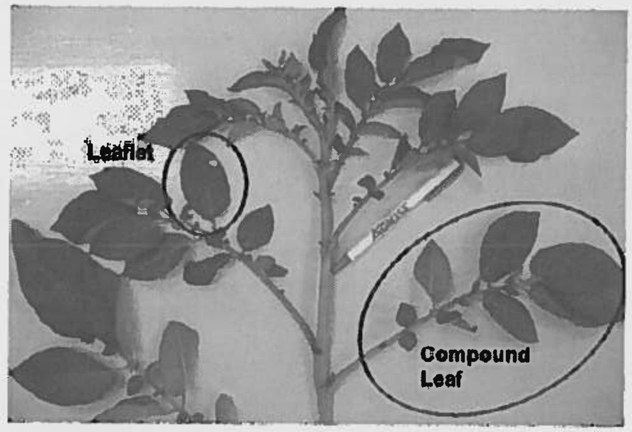
Seed potato growers must control problem populations of aphids early to maintain seed quality. The amount of potato leaf roll virus (PLRV) that spreads in a field is influenced by the population of aphid vectors in the field, the incidence of PLRV in the aphid vector and the incidence of PLRV in the field. To determine the potential for leaf roll virus spread, aphids must be identified and counted starting in early July when aphids begin to occur in potato fields. Divide fields into four plots, 25 leaves are taken from each of the four plots, and potato aphids and green peach aphids are counted on each compound leaf sampled (figure 3.6-3). A ten-powered magnifying lens is required to identify young aphids. The large body size and elongated shape of the potato aphid distinguish it from the smaller oval-bodied green peach aphid. Green peach aphids are typically found on the lower 1/3 of the canopy, nearer the ground. BA and PA are typically found in the upper 2/3 of the canopy. It should be noted that depending on how quickly the aphids are located after colonizing a plant, green peach aphids might still be found in the upper 2/3 of the canopy if insufficient time has passed for it to move to the lower canopy.

Seed potato growers must control problem populations of aphids early to maintain seed quality.

The number of aphids detected in a count is totalled and compared with the economic threshold for that field. Thresholds for green peach aphid are based on sampling 100 lower leaves (25 lower leaves in each of 4 areas of a field). The economic threshold is 3-10 aphids per 100 lower compound leaves for seed and 30-100 aphids per 100 lower leaves for processing. There currently are no established economic thresholds for buckthorn and potato aphids.

In order to accurately identify aphid species, consult with an agrologist. Check with your provincial specialist for recommendations on which registered products are most effective for controlling aphid populations. Repeated applications of other insecticides may select for resistance very rapidly, and the second and subsequent uses of the compound may not be effective.

Figure 3.6-3 Compound Leaf (Courtesy of Agvise Laboratories)



Leafhoppers

The potato and the six-spotted leafhopper species occur in Western Canadian potato fields. The most abundant species is the potato leafhopper, which feeds and reproduces on potatoes. The adult potato leafhopper is an active, narrow-bodied, pale green insect about 1/10th of an inch (3 mm) in length. The wings are pointed and somewhat longer than the body (Plate 9). Potato leafhopper nymphs are found on the underside of potato leaves (Plate 10). They are small, wingless versions of the adult, neon green in colour, and move very quickly in a crab-like motion. Potato leafhoppers do not over winter in Western Canada, but migrate from the southern United States in mid-June. This generation gives rise to a second, larger generation in August. The potato leafhopper injects a toxin into the plant, which results in hopper burn, a yellowing and curling of the tips and margins of the leaflets, which ultimately turn brown and brittle. The damaged plants die prematurely and the yield may be reduced.

The potato leafhopper injects a toxin into the plant, which results in hopper burn, a yellowing and curling of the tips and margins of the leaflets, which ultimately turn brown and brittle. The damaged plants die prematurely and the yield may be reduced.

Economic thresholds are determined by counting the wingless nymphs on compound leaves taken from mid canopy. Sample 100-175 plants from three to five areas of the field. Calculate the average number of nymphs per 10 compound leaves (Figure 3.6-3). The action threshold, at which an insecticide application is needed to prevent hopper burn and yield loss, is 1 nymph per 10 leaves. In years with abundant leafhoppers, this threshold may be exceeded twice, once in the first generation and once in the second generation. However, in many years the threshold is never reached.

The six-spotted leafhopper is normally much less abundant than the potato leafhopper. This species does not reproduce on potatoes, so only winged adult forms will be detected on potato plants. The adult six-spotted leafhopper is a tapered, pale grey-green insect, which flies actively. The insect is about 1/10th of an inch (3 mm) long and the head is marked with paired dark spots. Six-spotted leafhopper eggs over-winter on fall-sown cereals and grasses and hatch in May into tiny, black, wingless nymphs. These reach maturity in about three weeks, and as cereals and grasses mature in early summer, adult six-spotted leafhoppers disperse to other plant species, including potatoes. In addition to this resident population, adults migrate in large numbers from the southern United States.

This leafhopper does little direct damage to potatoes but spreads the pathogen causing aster yellows or purple-top wilt disease. The sucking adults feed on infected plants and then spread the disease to healthy potatoes. This disease is not of economic importance on the Canadian Prairies.

Weed control is the major cultural control method for the six-spotted leafhopper. Weeds provide a place for the insects to breed and are source of the pathogen that causes purple top wilt. Where six-spotted leafhopper populations are large, and especially if purple-top wilt or aster yellows has been found in a grower's field or on neighbouring farms, insecticide control measures must be taken.

Wireworms

Several species of wireworms infest Western Canadian potato fields. Wireworms are the larvae (Plate 11) of slender black beetles known as click beetles. The larvae are elongate-segmented insects that are glossy brown or brownish-white and are usually slightly darker at each end. Adult click beetles emerge in the spring from the soil where they wintered. Shortly after mating, the female beetles lay up to 300 eggs in the soil, usually around grass roots. Eggs hatch within a few weeks, and the larvae begin feeding on root hairs and fungi. At this stage, they are usually overlooked as they are small and the injury they cause is negligible. Larvae go through about ten moults over a period of several years before pupating. With increasing size, their feeding habits change. After two moults, larvae can feed on most underground parts of newly germinating plants. Later stages are increasingly voracious and injurious to roots, seeds and underground storage organs such as potatoes. It is the later larval stages that cause the greatest damage to potatoes. Wireworms may reach 1.2 inches (3 cm) in length and, although they have flexible bodies, they are relatively tough and resistant to crushing. They have three pairs of short legs close to the front end. The rear segment is flattened and either comes to a point or has paired hooks separated by a central gap.

The adults do not attack potatoes, however the larvae feed on potato seed pieces and daughter tubers. Wireworm damage to seed pieces provides an entry point for blackleg and *Rhizoctonia* disease organisms. The greatest damage occurs when larvae tunnel into processing or table daughter tubers, rendering them unmarketable.

Wireworms thrive in grassland, so the most severe damage occurs following pasture. Of the field crops grown on the Canadian Prairies, wireworms prefer cereals. Continuous cropping with cereals favours increased wireworm populations. Non-cereal crops, such as weed-free alfalfa, impair the survival of newly hatched larvae, however, once larvae have completed one season of development they are tolerant of starvation and may be able to survive up to 2 years without a suitable food crop. For this reason, rotation by itself is seldom an effective control measure.

Since transportation in soil on machinery is of the main ways in which many species of wireworms move to new areas, precautions should be taken to prevent this. For example, areas in a field with known infestations can be cultivated or harvested last, and the implements thoroughly cleaned after.

Although wireworms tend to remain in the same area of a field throughout their larval development, they move vertically in the soil to find food, and in response to soil moisture and temperature. Wireworms searching for food detect carbon dioxide and home in on its source. This characteristic can be used to detect wireworms by using baits that give off carbon dioxide. Baiting provides a poor estimate of wireworm density in a field, but it is a quick way of determining whether the pest is present. A mixture of grain corn and wheat should be moistened to start germination and placed into a nylon mesh bag and buried 4 to 6 inches (10-15 cm) into the soil and marked with a flag. Several baits should be buried randomly over the field. Every two weeks, the baits should be excavated and inspected for the presence of larvae.

Continue baiting until wireworm activity is detected or until early September when larvae activity ceases. Baits do not work in soil that is either excessively wet or too dry.

Baits will enable growers to delineate areas of a field where wireworms are present, which may augment evidence of their presence from previous tuber damage. Because of the long lifespan of wireworms, damage may continue in the same field for several years, although severity will depend on weather and crop rotation. At the time of publication, Thimet is the only insecticide registered for control of wireworm. This product will no longer be available after 2004. Alternative fields should be considered if populations of wireworms are high.

Wireworm larvae cause the greatest damage by tunnelling into processing or table daughter tubers, rendering them umarketable.

Variegated cutworm
Variegated cutworm caterpillars occasionally infest potato fields late in the season. This caterpillar is about 1.5-2" (40 to 50 mm) long when mature and grey to dull brown with black stripes along the side. It also has a row of yellow to orange spots along the top line and a prominent black "W" on top of the last body segment. Adults are brown miller moths. Larvae feed on the plants above ground, causing defoliation, but are found in the soil during the day. Field inspection for this pest is best accomplished in the morning. They feed readily on foliage but do not damage the tubers. As with other defoliating pests (CPB, flea beetles), late season potato crops can withstand up to 25% defoliation without suffering yield losses.

3.6.3 Weed management (B. Geisel)

Weeds compete directly with the potato plant for light, water and nutrients. Dense weed infestations restrict growth resulting in smaller tubers, lower dry matter content and poor quality. In addition to reducing yield and quality, weeds:

- Interfere with the harvesting operation.
- Interfere with in-field seed inspections
- Interfere with roguing of seed fields
- Restrict air flow through the canopy, which increases the potential for disease development
- Provide alternate hosts for diseases and the insects capable of spreading disease.

Competition between potatoes and weeds should be minimized from planting to the time of canopy closure; 6 to 7 weeks later. Weeds that emerge after row closure usually will not compete with the potato crop so long as the canopy is uniform and dense. Crop uniformity and density is determined by the stature of the variety and the uniformity of plant spacing. Plant misses as a result of poor quality seed, planting into cold soil or a malfunctioning planter will reduce crop density and competitiveness with weeds. It is important that the planter be operating efficiently not only to produce a high yield, but also to produce a uniform competitive plant stand. See *Planter Operation* in section 3.3.3 *Planting for Better Stand, Yield and Quality.*

Competition between potatoes and weeds should be minimized from planting to the time of canopy closure; 6 to 7 weeks later. Weeds that emerge after row closure usually will not compete with the potato crop so long as the canopy is uniform and dense.

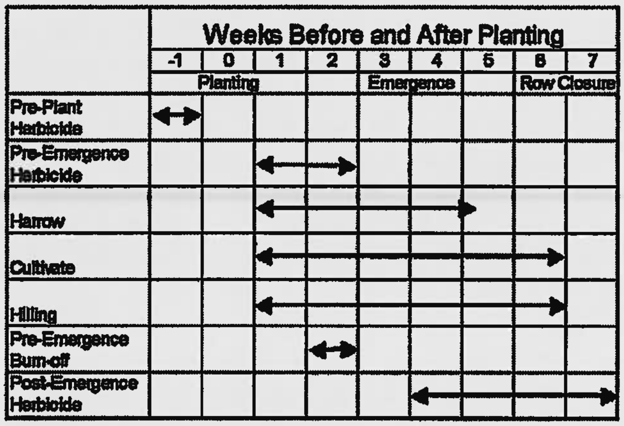
A potato grower's weed control strategy should be an integrated approach consisting of cultural, mechanical and chemical methods to control weeds.

Cultural methods include field selection, management of weeds in crop rotation and preventing the entry of new weeds into a field. Growers should be familiar with weed problems from previous crops because this information is essential for field selection. It is important to select a field free from weed problems, which cannot be controlled by tillage and herbicides used in the production of potatoes. Potato growers should attempt to control perennial weeds such as Canada thistle and quack grass, in other crops in the rotation because there are few herbicides registered for use on potatoes that are effective against these weeds. It is also important to prevent the entry of new weeds into the field via equipment, livestock and manure. Ideally, escape weeds should not be allowed to set seed.

A combination of the following chemical and mechanical weed control methods is used to control weeds in the potato crop: (Figure 3.6-4):

- Herbicides (pre-plant incorporated, pre-emergence, pre-emergence burn-off and post-emergence). Consult with your *Provincial Guide to Crop Protection* for information about pesticides registered for application on potatoes.
- Mechanical (harrowing, cultivation and hilling)

Figure 3.6-4 Timing of Weed Control Operations Based on Number of Weeks Before and After Planting.



Herbicide Weed Control

Pre-plant incorporated herbicides are effective in controlling a broad spectrum of annual weeds early in the season. Incorporation of pre-plant herbicides dries and compacts the soil and buries crop residue, leaving it susceptible to wind erosion. Soil-applied herbicide should only be used in areas that receive adequate rainfall or where irrigation is available to activate the herbicide. Cultivation and hilling will disturb the herbicide treated soil allowing weeds to germinate, so apply pre-emergence herbicides after hilling.

Potatoes emerge approximately 15 to 30 days after planting. In that time, a significant number of weeds can germinate. An application of a non-selective herbicide just prior to emergence of potatoes will control annual weeds and set back perennial weeds. Burn-off herbicides are not affected by tillage operations. If hilling is performed just prior to emergence of potatoes than a pre-emergent herbicide may not be required.

Post-emergent herbicides are most effective when applied to weeds just after emergence and through the cotyledon stage of growth.

Herbigation can be used to apply herbicides in Western Canada. Herbigation is the process of applying an herbicide to the soil or plant surface by injecting the chemical into the irrigation water. Some herbicides are more effective if applied with irrigation water. This is especially true for pre-emergence herbicides that require moisture to be activated. Not all herbicides that are registered for use on potatoes can be applied through herbigation. Consult the chemical manufacturer or your local agricultural representative before herbigating.

It is important that a pre-emergence herbicide be in the top 3 inches (7.5 cm) of soil, when applied by herbigation. The amount of irrigation water required to incorporate the herbicide will depend upon the water holding capacity of the soil, soil moisture status at the time of herbigation and the desired incorporation depth. To ensure uniform chemical distribution, use only centre pivot or linear irrigation systems and apply when wind velocities are less than 10 mph (16 kph). Herbigation should not be carried out without having the proper anti-pollution systems in place to prevent pesticides from entering the water source. Refer to the following publications for information about anti-pollution safety devices on an herbigation system: Alberta Agriculture's *Chemigation Injection in Irrigation Systems* Agdex 753-2, Oregon Statue University's *Chemigation in the Pacific Northwest* PNW 360 or the University of Nebraska's *Anti-Pollution Protection when Applying Chemicals with Irrigation Systems* EC 89-730-B.

Always consult the current edition of your *Provincial Guide to Crop Protection* for detailed information concerning herbicides registered for potatoes, varietal restrictions, application rates, pre-harvest intervals and weeds controlled. Growers should use this reference as a guide and always read the herbicide label for specific instructions.

Mechanical Weed Control

Tillage is an effective tool for controlling annual weeds, however, if performed under the wrong conditions it can have a deleterious effect on the efficiency of harvesting operations, yield and quality. Tillage performed at any stage of growth will dry and compact the soil. Tillage performed when the plants are greater than 6 inches (15 cm) in height will prune roots and damage foliage. These effects can result in more than a 5% loss in yield. Tillage performed under wet conditions, will produce soil clods that will reduce harvesting efficiency and increase the incidence of blackspot bruising. For these reasons, potato growers should rely on herbicides for weed control and perform as few tillage operations as possible. Of the available tillage operations, only hilling is required in the production of potatoes. It is becoming more common for potato growers to perform only a single cultivation-hilling operation just prior to or shortly after emergence.

Tillage is an effective tool for controlling annual weeds, however, if performed under the wrong conditions it can have a deleterious effect on the efficiency of harvesting operations, yield and quality. For these reasons, potato growers should rely on herbicides for weed control and perform as few tillage operations as possible.

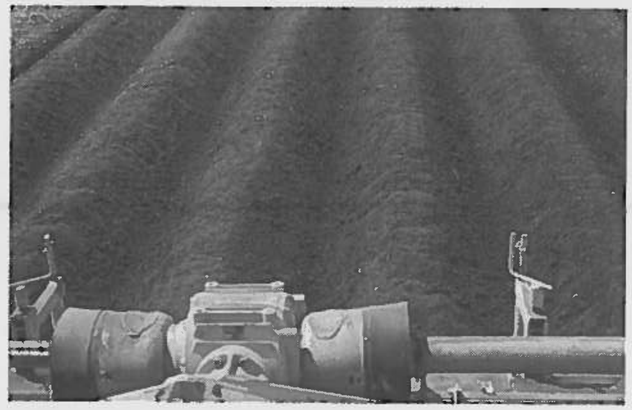
Mechanical tillage operations harrowing, cultivation and hilling operations can be performed before and after emergence; separately or combined (Figure 3.6-4):

Harrowing is performed with spring tooth harrows and if carried out when the weeds are just emerging, it can be an effective method of controlling weeds in the planted row. Harrowing can be performed separately or in combination with cultivation. Harrows should not be used after the plants are 2 inches (5.0 cm) in height, due to excessive damage to the roots, stolons and foliage.

Inter-row cultivation is performed with an S-tine shank cultivator or a rotary hoe and is most effective in controlling annual weeds between the rows. The cultivator can be adjusted to throw soil around the base of the plants, which will bury weed seedlings or it can be equipped with a spring tooth harrow to control weeds in the planted row. The S-tine cultivator is also used to loosen soil, which aids in the hilling operation. Inter-row cultivation should be carried out before the plants are 8 inches (20 cm) in height to avoid excessive root pruning.

Hilling is the only tillage operation necessary in the production of potatoes. The objective of hilling is to cover the daughter tubers with sufficient soil to prevent greening, minimize infection with late blight, minimize frost damage, improve drainage in the area of tuber formation and to facilitate harvest. Rotary hoes, discs, mouldboards, or power hillers equipped with a metal mould are commonly used to shape loose soil into a hill. The hilling implement should be adjusted to produce a wide, flattened hill ideal for protecting the tubers from sunlight, late blight spores and frost (figure 3.6-5). To effectively control weeds, hilling must take place before the weeds get past the two true leaf stage. Hilling can be performed pre or post emergence. Regardless of the hilling implement used, emerged plants should not be covered with soil. This sets the plants back and delays growth. It is recommended that power hilling be carried out prior to emergence to avoid covering the plants. Post-emergent hilling, other than power hilling, should be completed before the plants are 8 inches (20 cm) in height to avoid damage to the roots and foliage.

Figure 3.6-5 Ideal profile of a potato hill (Courtesy of Gaia Consulting Limited)



3.6.4 Disease Management (Tracy Shinners-Carnelley, Piara Bains, Debbie McLaren, Jill Thomson)

Potato plants are susceptible to a wide variety of diseases that can severely reduce yield, quality and storability of tubers. Diseases can occur in the field or in storage and are caused by infectious bacteria, fungi, viruses and other related organisms.

Most infectious potato diseases can be controlled using certified seed, proper sanitary practices, crop rotation, and pesticides. The following are the most serious diseases of potatoes in the Prairies. Consult your provincial Guide to Crop Protection for a list of chemicals registered for control of potato diseases.

Bacterial Diseases

Bacterial Ring Rot (Plate 12)
Bacterial ring rot is a highly infectious disease caused by the bacterium *Clavibacter michiganensis,* formerly known as *Corynebacterium sepedonicum.* This disease can cause serious losses and is a designated pest in provincial Plant Disease Acts. The Canadian Food Inspection Agency has a zero tolerance for bacterial ring rot in seed potatoes.

Foliar symptoms of the disease vary with the potato variety. Symptoms are not always expressed or may be masked by other stresses on the plant. Ring rot may cause wilting of the lower leaves. Leaves on infected plants yellow and the outer edges may roll up and later become brown and brittle. The lower stem of infected plants will exude a milky ooze when cut and squeezed. Tuber symptoms are noticeable as a cheesy cream-coloured liquid that oozes from the vascular ring when tubers are cut at the stem end and squeezed. As the rot progresses, the vascular ring breaks away from the rest of the tuber. Secondary rot organisms may also infect the tubers and make it difficult to distinguish the ring rot symptoms. Severely infected tubers turn dark brown or black and completely rot away inside.

During seed cutting, bacteria from infected tubers are smeared on the cutting knives, consequently healthy seed pieces become infected. Ring rot bacteria can survive for five years in dried potato stems and for two years on dry burlap, plastic or plywood surfaces. The bacteria however, live only a short time in soil and are normally killed between fall and winter if all plant debris is ploughed down. Ring rot bacteria can over-winter in infected tubers that survive the winter in the field or in cull piles.

Control Strategies:

- Plant certified seed
- Thoroughly clean and disinfect equipment, tools, trucks and storages with a quaternary ammonium disinfectant (see section 3.2.3 *Sanitation, Handling and Storage of Seed Lots*), or limit movement of machinery and personnel between operations (especially seed)
- Dispose of any crops infected with ring rot
- Dispose of mildly infected crops by processing out-of-field rather than out-of-storage
- Sprout inhibit infected potatoes, so they will not grow
- Plant crops other than sugar beets after potatoes
- Plough under infected potato debris or unharvested potatoes prior to winter
- Allow at least one year before replanting potatoes in an infested field
- Dispose of all used potato sacks or bags
- Destroy cull piles by freezing or burying

Bacterial Soft Rot (Plate 13)
Bacterial soft rot is a common and often serious disease that can affect tubers in storage, in the ground prior to harvest, or seed pieces after planting. The bacterium *Erwinia carotovora* var. carotovora and certain other species of soil and tuber-borne bacteria cause bacterial soft rot. Infected tuber tissue is cream to tan in colour and has a soft granular texture. Bacterial soft rot commonly invades tubers that have been frozen, those that have moisture on the surface, or have damaged skin due to mechanical damage or infection by other pathogens. Tubers infected with Pythium leak, pink rot, ring rot, *Fusarium* dry rot, or late blight are prone to soft rot. When cold seed pieces are planted into warm, moist soil, moisture may condense on the surface of the seed piece and favour soft rot development. Bacterial soft rot is also common in tubers harvested from waterlogged soils.

Soft rot may also cause rapid and severe breakdown of washed and packaged fresh-market potatoes if they are not completely dried prior to packaging. Early season potatoes with immature skin are most susceptible to this type of soft rot.

Control Strategies:

- Prior to planting, warm seed tubers to approximately the same temperature as the soil, to reduce condensation on the tubers, which promotes rot
- Clean and disinfect seed cutters, handling equipment, and trucks
- Minimize mechanical damage during harvesting, handling, and packing operations
- Avoid frost injury and properly dry frozen tubers in storage. (See section 3.9.4 *Special Storage Problems*).
- Use clean water that is changed often or chlorinated during washing operations
- Remove potato cull piles, discarded vegetables and plant refuse from fields and storage
- Control other tuber diseases
- Prevent condensation water from forming on tubers by ensuring that cold tubers are ventilated with cool air.

Blackleg (Plate 14)
Blackleg is a common disease of potato caused by the bacterium *Erwinia carotovora* var. *atroseptica*. Symptoms of the disease are noticeable as soft, water-soaked dark brown to black lesions on the stem. Under humid conditions, infected stems may be slimy, but appear shrivelled under dry conditions. Tuber soft rot may also develop. Blackleg bacteria over winter in the soil and on tubers. Tuber borne bacteria are spread during seed cutting, handling, and planting.

Control Strategies:

- Plant blackleg-free, certified seed
- Clean and disinfect seed cutters, handling equipment, and trucks
- Plant in warm soil
- Prevent stem damage during cultivation, roguing and harvesting
- Rogue diseased potato plants, ensuring they do not come into contact with other plants in the field (see section 6.3.2 *Disease Prevention, Roguing and Insect and Irrigation Management*).

Common scab (Plate 15)
The bacteria *Streptomyces scabies* cause common scab. The scab organism is widespread, occurring naturally in soil where it lives on plant debris. The pathogen causes scab-like lesions on the tuber, which vary in type: erumpent (slightly raised), russet (superficial), and sunken (pitted). Lesions may be circular, but often coalesce to

form large, irregular patches on the tuber surface. Scab does not affect yield directly but reduces quality, and may result in higher grade-out. Common scab is more prevalent under hot, dry conditions and in soils with high organic matter. The organism prefers a pH of 5.5-8.

Control Strategies:

- Plant disease-free seed into non-infested soil
- Beginning at tuber initiation, maintain high soil moisture for 4-6 weeks
- Increase time between potato crops to 3-4 years
- Plant early, harvest early
- Plant less susceptible cultivars such as Russet Burbank

Fungal Diseases

Early blight (Alternaria solani) (Plate 16)
Each season, early blight causes significant yield losses on the Prairies. The pathogen causes dark brown to black concentric lesions on leaves and elongated brown or black lesions on stems and petioles. Leaf lesions become angular if a large vein retards them. The lesions enlarge, join together and may cover the entire leaf, which will eventually die. The pathogen may occasionally cause sunken circular to irregularly shaped lesions with a raised purple to brown border on the tuber, however, these symptoms have never been reported in Western Canada. The fungus can survive over winter in soil or on plant debris and initiate infection in the crop. Lesions on infected potato plants produce spores that spread to healthy plants and cause infection. The pathogen attacks weaker tissues; young tissue with high nitrogen content is somewhat resistant to the disease. Alternating wet and dry conditions and temperature between 64 and 77°F (18 and 25°C) are very favourable for disease development during the growing season.

Control Strategies:

- Plant disease-free seed
- Maintain good soil fertility and crop vigour
- Harvest when skin is mature to avoid bruising and in turn infection of tubers
- Avoid continuous potato rotations (i.e. planting potatoes in subsequent years in the same filed)
- Apply protectant fungicides to the foliage, and follow a fungicide program throughout the growing season. Consult the provincial Guide to Crop Protection for registered fungicides

Fusarium dry rot, seed piece decay, and wilt *(Fusarium spp.)* (Plate 17)
Potatoes can be infected by different *Fusarium* spp. throughout the season. The various *Fusarium* pathogens cause seed-piece decay, wilt, and dry rot. The disease may initiate from infected seed or from inoculum present in the soil. Wounding is necessary for the development of dry rot and seed piece decay. Wounds to seed pieces at planting are ports of entry for the pathogen to cause seed rot. Wounding at harvest leads to dry rot development in storage. Vascular wilt develops as a result of soil-borne *Fusarium* infection of the roots. In the field, the symptoms of *Fusarium* wilt resemble those of *Verticillium* wilt, and a lab test is required to distinguish these diseases. Tuber yield and quality may be reduced due to wilt, but this disease is not as common as *Fusarium* dry rot.

Control Strategies:

- Avoid wounding tubers at any stage of cropping cycle
- Provide conditions that encourage proper wound healing
- Use registered fungicide seed treatments
- Avoid planting in extremes of cold or hot and dry or soggy soil
- Harvest in dry and cool weather
- Promote wound healing after harvest: 50-55°F (10-13°C) relative humidity at 95% with plenty of air for 10-14 days
- Apply post-harvest fungicide (resistance of *Fusarium* spp. to thiabendazole may reduce effectiveness)

Late blight (Phytophthora infestans) (Plates 18, 19 & 20)
Late blight is one of the most devastating diseases of potatoes. The pathogen can infect all parts of the plant. Depending upon the environmental conditions and age of the tissue, appearance of the lesions may vary. The disease starts as small necrotic spots, which may or may not be surrounded by a pale green border. Lesions may also start as small water soaked areas at the tips of the leaf and enlarge inward. Older lesions generally have a necrotic centre and a pale green border. Dark green to black water soaked lesions develop on stems and petioles. Stem and petiole infections destroy soft tissue and leave only structural parts of the stem. As a result, stems remain standing in heavily infested, defoliated fields. Under humid conditions, a white fluffy growth appears at the lesion edges on the under side of infected leaves.

Tubers near the soil surface can be infected if they are exposed or spores are washed into the soil. An irregular and shallow (1/4-1/2 inch, 4-13 mm) coppery brown dry rot spreads through the outer tissue of the tuber. In storage, infected tubers are susceptible to secondary rots caused by other fungi and bacteria; this can result in extensive damage.

The late blight pathogen can survive only in living host tissue. It is known to over-winter in seed tubers, cull piles, and volunteer potatoes that over-winter in the field.

High humidity and temperatures of 64-71°F (18-22°C) are ideal for development of this disease.

Control Strategies:

- Use certified disease-free seed
- Destroy cull piles by freezing or deep burying
- Destroy volunteer potato plants in nearby fields
- Throughout the season, destroy (desiccate, disc or flail and desiccate) infected plants to avoid spread
- Reduce periods of leaf wetness and high humidity within the crop canopy by appropriately timing irrigation
- Follow a recommended fungicide spray program. The program should start prior to the arrival of the pathogen. Consult your provincial Guide to Crop Protection for registered fungicides.
- Consult your local late blight forecast for disease risk information, if available
- Desiccate vines prior to harvest (refer to section 3.8.3 *Vine Killing*).

Leak (Pythium ultimum) (Plate 21)

Leak is a tuber disease that has the potential to cause significant storage losses. Diseased tissue of tubers infected with leak is soft, watery, granular and dark grey or black in colour. Severely infected tubers may drip or leak, however, in less advanced stages, infected tissue may only be seen when tubers are cut. There is usually a distinct line between healthy and diseased tissue. Tubers may develop soft rot, and then become slimy and foul smelling. The fungus is present in many soils where it over-winters in plant debris, particularly in wet soils. Tubers become infected through wounds in the periderm. The incidence of leak increases with warm temperatures, as 77-89°F (25-30°C) is ideal for disease development.

Control Strategies:

- Grow potatoes on well-drained soils
- Harvest when tubers are mature
- Harvest below a tuber pulp temperature of 65°F (18°C), especially if the soil is moist
- Grade infected tubers prior to storage to reduce spread to healthy tubers
- Store tubers promptly after digging at recommended temperatures and humidity
- Cool tubers harvested in hot sunny weather to below 50°F (10°C) and market immediately
- Consult your provincial Guide to Crop Protection for registered fungicides

Pink Rot (Phytophthora erythroseptica) (Plate 22)

The symptoms of pink rot are typically observed in tubers, but severe infections may develop foliar symptoms such as wilting, yellowing, and aerial tubers. Infected tubers exude a clear, watery liquid. The tissue remains intact, but has a rubbery texture. When infected tubers are cut open, a pink colour develops within 30 minutes, and later turns black. The tuber decay may proceed into the tuber from the stolon end, and a line may be visible between healthy and infected tissue.

The pink rot pathogen lives in soil and can infect any below ground part of the plant. The pathogen thrives in wet, poorly drained soils and disease progresses quickly during warm temperatures. The disease can spread to healthy tubers during harvest and storage.

Control Strategies:

- Plant in well drained soils
- Avoid wounding during harvest and handling
- Grade infected tubers prior to storage to reduce spread to healthy tubers
- If pink rot infected areas of fields are identified or suspected, market directly after harvest. If this is not possible, store separately from healthy tubers
- Use a fungicide registered for pink rot control. Consult your provincial *Guide to Crop Protection* for recommended products.

Powdery scab (Plate 23)

This disease has been a serious problem for potato growers in New Zealand and parts of Europe for many years, and has recently been recognized as a problem in North America. Powdery scab is caused by the fungus *Spongospora* subterranea. It produces a resting spore stage (spore balls) that can survive in soil for at least six years. Initial infection occurs at early tuber set, and is favoured by high soil moisture and soil temperatures of 57-64°F (14°C-18°C). The pathogen causes scabs that are initially rounded and discrete, with torn edges of potato skin surrounding the scabs. Lesions frequently form in a band around the tuber or are clustered at one end. Later lesions may coalesce. By harvest time a dry, powdery mass of spore balls may be present in the scab lesions. The presence of these ovoid spore balls, visible under a dissecting microscope, is necessary for a positive identification of the pathogen. It is possible to confuse powdery scab lesions with those produced by common scab. Powdery scab also infects root tissue, forming galls 1/8-3/8" (1-10 mm) that produce spore balls that remain in the soil at harvest. Powdery scab infections increase grade-out, and the scabs may allow entry of secondary rot organisms. The powdery scab fungus is also the only known vector of potato mop-top virus (Refer to the section on mop-top virus).

Control Strategies:

- Plant disease-free seed into non-infested soil
- Reduce soil moisture levels at tuber set
- Plant late to increase temperature at tuber set, harvest early

- Increase time between potato crops to at least 6 years
- Plant less susceptible cultivars such as Russet Burbank
- No registered fungicides are available (as of December 2001)

**Differentiation between common and powdery scab is important to allow correct management decisions to be made.

Rhizoctonia stem canker and black scurf
(Rhizoctonia solani) (Plate 24)
The symptoms of the disease include development of rusty brown lesions on underground stems and stolons and black sclerotia (fungal bodies) on progeny tubers. The leaves may turn pale green or purple and become curled and upright. Development of aerial tubers in leaf axils may also be observed. Under humid conditions, a white cottony growth develops on the lower stem. The disease initiates from black fungal bodies present on infected seed or from the pathogen present in the soil on plant debris. Cooler conditions at planting favour the development of *Rhizoctonia*. Delayed emergence increases the likelihood of infection.

Control Strategies:

- Use only certified and black scurf-free seed
- Use a four year rotation, preferably with cereals
- Plant in warm (60-68°F or 16-20°C), well-drained soil
- Treat seed tubers with a registered fungicide seed treatment
- Harvest the tubers as soon as they are mature, within 4 weeks of vine kill

Seed-Piece Decay
Several species of soil and seed-borne fungi and bacteria cause seed-piece decay. Seed-pieces may develop dry rot or soft rot depending upon the microorganisms involved. Consult individual diseases for their seed piece decay phase.

Control Strategies:

- Avoid bruising the seed
- Preferably plant whole seed
- If using cut seed, follow proper cutting, fungicide seed treatment and storage procedures (see section 3.2.5 *Seed Cutting*)
- Prevent condensation on the surface of the seed by warming the seed near to soil temperature prior to planting, and plant in a warm, moist-but-not-wet soil to promote wound healing and rapid sprout growth. If soil temperature is too cold (below 50°F or 10°C) cut seed will not suberize, if it is too warm (above 64°F or 18°C) it is very favourable for multiplication of pathogens.
- Avoid exposure of cut seed to hot sun or drying winds

Silver scurf (Helminthosporium solani) (Plate 25)
This is a disease of the potato skin. The disease has markedly increased since the early 1990s due to the development of resistance in isolates of the pathogen to thiabendazole (Mertect), the only fungicide that was recommended for control of this disease. The skin spots, which are small and pale brown at harvest, enlarge during storage. Older lesions appear silvery, especially when wet. The disease, though more pronounced on white or red-skinned tubers is also found on russet-skinned cultivars. Although the pathogen can survive on plant debris in soil, the diseased seed tubers are considered the most important source of silver scurf initiation in the field. Under warm and humid conditions, the pathogen multiplies and infects daughter tubers. Delayed harvest, especially after vine kill, increases the disease severity. New tubers can be infected during harvest by intermingling with diseased tubers and during the first 2-3 weeks of storage. The pathogen can survive on structural material.

Control Strategies:

- Plant certified silver scurf-free seed
- Treat seed tubers with a fungicide seed treatment registered to control silver scurf.
- Avoid planting potatoes in a field that had silver scurf the previous season
- Apply post-harvest fungicide treatments to newly harvested tubers (resistance in pathogen populations to thiabendazole may reduce effectiveness of this fungicide)
- Thoroughly disinfect storages before filling
- Harvest as soon as possible after vine kill or maturity
- Reduce the amount of soil and plant debris going into the storage
- Use air to dry wet tubers
- Remove field heat from tubers as soon as possible, and avoid conditions that promote condensation in storage.

Verticillium wilt *(Verticillium spp.)*
Verticillium wilt of potato can be caused by *V. dahliae* or *V. albo atrum*. The disease can have a significant impact on the crop by reducing both tuber yield and quality. Plants infected with wilt start to show symptoms in the middle of the growing season. Individual leaves first turn pale green or yellow, leaves on affected stems then wilt, and finally the entire plant dies prematurely. Initial symptoms often develop on one side of the plant. The lower stems of diseased plants and tubers have brown discolouration in the vascular tissue when cut open.

Verticillium spp. are soil-borne fungi and once established, can live for long periods in the soil even if a potato crop has not been planted for many years. The pathogen can become established in a field through the use of infected seed or by movement of infested soil.

Control Strategies:

- Maintain fertility at levels optimum for high yield
- Irrigate to reduce moisture stress after flowering and during tuber bulking, but do not over-water
- Disease severity may be reduced by incorporating green manure crops in the season prior to potato production
- Practice at least a three year rotation, and preferably a four year rotation
- Do not contaminate clean fields with soil from diseased fields, diseased tubers or plant refuse.

Viral Diseases
Of the more than 27 viruses that have been reported to infect potatoes, potato leafroll virus (PLRV) and potato virus Y (PVY) are distributed worldwide and have often been reported to be the most damaging. These are the two most economically important viruses in the Prairie potato crop.

Potato Leafroll Virus (Plate 26)
PLRV is an aphid-transmitted virus. Primary symptoms appear after the virus is transmitted from an infected aphid to a healthy plant. Primary symptoms include upright, rolled leaves and slight yellowing that appears mainly in the young leaves. In some cultivars, young leaves are pink to reddish beginning at the leaf margins. Leaf rolling may only be evident at the base of the leaflet rather than the whole leaflet, and may eventually spread to the lower leaves. Plants infected early in the season may also be dwarfed. In late season infections, primary symptoms may not appear, as potato plants develop resistance to foliar infection with age, which makes diagnosis difficult.

Secondary symptoms occur when an infected tuber produces an infected plant. Leaf yellowing, along with leaf rolling are often associated with the lower leaves. Leaves are dry, stiff and leathery, and make a paper-like, crisp sound. Plants are often stunted. Secondary symptoms are not as evident in the top of a plant.

PLRV causes net necrosis in infected tubers, rendering them unmarketable (Plate 27). Internal net necrosis is visible when the tuber is cut and is particularly marked in certain cultivars, the most susceptible being Russet Burbank. Net necrosis causes browning of the vascular system within the tuber and is primarily seen when the virus is spread to healthy plants from aphids. It can be seen in tuber-borne infected plants if the disease pressure is high. Timing of net necrosis development in the tuber is dependent on the time of infection in the field. At harvest, tubers may exhibit net necrosis if the plant was infected with the virus early in the growing season. If infection occurred in August or later, net necrosis will not likely show up at harvest but will develop later in storage.

PLRV infection may result in reduced tuber size and number, and yield loss can be as severe as 60-90%. PLRV can also result in rejection of seed lots for certification, and infected tubers with net necrosis are not acceptable for processing.

PLRV is spread primarily by aphids that colonize potatoes, but it is also tuber-borne and therefore spread by infected seed tubers. The most efficient vector is the green peach aphid (3.6.2 Insect Management). PLRV is the only known persistently transmitted potato virus. Persistent means that once the aphid acquires the virus, it carries it for life. PLRV is concentrated in the phloem (vascular) tissue of the plant and is acquired only by an aphid that chooses to feed on an infected plant. Once the aphid acquires the virus from an infected plant, at least 24 hours or more are needed until the newly infected aphid can transmit the virus. Long distance spread of the virus occurs by wind-borne winged aphids. Short distance spread occurs by non-winged aphids moving from plant to plant. PLRV is not mechanically transmitted and therefore aphids are solely responsible for the in-season spread of the disease. Sources of PLRV include plants grown from infected tubers and diseased volunteer potato plants.

Control Strategies:

- Plant virus-free, certified seed, remove volunteer hosts, and rogue infected plants early to eliminate virus inoculum.
- Management of aphids is an integral part of PLRV management. Control aphids to eliminate aphid vectors during seed production, during aphid population outbreaks and when cultivars susceptible to net necrosis are grown.
- Scout fields regularly and use established action thresholds to determine when insecticide sprays are recommended

Potato Virus Y (Plate 28)
PVY is a common virus that may infect many crops including potato, tobacco, pepper and tomato. Common strains of the virus PVY^O occur worldwide. Primary symptoms of PVY^O, depending on the cultivar, are necrosis, yellowing of leaflets, mottling, leaf dropping and sometimes premature death. Necrosis may cause leaves to collapse and remain attached to the stem.

Symptoms of secondary PVY° infection include mottling, crinkling of the leaves, and stunting of the plants. Foliar and stem necrosis may occur. Necrosis following primary infection is usually more severe than following secondary infection. The foliar mosaic symptom (intermingled light green and yellow coloration) may be masked at high (77°F or 25°C) and very low (50°F or 10°C) temperatures, but at high temperatures the disease can be identified by the rugosity (crinkling) of the foliage.

PVY is one of the more damaging potato viruses and can have a significant impact on yield. Infection results in reduced tuber number and size. Complete failure of a potato crop may also occur. PVY can also result in rejection of seed lots for certification.

PVY is an aphid-transmitted virus and spread depends mainly on the presence of winged aphids. PVY is transmitted in a non-persistent manner. The aphid can acquire the virus and infect healthy plants in only a few seconds. After a brief period of feeding on healthy plants, infected aphids rapidly lose their virus charge and must again feed on a PVY infected plant to continue to transmit PVY. To determine suitability of a plant as a host, aphids sap-sample the epidermal tissue of a plant. Many aphid species that don't reproduce on potatoes will sap-sample potato foliage, and during this process can spread PVY.

Control Strategies

- Crop borders planted to non-virus host plants such as soybean or wheat provide a landing site where aphids can "clean" their mouthparts from non-persistent viruses before moving into the potato crop. Spread of PVY in potato from sources outside the field can be reduced by up to 60% by using crop borders.
- Plant virus-free, certified seed
- Plant early and rogue out diseased plants
- Apply effective aphidicides
- Vine-kill as early as possible and continue use of an effective aphidicide if needed until vines are completely dead

Potato Mop-Top Virus (Plates 29, 30 & 31)

PMTV is considered to be an economically important disease of potato. It occurs throughout parts of Europe, South America, Asia, and has recently been detected in North America. PMTV is present in Canada, but the distribution within the country is not known. Foliar symptoms of the disease include dwarfing of shoots resulting in a "mop-top" appearance; pale green V-shaped markings on young leaves; and bright yellow blotches, mottling, rings, and V-shapes on leaves. Tuber symptoms of PMTV infection may include cracking, internal spots, and necrotic rings or arcs referred to as spraing. Tuber symptoms may be difficult to distinguish from tobacco rattle virus or physiological disorders.

PMTV is spread by *Spongospora subterranea*, the fungus that causes powdery scab. The virus survives in the soil within the spore, and together the spore and virus may remain dormant for many years. Plants become infected with PMTV when virus-carrying powdery scab spores infect potato roots, stolons, or tubers. PMTV is also seed-borne. Symptom expression in foliage and tubers is quite variable and is influenced by the type of infection (soil or seed-borne), cultivar, and environmental conditions.

Control Strategies

- Avoid introducing powdery scab and PMTV into uninfested soils by using disease free seed and sanitation practices. Sanitation should be aimed at preventing the movement of powdery scab infested soil on seed, equipment, and in irrigation water.

Follow control recommendations for powdery scab.

For further details regarding virus management in seed potatoes, please see selected reference number 4.

Selected References

1. Delgado-Sanchez, S. and Grogan, R.G. 1970. Potato Virus Y. No. 37 in: Descriptions of Plant Viruses. Commonw. Mycol. Inst., Assoc. Appl. Biol., Kew, Surrey, England.

2. Stevenson, W.R. (Editor). 2001. Compendium of Potato Diseases – Second Edition. APS Press, St. Paul, MN. 125 pp.

3. Peters, D. 1970. Potato leafroll virus. No. 36 in: Descriptions of Plant Viruses. Commonw. Mycol. Inst., Assoc. Appl. Biol., Kew, Surrey, England.

4. Radcliffe, E.B., Ragsdale, D.W., MacRae, I.V. and Suranyi, R. 1999. Aphid Alert. Recommendations for virus control in seed potatoes. http://ipmworld.umn.edu/aphidalert/alert7.htm

5. Waterworth, H.E. and Hadidi, A. Economic losses due to plant viruses. Pages 1-13 In: Plant Virus Disease Control. A. Hadidi, R.K. Khetarpal and H. Koganezawa, eds., APS Press, St. Paul, MN, 684 pp.

Potato Spindle Tuber Viroid

PSTVd is a serious disease of seed potatoes caused by the spindle tuber viroid. The Canadian Food Inspection Agency has a zero tolerance for PSTVd in seed potatoes. Plants infected with PSTVd are upright, dwarfed, and much thinner than uninfected plants. The stems are often more branched and the branches form very sharp angles where they join to the stem. Affected tubers are dwarfed and are usually narrow and spindle-shaped. Eyes are numerous and the tubers are often cracked. PSTVd is spread by contact, but chewing and sucking insects such as aphids, grasshoppers, Colorado potato beetles, and flea beetles have been implicated in the field spread of this disease. Seed-cutting knives, planters and infected seed (tubers and true seed) also spread PSTVd.

Control Strategies

- Plant certified disease free seed
- Plant whole seed
- Wash knives and other equipment with detergents, household bleach or quaternary ammonia compounds, especially between seed lots
- Control insects
- Remove diseased plants, ensuring that the entire plant is removed.
- Avoid leaf contact by people and equipment during field operations

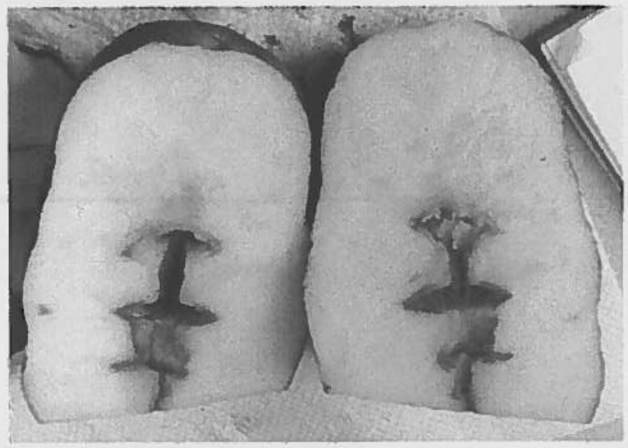
Environmental Diseases

Blackheart (Plate 32)
Blackheart results from an insufficient oxygen supply to internal tuber tissue. The centre of the tuber turns blue-black. The tuber tissue associated with blackheart remains firm, as opposed to the black, soft watery tissue resulting from leak infection. Blackheart may develop if tubers are held in low oxygen environments. This can occur in less than ideal storage conditions, water logged soils, or if condensation forms on tubers. Blackheart is prevented by proper ventilation, storing at recommended temperatures, and improvement of soil drainage.

Hollow Heart (Figure 3.6-6)
Hollow heart, a cavity near the centre of the tuber, results from rapid tuber growth. The disorder is found primarily (but not only) in large potatoes. Walls of the cavities are white to light brown. The disorder is difficult to detect because affected tubers have no external symptoms. They can only be removed with expensive X-ray grading equipment. Hollow heart is promoted by growing conditions that cause rapid tuber enlargement. Poor stand increases the incidence of hollow heart. To reduce hollow heart:

- Plant susceptible varieties at closer spacings. See section 3.1.4 *Variety Descriptions* for details on varietal susceptibility.
- Maintain uniform soil moisture throughout the entire growing season
- Plant to maximize stand of uniform plants and minimize misses
- Ensure adequate potassium fertility

Figure 3.6-6 Hollow heart (Courtesy of Manitoba Agriculture and Food



Malformed Tubers
Extreme soil temperatures may cause secondary growth, knobs, and other tuber deformities. Other conditions such as nutrient and water imbalances have also been implicated in irregular tuber development. Growth cracks may arise from rapid tuber growth and are often the result of improper fertilizer placement. To prevent or reduce malformed tubers:

- Maintain uniform soil moisture, particularly during tuber development
- Apply recommended fertilizer rates
- Establish a high stand of uniform plants to control tuber growth rates
- See section 3.1.4 *Variety Descriptions* for details on varietal susceptibility

Low Temperature Injury
Low temperature or freezing injury can occur to potatoes that are exposed to a heavy field frost or to tubers that have been excessively chilled in storage. Frozen tissue, upon thawing, discolours and breaks down into a soft watery mass (Plate 33). Chilling injury often results in streaks of discolouration in the vascular tissue of the tuber. Frozen or chilled potatoes should not be used for seed as cut surfaces may not heal and seed piece decay will result. Low temperature injury losses can be reduced or prevented by:

- Storing at temperatures above 37°F (3.0°C)
- Proper ventilation and temperature control. See Section 3.94 *Special Storage Problems* for more details
- Culling frozen potatoes prior to storage

3.7 Sprout Inhibition in the Field
(K. Lockhart)

Sprout inhibition is essential to maintain tuber quality for the table and processing markets stored past January. Sprouting causes tuber dehydration, physiological aging and affects the appearance of the tuber for the table market. Sprout inhibition is achieved through a combination of proper storage management and the use of a sprout inhibitor. There are two sprout inhibitors registered for use in Canada. MH60, which is applied to the crop approximately 2-3 weeks before harvest or vine kill or Chloroprophan (CIPC), which is applied to potatoes in storage (see section 3.7 *Sprout Inhibition in the Field*).

Sprout inhibition is essential to maintain tuber quality for the table and processing markets stored past January. Sprouting causes tuber dehydration, physiological aging and affects the appearance of the tuber for the table market.

Maleic hydrazide (MH), commonly available as Royal ®MH60SG, is registered for field application to prevent sprouting in storage. There are many advantages to field applying a sprout inhibitor:

- MH can be applied to very small plots of potatoes.
- Potatoes are not subject to the in-storage stress associated with CIPC application.
- Storages containing MH60-treated potatoes do not become contaminated with sprout inhibitor residues and pose no restrictions for the future storage of potato seed. CIPC-treated storages are contaminated with sprout inhibitor and should not be used for seed storage until thoroughly cleaned.
- Field treating reduces the likelihood of volunteer potatoes the following spring.

To achieve the best results from MH60 consider the following:

MH60 is translocated from the vines to the tubers. Translocation will only occur if the vines are healthy. Diseases, insect damage, weeds, environmental stress, senescence and poor application interfere with translocation of MH60 and will reduce the effectiveness of the sprout inhibitor.

MH must be applied after tuber formation and cell division are complete. Normally MH is applied at least 2 weeks prior to vine killing, harvest or frost. Tubers should be at least 2.5 inches (6-7 cm) in diameter at the time of application. Incorrect timing can result in a yield loss or inadequate sprout inhibition.

Growers should read the label before applying MH60. Apply Royal ®MH60SG at a rate of 2.29 kg/ac (5.65 kg/ha), in a minimum of 27 gpa (300 l/ha) of water by ground equipment, or a minimum of 40.5 l/ac (100 l/ha) by aerial equipment.

Plate 3. Colorado potato beetle adult. (Courtesy of C. Schaupmeyer)

Plate 4. Colorado potato beetle egg mass. (Courtesy of C. Schaupmeyer)

Plate 5. Colorado potato beetle larvae. (Courtesy of C. Schaupmeyer)

Plate 6. Potato flea beetle. (Courtesy of Agriculture and Agri-Food Canada)

Plate 7. Winged aphid. (Courtesy of Agriculture and Agri-Food Canada)

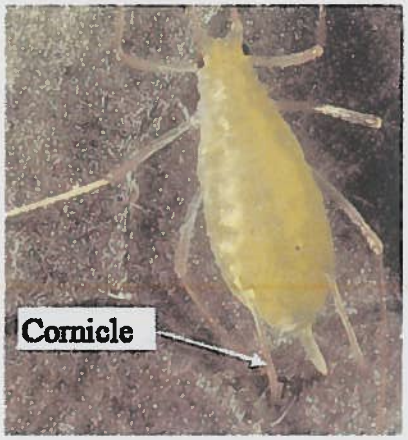


Plate 8. Aphid nymph with cornicles. (Courtesy of Agriculture and Agri-Food Canada)

Plate 9. Leafhopper adult. (Courtesy of North Dakota State University)

Plate 10. Leafhopper nymph on left. (Courtesy of North Dakota State University)

Plate 11: Wireworm larvae. (Courtesy of C. Schaupmeyer)

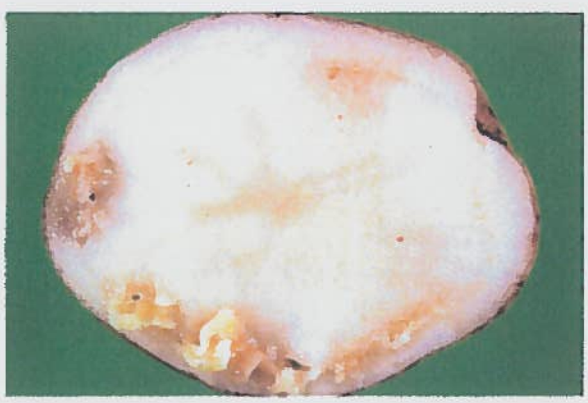


Plate 12. Internal symptoms of bacterial ring rot. (Courtesy of Manitoba Agriculture and Food)

Plate 13: External and internal symptoms of bacterial soft rot. (Courtesy of Manitoba Agriculture and Food)

Plate 14. Blackleg. (Courtesy of P. Bains, Alberta Agriculture, Food & Rural Development)

Plate 15. Common scab. (Courtesy of J. Thompson, University of Saskatchewan)

Plate 16. Early blight leaf lesion. (Courtesy of C. Schaupmeyer)

Plate 17. Fusarium dry rot. (Courtesy of P. Bains, Alberta Agriculture, Food and Rural Development)

Plate 18. Late blight leaf lesion. (Courtesy of R. Howard, Alberta Agriculture, Food and Rural Development)

Plate 19. Late blight stem lesion. (Courtesy of R. Howard, Alberta Agriculture, Food and Rural Development)

Plate 20. Late blight tuber lesion. (Courtesy of B. Geisel, Gaia Consulting Ltd.)

Plate 21. Pythium leak. (Courtesy of Manitoba Agriculture and Food)

Plate 22. Pink rot. (Courtesy of Manitoba Agriculture and Food)

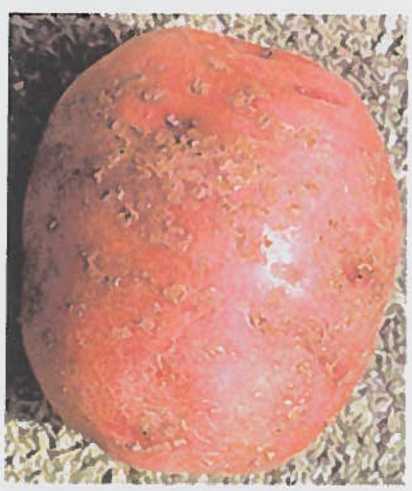


Plate 23. Powdery scab. (Courtesy of J. Thompson, University of Saskatchewan)

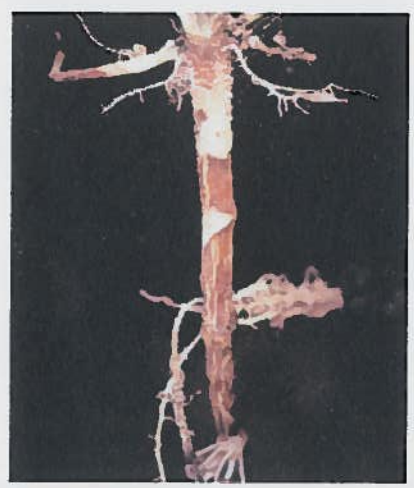


Plate 24. *Rhizoctonia* stem canker. (Courtesy of P. Bains, Alberta Agriculture, Food and Rural Development)

Plate 25. Silver Scurf (Courtesy of R. Howard, Agriculture and Agri-Food Canada)

Plate 26. Potato leaf roll virus (PLRV) symptoms. (Courtesy of R. Singh , Agriculture and Agri-Food Canada)

Plate 27. Net necrosis in tuber caused by PLRV. (Courtesy R.P. Singh, Agriculture and Agri-Food Canada)

Plate 28. Potato virus Y (PVY) infected plant. (Courtesy of D. Lidgett, Manitoba Seed Potato Grower's Association)

Plate 29. Potato mop top virus chevron. (Courtesy of Scottish Agricultural Science Agency)

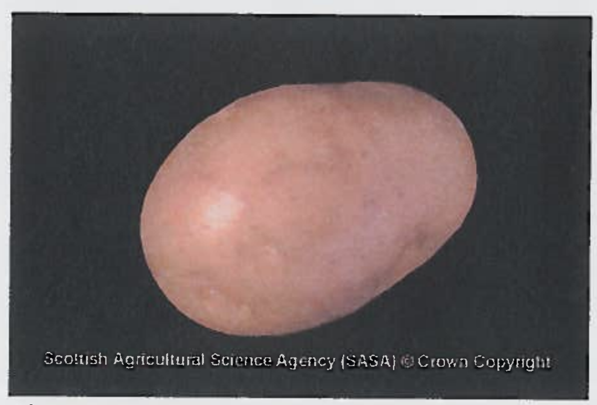


Plate 30. Potato mop top virus external tuber symptoms. (Courtesy of Scottish Agricultural Science Agency)

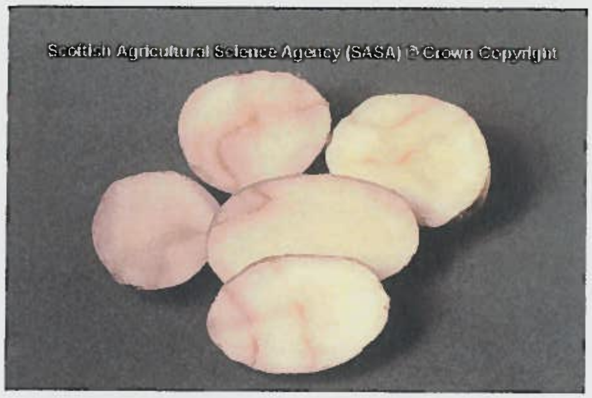


Plate 31. Potato mop top virus internal tuber symptoms. (Courtesy of Scottish Agricultural Science Agency)

Plate 32. Blackheart internal tuber symptoms. (Courtesy of Manitoba Agriculture and Food)

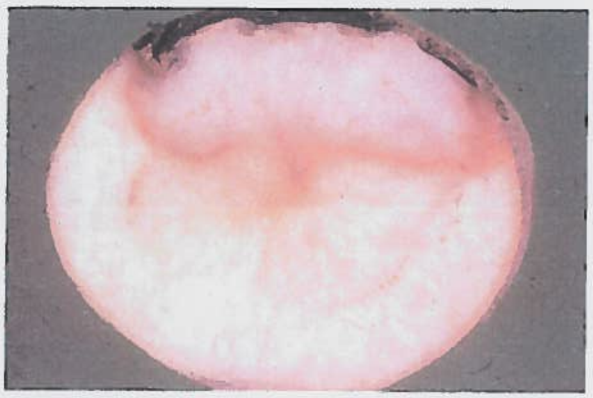


Plate 33. Low temperature injury of tuber. (Courtesy of Manitoba Agriculture and Food)