POTATOES

POTATOES

CROP OVERVIEW, GROWTH & DEVELOPMENT

Figure 1.
Potatoes
(*Gardens for All Book of Potatoes*, 1980)

Potatoes are an important cash crop in the Klamath Basin. Of all the crops grown on the leased lands, potatoes have the greatest variety of pests. Some of these pests, mostly diseases, will be present to a greater or lesser extent, every year. Other pests recur more or less often, depending on a variety of factors, including weather, field history, soil quality, and the crop management practices used by the grower. One of the crop management practices with the most influence on potato diseases is irrigation.

The frequency and duration of irrigation have a direct influence on the occurrence and severity of fungal and bacterial diseases. Most of these organisms require moisture on the foliage, stem, or roots to germinate and infect the plant. Irrigation schedules that allow potato plants to remain wet for long periods create conditions favorable for infection and spread of early blight, late blight, and *Sclerotinia* spp.-induced diseases. Excessive soil moisture, combined with poor drainage, create conditions amenable to infection of tubers by a host of organisms, including late blight, soft rot, pink rot, and pythium leak. At planting time, excessive soil moisture can cause seed-piece decay. As noted in the introduction to this workbook, soil quality and organic matter content have a large influence on drainage and soil moisture retention and, therefore, incidence of disease.

Table 1.
Status of potato pests on Refuge lands

Major Pests (as noted by ♦)	**Minor Pests** (as noted by ♢)
Invertebrates	**Invertebrates**
green peach aphid	flea beetles
loopers	wireworms
cutworms	
potato aphid	
grasshoppers	
yellowstriped armyworm	
root-knot nematode	
lesion nematode	
Diseases	**Diseases**
early blight	potato virus X
late blight	leak
white mold	fusarium dry rot
potato leaf roll virus	black dot
potato virus Y	scab
pink rot	bacterial ring rot
soft rot	potato virus S
rhizoctonia	potato virus A
blackleg	silver scurf
verticillium wilt	

MONITORING

There are several pests of potatoes for which monitoring programs have proven valuable. Aphids should be monitored using leaf counts. Experimental thresholds are provided which may save treatment costs. Cutworms, armyworms, and loopers also can be damaging and should be monitored. There are no action thresholds established for most species of caterpillars (although some experimental thresholds are provided) in potatoes, so grower experience is important in deciding what level of damage to foliage is economic.

Monitoring is important in disease management to determine when and where treatments are needed. Some guidance may be provided by the disease forecasting software in the potato crop management program, WISDOM, developed by the University of Wisconsin. See Field Trial Recommendations.

Table 2.
Summary of monitoring methods and action thresholds for pests of potatoes

Pest	When/how to scout	Interim action threshold*	Remarks
Green peach aphid	Weekly monitoring for the green peach aphid should begin in early June when the winged forms begin migration into potato fields. Sample 100 leaves, taking 50 bottom leaves on a line from one corner to the center of the field, and another 50 bottom leaves on a line from the center to another corner of the field.[1] This should provide a randomly selected sample that is representative of the field. The leaves should be picked without prior examination to avoid sampling bias.	If the sampling outlined under scouting reveals the presence of any aphids on more than 5 leaves out of 100 (a 5 percent infestation), then the field should be treated.	Infestations are more likely to begin at field edges, particularly those areas upwind of the prevailing spring winds. If aphids are present, then sampling should proceed. Plants from which the leaves are selected should be chosen randomly.
Green peach aphid (alternative threshold,[2]) Please note that these thresholds were developed for Russet Burbank. If other more resistant varieties have been planted, it may be safe to adjust the action thresholds upwards.	Weekly monitoring for the green peach aphid should begin in early June when the winged forms begin migration into the potato fields. Collect 25 leaves (not leaflets) from each of five locations within a field. Sampling locations should be randomly dispersed around the field. The pattern on a die with 5 spots is one possible model for sample locations. The leaves should be collected from the middle of the plant canopy.	**Fresh Market or Processing** Early season - 50 wingless aphids (all species) After bloom - 100 wingless aphids (all species) **Fresh Market or Processing in Seed Production Area** 7.5 green peach aphids 50 aphids (all species) **Seed Potatoes for Leaf Roll Virus Management** 2.5 green peach aphids for leaf roll virus susceptible varieties 7.5 green peach aphids for leaf roll virus resistant varieties 25 potato aphids	These thresholds[2] are recommended for potatoes grown in the Midwest and should be tested for the Klamath Basin. The thresholds are generally higher than those recommended by U.C. guidelines, and may save growers some money by decreasing the need for treatments. Collect 25 leaves (not leaflets) from each of five locations within a field. The leaves should be collected from the middle of the plant canopy.

Pest	When/how to scout	Interim action threshold*	Remarks
Cabbage Looper, Alfalfa Looper, Variegated Cutworm, Spotted Cutworm, Army Cutworm, Red-backed Cutworm, (These monitoring recommen-dations are taken from the WISDOM potato management software[3])	Shake the foliage of 5-foot sections of two adjacent rows into the furrow and count the larvae on the soil surface. Divide the number of larvae counted by five. The resulting number is the number of worms per row foot. Sample at least five sites per 30 acres and add one additional sample site for each additional 20 acres. Weekly sampling for larvae is the recommended method. Excrement and fresh feeding damage usually are good indicators of the presence and size of larvae.[9]	**Prior to July 25**: Control measures are recommended if the cutworm and looper counts exceed four per row foot as a field average. **After July 25**: Control measures are recommended if the cutworm and looper counts exceed eight per row foot as a field average. Treat when loopers are numerous and ragging of leaves is obvious. Most plants can withstand substantial defoliation without serious reduction in yield. Spot treatments are usually adequate for infested seedlings. Loopers are best treated while they're small.	These action thresholds have not been validated in Klamath Basin for looper/cutworm populations on potatoes. If the action thresholds are validated for the Klamath Basin, they will provide the growers with better guidelines for control of loopers and cutworms.
Black cutworm	The first generation, active during May and June, causes the most damage, so monitoring should be targeted for before and during this time frame.	2 plants per 100 with black cutworm larvae present[2]	Larvae feed at night, cut off young plants at soil line. Young larvae (less than 0.5 inch long) feed above ground. Larger larvae feed at, or just below, the soil surface
Variegated cutworm	Adults emerge in June, lay several hundred eggs in clusters on grass, weeds, and vegetables so monitoring should be targeted for June and after. (For how to scout, see loopers/cutworms, above.)	4 cutworms per row foot[2] 2.6 larvae/ plant, full bloom* 43.3 larvae/ plant, full growth* 34.1 larvae/ plant, maturity *For Russet Burbank, larval numbers refer to third and fourth instar[4]	The variegated cutworm is the only species that commonly feeds during the day. Foliage feeder and heavy infestations can cause complete defoliation. Not as closely associated with grasses as other cutworm species.
Grasshoppers	Oviposition sites for the grasshoppers should be identified and monitored.	No action thresholds have been developed for grasshoppers in Klamath Basin. Treatment should take place when nymphs first emerge if it's thought that unusually large populations are present.	

Pest	When/how to scout	Interim action threshold*	Remarks
Yellowstriped armyworm	Young larvae of this species are day feeders and may be found on terminal buds and leaves. This foliage-feeding stage is the phase most easily sampled and controlled. Monitor armyworm larvae with a sweep net. The larvae must be at least 0.5 inch long for accurate counting and to evaluate for parasitism and disease. Check fields weekly from June through September, or more often if heavy populations develop. The presence of a number of diseased larvae in the field may indicate that a natural epidemic may soon occur.	There are no action thresholds developed for armyworms. However, since this pest is considered a type of cutworm, the sampling methods and action thresholds outlined for loopers/cutworms above *may* be applicable.	It should be noted that potato plants (and most other crops), particularly older plants, can withstand some defoliation without any loss of yield. A monitoring program that includes assessment of natural enemy populations is essential for the most effective armyworm control.
Flea beetles	Visual observations of adult feeding damage are the primary monitoring method, though sweep nets can be useful for sampling adults. Because adults often overwinter at weedy field edges or near structures, early season monitoring of these areas may be helpful for detecting initial infestations.	There is no established action threshold for flea beetles on potatoes because treatment is so rarely needed.[5]	
Diseases	Fields should be visited *at least* weekly from crop emergence to harvest to determine the progress of the crop and accompanying pests.	Very few action thresholds have been developed for plant diseases. However, disease prediction programs, such as the WISDOM software, are useful in some cases when deciding the best timing for fungicide applications.	It is useful to keep good records as to the existence/severity of the disease problems in each field. This way, fields with economically damaging levels can be avoided.

Pest	When/how to scout	Interim action threshold*	Remarks
Early blight	Problem areas, where early blight has been noticed in the past or that have poor drainage, should be given special attention.		
Late blight	Fields should be closely monitored after possible late blight infection periods occur. Studies in Israel noted that late blight infection was greater on morning-irrigated potatoes than on potatoes irrigated at midday or evening.[6] A rule of thumb: if rainfall or irrigation water exceeds 1.2 inches in a 10-day period, good conditions for late blight exist.		Blight forecast methods developed for northern areas in the United States are not useful in California, except possibly coastal areas.[6]
White mold	Scouting for white mold is especially important as row closure is beginning. Look for the “miniature mushrooms” (apothecia) and/or infections (described above) on older plant tissue, such as lower leaves.		Treatment decisions will be based on scouting information in the context of the upcoming weather. Consideration must also be given to the irrigation cycle (e.g., if the weather outlook is dry, the field just irrigated, and relatively few apothecia present in the field, the grower may decide to delay treatment until prior to the next irrigation or predicted rain).
Black scurf	It is useful to keep good records as to the existence/severity of the black scurf problem in each field. This way, fields with economically damaging levels can be avoided.		
Black leg, Soft rot	During regular weekly monitoring, scouts should be looking for black leg or soft rot symptoms during cool, wet periods.		

Pest	When/how to scout	Interim action threshold*	Remarks
Black dot	Wilt symptoms progress rapidly compared to Verticillium wilt symptoms. Diseased stems and tubers will have small, black, dot-like fungal structures.		
Silver scurf	Tubers in storage should be monitored for the following symptoms: small, light brown lesions that may develop into larger lesions with a distinctly gray or silvery sheen, particularly when wet. Tubers may shrivel in storage from fungal-induced moisture loss.		
Pink rot	Tubers in storage should be monitored for the following symptoms: Infected tubers may ooze in storage, spreading spores wherever the liquid touches. The disease gets its name from the color, usually a salmon pink, infected tissue displays within half an hour of being exposed to air. The exposed surface will turn black after about an hour of air exposure.		
Fusarium wilt	The lower leaves of a plant infected with Fusarium wilt may turn yellow and begin to wilt rapidly.		

Pest	When/how to scout	Interim action threshold*	Remarks
Fusarium dry rot, Fusarium seed piece decay	Tubers in storage should be monitored for the following symptoms of dry rot: sunken or wrinkled skin. Secondary bacterial and fungal infections may mask these symptoms with moist rot and various colors of fungi. Seed piece decay: lesions begin on cut surfaces as sunken rust-brown to black depressions.		
Verticillium wilt, Potato early dying	Scouts should monitor weekly for signs of wilt. Particular attention should be paid to Verticillium wilt monitoring around blossom time. Scouts should be alert to symptoms on lower leaves, such as wilting and epinasty.		
Leaf roll virus	Early symptoms of leaf roll virus will appear about 1 month after planting when the plants are about 6 inches high. Scouts should keep alert for plants with leaf roll symptoms—tubers are smaller and more upright than normal, with a pale cast to the leaves. The leaves, especially the lower ones, will be rolled and have a thick, leathery, brittle texture. These plants should be selectively removed.		Monitoring of green peach aphid populations, their parasites and predators and selectively removing diseased plants and volunteers are critical.

Pest	When/how to scout	Interim action threshold*	Remarks
Potato virus Y	Seed piece infections will cause plants to develop yellow and green mottling, dead spots of leaf tissue (necrosis), wrinkling, and medium to heavy dwarfing, and occasionally, death. Tubers will be smaller than normal. Current season infection (by aphids or mechanical transmission) will cause many of the same symptoms as seed piece infection but is generally not as severe.		This virus is more of a problem for the potato seed piece market, not applicable to Refuge-grown potatoes.
Northern root-knot nematode, Columbia root-knot, and Root-lesion nematodes	Sampling for the presence of nematodes in the soil is best accomplished by soil sampling in the late summer. Root zone soil samples should be taken immediately after harvest or just prior to harvest if crop showed signs of damage. Fields should be divided into blocks of 20 acres which have similar damage, soil texture or cropping history. Several subsamples from each block should be well-mixed to create a single, one quart sample. Soil samples should be kept cool, but not frozen.	The presence of any *M. chitwoodi* nematodes may be cause for concern. For *M. hapla,* populations below 100 per pint of soil, control strategies should not be necessary.	Local experiment stations can provide details needed for labeling samples and laboratories that can analyze them. Identification of different species of lesion nematodes is difficult. It is probably safe to say that some root-lesion nematodes exist in every potato production area of the U.S., if not every field.

* Interim Action Thresholds will be used as guidelines on leased-lands until they are validated.

INVERTEBRATE PESTS

♦ GREEN PEACH APHID – *Myzus persicae*

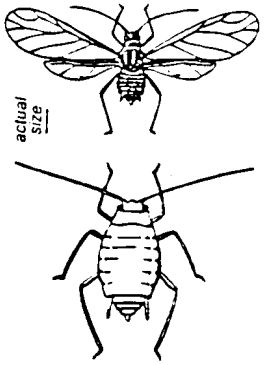

Figure 2.
Green peach aphid
(after USDA Bull. 1371)

Life Cycle, Host Crops, Seasonal Development

The green peach aphid is found wherever potatoes are grown in the U.S. This aphid is one of the primary transmitters of several viral diseases of potatoes, two of which can be potentially devastating in the West. It is also resistant to more insecticides than any other insect.

The green peach aphid overwinters in the egg stage on peach trees and related species (i.e., apricot, cherry, or plum), although peach is the preferred host. In the Klamath Basin, the green peach aphid is probably blown in from the south. Some eggs may overwinter on local peach or a related *Prunus* species, such as those that grow abundantly in the Klamath Basin. One peach tree may harbor enough winged green peach aphids to cause economic infestations in 500 acres of potatoes.[7] During late spring, the winged forms will migrate from the primary peach host to colonize up to 100 different species of secondary hosts, one of which is potato. A single wingless aphid will generally produce over 60 offspring, each individual requiring 7 to 13 days to mature.[7] Optimum temperature for green peach aphid reproduction is 70 degrees F.

Damage and Symptoms

High populations of green peach aphid can cause direct feeding damage to potato plants, but of greater concern (particularly to seed potato growers) is the ability of green peach aphids to transmit potato leaf roll virus and potato virus Y. The tubers of some cultivars, such as Russet Burbank, Norgold Russet, Green Mountain, and Irish Cobbler, will display net necrosis symptoms if the plant is infected by the leaf roll virus. Net necrosis results when the vascular tissue in the potato becomes discolored. Plants grown from leaf roll virus-infected tubers will be smaller and more upright than normal with a pale cast to the leaves. The leaves, especially the lower ones, will be rolled and have a thick, leathery, brittle texture. Additional information about these viruses can be found under Diseases.

Short- and Long-term Management Recommendations

▶ *Monitoring*

- Weekly monitoring for the green peach should begin in early June when the winged forms being migrations into potato fields. Sample 100 leaves, taking 50 bottom leaves (not leaflets) on a line from one corner to the center of the field, and another 50 bottom leaves on a line from the center to another corner of the field.[1] This should provide a randomly selected sample that is representative of the field. The leaves should be picked without prior examination to avoid sampling bias. If this sampling reveals the presence of aphids on more than five leaves out of 100 (5 percent infestation), then the field should be treated.

Infestations are more likely to begin at field edges, particularly those areas upwind of the prevailing spring winds. If aphids are present, then sampling should proceed. *Plants from which the leaves are selected should be chosen randomly.*

- Alternative thresholds were developed on Russet Burbank.[2] If more resistant varieties have been planted, it may be safe to adjust the action thresholds upwards. The following thresholds are recommended for potatoes grown in the Midwest and should be tested for the Klamath Basin. The thresholds generally are higher than those recommended by U.C. guidelines, and may save growers money by decreasing the need for treatments.

  Weekly monitoring for green peach aphids should begin in early June. Collect 25 leaves (not leaflets) from each of five locations within a field. The sampling locations should be dispersed randomly. The pattern on a die with five spots is one possible model for sample locations. The leaves should be collected from the middle of the plant canopy.

  Fresh Market or Processing
  Early season - 50 wingless aphids (all species)
  After bloom - 100 wingless aphids (all species)

  Fresh Market or Processing in Seed Production Area
  7.5 green peach aphids
  50 aphids (all species)

  Seed Potatoes for Leaf Roll Virus Management
  2.5 green peach aphids for leaf roll virus susceptible varieties
  7.5 green peach aphids for leaf roll virus resistant varieties
  25 potato aphids

Cultural

- Eliminate host weeds which may serve as early-season hosts on which aphid populations may increase before spreading to potatoes. Host weeds include malva, penny cress, various other mustards, nightshade, and volunteer potatoes. The last two may act as reservoirs for the leaf roll virus. Other cultural recommendation are noted under Field Trial Recommendations.

Biological

- No potato cultivars resistant to green peach aphid exist, although there are some cultivars that have resistance to leaf roll virus and do not show net necrosis symptoms. When the crop is grown without insecticides, aphids rarely become abundant enough to cause damage attributable to simply feeding, since their populations are effectively regulated by their natural enemies. [7] Other biological control recommendations are noted under Field Trial Recommendations.

Table 3.
Aphid predators and parasites

Natural enemy	**Type of organism**	**Commercially available***	**Host plant (pollen/nectar source for beneficial insect)**
syrphid larvae	fly larva	no	Carrot family (Queen Anne's lace, dill), sunflower family (sunflowers, dandelion, goldenrod), buckwheat, sweet allyssum, coyote brush, knotweed Protect plants from wind.
green lacewing (*Chrysoperla carnea*)	adult and larval insect are both aphid predators	yes	Carrot family (Queen Anne's lace, dill), sunflower family (sunflowers, dandelion, goldenrod), buckwheat
Beauveria bassiana	fungus	yes	Avoid fungicide sprays.
Diaeretiella rapae	parasitic wasp	yes	Nectar-rich plants with small flowers such as mustard, white clover, dill, parsley, sunflower, hairy vetch, buckwheat, cowpea, common knotweed, and Queen Anne's lace
Aphidius spp.	parasitic wasp	yes	Mustards, white clover, carrot family plants such as Queen Anne's lace, dill
Coccinella septempunctata, Hippodamia convergens, and other species of lady beetles	lady beetle, both adult and larvae are aphid predators	yes	Carrot family (Queen Anne's lace, dill), sunflower family (sunflowers, dandelion, goldenrod), buckwheat, crimson clover, hairy vetch, grains and native grasses, buckthorn, saltbush and black locust

* Most of these beneficial organisms are probably already present to some extent in Klamath Basin.

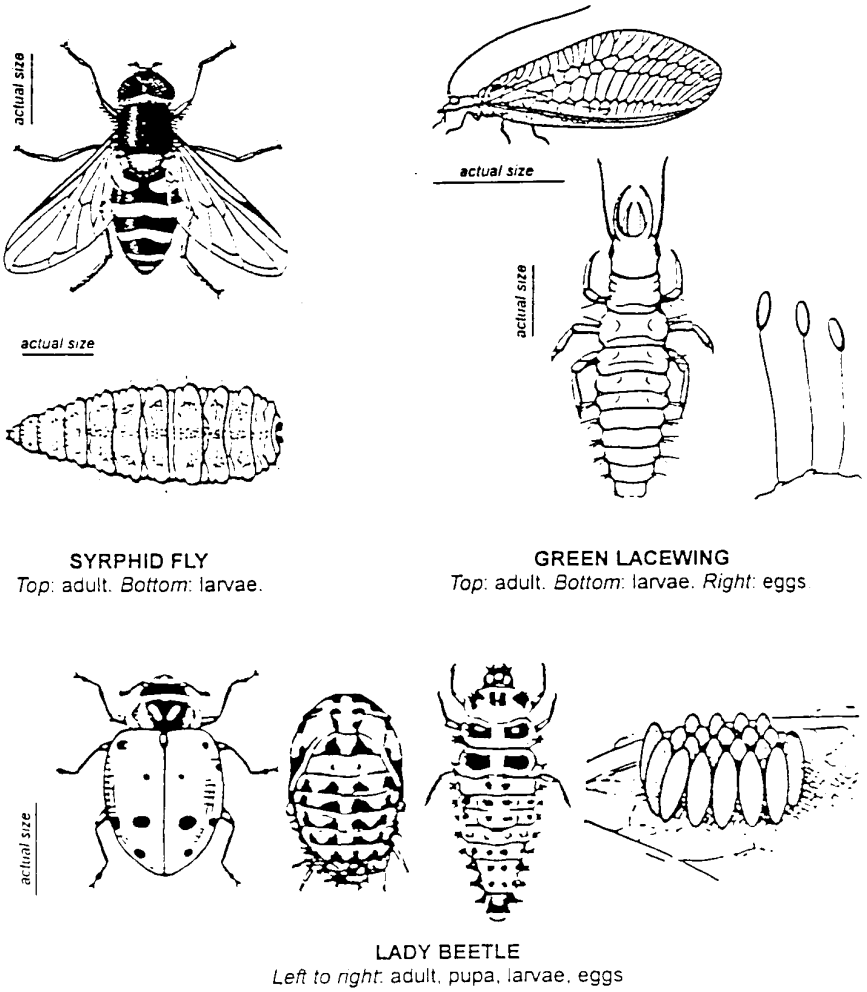

Figure 3.
Beneficial insects effective against pests found in potatoes
(Syrphid fly: after USDA Bull. 1930. Green lacewing: after Ext. Serv. 4-H Handbook. Lady beetle: *Handbook of the Insect World*, Hercules Powder Co.)

▶ *Chemical*

- The green peach aphid has demonstrated resistance to every major class of insecticides, so resistance to compounds approved for leased-land use, such as Admire, Provado, and Malathion, can be developed quickly by overtreatment. The use of Malathion, especially, should be questioned, as control of aphid populations requires several applications of this chemical, decimating populations of beneficial insects. Multiple applications only speeds the build-up of chemical resistance in aphids.

- Seed piece treatment at planting with a systemic insecticide such as Admire will generally prevent the build-up of early season aphids populations and will not impact wildlife or natural enemies.

- The preferred alternative to Malathion for aphid control is Provado. Provado, a systemic insecticide, is the foliar-applied equivalent to Admire. (Admire can only be soil- or seed-piece [in furrow] applied.) The active ingredient of both Provado and Admire is imidicloprid. Provado is relatively non-toxic to beneficials, so fits in well with an IPM program.

- Even with systemic insecticides, good coverage of the plant is important as the green peach aphid is found on the middle and lower parts of the plant. For later-season aphid populations, it is important to treat only when the action thresholds are exceeded.

♦ POTATO APHID – *Macrosiphium euphorbiae*

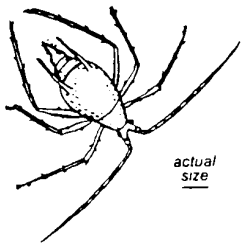

Figure 4.
Potato aphid
(*Handbook of the Insect World*,
Hercules Powder Co.)

Life Cycle, Host Crops, Seasonal Development

Potato aphids overwinter in the egg stage. Eggs usually are found on plants of the rose family, such as domesticated roses, wild rose, apples, pears, and quince. After hatching in the spring, several generations of this aphid will feed on the rose prior to developing winged forms in late June or July and migrating to potatoes. Populations can then develop quickly, with 2 to 3 weeks between generations. Adult potato aphids are considerably larger than green peach aphids, although management and damage from these pests are quite similar. Alternate hosts include tomato, groundcherry, and nightshades. The latter is a preferred host.

Damage and symptoms

This aphid is generally less damaging than the green peach aphid because it is not an efficient carrier of potato leaf roll virus, or viruses Y and A.[7][15]

Short- and long-term management recommendations

▶ *Monitoring*

- Control of potato aphids is needed only at very high populations which damage plants by draining away plant sap. For action thresholds, refer to alternative thresholds for green peach aphid in *Table 2*.

▶ *Cultural*

- See green peach aphid.

▶ *Biological*

- See green peach aphid.

▶ *Chemical*

- It is very rare that the potato aphid requires chemical treatment separate from treatment for the green peach aphid. Treatment for the green peach

aphid will control this pest.

♦ CABBAGE LOOPER – *Trichoplusia ni*

♦ ALFALFA LOOPER – *Autographa californica*

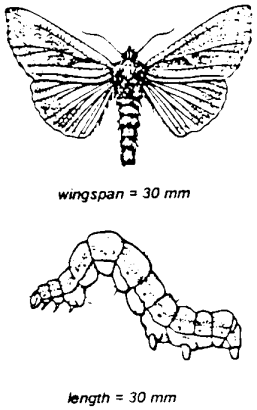

Figure 5.
Cabbage looper
Top: adult. *Bottom:* larvae
(after USDA Bull. 1371)

Life Cycle, Host Crops, Seasonal Development

Loopers are occasional pests on potatoes grown on the leased lands. The cabbage looper overwinters as a greenish-brown pupa less than 1 inch long within a thin silken cocoon. The brownish adults emerge in the spring, feeding, mating and laying eggs nocturnally. The moths are nocturnal fliers, but can be seen during the day resting on the underside of host leaves. Up to 350 very pale green eggs are laid singly on the upper leaf surface of host plants including mustards, pea, beets, potato, and tomato, among others. Alfalfa loopers are considered general feeders, preferring alfalfa, clover, and lettuce along with potato and canola. It is uncertain whether or not either looper overwinters in the Klamath Basin. The adults may migrate in from the south.

Damage and Symptoms

Larvae begin feeding on the underside of leaves and as they increase in size, chew large holes in the foliage. Larvae feed high on the plant and are usually easily seen, but are rarely present in damaging numbers in potatoes. The worst damage is usually caused by the second generation of larvae in late summer around August. High populations can defoliate plants and reduce crop yield.

Short- and Long-term Management Recommendations

▶ *Monitoring*

- These monitoring recommendations are taken from WISDOM potato management software.[3] Shake foliage of 5-foot sections of two adjacent rows into the furrow and count the larvae on the soil surface. Divide the number of larvae by 5. The result is the number of worms per row foot. Sample at least five sites per 30 acres and add one additional sample site for each additional 20 acres.

  Weekly sampling for larvae is the recommended method. Frass (larval excrement) and fresh feeding damage are usually good indicators of the presence and size of larvae.[8]

  Prior to July 25, control measures are recommended if larvae counts exceed four per row foot as a field average. After July 25, control measure are recommended if larvae counts exceed eight per row foot as a field average. Treat when loopers are numerous and ragging of leaves is obvious. Depending on the stage of development, most healthy plants can withstand some defoliation (20-60%) without serious reduction in yield.[62] Spot treatments usually are adequate for infested seedlings. Larvae are best treated while they are small. These economic thresholds

have not been validated in Klamath Basin for larvae populations on potatoes. If these economic thresholds are validated locally, growers will have better guidelines for control of larvae.

- For some advance warning about how large a population might develop and when larvae might first begin appearing, monitor looper flights using pheromone traps. This is most easily accomplished by using cabbage looper pheromone traps which are commercially available.[9] See Useful Contacts and Resources.

▶ *Cultural*

- See Field Trial Recommendations for pest break strips under "Aphids".

▶ *Biological*

- *Bacillus thuringiensis* var. *kurstaki* (*B.t.k.*) is recommended for control of loopers on potatoes. *B.t.k.* has proven to be an effective control for a wide range of caterpillars on a variety of conventionally grown crops and is not toxic to beneficial insects. *B.t.k.* works most effectively when used against small larvae.

▶ *Chemical*

- Sevin XLR Plus and Pounce are PUP-approved for control of loopers on potatoes. However, use of these chemicals will destroy beneficial insects and the grower will lose the natural control provided. It is recommended *B.t.k.* be the first line of defense against loopers. If that fails, Sevin XLR or Pounce should be used.

♦ BLACK CUTWORM – *Agrotis ipsilon*
♦ VARIEGATED CUTWORM – *Peridroma saucia*
♦ SPOTTED CUTWORM – *Euxoa auxilaris*
♦ ARMY CUTWORM – *Wuxoa auxilaris*
♦ RED-BACKED CUTWORM – *Euxoa ochrogaste*

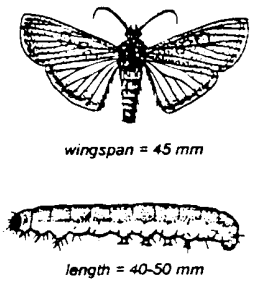

Figure 6.
Variegated cutworm
Top: adult. *Bottom:* larvae.
(after Iowa Agric. Stn. Circ. 101)

Life Cycle, Host Crops, Seasonal Development

Several species of cutworms may be present on leased lands although it is not known which species are the predominant pest(s). Cutworm larvae are rather large caterpillars, reaching 1.5 to 2 inches long when fully grown. Cutworm larvae attack a wide variety of vegetable and field crops, especially in the seedling stage. Cutworms are an early-season pest on the leased land. Seedling and young potato plants are most susceptible to cutworm damage; damage to older plants is minor.

All cutworm adults are moths with dark gray forewings, variously marked, and lighter colored hind wings. They feed at dusk on flower nectar and are attracted to lights. They tend to lay their eggs on plants in grass sod or weedy fields. Larvae go though several molts and eventually enter the soil to pupate. Once the larvae reach the "cutting" stage, they are 0.5 inch long and cut the stem at, or just below the soil surface. One large larvae may destroy several plants in one evening. The larvae will often pull the stem of

the severed plant into their subterranean burrows. This type of injury is common during extended periods of dry weather.[3]

Black cutworm larvae feed at night and cut off plants at the soil line. Young larvae (less than 0.5 inch long) feed above ground. Larger larvae feed at, or just below the soil surface. Black cutworms are a greasy gray to brown, with faint lighter stripes. The black cutworm overwinters as a larva or pupa and produces two to three generations per year. The first generation, active during May and June, causes the most damage.

Eggs are laid singly, or a few together, on stems or leaves of plants in low spots in a field, or on land that has been flooded. Generally, black cutworm moths will not lay eggs in fields that have already been planted. Oviposition (egg-laying) typically is concentrated on low-growing vegetation such as chickweed, curly dock, mustards, or plant residue from the previous year's crop. As a result, heavy spring weed growth, newly broken sod, previous crop, and plant debris all increase the risk of black cutworm infestations.

The ***variegated cutworm*** is the only species that commonly feed during the day. It is a foliage feeder and heavy infestations can cause complete defoliation. This pest is not as closely associated with grasses as are other cutworms. The larvae are dark gray with a light stripe on the side and small yellow-to-orange spots on top of the abdominal segments. The variegated cutworm overwinters as partially mature larvae or pupae and has two generations per year. Adults emerge in June, lay several hundred eggs in clusters on grass, weeds, and vegetables. Bare eggs are laid in bunches of 60 or more on stems or leaves of low plants, twigs, branches, fences, and buildings.

Young variegated cutworm larvae feed on the terminal growth while older larvae feed near the ground. The other species, except army cutworm, are either nocturnal or subterranean and are rarely seen even when their damage becomes obvious.

The ***spotted cutworm*** is a climbing worm that generally feeds on foliage and shoots. It overwinters as large larvae and has two to three generations per year. Eggs are laid singly or in rows/patches of several dozens, mostly on leaves. Each segment of the posterior half of the larvae has a pair of elongated, wedge-shaped black dashes on the upper side that increase in size toward the rear of the insect.

The ***army cutworm*** is mostly a surface feeder, rarely burrowing; it may 'march.' The army cutworm overwinters as half-grown larvae and has one generation per year. Eggs are laid singly in or on the soil. The larvae are pale greenish gray to brown, with the back pale-striped and finely splotched with white and brown.

Red-backed cutworm larvae feed beneath the soil surface on roots or stems of plants and on foliage at night. Most severe damage occurs April through June. The red-backed cutworm overwinters as first instar larvae in eggs. It has one generation per year. Larvae often have a red or reddish

brown top stripe, usually extending the length of the body.

Table 4.
Cutworm living habits [10][11][2][4]

Name	Feeding habit	Overwinters as/generations per year	Egg-laying habit	Description
Black cutworm, *Agrotis ipsilon*	Larvae feed at night, cut off young plants at soil line. Young larvae (less than 0.5 inch long) feed above ground. Larger larvae feed at, or just below, the soil surface.	Larva or pupa/ 2 to 3 generations per year. The first generation, active during May and June, causes the most damage.	Lays eggs singly, or a few together on stems/leaves of plants in low spots in field, or on land that has been flooded	Greasy gray to brown with faint, lighter stripes
Variegated cutworm, *Peridroma saucia*	Only species that commonly feeds during the day. Foliage feeder and heavy infestations can cause complete defoliation. Not as closely associated with grasses as other cutworm species.	Partially mature larvae or pupae/two generations per year. Adults emerge in June, lay several hundred eggs in clusters on grass, weeds, and vegetables	Lays bunches of bare eggs (60 or more) on stems/leaves of low plants, twigs, branches fences, buildings.	Dark gray with a light stripe on the side and small yellow to orange spots on top of the abdominal segments
Spotted cutworm, *Euxoa auxilaris*	A “climbing” cutworm that generally feeds on foliage and shoots.	Large larvae/2 to 3 generations per year.	Eggs laid singly or in rows/ patches of several dozen, mostly on leaves.	Each segment of posterior half of larva has a pair of elongated wedge-shaped black dashes on the upper side which increase in size toward the rear of the insect.
Army cutworm, *Euxoa auxilaris*	Mostly a surface feeder with little burrowing; may “march”	Half-grown larvae/one generation per year.	Eggs laid singly in or on the soil.	Pale greenish gray to brown with the back pale-striped and finely splotched with white and brown.

Name	Feeding habit	Overwinters as/generations per year	Egg-laying habit	Description
Red-backed cutworm, *Euxoa ochrogaster*	Larvae feed beneath soil surface on roots/stems of plants and on foliage at night. Most severe damage occurs April through June.	As first instar larvae in egg/one generation per year.		Larvae often have a red or reddish brown top stripe, usually extending the entire length of the body.

*For Russet Burbank, larval numbers refer to third and fourth instars.[4]

Damage and Symptoms

The most important types of damage are destruction of seedlings, and shallow holes chewed in tubers. Larvae tend to feed at night or on cloudy days, and hide in the soil or under foliage during the day. Newly hatched larvae are unable to chew entirely through the leaf surface resulting in a "window pane" appearance on the leaves. As black cutworm larvae grow, their feeding damage ranges from pinholes in the leaves to complete defoliation. Alternately, young variegated cutworm larvae feed on the terminal growth, while older larvae feed near the ground. Once the larvae reach the "cutting" stage, they are 0.5 inch long and cut the stem at, or just below the soil surface. This damage is often the first sign of an infestation. One large larvae may destroy several plants in one evening. The black cutworm will often work its way down a row of potatoes, cutting off one plant after the next in a line. The larvae will often pull the stem of the severed plant into their subterranean burrows.[3] This type of injury is common during extended periods of dry weather.

Short- and Long-Term Management Recommendations

Monitoring

- For monitoring of variegated, spotted, army, and red-backed cutworm, see loopers section which provides a combined threshold for these three species and loopers. For black cutworm, the action threshold is two plants per 100 with black cutworm present.[2] For variegated cutworm, the action threshold used for potatoes in the Midwest is four cutworms per row.[2]

  Another set of action thresholds that perhaps better reflect the potential for economic damage at different growth stages of the plant are 2.6 larvae/plant at full bloom, 43.3 larvae/plant at full growth, and 34.1 larvae/plant at maturity (these numbers were developed on Russet Burbank and refer to third and fourth instars[4]). This stage of larvae are the first to eat complete holes in potato leaflets and can be used as an indicator of cutworm infestation. When holes begin to appear in leaves,

ground searches around each plant need to be made to determine larval population density of instars three and four to determine potential heavy defoliation by fifth- and sixth-instar larvae.

- Timely detection is critical if insecticidal treatment is to be effective. Pheromone traps are useful for monitoring moth activity but do not correlate well with predictions of whether damage will occur, or when or where damage may be expected. Look for the presence of cutworm larvae early in the season, and after destruction of adjacent habitats. Cutworms are most active at night, so are best scouted after dark, with a flashlight. Look for cutoff or damaged seedlings and dig around the base of the plant to locate the larvae.[12]

Cultural

- Crop rotation is an important cultural control tool for cutworms, since populations can build in crops preceding potatoes. Alfalfa and cereals are especially good hosts for cutworms, so growers should avoid planting fields to potatoes if monitoring shows high populations of cutworms in the previous crop.

- Tillage prior to seeding is an effective means of preventing cutworm damage. Clean tillage to remove all weedy vegetation, at least 10 days prior to planting, reduces the number of cutworm larvae. Control of weedy vegetation at field borders also reduces the number of invading larvae. Keeping fields weed free is important because weeds, especially grasses, serve as alternate hosts for cutworms.

Biological

- It is recommended that beneficials be conserved by limiting insecticide applications. Cutworm larvae have a number of natural enemies. Predators include several species of ground beetles. Parasites include tachinid flies and braconid wasps. Cutworms may also be attacked by fungi, bacteria, and nematodes.[13] However, some of these are less effective against subterranean species.

- One biological control agent (an insect-eating nematode) is amenable to human manipulation and has proven effective

against cutworms.[14] The commercial formulation is BioVector. See Field Trial Recommendations.

▶ Chemical

- Sevin is one of two PUP-approved products for cutworm control on Tule Lake Refuge. Pounce is also used for cutworm control. Applications should be made under warm, moist conditions in the evening or at night, when cutworm activity is highest.

♦ GRASSHOPPERS - *Melanoplus* spp. and *Camnula pellucida*

Life Cycle, Host Crops, Seasonal Development

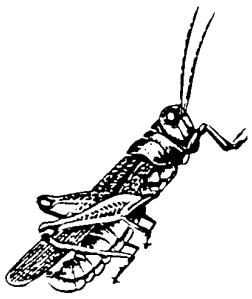

Figure 7. *Grasshopper* (*Handbook of the Insect World*, Hercules Powder Co.)

According to Dr. Mark Quinn, grasshopper researcher on the Klamath Forest NWR and adjacent area, the major pest species of grasshopper in the Klamath area is the clear-winged grasshopper, *Camnula pellucida*. Scott Stenquist, Regional IPM Coordinator for the Service, confirms that *Melanoplus* spp. also are present on the Refuge lands. Grasshoppers may migrate from rangeland (especially if it is overgrazed) to grain or potato crops on adjacent land.

Damage and Symptoms

- Both adults and nymphs may feed on potato foliage. Heavy infestation will strip a plant of all foliage. Lighter infestations will cause a ragged appearance on leaves.

Short- and Long-term Management Recommendations

▶ Monitoring

- Oviposition sites for the grasshoppers should be identified and monitored. Infestations generally will start at field edges as grasshoppers migrate into the crop from other locations.

▶ Cultural

- Most grasshopper problems begin in adjacent rangelands, not in the fields.

▶ Biological

- Mycotrol (by Mycotech) is a formulation of *Beauveria bassiana* (a fungus) effective against grasshoppers that is now in the registration process at both the EPA and CalEPA. It is expected to be on the market by summer 1997.

  It also should be noted that for IPM to be effective, some monitoring of off-refuge locations of grasshopper egg laying may be needed. Monitoring and treatment of these areas may require the permission of private landowners.

▶ Chemical

- There are currently no PUP-approved insecticides available for grasshopper control on the leased lands. However, according to Dr. Mark Quinn, spot treatments of a 2 percent carbaryl/bran mix applied at 2 lbs. per acre on "hatching beds" is very effective in controlling grasshopper populations. Since the rate of active ingredient (carbaryl) applied is roughly half an ounce per acre, it has minimal effects on wildlife.

♦ YELLOWSTRIPED ARMYWORM – *Spodoptera ornithogalli, s. praefica*

Life cycle, host crops, seasonal development

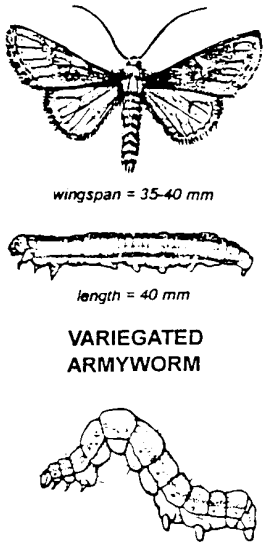

Figure 8. *Armyworm vs. looper* (Armyworm: *Insects of Economic Importance in the Northwest*, OSU, Corvallis, OR. Looper: after USDA Bull. 1371.)

Yellow-striped armyworm larvae have a pair of triangular black spots on the top side of most of its body segments and often has a bright orange stripe just outside these spots on each side. Armyworm populations are recurrent, with large numbers occurring only every few years.[15] Some armyworms will "loop" as they crawl and may be mistakenly identified as loopers. True loopers, such as the cabbage and alfalfa loopers, have only two prolegs (the legs toward the posterior of the larva). Armyworms have four pairs of prolegs.

Armyworm eggs are laid in clusters, which the female covers with scales. The larvae occur from June through September. Larvae develop rapidly over a period of 2 to 3 weeks after hatching. They pupate on or near the soil surface, where they overwinter. Typically four to five generations develop each year in California, but in Klamath Basin, there are probably two overlapping generations each year.

Damage and Symptoms

These pests can defoliate plants, usually only near field edges. They can also damage exposed tubers, similar to cutworm damage.

Short- and Long-term Management Recommendations

▶ Monitoring

- Young larvae of this species are day feeders and may be found feeding on terminal buds and leaves. This foliage-feeding stage is the one most easily sampled and controlled. Monitor young armyworm larvae with sweep nets. The larvae must be at least 0.5 inch long for accurate counting, and to evaluate for parasitism and disease. Check fields weekly from June through September, or more often if heavy populations develop. The presence of a number of diseased larvae in the field may indicate a soon-to-develop natural epidemic. Older larvae generally are found in residue at the soil surface; this is where sampling should take place after mid-July. There are no action thresholds developed for armyworms. However, since this pest is considered a type of cutworm, the sampling methods and action thresholds outlined for looper and cutworms *may* be applicable.

To help avoid unnecessary treatments, two things should be kept in mind. First, depending on the state of development, most healthy potato plants can withstand some defoliation (20-60%) without serious reduction in yield.[62] Second, a monitoring program that includes assessment of natural enemy populations is essential for the most effective armyworm control.

▶ *Cultural*

- The technique of placing strips of aluminum sheeting vertically along the field edge is used principally as a vole management tool (for more on this technique, see Vertebrate Pests), but coincidentally prevents migrating armyworms from entering potato fields. An alternative to this is plowing a deep trench with the steep side toward the potato field. Applying pesticides to the bottom of the trench will kill the armyworms trapped (or slowed) by the trench. This is only practical against large migrations of armyworms. The aluminum sheeting technique may be more effective, with less environmental impact, and will help protect tubers against voles.

▶ *Biological*

- The most important way of controlling armyworms is by enhancing natural biological control. When pesticides are applied to control other potato insect pests, they can also disrupt beneficials that would control armyworms.

- Predators of armyworms include bigeyed bugs, damsel bugs, lacewings, spiders and pirate bugs. Many parasites also attack these pests. The wasp, *Hyposoter exigua*, is known to be especially effective against beet armyworms.[15] Viral diseases of armyworms also play an important role in their control. Growers can enhance and preserve the potential for biological control by providing shelter and protection for beneficials (e.g., by providing borders planted with beneficial insect habitat, such as alfalfa).

▶ *Chemical*

- It is rarely necessary to treat a whole field for yellowstriped armyworms.[15] It is recommended that strip or spot treatments along the field edges where infestations are more likely to occur are more appropriate. However, Sevin XLR Plus is PUP-approved for control of armyworms Sevin is toxic to many species of beneficial insects and the grower will lose the natural control provided.[63]

◊ WESTERN POTATO FLEA BEETLE – *Epitrix cucumeris*
◊ THREESPOTTED FLEA BEETLE – *Disonycha triangularis*
◊ PALESTRIPED FLEA BEETLE – *Systena blanda*

Life Cycle, Host Crops, Seasonal Development

Three species of flea beetles are present on Refuge lands; it is not known

which of the species is most destructive to potatoes. Because the damage they cause is relatively minor or occasional, flea beetles are not considered an important pest of potatoes.

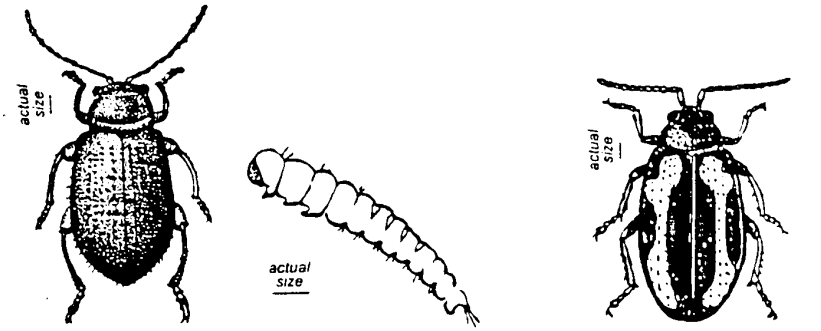

Figure 9.
Western potato flea beetle and striped flea beetle
(*Handbook of the Insect World*, Hercules Powder Co.)

Flea beetles are tiny; roughly 0.25 inch long. Potato flea beetles are shiny black, whereas threespotted flea beetles are slightly larger (two to three times) and have an orange-colored mid-back with three dark spots. Palestriped flea beetles are about the same size as the threespotted, but are dark brown and have a long creamy white strip down each wing cover. All flea beetles have large back legs and jump vigorously when disturbed.[16]

Adult western potato flea beetles overwinter in debris around field margins.[11] They become active in late March and early April and feed first on weed hosts, then later move to emerging seedlings, and may begin damaging the crop.

Eggs are laid in the soil near the base of plants in May, and larvae are present in the soil during June and July when pupation occurs in the soil. Beetles begin emerging in late July and disperse within the same field or to weedy margins. Eggs are laid, and larvae from this generation are present in August and early September. Generally, there are one to two generations per year.

Damage and Symptoms

Flea beetle larvae may damage tubers, and adult feeding will create many small holes in the leaves. High populations of adults causing a shothole appearance may indicate potentially damaging larval populations later in the season.[5]

Damage often occurs in localized pockets in a field, especially where adults are entering a field from a weedy border area, or in areas previously infested with weeds. Some sites experience yearly problems with flea beetles, whereas other sites have problems less frequently.[17]

Short- and Long-term Management Recommendations

Monitoring

- Visual observations of adult feeding damage are the primary monitoring method, though sweep nets can be useful for sampling adults. Because adults often overwinter at weedy field edges or near structures, early season monitoring of these areas may be helpful for detecting initial infestations.

Cultural

- Keep fields free of preferred weed hosts, especially field bindweed and mustard. Crop rotations are ineffective because of the mobility of the adults, and because of their wide range of wild hosts.

Biological

- No economically significant biological controls exist. The main "natural" controls are climatic factors, which limit beetle numbers and distribution.[18]

Chemical

- No requests have been made for a PUP-approved chemical to treat flea beetles on potatoes. It should be noted that if Admire is used as a seed-piece treatment on potatoes (for early season aphid control), it will probably provide some control of flea beetles as well.

DISEASES

Diseases and Water Management

Table 5.
Potato cultivars resistant and susceptible to various diseases of potatoes

Disease	Resistant cultivars	Susceptible cultivars	Remarks
Late blight	Fundy, Kennebec, Brador, Onaway, Nooksack, Rosa, Sebago		The cultivars listed under "resistant" are those cultivars that were resistant to the "old" late blight strain which reproduced asexually
Early blight	Rosa		
Blackleg	Belleisle		
Early dying	Atlantic, Yukon Gold, Belrus, Rhinered		
Leaf roll virus	Rosa, Abnaki, Alamo, Cascade, Cherokee, Chieftan, Houma, Merrimack, Pungo, Redskin, Reliance, Saco Sebago, Wauseon, Yukon Gold	Highly Susceptible: Norchip, Norgold Russet, Russet Burbank, Sebago. Moderately Susceptible: Norland, Red Pontiac, Shepody	Katahdin and Kennebec are somewhere between "resistant" and "moderately susceptible." They were listed under each category by different authors.
Scab	Atlantic,* Norchip, Norland, Shurchip, Superior		
Verticillium	Shurchip, Abnaki	BelRus, Butte, Hilite Russet, Irish Cobbler, Kanona, Kennebec, Lemhi Russet, Norgold Russet, Onaway, Russet Norkatah, Sangre, Shepody, Superior, Viking, White Rose	See the Verticillium section for more information on resistant and susceptible cultivars.
Fusarium dry rot	Arran Banner, Arran Victory, Kennebec, Green Mountain, Teton, Hudson, Superior, Russet Burbank, Hunter, Epicure, Belleisle	Doon Star, Arran Pilot, Keswick, Sebago	
Fusarium tuber rot	Kennebec, Acadia Russet, Belleisle, Shepody, Tobique		

Disease	Resistant cultivars	Susceptible cultivars	Remarks
Fusarium wilt	Pontiac, Katahdin, Sebago, Arnica, Hindenburg		
Virus A	Belchip, Delta Gold		
Virus X	Belchip, Atlantic,* Katahdin, Kennebec		
Virus Y	Avon, Katahdin, Kennebic, Monona, Nordak, Norgleam, Oromonte, Saco, Snowflake, York, Caribe, Russette		

Sources: [19][20][21]

*Astericked varieties are being tested at the Intermountain Research and Experiment Center (IREC)

Rotations

Crop rotation is one of the foundations of a successful IPM program. Growers in Klamath Basin are already using crop rotations to combat potato pests, some of which are similar to those described here. Some additional crop rotation options, as well as comments relating to strengths or weaknesses of each crop rotation are listed. There are additional crop rotations that could be used in Klamath Basin, depending on crop marketability and the various costs and benefits associated with each 3-to-4-year rotational system. See page 30 for additional crops.

Table 6.
Some crop rotation options to combat potato pests

Rotation/# years	Location/ farm size	Comments
grain-potato-grain-potato/2 years total rotation	Bingham Co., Idaho/1000 ac.	
3 years alfalfa-potato/4 years total rotation	Bingham Co., Idaho/1000 ac.	Potato yields of 7-14 oz. range were 8% higher following alfalfa than following grain. Hairy nightshade, wild oat, Canada thistle and field bindweed were less of a problem in potatoes following alfalfa than following grain, but quackgrass was more of a problem. There was less Verticillium wilt and early blight in potatoes following alfalfa than following grain.
grain-green manure (Austrian winter pea)-potato/3 years total rotation	Madison Co., Idaho	Total fertilizer inputs for potatoes and grain were about one-half those of conventional farms in the area. Potato yields for this low-input system were about 2.5 tons/acre higher than the average for the conventional farms in the area. Grain yields were average for the area. Potato quality was above average and potato disease problems were greatly reduced. Savings resulting from reduced fertilizer and pesticide inputs averaged $28,000 in 1994 compared to conventional farming systems. Economic analysis of this farming system on a 3-year rotational basis shows that net return was similar to a grain-grain-potato rotation.
cash crop-rapeseed-potatoes/3 years total rotation cash crop-Sudangrass-potatoes/3 years total rotation	Prosser, WA	Rapeseed and Sudangrass green manures grown prior to potatoes have provided up to 86% control of root-knot nematode, while Sudangrass has reduced Verticillium wilt by 25-50%. Rapeseed cover crops also can reduce or eliminate herbicide applications in potatoes ($30-$45/acre) without affecting yields. Lengthening rotations and including rapeseed, mustard, or Sudangrass as rotation crops or winter cover crops shows considerable potential for reducing reliance on fungicides and fumigants for disease and nematode control, while maintaining an economically-viable farming system.
cash crop-canola-potatoes/3 years total rotation	Eastern Idaho, two growers	Two growers in eastern Idaho obtained potato yield improvements of 10-20% when their fields were previously cropped to canola compared to barley.

♦ EARLY BLIGHT – *Alternaria solani*

Life Cycle, Host Crops, Seasonal Development

Early blight is basically a disease of older plants, or plants that have experienced some stress, such as infection by some other plant pathogen, or deficiencies of nitrogen or water. The lower leaves are generally the first leaves infected. Early blight may first appear early in the season, but the rate

of infection accelerates rapidly after flowering. Tomato and other solanaceous plants are hosts, and it has been reported on other plants, such as some *Brassica* spp. There are several races of this pathogen, some of which are highly virulent, others are saprophytic (living in the soil on dead organic matter). The pathogen can survive on crop debris, as a saprophyte in the soil, in infected tubers and on other hosts.

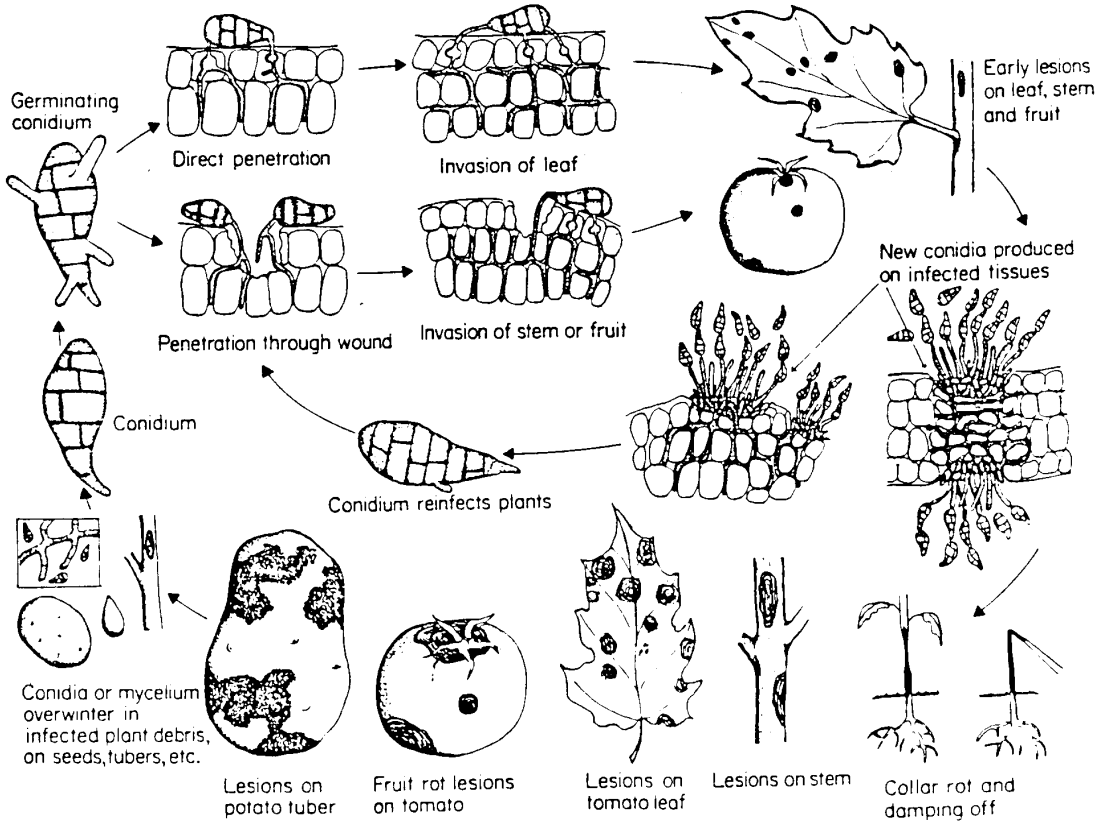

Figure 10.
Disease and symptoms of diseases caused by Alternaria
(copied with permission from Academic Press)

Damage and Symptoms

The most severe damage generally occurs on early maturing varieties. However, within each maturity group, some varieties will have greater resistance to foliar infection by early blight than others. Infection begins as small dark brown spots on lower leaves. As the infection enlarges, the spots will become restricted by the leaf veins and take on an irregular, angular look. Close inspection of the infection will reveal a series of dark, more-or-less concentric lines within the infected area. These lesions will enlarge and may coalesce as the disease progresses. Tubers may also become infected and will have irregularly shaped, sunken lesions with somewhat dark borders. The infections are shallow and cause a brown discoloration to the tuber flesh. These lesions can increase in size during storage, and reduce the saleability of the crop. They are most troublesome on white- and red-skinned chip-processing varieties.

Short- and Long-term Management

Recommendations

Monitoring

- Fields should be visited *at least* weekly from crop emergence to harvest to determine the progress of the crop and accompanying pests. Problem areas, where early blight has been noticed in the past or that have poor drainage, should be given special attention.

Cultural

- Growers should select a marketable cultivar with the greatest resistance to early blight and which also fits in with other aspects of an integrated pest management program (see *Table 7*.)

Table 7.
Degree of cultivar resistance to early blight

Highest susceptibility → Lowest susceptibility

Lowest susceptibility ↓

Early- and midseason cultivars	Late-season cultivars	Very late cultivars
Norland	Russet	Butte
Redsen	Burbank	Nooksack
BelRus	Kennebic	Ontario
Norchip	Katahdin	
Norgold	Rosa	
Russet		
Early Gem		
Superior		
Monoma		
LaChipper		
Atlantic		

Source: [22]

Water management for early blight prevention requires a delicate balance. Too much water will leach soil nitrogen. Nitrogen and phosphorus deficiencies can promote susceptibility to early blight. However, too much nitrogen can reduce yield and delay maturity. Thus, soil fertility, especially nitrogen levels, should be closely monitored. This can be done through petiole analysis. On the other
hand, too little soil moisture will stress the plant, causing earlier than normal yellowing and death. This is a condition conducive to early blight development. The overhead irrigation used on the leased lands creates ideal situations for infection and spread of foliar pathogens, such as early and late blight. Frequency and duration of irrigations are important factors influencing early and late blight's ability to infect plants. Ideally, irrigations should correspond with dew periods to minimize duration of plant surface wetness. If irrigating during dew periods is not possible, overhead irrigations should be timed so plants surfaces dry prior to dew formation,

or prior to morning irrigation.

▶ *Biological*

- No biological controls are currently known.

▶ *Chemical*

- Both aerial and ground sprays of Dithane F-45 (Mancozeb) and Maneb, a similar formulation, are PUP-approved for control of early blight. Dithane is a protectant fungicide, requiring applications spaced 10 days apart to provide disease control. It is also recommended that the disease prediction program in WISDOM be validated (see Field Trial Recommendations).

- A study based out of south-central Washington[23] noted that "fungicides applied either by aircraft or through center-pivot irrigation for control of early blight do not provide economic benefits under growing conditions in Washington." The fungicides tested were fentin hydroxide and chlorothalonil. Growing conditions in this case are probably different from those in Klamath Basin, but this points out the role climate plays in the spread of this disease. It also highlights the possible savings that might be achieved during warm, dry growing seasons if a disease forecasting system was validated for this area.

♦ LATE BLIGHT – *Phytopthora infestans*

Late blight was first detected on the Tule Lake Refuge in August 1997.

Life Cycle, Host Crops, Seasonal Development

New races of late blight that are not sensitive to metalaxyl have created problems for potato growers across the U.S. Ideal conditions for an epidemic of late blight are: night temperatures of 50 to 60 degrees F along with fog, heavy dew, rain, or overhead irrigation; and day temperatures of 60 to 70 degrees F for 4 to 5 consecutive days.

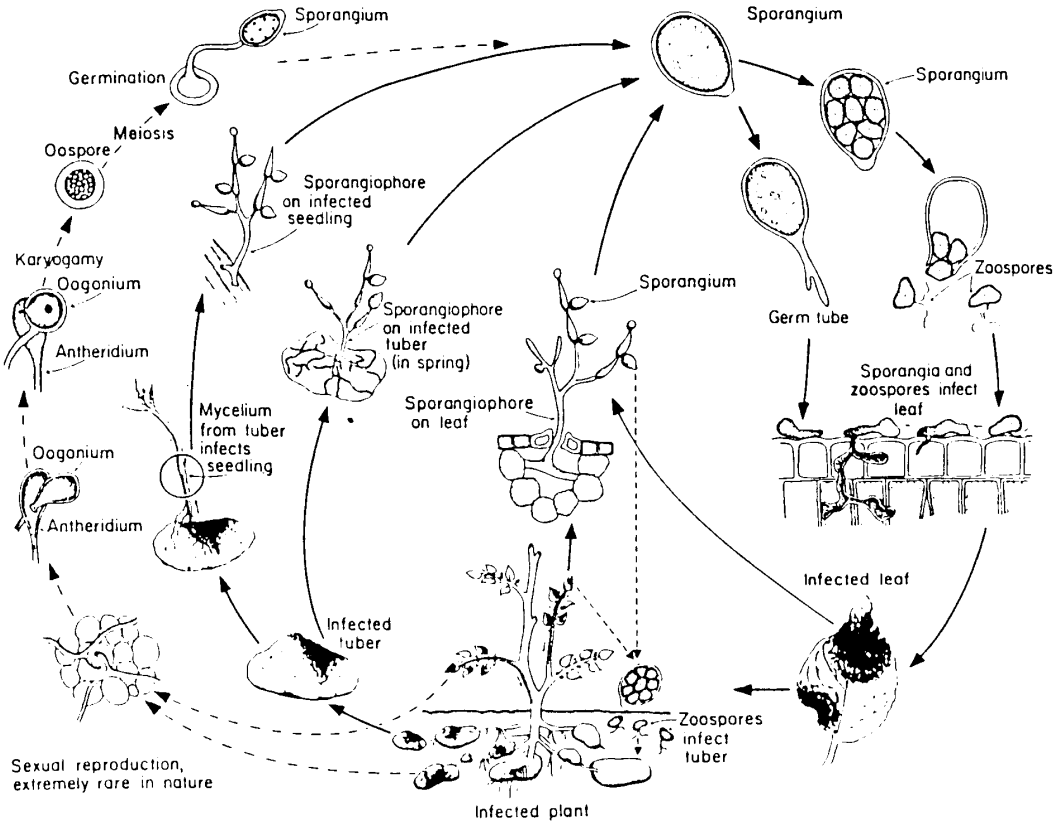

Figure 11.
Disease cycle of late blight of potato and tomato caused by Phytophthora infestans
(copied with permission from Academic Press)

Table 8 .
Temperature influence on late blight fungal activity

Temperature	**Relative humidity**	**Fungal action**	**Comments**
37-79 F (64-72 optimum)	90%	Spores (sporangia) are formed on undersides of leaf.	
70-79 F		Spores germinate directly, forming infectious germ tube which penetrates plant tissue.	One infection per spore. New spores produced 3 to 5 days after initial infection.
<65 F (optimum is 54 F)		Spore contents divide into 6 to 8 zoospores.	6 to 8 infections per “mother” spore. Zoospores mobile in water, but sensitive to drying.
>86 F		unfavorable to disease development	

Damage and Symptoms

The disease attacks leaves, stems and tubers. The first sign of infection is a water-soaked appearance on the leaves, which, in dry weather, quickly turns dark brown and brittle. The infected areas may be surrounded by a halo of chlorotic, or yellowed, tissue. During moist weather, a white cottony growth will develop on the underside of the leaves. Infected stems and petioles will turn dark brown or black. During moist weather, whole plants may be killed in a short time.

Short- and Long-term Management Recommendations

Monitoring

- Blight forecast methods developed for northern areas in the U.S. are not useful in California, except possibly coastal areas.[24] Fields should be closely monitored after possible late blight infection periods occur.

Cultural

- The duration of periods of uninterrupted leaf wetness is a critical factor in successful infection by the late blight.[22] Therefore, sprinkler irrigation should be carefully scheduled with this in mind, particularly later in the season when the closed potato canopy provides ideal conditions for late-blight development. Studies in Israel noted that late-blight infection was greater on morning-irrigated potatoes than on potatoes irrigated at mid-day or evening.[24] A rule of thumb: if rainfall or irrigation water exceeds 1.2 inches in a 10-day period, good conditions for late blight exist.

- Because of the increased virulence of the new strains of late blight, and the possibility of spreading spores during seed piece cutting and planting, a new type of planter has been developed. Called the AireCup planter, it uses vacuum pressure to pick up seed pieces (instead of picks or cups) and may help prevent early infection of seed pieces by late blight and other pathogens. According to its manufacturer, this planter uses a vacuum to pick up single seed pieces, and air pressure to place the seed pieces in the potato rows. It is capable of planting accurately at a speed equal to or greater than pick planters. The manufacturer, which makes both planter types, notes that the AireCup planter is more accurate, and has fewer skip and doubles than its pick planter, according to recent tests in Washington State. See Useful Contacts and Resources.

- Use of certified seed is not a guarantee against late blight. Certified seed will certainly reduce the amount of infestation due to infected seed pieces, but will not prevent current-season foliar infection from other sources, such as neighboring fields. Careful attention should be paid to seed potatoes. Any tubers that are discolored or show signs of Phytophthora infection should be culled and destroyed. Do not mix seed lots. It may be worthwhile to investigate the severity of late blight in the area from which seeds potatoes have been ordered. Planting should take place when soil temperatures are 50 degrees F and rising.

- Planting depth and tilling operations should be carefully monitored. Shallow planting can expose tubers to late blight spores washing down from leaves, creating problems later during storage and sale.

- Tomato, pepper, and eggplant are hosts to late blight and should not be allowed to grow on the leased lands in the future. Nightshade is also host to late blight. Volunteer potatoes and host weeds need to be controlled. This will reduce the number of overwintering sites for the fungus, keeping its early-season infectious stages low.

- In Klamath Basin, frost is usually the vine-killing agent for late-season varieties. Mid- and early-season varieties may require a vine desiccant. Diquat is PUP-approved for this purpose. Vines should be killed a minimum of 2 weeks prior to harvest. The vines should be completely dead, otherwise tubers coming into contact with them risk late blight infection.

▶ *Biological*

- No biological controls for late blight are known.

▶ *Chemical*

- Four new fungicides have been given Section 18 emergency use permits by the EPA for use against late blight: Tattoo C, Curzate M-8, Acrobat MZ, and Manex C-8. Tattoo C and Curzate M-8 have been approved in California and are also PUP-approved. Both of these chemicals are restricted to no more than five applications per year. Further restrictions concerning the ingredients of these fungicides must be observed: Curzate M-8 contains mancozeb, which is restricted to 11.2 lbs. active ingredient (ai) per acre per growing season. Tattoo C contains chlorothalonil, restricted to 12 lbs. ai per acre per growing season.

- Both of these chemicals are systemic, but do not have the mobility within the plant that metalaxyl (Ridomil) has. For this reason, they may not protect rapidly growing shoots from infection and should be used in a preventative treatment program. Good coverage is essential and ground-applied treatments will usually be more effective providing coverage of lower leaves compared to aerial applications, especially as the row is closing.

- Copper hydroxide/ridomil mixes are PUP-approved for control of late blight. Care must be taken using the copper sprays due to the potential for copper buildup in the soils. Copper can become toxic to plants if concentrations in the soil become too high.

♦ WHITE MOLD – *Sclerotinia sclerotiorum*

Life Cycle, Host Crops, Seasonal Development

White mold is an important pest of potatoes in Klamath Basin. It is also called sclerotinia stalk rot. White mold is a cool-season disease. This fungus

overwinters in the soil as sclerotia (small, black reproductive structures) or in crop residues. When moisture is sufficient, usually around the time of row closure, sclerotia within 2 inches of the soil surface will form apothecia, which are essentially miniature mushrooms. The apothecia will forcibly eject spores (ascospores) over a 2-to-8-week period beginning at row closure. If stems or leaves are wet for 48 hours or more, these spores will germinate and infect the plant. Healthy, vigorous tissue is usually not affected. The ascospores more easily infect older and/or dying tissues. Adjacent healthy tissue is subsequently infected.

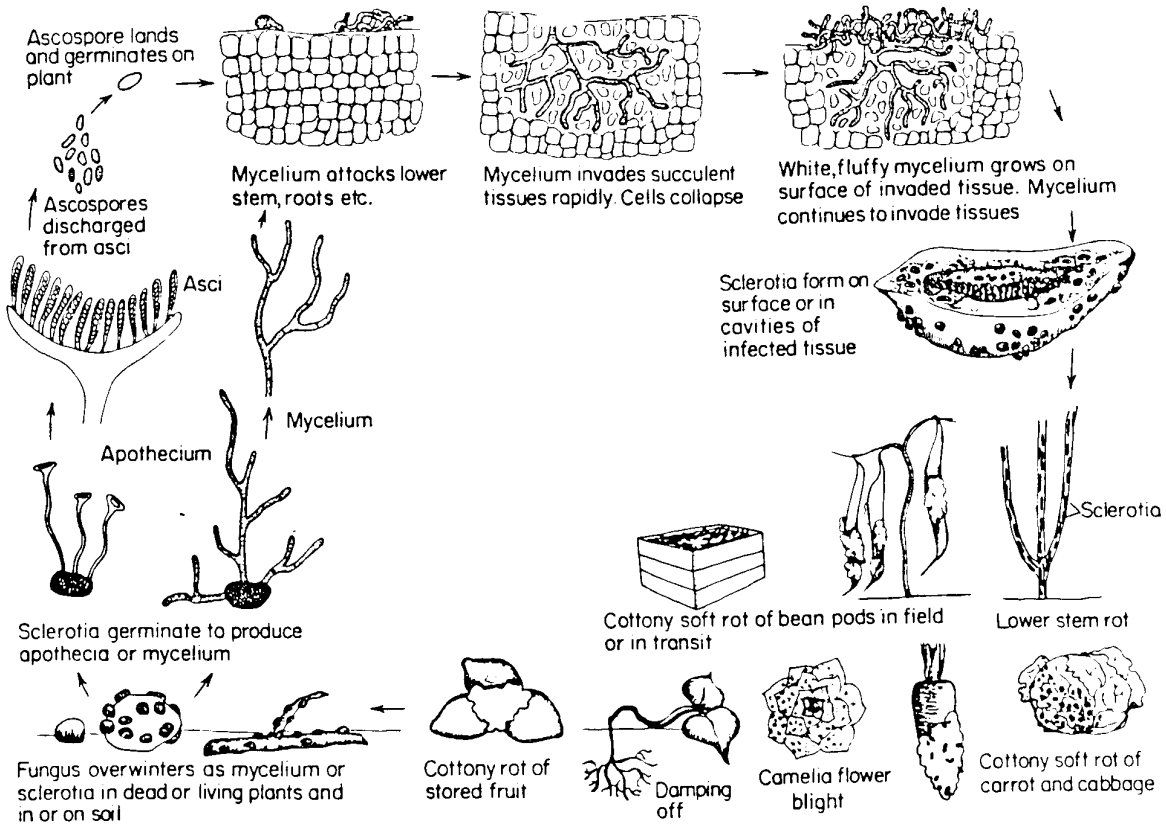

Figure 12.
Development and symptoms of diseases of vegetables and flowers caused by Sclerotinia sclerotiorum
(copied with permission from Academic Press)

Depending on the amount of organic matter available in the soil, the fungus may form a mycelial mat directly on the soil. Sclerotia formed in plant stems are returned to the soil as the plant material decays. Sclerotia can survive for at least 3 years in the soil. Host crops include a wide range of broadleaved crops and weeds. White mold has the ability to grow on residues of some non-host crops during moist, mild spring and winter weather.

Damage and Symptoms

Infections can be identified in the field; a white cottony mass (mycelia) will cover a water soaked lesion. Sclerotia may be seen along with more mycelia

inside the hollowed out stem. If the lesion dries out, it will develop a tan-brown color and may girdle the stem. White mold most seriously affects the late-maturing varieties (such as Russet Burbank) that have relatively dense growth.

Short- and Long-term Management Recommendations

Monitoring

- Scouting for white mold is especially important as row closure is beginning. Look for the "miniature mushrooms" (apothecia) and/or infections (described above) on older plant tissue, such as lower leaves. Treatment decisions will be based on this scouting information in the context of the upcoming weather. Consideration must also be given to the irrigation cycle (e.g., if the weather outlook is dry, the field just irrigated, and relatively few apothecia present in the field, the grower may decide to delay treatment until prior to the next irrigation or predicted rain).

Cultural

- Sclerotia are killed 3 to 6 weeks after flooding a field, so sump rotation, or simply temporary flooding of a field would help control this disease. Rotating to grain crops for 4 or more years will greatly reduce the incidence of this disease.

- When disease first appears (usually during a 2-8 week period beginning at row closure), irrigation should be minimized as much as possible to allow the plant canopy to dry out to halt disease development. However, water stress can lead to higher numbers of irregular, malformed tubers and lower yields, so soil moisture should be monitored closely.

- An alternative to completely halting irrigation is to stop irrigating in the early afternoon to allow the canopy to dry out. Aligning crop rows parallel with the prevailing winds during this critical period may help the crops dry out more quickly.

Biological

- A new product, BioTrek 22G, manufactured by Wilbur Ellis, may provide some control of white mold. BioTrek 22G contains *Trichoderma harzianum*, a fungus parasitic on *Sclerotinia sclerotiorum*. This product may prove to be effective against *Rhizoctonia* and other soil diseases, but will need PUP approval. It is also sold as a growth promoter under different formulations and tradenames. See Useful Contacts and Resources.

Chemical

- Rovral is the PUP-approved chemical generally used to control this disease, using both chemigation and aerial application. Applications usually begin around the time of row closure.

♦ RHIZOCTONIA (BLACK SCURF) – *Rhizoctonia solani*

Life Cycle, Host Crops, Seasonal Development

This pathogen is present in all potato-growing areas. Most damage occurs during the early part of the growing season, particularly when infected tubers are planted. Cold, wet soils can increase problems with this disease. The fungus survives in the soil, either as mycelia associated with decomposing plant residues, or as sclerotia, "the dirt that won't wash off", on non-harvested tubers. Soil-borne infections (known as the chronic phase of the disease) generally will not infect the sprouts, but rather cause a decrease in tuber quality and yield by "pruning" tubers and causing reddish-brown lesions on the tubers which may develop later into cankers.

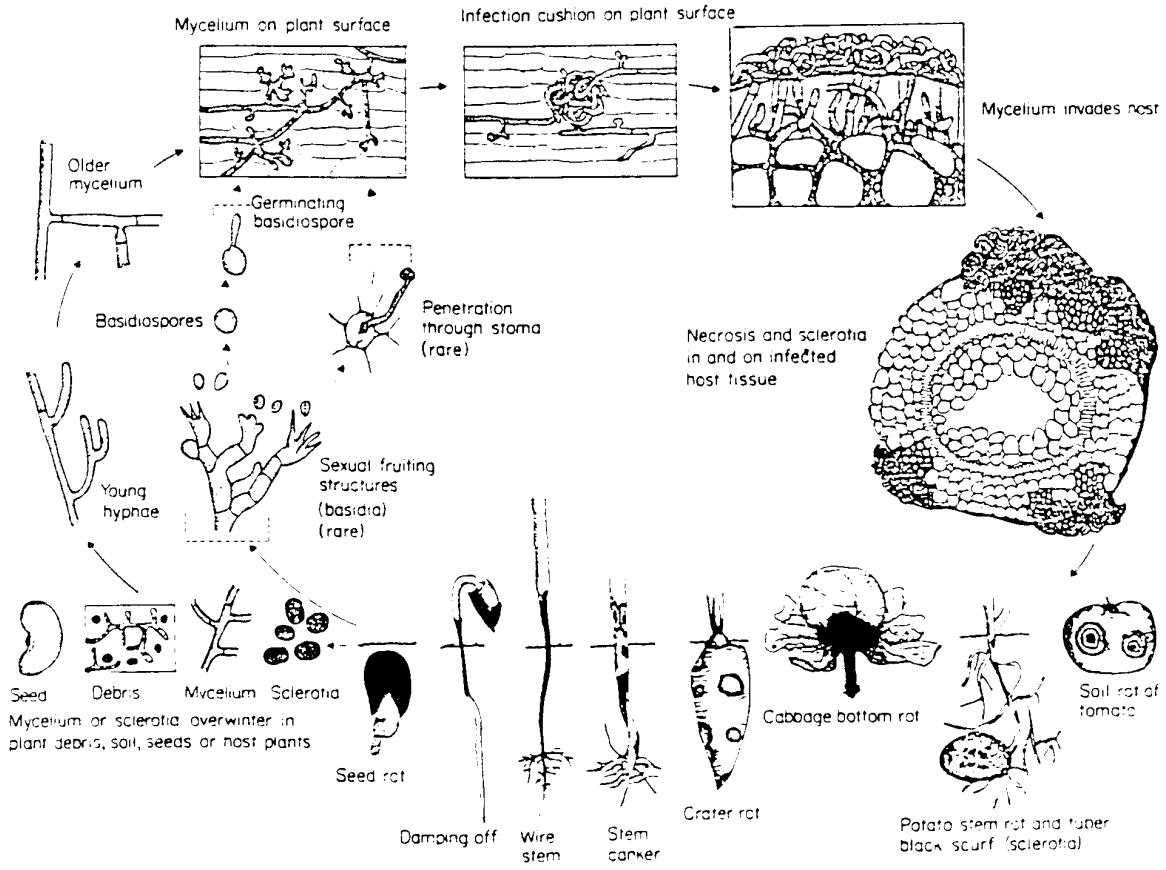

Figure 13.
Disease cycle of Rhizoctonia solani (Thanatephorus cucumeris)
(copied with permission from Academic Press)

Damage and symptoms

Infected tubers will have dark-colored sclerotia which look like dirt that will not wash off. Tubers may also be malformed, cracked, pitted, or display stem end necrosis. Young plants which develop from infected seed pieces

are most severely affected. Sprouts may be completely girdled by lesions and killed. Partially girdled stems will slow growth and development and may result in stunting and rosetting of plant tops, purple pigmentation of leaves, upward leaf roll and chlorosis (usually most severe at the top of the plant).

Short- and Long-term Management Recommendations

▶ *Monitoring*

- It is useful to keep good records as to the existence/severity of the black scurf problem in each field. This way, fields with economically damaging levels of black scurf can be avoided.

▶ *Cultural*

- Avoid growing sugarbeets prior to potatoes, as this tends to increase Rhizoctonia problems. Crop rotation to non-host crops, such as cereals, for at least 2 to 3 years, can reduce disease incidence. A table describing a possible crop rotation is presented under nematodes.

- Plants closely related to potato, such as tomato, eggplant, black nightshade, and jimsonweed (along with volunteer potatoes) may be host to Rhizoctonia.

- Planting certified seed, as specified in leased-land contracts, significantly reduces poor stands and sprout death associated with Rhizoctonia. However, even using certified seed will not eliminate the problem, as the fungus survives in the soil, either as mycelia associated with decomposing plant residues, or as sclerotia on non-harvested tubers. The sclerotia may form on the surface of tubers under cool moist conditions, usually after the vine has begun to die. Therefore, irrigation prior to the time of expected harvest should be avoided.

▶ *Biological*

- Research in greenhouses and in the field has shown that both stem canker and black scurf can be significantly reduced by dusting seed pieces with fungal antagonists of *Rhizoctonia* spp.[25][26] Both infection by *Rhizoctonia* spp. and the viability of sclerotia (both on the potato and in the soil) were decreased. The fungal antagonists included *Trichoderma viride*, *Gliocladium virens*, and *Verticillium biguttatum*. The first two species listed are commercially available (see Field Trial Recommendations). There are many scientific investigations which have examined various aspects of biological control of Rhizoctonia.[27][28][29]

▶ *Chemical*

- TOPS (Thiophanate methyl) is commonly used as a seed treatment to protect against this disease and should be considered for PUP-approval if growers request it.

♦ BLACKLEG – *Erwinia carotovora* subsp. *atroseptica*

♦ SOFT ROT – *E. carotovora* subsp. *carotovora*

Life Cycle, Host Crops, Seasonal Development

These pathogens are closely related and both may cause the symptoms associated with blackleg and soft rot. The bacteria cannot survive independently in soil for greater than one cropping season. Cool, wet conditions, and poor aeration are favorable conditions for infection.

Damage and Symptoms

Above-ground symptoms include poor stands (non-emergence), darkening and wilting of stems, and general stunting and unthriftiness of the plant.

Short- and Long-term Management Recommendations

▶ *Monitoring*

- During regular weekly monitoring, scouts should be looking for black leg or soft rot symptoms during cool, wet periods.

▶ *Cultural*

- Since the bacteria are probably present on most potatoes (and therefore on seed pieces), it is important to avoid environmental conditions and cultural practices that promote the bacteria's growth and spread. Good sanitation is essential. Planting whole, B-size seed potatoes reduces one source of infection/spread— seed cutting. If seed cutting is done, then equipment should be kept clean and disinfected often to avoid spreading bacteria (and other pathogens) from infected to non-infected pieces. Tubers should be warmed to 55 to 60 degrees F prior to planting and should be handled gently to avoid bruising—conveyors should be constantly adjusted to ensure that the pieces drop no further than 6 inches when loading/unloading. Planting certified seed will indirectly reduce problems because infection by other pathogens can predispose the seed pieces to infection by bacterial rots. If these diseases have been a problem in a particular field, then rotations with onions or sugarbeets should be avoided, as these are also hosts to the soft rot bacteria. Plant into well-drained soil and don't over-irrigate. This will avoid the anaerobic conditions which favor infection and spread of the bacteria. This is one instance in which a management option for one pest, that is, irrigation for cutworm control, is in direct conflict with management for another pest—which is to avoid overirrigation to control soft rot. In cases such as this, management should be directed at the pest that has the greater potential to cause economic damage to the crop.

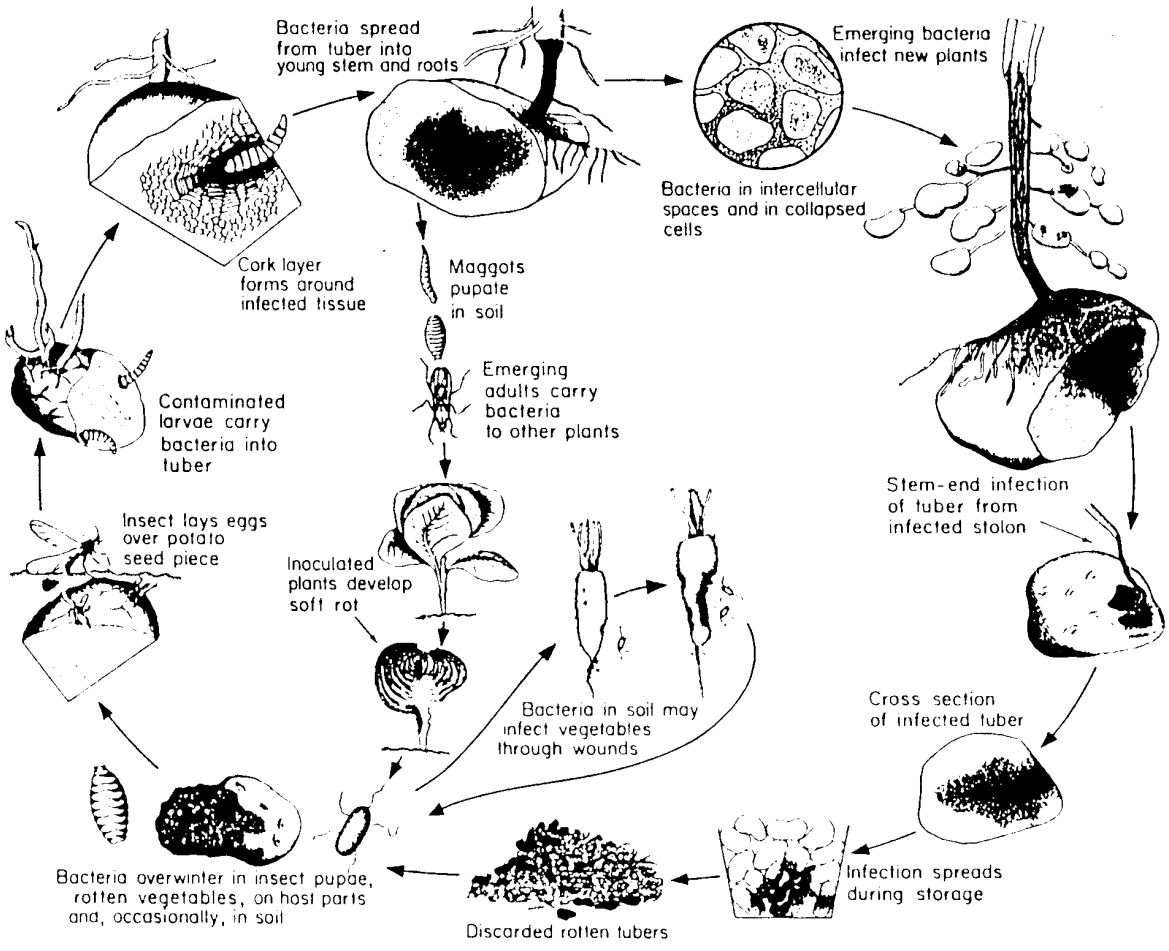

Figure 14.
Disease cycle of bacterial soft rot of vegetables caused by soft-rotting Erwnia *sp.*
(copied with permission from Academic Press)

- Ideally, harvest soil temperatures should range between 50 to 65 degrees F. Higher temperatures may lead to tuber breakdown in storage. If waterlogging has occurred in low spots in the field, these areas might better be left unharvested. Other conditions to avoid are immature tubers, and free water on tuber surfaces, either during or after harvest.

▶ *Biological*

- Several researchers have investigated the ability of some *Pseudomonas* spp. bacteria to control soft rot and black leg.[30][31][32] All have reported significant decreases in root rot or a decrease in populations of the disease-causing Erwinia around the root. Half of the field plots of *Pseudomonas* spp.-treated seed pieces in California and Idaho showed yield increases of 14 to 33 percent.[32] There are now commercially available formulations of Pseudomonas. Stine Seed Co. (see Useful Contacts and Resources) sells Blue Circle and Deny, formulations active against soil pathogens. EcoSoil also markets a *Pseudomonas* spp.-based formulation effective against soil pathogens.

▶ *Chemical*

- Fungicides are not active against bacteria, but seed treatment may reduce infections of fungal pathogens which then predispose the seed piece to bacterial infection. Much will depend on the local soil and climate conditions when the seed piece is planted. One seed treatment is Thiophanate methyl (TOPS): 1 lb/100 lb cut seed pieces. Although the cost-effectiveness of this treatment for soft rot control is uncertain, TOPS seed treatment will help control other fungal pathogens attacking seed pieces and should be considered for PUP approval if growers request it.

◊ BLACK DOT – *Colletotrichum atramentarium*

Life Cycle, Host Crops, Seasonal Development

Although this disease is widespread, it is of unknown economic importance.[15] Host plants include tomato, eggplant, and pepper. The pathogen that causes black dot is not aggressive, and often invades plants only after they've been stressed by infection of some other disease.

Black dot is most frequently associated with light sandy soils, low nitrogen, high temperatures, and poor soil drainage. These are conditions that rarely occur on the leased lands. The pathogen overwinters as very small sclerotia on the surface of tubers or plant debris in the field.

Damage and Symptoms

The symptoms are similar to either Fusarium or Verticillium wilt. Early symptoms are yellowish upper leaflets, which subsequently roll upwards. These leaves will eventually droop and die. Plants are unhealthy looking and the lower stem and stolons may turn reddish-purple. Roots become brown, then black.

Short- and Long-term Management Recommendations

▶ *Monitoring*

- Black dot symptoms progress rapidly compared to Verticillium wilt symptoms. Diseased stems and tubers will have small, black, dot-like fungal structures.

▶ *Cultural*

- Crop rotations to cereals or other non-host plants for 2 to 3 years is important. Best management practices should be followed for crop and soil management to avoid creating conditions conducive to disease development. These practices would include the following: establishing an appropriate crop rotation; avoiding poorly drained land, or land that is heavily infested with soil-borne pathogens; selecting disease-resistant cultivars for planting; planting only high-quality certified seed tubers;

proper seed-piece handling, providing balanced fertility (avoid excess nitrogen); and carefully managing irrigation to avoid overwatering.[33]

▶ Biological

- No biological controls are known.

▶ Chemical

- Chemical control generally is not necessary if cultural recommendations are followed.

◊ SILVER SCURF – *Helminthorsporium solani*

Life Cycle, Host Crops, Seasonal Development

Silver scurf is endemic to most potato-growing areas, but is considered a minor pest. This is a tuber disease with no foliage symptoms, found only on potatoes. It is more of a problem in the muck soils found on the leased lands than on sandy soils. The pathogen overwinters either in the soil, in tubers in storage, or in the field. High soil moisture and high storage humidity favor development of the infection.

Damage and Symptoms

Symptoms show only on the tubers, which begin as small, light brown lesions and may develop into larger lesions with a distinctly gray or silvery sheen, particularly when wet. Tubers may shrivel in storage from fungal-induced moisture loss. Black dot lesions are similar to those of silver scurf, but the latter does not produce sclerotia on the lesions.

Short- and Long-term Management Recommendations

▶ Monitoring

- Tubers in storage should be monitored for symptoms described above.

▶ Cultural

- Plant certified seed and rotate crops. Once mature, potatoes should be harvested as soon as possible. Tubers remaining in moist soil will suffer more damage than those harvested earlier. Disease severity is greatest on early maturing cultivars, intermediate on cultivars of medium maturity, and least on late-maturing cultivars.[34] Tubers suspected of being infected should be marketed as soon as possible. Storage should follow curing and holding procedures which maximize wound healing and minimize chances for infection. High humidity in storage favors the disease.

▶ Biological

- No biological controls are known.

▶ Chemical

- Seed treatment appears to be ineffective against this disease, and is of

questionable cost/benefit.

♦ PINK ROT – *Phytophthora erythroseptica*

Life Cycle, Host Crops, Seasonal Development

Although pink rot is important in Klamath Basin, it is a relatively minor disease elsewhere. It is caused by several species of *Phytophthora* (closely related to the late-blight pathogen) and is favored by warm, wet summers and over-irrigation, which allows for infection by zoospores ("swimming" spores). Specifically, several consecutive days of soil temperatures over 70 degrees F combined with saturated soils during tuber maturation may bring on the disease. The fungus can overwinter for up to several seasons as resistant spores (oospores) in the soil or as mycelia in infected potato tissue.

Damage and Symptoms

Infected tubers may ooze in storage, spreading spores wherever the liquid touches. The disease gets its name from the color infected tissue displays (usually a salmon pink) within half an hour of being exposed to air. The exposed surface will turn black after about an hour of air exposure.

Short- and Long-term Management Recommendations

▶ *Monitoring*

- Tubers in storage should be monitored for symptoms described above.

▶ *Cultural*

- Cultural controls are aimed at avoiding conditions that favor disease. Crop rotation away from potatoes for at least 4 years will reduce soil-borne sources of the pathogen**.** Seed pieces should be planted in soil with good drainage. Chronically wet, poorly drained soils should be avoided, as should those fields with a history of pink rot. Excessive irrigation should be avoided, particularly prior to harvest. Tubers should be gently handled during harvest to prevent wounding. Only healthy, undamaged tubers should go into storage.

▶ *Biological*

- No biological controls are currently known.

▶ *Chemical*

- Metalaxyl (Ridomil), a PUP-approved chemical, applied at late flowering and again 2 to 3 weeks later may provide control.

♦ FUSARIUM DRY ROT, FUSARIUM SEED PIECE DECAY AND FUSARIUM WILT – *Fusarium* spp.

Life Cycle, Host Crops, Seasonal Development

These diseases occur wherever potatoes are planted and in the case of dry rot and seed piece decay, may be the single-most important cause of post-harvest losses in potatoes. Fusarium wilt is favored by hot weather and moist soils: poor soil drainage may cause severe problems with this disease. In contrast, Verticillium wilt is usually characterized as a cool weather disease.[35]

There are several pathogens responsible for these diseases, including various species of *Fusarium* and also *Erwinia carotovora* bacteria (partially responsible, along with *Fusarium* spp., for seed piece decay). Fusarium dry rot and Fusarium seed piece decay are actually the same disease expressed differently under differing conditions; one in a storage environment (dry rot) and the other in the soil (seed piece decay). These pathogens are opportunistic— they cannot infect intact tuber skin, eyes, or suberized (scarred but healed) seed pieces. Various cuts and wounds from harvesting, storage, grading, processing, are the main entryways to infection. Insect and rodent damage, along with frost also provide infection pathways.

The various species of *Fusarium* responsible for these diseases can survive years in the soil. Some infections develop prior to harvest, but typically the infection begins as a result of harvest wounds. Initially, small brown lesions occur at wounds within 3 to 4 weeks of harvest. The lesions gradually enlarge during storage and, depending on the temperature, may take several months to fully develop. The infections become dormant at temperatures below 40 degrees F, but resume rapid growth at temperatures greater than 50 degrees F.

Damage and Symptoms

Dry rot is perhaps the most important post-harvest disease of potatoes. Infected tubers will have a dry rot under a sunken or wrinkled skin. Secondary bacterial and fungal infections may mask these symptoms with moist rot and various colors of fungi.

Seed piece decay is another expression of the same disease complex. Seed tubers may be infected prior to shipment. If so, then the cutting process may spread the pathogen to non-infected tubers. Lesions begin on cut surfaces as sunken rust-brown to black depressions.

Lower leaves may turn yellow and begin to wilt rapidly on a plant infected with Fusarium wilt. Fusarium wilt symptoms are similar to those of Verticillium wilt and the two are often confused. This situation is not helped by the fact that the ranges of the two diseases frequently overlap. However, Fusarium wilt will invade cortical areas (the white, spongy material inside the stem) next to the vascular tissue and Verticillium wilt will not generally do this.[36]

Short- and Long-term Management Recommendations

Monitoring

- Tubers in storage should be monitored for symptoms described above.

Cultural

- Management of this disease depends primarily on clean equipment, good harvest procedures which minimize bruising, combined with proper storage operation (see *Table 9*). Avoid harvesting potatoes on cold, frosty mornings, as bruising occurs more easily in these situations. For Fusarium wilt management, use resistant cultivars, crop rotations and avoid overirrigation.

Table 9.
Post-harvest cultural controls for Fusarium prevention

Curing (1-2 weeks)	How to cool	Holding period; cooling temperature for tuber	Before marketing
tuber pulp temps: 55-60° F if tubers are healthy, 50° F is some tuber decay is present (this will promote rapid wound healing)	Rapidly if market is for seed, or fresh-market.	38-40° F for seed & fresh-market	Warm slowly to 50-55° F over several weeks
	Cool slowly for processing market: lower tuber pulp temp by 2-3° F per week.	45° F for french fry tubers	
		50-55° F for chippers	

Biological

- See Field Trial Recommendations.

Chemical

- The Service has no control over post-harvest treatment of potatoes, as long as treatment does not occur on leased lands. Post-harvest treatment using thiabendazole (TBZ) is an option, although there are reports that many field isolates of Fusarium are resistant to TBZ. TBZ is not

recommended for seed piece treatment because it retards wound healing.[24] Thiophanate methyl (TOPS) should be considered for seed piece treatment.

♦ VERTICILLIUM WILT – *Verticillium dahliae*
♦ POTATO EARLY DYING

Life Cycle, Host Crops, Seasonal Development

Verticillium wilt is one of the primary causes of potato early dying (PED) which can be a limiting factor in potato production in many areas, including the Pacific Northwest. PED is thought to result from a combination of pathogens acting together, including nematodes (*Pratylenchus penetrans*) and fungi (*Verticillium albo-atrum,* and *V. dahliae*.) Other organisms also may contribute to PED. Verticillium is generally considered a cool-weather disease, in contrast with Fusarium wilt, which is favored by hot weather.[35]

Verticillium spp. enters the roots through the root hairs. Infection will proceed throughout the vascular system of the plant. Grasses are not hosts to Verticillium.

Damage and symptoms

Symptoms usually begin around blossom time and develop first on lower leaves. Symptoms include wilting and epinasty (whole leaves, including petioles drooping from the main stem). The plant becomes unthrifty in appearance—leaves develop a yellowish cast and finally turn brown. These symptoms progress up the plant, eventually affecting the entire stem. Vascular tissue of the stem turns a light brown color. This can best be observed by cutting the stem at an angle at ground level.

Short- and Long-term Management Recommendations

▶ *Monitoring*

- Scouts should monitor weekly for signs of wilt. Particular attention should be paid to Verticillium wilt monitoring around blossom time. Scouts should be alert to symptoms on lower leaves such as wilting and epinasty.

▶ *Cultural*

- Crop rotation with grasses, cereals, legumes, and other non-host crops is effective in limiting this disease, particularly in soils where propagule (sources of infection) counts are relatively low (< 10 per cc soil, or 165 per cubic inch). Recommended crops include, but are not limited to, sugarbeets, onions, alfalfa, peas, and late planting of Sudangrass following grain or peas.[15] Commercial-scale field trials in Idaho[37] have shown that incorporation of Sudangrass as a green manure prior to potatoes decreased Verticillium wilt by 24 to 29 percent, and increased marketable

tuber yields by 24 to 38 percent compared to potatoes following barley or fallow. Weed hosts, including lambsquarter, Shepherdspurse, dandelion, and field horsetail should be controlled. Both of the following tables are included because there are discrepancies between the two authors about some cultivars.

Table 10.
Relative resistance of potato cultivars to Verticillium[35]

Wilt-resistant cultivars	Tolerant, but not resistant (produce satisfactory crops despite infection)	Susceptible cultivars
Abniki, Cariboo, Cascade, Nooksack, Raritan, Seminole, Targhee	Reliance, Shurchip	Arrn Consul, Avon, Belleisle, Cherokee, Chieftain, Chippewa, Earlaine, Epicure, Fundy, Irish Cobbler, Kennebic, Keswick, Norchief, Norchip, Norland, Onaway, Red La Soda, Red Pontiac, Russet Burbank, Sebago, Sioux, Superior, Triumph, Warba, Waseca, Wauseon, White Rose, York

Table 11.
Relative resistance of potato cultivars to Verticillium[33]

Wilt-resistant cultivars	Moderately resistant cultivars	Susceptible cultivars
Abnaki, Century Russet, Desiree,* Elba, Gemchip, Ranger Russet,* Reddale, Rideau, Russette, Targhee	Allegany, Atlantic,* Centennial Russet, Frontier Russet, Hampton, Katahdin, MaineChip, Monona, Norchip, NorKing Russet, Portage, Prestile, Russet Burbank, Russet Nugget	BelRus, Butte, Hilite Russet, Irish Cobbler, Kanona, Kennebec, Lemhi Russet, Norgold Russet, Onaway, Russet Norkotah, Sangre, Shepody, Superior, Viking, White Rose.

*Asterisked varieties are being tested at the Intermountain Research and Experiment Station (IREC)

- Minimal irrigation early in the season may have a dramatic effect on the severity of the disease. The critical time is from emergence to tuber initiation, roughly a 4-week period. If irrigation is kept to a minimum then (soil water content of roughly 70 to 75 percent available soil moisture), the onset of early dying will be delayed, and its severity reduced.[33]

▶ *Biological*

- See Field Trials Recommendations.

▶ *Chemical*

- Metam 426 is PUP-approved for control of Verticillium.

♦ POTATO VIRUSES (Y AND LEAF ROLL)

◊ POTATO VIRUSES (X, A, S)

Life Cycle, Host Crops, Seasonal Development

The two most important aphid-transmitted virus diseases of potatoes in Klamath Basin are potato leaf roll virus (leaf roll virus) and potato virus Y (virus Y).

Leaf roll virus: This virus is known as a persistent virus, because once a green peach aphid has fed on an infected plant and the virus incubates within the insect for several hours, the insect may carry the virus for the remainder of its life. Infected seed pieces are the most important source of the leaf roll virus. Other sources include cull potatoes, volunteer potatoes and plants in the potato family such as nightshade and tomato. Host plants outside the potato family include three species of Amaranthus: *A. caudatus*, *A. graecizans*, and redroot pigweed (A. *retroflexus*).

Virus Y: Diseases caused by this pathogen have several names, including severe mosaic, leaf-drop streak, and potato veinbanding mosaic.[38] Virus Y is known as a stylet-borne virus, and is not a lifetime infection (a stylet is a straw-like tube which aphids use to suck plant juices). Because the virus attaches to the stylet, it can be transmitted in a matter of seconds to another plant. Aphids usually retain the virus for no more than an hour. Green peach aphid and the buckthorn aphid are the most important carriers. The potato aphid is considered a poor vector of both PVY and PLRV.[7] This virus has a broad host range, including other potato family members (pepper, tomato, and tobacco) in addition to many weed species, such as nightshade and groundcherry. The principal sources of the virus are infected potato seed stocks and volunteers. Virus Y can also be transmitted mechanically.

Damage and Symptoms

Plants grown from leaf-roll-virus-infected tubers will be smaller and more upright than normal, with a pale cast to the leaves. The leaves, especially the lower ones will be rolled and have a thick, leathery, brittle texture. Early symptoms will appear about 1 month after planting when the plants are about 6 inches high. (When monitoring for the green peach aphid, scouts should stay alert for plants with these symptoms so they can be selectively removed.) In-season infections are generally less obvious, with the leaf roll occurring in the upper leaves as opposed to the lower leaves. Tubers from cultivars susceptible to this virus (see *Table 5*) will display net necrosis symptoms which may develop to an even greater degree once in storage. Russet Burbank is the most susceptible cultivar to net necrosis. Yields can be severely affected, and for seed potatoes, even a low percentage of infection may result in loss of grade or outright rejection of the crop for

certification.

Virus Y: Symptoms will vary depending on the cultivar involved. Seed piece infections will cause plants to develop yellow and green mottling, dead spots of leaf tissue (necrosis), wrinkling, medium to heavy dwarfing, and, occasionally, death. Tubers will be smaller than normal. Current season infection (by aphids or mechanical transmission) will cause many of the same symptoms as seed piece infection but is generally not as severe.

Short- and Long-term Management Recommendations

Monitoring

- Conscientious monitoring of green peach aphid populations and their parasites and predators, and selectively removing diseased plants and volunteers are critical. Early symptoms of leaf roll virus will appear about 1 month after planting when the plants are about 6 inches high. Scouts should remain alert for plants with leaf roll symptoms—plants grown from leaf roll virus-infected tubers will be smaller and more upright than normal with a pale cast to the leaves. The leaves, especially the lower ones will be rolled and have a thick, leathery, brittle texture; these plants should be removed.

Cultural

- It is important to plant certified seed to begin the season with healthy plants. Recent research has shown that in some cultivars, such as Cascade, resistance to leaf roll virus increases as the potato plant ages. Therefore, early season (0 to 60 days after emergence) protection against leaf roll virus infection is important in protecting both tubers and plants from becoming infected. Although no potato cultivars are resistant to aphids, some varieties of potatoes are more susceptible to leaf roll virus than others. Planting leaf-roll-virus-resistant varieties (if a market exists for those varieties) may decrease costs associated with green peach aphid and virus control. Other cultural controls include managing the leaf roll virus transmitters (i.e., eliminating overwintering sites of aphids and destroying leaf-roll-virus-host weeds).

- ***Virus Y***: Research has shown that planting a non-virus Y host border (such as grains) roughly 30 feet wide on all sides of the field will decrease transmission of virus Y.[39] This is used mostly in growing seed potatoes. The aphids will feed on the border plants and lose their "charge" of virus particles. In the event they continue in the direction of the potatoes and feed, they will not be carrying the virus. Volunteer potatoes should be eliminated along with other virus Y hosts such as potato family members (pepper, tomato, and tobacco), and nightshade and groundcherry.

Biological

- There are no direct biological controls for leaf roll virus. However, control of aphid populations by natural enemies will reduce the chances of the virus spreading (see "Biological" section for green peach aphids).

It is important to conserve natural enemies by treating only when action thresholds are exceeded, and using materials that have the least impact on non-target organisms. When the crop is grown without insecticides, aphids rarely become sufficiently abundant to cause direct damage as they are effectively regulated by their natural enemies.[7]

▶ *Chemical*

- Because of the rapid transmission of virus Y from aphid to host plant, insecticides are not effective in preventing the spread of virus Y. The leaf roll virus can be transmitted before the vector has contacted enough insecticide to be killed.[7] However, it stands to reason that the fewer aphids in a field, the less chance of within-field transmission of a virus. The cost of the control (both economically and from the standpoint of its effect on aphid parasites and predators) must be weighed against the benefits obtained. Chemical control options and action thresholds are described in detail in the green peach aphid section. It should be noted that late-season aphid pressure is often more severe in potatoes treated with a soil systemic at planting than in untreated potatoes. Late-season outbreaks in aphid populations may be a consequence of early-season control measures; these prevent the establishment of aphids *and* their natural enemies.[7]

♦ NORTHERN ROOT-KNOT NEMATODE – *Meloidogyne hapla*
♦ COLUMBIA ROOT-KNOT NEMATODE – *M. chitwoodi*
♦ ROOT-LESION NEMATODE – *Pratylenchus penetrans*

Life Cycle, Host Crops, Seasonal Development

Root-knot nematodes: These nematodes generally have a wide host range and are well-adapted to surviving harsh environments. Egg masses may be attached to host plant roots, or free in the soil. The infective stage hatches from the egg and migrates through the soil, perhaps following the "smell" of chemicals emitted by potato (or other host) roots.

These nematodes can be found quite deep in the soil; the Columbia root-knot nematode has been found 5 to 6 feet below the surface, so fumigation will be ineffective in the short term, at least. The number of generations per year, usually one to five, is related to soil temperature. A generation is produced every 20 to 60 days.

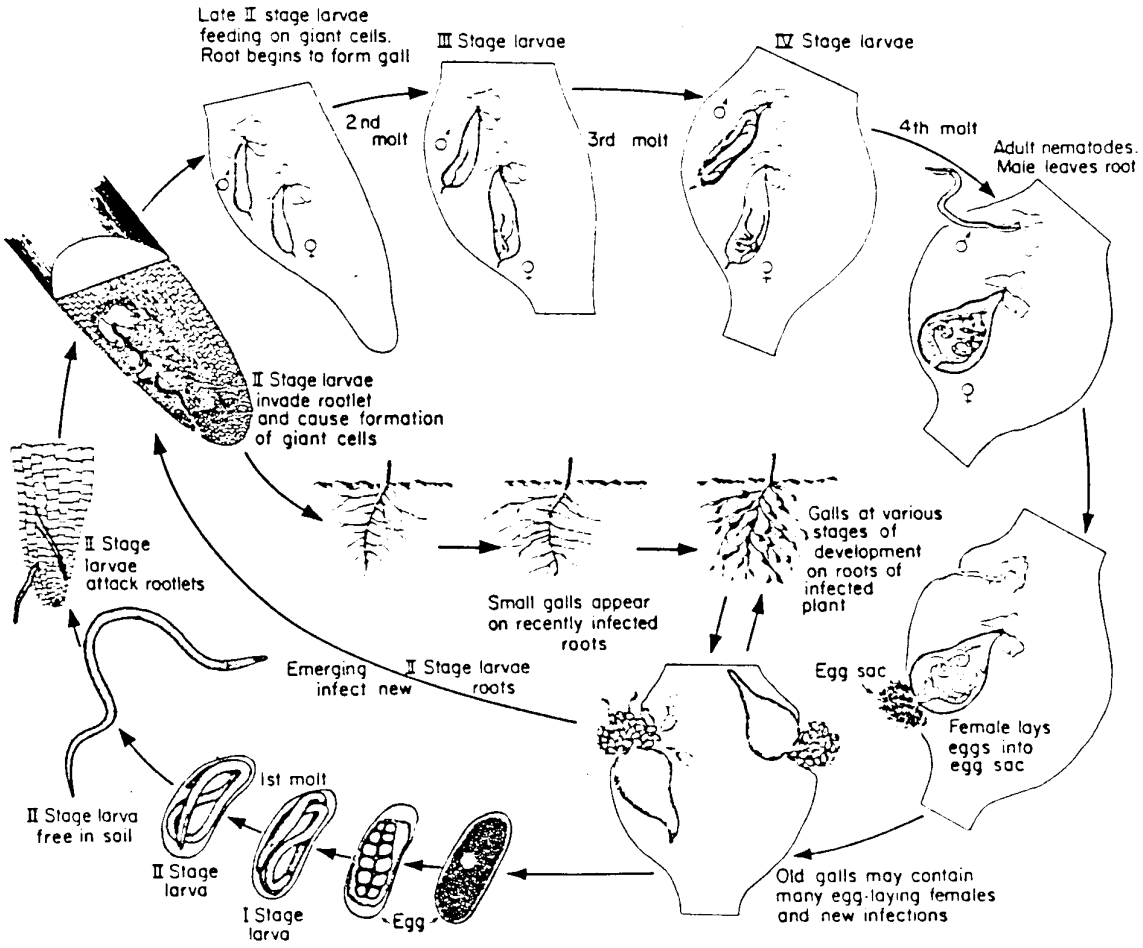

Figure 15.
Disease cycle of root-knot caused by nematodes of the genus Meloidogyne
(copied with permission from Academic Press)

Root-lesion nematodes: All root-lesion nematodes feed on roots and although some species of lesion nematodes cause serious damage on potato tubers, they are not known to occur in the western U.S. These nematodes have a wide host range, but hosts may be divided into two categories; those hosts which support expanding nematode populations, and those hosts which support enough reproduction to maintain population levels.[40]

Damage and Symptoms

The northern root-knot nematode causes small galls on potato roots and generally does not affect tuber surface. It also may cause extensive lateral root formation. The Columbia root-knot nematode, on the other hand, will cause wart-like bumps to develop on tubers. Depending on the water and nutrient stress of the plant, these nematodes may cause other symptoms ranging from yellowing of foliage and stunted plants, to small tubers and internal browning of tubers.

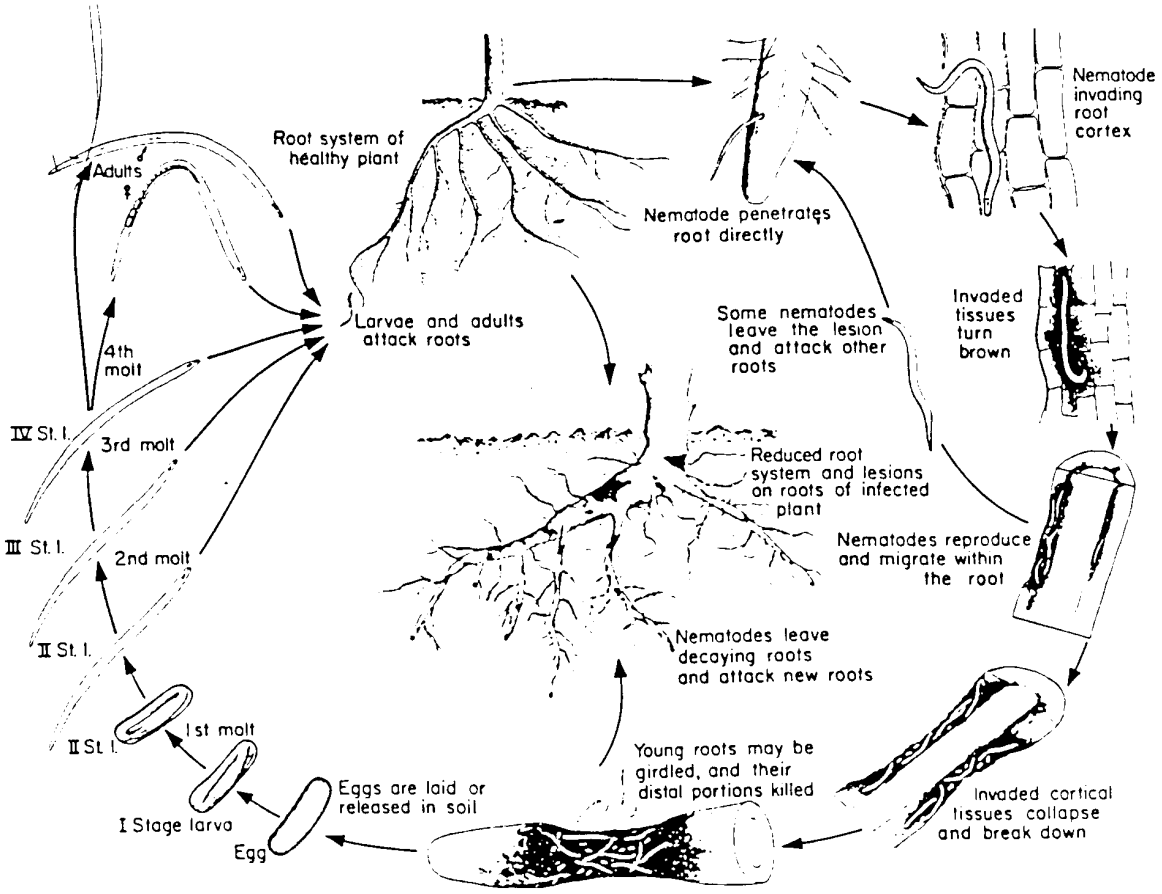

Figure 16.
Disease cycle of the root-lesion nematode Pratylenchus *sp.*
(copied with permission from Academic Press)

Two species of the root-lesion nematode, *P. penetrans* and *P. neglectus*, may cause increased susceptibility of infested potatoes to Verticillium wilt,[15] although a more recent publication,[40] notes the two Verticillium-interacting species as *P. penetrans* and *P. scribneri.*

High populations of nematodes will cause similar symptoms in all hosts: retarded root growth (and above-ground stunting due to retarded root growth) and chlorosis of foliage. Tubers generally show little visible damage.

Short- and Long-term Management Recommendations

Monitoring

- Sampling for the presence of nematodes in the soil is best accomplished in the late summer. Root-zone soil samples should be taken immediately after or just prior to harvest if the crop showed signs of damage. Fields

should be divided into blocks of 20 acres that have similar damage, soil texture, or cropping history. Several subsamples from each block should be well mixed to create a single, 1-quart sample.

The presence of any *M. Chitwoodi* nematodes may be cause for concern. For *M. hapla* populations below 100 per pint of soil, controls should not be necessary. Soil samples should be kept cool, but not frozen. Local experiment stations can provide details needed for labeling samples and suggest laboratories that can analyze them. Identification of different species of lesion nematodes is difficult. It is probably safe to say that some root-lesion nematodes exist in every potato production area of the U.S.

▶ *Cultural*

- The combination of crop rotations and use of rapeseed or Sudan cover crops can be effective suppressing both the northern root-knot nematode and the Columbia root-knot nematode.[41][37]

- Rapeseed and Sudangrass green manures grown prior to potatoes at Prosser, Washington, provided 72 and 86 percent control of the root-knot nematode on potatoes.[37] In the same study, on-farm research in western Idaho showed that rapeseed green manures decreased soil populations of root-lesion nematodes to a greater extent than did Sudangrass green manures.

Table 12.
Some hosts of root-knot species that infest potatoes in the Klamath Basin [a] [15]

	Columbia *M.chitwoodi*	Northern *M. hapla*
Crop		
Alfalfa	+[b]	+
Beans	+	+
Carrots	+	+
Cole crops	+	+
Corn	+	-
Eggplant	-	+
Grains	+	-
Grapes	-	+
Hops	-	-
Lettuce	?	+
Mint	-	+
Melons	-	+
Peas	+	+
Peppers	-	+
Strawberry	-	+
Sudangrass	-	-
Sugar beet	+	+
Tomato	+	+

	Columbia *M.chitwoodi*	Northern *M. hapla*
Weed		
Barnyardgrass	-	-
Bindweed	?	+
Canada thistle	+	+
Foxtails	-[c]	-
Kochia	?	+
Lambsquarters	-	+
Mallow	?	+
Mustards	-	+
Nightshades	-	+
Pigweeds	-	-
Russian thistle	-	?
Sowthistle	+	+

[a] (+ = good host, - = poor or nonhost, ? = unknown)
[b] Alfalfa is a host for race 2 of *M. chitwoodi*.
[c] Green foxtail is a moderate host, yellow foxtail and meadow foxtail are poor or nonhosts.

- Flooding the soil for 7 to 9 months kills nematodes by reducing the amount of oxygen available for respiration and increasing concentrations of naturally occurring substances, such as organic acids, methane and hydrogen sulfide, that are toxic to nematodes.[40] Flooding works best if both soil and air temperatures remain warm. An alternative to continuous flooding is several cycles of flooding (minimum 2 weeks) alternating with drying and disking.[40]

- It was noted above that the combination of crop rotations and use of rapeseed or Sudan cover crops can be effective in suppressing both the northern root-knot nematode and the Columbia root-knot nematode. Both rapeseed and Sudangrass contain chemicals (glucosinolates and dhurrin, respectively) which degrade into nematicidal compounds. Rapeseed-derived glucosinolates decompose into isothiocyanates, very similar to the active ingredient in metham sodium, a nematicide). Dhurrin decomposes in part into hydrogen cyanide, also a powerful nematicide.[42] If these crops were grown as green manures, then incorporated and the field flooded, the 7-to-9-month flooding period needed to kill the nematodes might be shortened.

Biological

- Abbot markets a new nematode-killing fungus, *Myrothecium verrucaria*, under the name of DiTera ES. There is also another promising biological control, the nematode parasite *Bacillus penetrans*, but a cost-effective mass-rearing technique must be developed before commercial production of this organism is possible. DiTera ES should be considered for PUP approval.

Chemical

- Various chemicals are registered for control of nematodes. Telone II was PUP-approved for use on the leased lands for 1 year, pending completion of soil fauna studies. However, considering its expense, the fact that it will only penetrate 2 feet in muck soils, the broad-spectrum effects of this chemical on soil ecology, and negative effects on biological controls in the soil, cultural practices such as covercropping with mustards or Sudangrass (or some combination) should be attempted prior to use of this chemical[1].

FUTURE VISION OF POTATOES ON THE REFUGE

The following text sets forth a description of how potatoes might be grown on the refuges 5 to 10 years from now, using IPM management techniques.

Growers have the option of rotating potatoes with rapeseed, Sudangrass, canola, legumes (vetch, Austrian peas, alfalfa), grains and other cash crops. Rapeseed provides good suppression of Verticillium wilt, and some growers can avoid an herbicide treatment due to weed suppression from rapeseed. Nematode populations also are kept under control using rapeseed green manure in combination with crop rotations. Some growers plant seed pieces with a vacuum planter, which avoids the wounds and potential inoculation associated with 'spike'planters. Conservation tillage of potatoes into grains is now done. It requires some modifications of machinery, but growers find that it conserves soil, soil moisture, and protects the young potato plants against 'sandblast' and mild frosts. Growers are pleased that this technique also has reduced problems with white mold and weeds in addition to saving money.

Disease-prediction software that incorporates weather data allows more precise timing of fungicidal treatments. Sometimes this results in fewer treatments, occasionally more treatments, when compared to the number of treatments prior to use of the software. However, growers agree that the treatments seem to be more effective in preventing infection and economic losses.

---

[1] Russ Ingham, Associate Professor in the Department of Botany and Plant Pathology at Oregon State University noted in a recent paper discussing nematode-suppressive cover crops, "Fumigation can be an effective control, but it is expensive and has undesirable impacts on non-target organisms in the soil. Because of the broad spectrum effects of fumigation, many beneficial soil ecological processes, such as nutrient cycling and biological control, are disrupted."

Growers have adopted biological seed treatments on some of their acreage as a result of field trials run on the leased lands. Although the treatments are a bit more expensive than conventional seed treatments, these costs are made up by the decreased loss of potatoes due to disease in storage.

The Service and environmental groups are pleased because farming practices are now more compatible with wildlife habitat objectives and Department of Interior policy on pesticides.

'IPM Potatoes' have found a ready market in the Bay Area, after a slow start, and are beginning to find buyers in Los Angeles and out-of-state markets. An intensive consumer education program, describing the requirements of IPM and the advantages to both growers and consumers, has been funded in part by CAL EPA and the National Potato Council, and has helped boost sales. Potato growers from around the country and from around the world come to observe the innovative techniques used to produce 'apples of the earth' in Klamath Basin.

Table 13.
Calendar of control options

Month	Recommended practice	Remarks
April	Preplant soil preparation, incorporation of cover crop. Seed pieces cut and suberized, or treated.	If rapeseed is covercrop, incorporation should take place at least two weeks prior to planting. Seed piece treatment will be determined in part by the pest problems noted in the records from the previous years' crop in the field to be planted.
May	Plant certified seed pieces. Cultivate (or apply herbicide) for weeds about 3 weeks after planting. Begin scouting fields as plants emerge. Monitor irrigation closely.	Ideal soil temperature is 55-60° F, which encourages quick emergence. Scouting should look for poor stands. Use action thresholds for aphids for treatment decisions. Look for cutworm damage. Keeping early season irrigation to a minimum, (soil water content of roughly 70 to 75 percent available soil moisture) may prevent or decrease damage Verticillium wilt later in the season.
June	Second cultivation (or herbicide treatment) if necessary. Begin fungicide applications for early blight, if necessary. Look for white mold around row-closure. Consider erecting aluminum sheeting around field for vole exclusion if adjacent alfalfa field is harvested.	Scouting will help determine if weed control is needed. Disease forecasting software in WISDOM program will help determine if and when fungicide treatments are necessary. White mold may be more severe if soils are unusually moist. Aluminum sheeting may also protect against armyworms.
July August	Continue scouting for aphids, other caterpillars, beneficials and diseases. Treatments as indicated by action thresholds (if they exist for pest).	Scouting should occur at least weekly, more often if populations show signs of rapid increase, or if crop is stressed. Be wary of late blight symptoms. If action thresholds do not exist, grower experience and market conditions will dictate treatment decisions.
September	Vines die back. Wait 2 weeks before harvesting potatoes for vines to die completely.	Waiting period between vine dieback and potato harvest to prevent spread of fungal spores (late blight & early blight) from foliage to tuber. Waiting period also allows tuber to mature, making them less prone to mechanical injury and infection. Ideal tuber pulp temperature of 50-65° F and 60-65% of available soil water will store better.
October	Begin cover crop planting.	Winter covers will protect against wind erosion of the soil and may offer management benefits for the following crop, such as weed, nematode, and disease suppression. slsj

FIELD TRIAL RECOMMENDATIONS

Trials are prioritized under each pest, with the most important trial listed first within each pest. Particularly important field trials are noted with the symbol: ☞

The recommendations below are suggested to help develop new information about alternative tillage, new crop rotations, and new cropping techniques (such as strip or border cropping). Any grower interested in experimenting and is a good observer can do these trials. Some results of these trials can be quantified by the grower as well (such as changes in yields or quality of the harvest). However, to develop a more detailed picture of what is happening in the field, it is recommended that the grower notify the IPM coordinator and researchers at the local experiment stations to inform them of the upcoming field trials. In this way, useful trial information may be communicated to others and/or refined and investigated further.

The factors reflected in this prioritization include beneficial impact of results, practicality, and success of the trial elsewhere.

The field trial recommendations fall into three main categories: 1) cover crops, crop rotations and conservation tillage; 2) providing on-farm habitat for beneficial organisms and; 3) biological seed treatments.

General Recommendation

☞ WISDOM is the name of a potato IPM software, developed by the University of Wisconsin. This software may be made available to the growers through a cooperative agreement with the Service. The various kinds of predictive information, particularly with respect to disease forecasting, should be validated for the Klamath Basin.

Green peach aphid

☞ **1. Strip Planting:** Field trials should be set up to investigate plants or plant combinations that, when planted in a strip alongside potatoes will provide some control of aphids (and other pests). Just as certain plants can provide habitat for pests, other plant species are favorable to populations of beneficial insects. Pest break strips[(43)] have been effective in enhancing biological control for a potatoes and several other row crops. Dietrick[(43)] noted that control was, "*...good to excellent. Insect predators and parasites keep aphid and caterpillars under control; leafhopper and leaf miner prefer alfalfa in pest break strips to other hosts."*

Large-scale trials occurred on a farm in central California. Managers made pest break strips five to seven beds wide (80-inch bed width) at intervals of 350 feet across the farm. Several mixes of grasses, legumes and wildflower were tested for effectiveness in supporting beneficial insects. The most effective mix was found to be predominantly alfalfa (60 percent) mixed with Dutch white clover, strawberry clover, berseem clover and crimson clover (10 percent each).

Recent research in England[(44)] indicates that by planting border strips (of plants providing food and nectar sources for hoverflies) along cereal fields, significant reductions of aphid populations can be obtained. Increased

populations of hoverflies extended up to 180 meters (195 yards) from the border strips. Bugg and Ellis[45] observed that flowers of canola attracted adults of the following species of hoverflies *(Syrphidae): Allograpta obliqua* (Say), *Sphaerophoria* spp., *Syrphus* spp., and *Toxomerus* spp. Larvae of all of these species are predators on aphids.

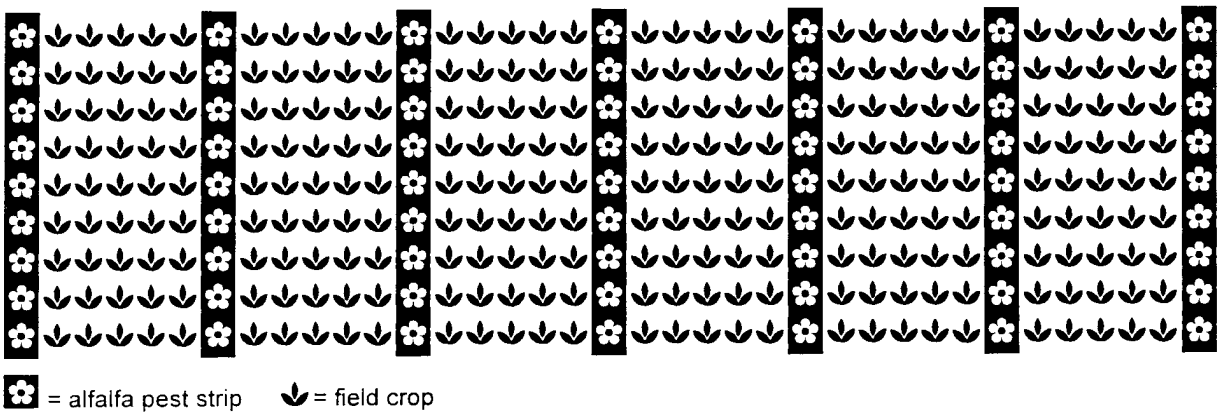

Figure 17.
Schematic diagram of pest break strip of alfalfa roughly 40 feet wide every 350 feet in a field crop. Field is about 2,100 feet along the long axis.

W.E. Chaney of the U.C. Cooperative Extension in Salinas, CA, has conducted field trials interplanting insectary plants (which provide beneficial insects pollen and nectar) with vegetables for biological control of the green peach aphid. He used sweet alyssum interplanted every 20 rows in a field of lettuce. Alyssum was chosen because it can be seeded instead of using transplants, and will flower in about 30 days. It does not attract either aphids or tarnished plant bugs, is non-aggressive, and provides a good food source for parasitic wasps. By adding sweet alyssum and other pollen and nectar plants to monoculture vegetables, natural enemies such as the green peach aphid parasite, *Diaretiella rapae*, will have a chance to play a greater role in vegetable pest control. Under ideal conditions, *Diaretiella rapae* parasitized 90 to 95 percent of available host aphids.[46] Chaney's trial in lettuce provided sufficient reduction of aphids to do without other controls. However, 5 percent of the production area was lost to alyssum. *On leased lands, acreage planted to insectary habitat will be subtracted from the total lease acreage, reducing annual rent. Row-crop acreage will not be reduced.*

Field trials with insect habitat strips could be done by farmers in cooperation with local researchers and Service staff.

☞ **2. Alternative action thresholds should be tested in Klamath Basin for the green peach aphid:** The thresholds* given below[2] are recommended for potatoes grown in the Midwest and should be tested for the Klamath Basin. The thresholds are generally higher than those recommended by U.C. guidelines, and may save growers some money by decreasing the need for treatments. Collect 25 leaves (not leaflets) from each of five locations within a field. The leaves should be collected from the middle of the plant

canopy.

Fresh Market or Processing
Early season - 50 wingless aphids (all species)
After bloom - 100 wingless aphids (all species)

Fresh Market or Processing in Seed Production Area
7.5 green peach aphids
50 aphids (all species)

Seed Potatoes for Leaf Roll Virus Management
2.5 green peach aphids for leaf roll virus susceptible varieties
7.5 green peach aphids for leaf roll virus resistant varieties
25 potato aphids

* *Please note that these thresholds were developed for Russet Burbank. If other more resistant varieties have been planted, it may be safe to adjust the action thresholds upwards.*

☞ **3. Develop more information about biological controls for green peach aphid (and other aphids) in Klamath Basin:** To develop the potential of natural enemies for control of plant pests, more must be learned about their habits. As noted above, certain plants can provide habitat for pests and other plant species favorable to populations of beneficial insects. Questions to be answered include: What are the main biological controls, how might they be enhanced/conserved, and what is their potential for providing control of the green peach aphid and other aphids? Also, what potential exists for management using releases of predators, such as green lacewings?

4. Effectiveness of neem seed oil/azadirachtin should be tested for aphid control: Recent lab and field research in British Columbia[47] indicates that neem seed oil and azadirachtin reduce aphid reproduction and survival. This decrease in fertility, and also the fact that aphids exposed to neem seed oil or azadirachtin produce large numbers of dead offspring, would integrate well with control by natural enemies. A number of formulations containing neem seed oil or azadirachtin are commercially available. Use of these product would require PUP approval.

Cabbage looper
Alfalfa looper

☞ **1. Validate the following action threshold on leased lands**. (These monitoring recommendations are taken from the WISDOM potato management software)[3]:

- Shake the foliage of 5-foot sections of two adjacent rows into the furrow and count the larvae on the soil surface. Divide the number of larvae counted by five. The resulting number is the number of worms per row foot. Sample at least five sites per 30 acres and add one additional sample

site for each additional 20 acres.

- Prior to July 25, control measures are recommended if the cutworm and looper counts exceed four per row foot as a field average. After July 25, control measures are recommended if the cutworm and looper counts exceed eight per row foot as a field average. Treat when loopers are numerous and ragging of leaves is obvious. Most plants can withstand substantial defoliation without serious reduction in yield. Spot treatments are usually adequate for infested seedlings. Loopers are best treated while they are small.

For some advance warning about how large a population might develop and when larvae might first begin appearing, monitor looper flights using pheromone traps. This is most easily accomplished by using cabbage looper pheromone traps which are commercially available.[9] See Useful Contacts and Resources.

☞ **2. Examine how biocontrol agents can be enhanced through the use of strip cropping insectary plants adjacent to potato fields.**

In the absence of chemical insecticides, a variety of predacious spiders, beetles, and other insects feed upon eggs and young looper larvae. Parasitic wasps and tachinid flies parasitize cabbage looper larvae in late summer. Both the fly and wasp parasites are moderately effective in suppressing looper populations.

Trichogramma spp., a small wasp that parasitizes eggs, also offers some control of the cabbage looper. *T. pretiosum* is the most common species and is commercially available in large quantities. It is also naturally occurring. This organism lives longer and can parasitize more eggs when nectar sources are available.

Due to the migratory behavior of the looper, however, there appear to be fewer natural controls in the Northwest than would exist were the insect present year round. Planting beneficial insect habitat along potato fields may increase populations of a variety of beneficial insects, providing better natural control. Ultimately, growers may benefit by needing fewer pest control treatments. (See Strip Cropping under Green Peach Aphid Field Trial Recommendations for more information about beneficial habitat.)

Black Cutworm
Variegated Cutworm
Spotted Cutworm
Army Cutworm
Red-backed Cutworm

1. Enhance habitat to increase predation of cutworms by bats and birds.

Significant or properly sited bat populations may be especially helpful in managing cutworm adults. Increasing bat habitat would be inexpensive, and

has the potential of dramatically decreasing cutworm and armyworm populations. A bat can eat its body weight in insects in one night.[48] Bats feed during the same time that cutworm and armyworm adults are active, and if insects are numerous, can significantly decrease pest populations. Bats may also have a repellant effect, as cutworm and armyworm adults are sensitive to bat echo location and may tend to avoid areas where this exists.[49]

Bat habitat can be dramatically increased by simple modifications of existing farm structures (i.e., adding a board to a beam with 0.75 inch spacers or hanging thin plywood sheets from the ceiling with plastic netting stapled to one side and 0.75 inch spacers between the sheets). It's best to start small and observe what the bats seem to like for habitat. Increasing bat habitat in barns or other structures with existing populations is easiest. To attract bats to new habitat, it helps if some diluted guano "paint" is used on the surface of the wood where the bats are to nest. However, barns with owls will not work, and metal surfaces are not appropriate for bats because they conduct too much heat away from the colony during cold weather.

Placing bat houses around fields is also an option. Bat houses need full sun exposure, and should be painted dark brown to black.

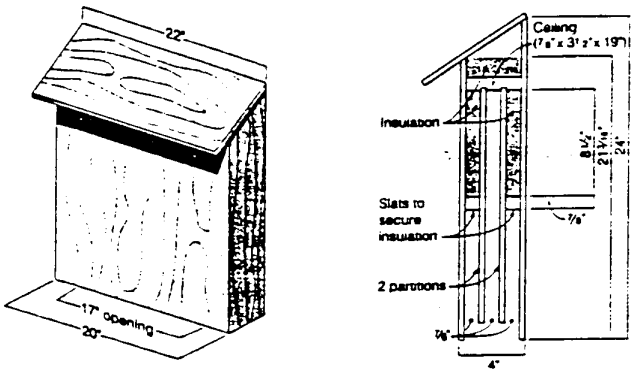

Figure 18.
Bat house
(*Farmer to Farmer*, December 1994)

Start small and observe what works. Growers would implement this effort with Service personnel lending support and providing information about the types of bats present in the area of the refuge and their habitat requirements.

☞ **2. Test the effectiveness of adding caffeine to *Bacillus thuringiensis* (*B.t.)* for cutworm control *and* test *B.t.* bait formulations for cutworm control**.

B.t. is a non-toxic formulation that can be effective for cutworm control. Laboratory and greenhouse tests showed that caffeine boosted the effectiveness of *B.t.* against armyworms (closely related to cutworms) up to 900 percent. Much like *B.t.,* caffeine interferes with the pests' digestive and nervous systems. It is most promising for pests that are only mildly susceptible to *B.t.* itself. Recipe: dissolve 13 oz. pure caffeine in water. Add

the solution to 100 gallons of standard *B.t.* spray. Apply as usual.[50] Caffeine can be obtained from most chemical supply houses and is also available in pill form from most pharmacies.

Bait formulations (sometimes using bran) containing *B.t.* var. *kurstaki* have been known to effectively control cutworm species when applied to soil.[51] Soilserve in Salinas is the label holder for *B.t.* bait. Soilserve hasn't been able to manufacture bait at the Salinas factory because it is not yet approved by Cal EPA. This bait is apparently used/registered in other states. Bait formulations would be considered for use on leased lands, after PUP approval, if it was determined they did not harm fish and wildlife. See Useful Contacts and Resources.

3. Determine the effectiveness of monitoring cutworm populations using pheromone traps. This should be combined with positively identifying the species of cutworms causing economic damage to potatoes.

Montana has had a statewide monitoring program since 1992 for pale western and army cutworms. Adults are monitored using pheromone traps during late summer through fall when they move from oversummering sites and begin mating and egg laying. Continuous, long-term monitoring provides information about population increases, and may indicate potentially damaging outbreaks.

However, this technique is effective only if the correct pheromone trap for a particular species of cutworm is used. This is why it is important to determine which species of cutworms are economically important.

4. Hold a seminar for growers concerning the use of *B.t. var kurstaki (k)*. The seminar could demonstrate the results at a field trial using *B.t.k.* for cutworm control. *B.t.k.*'s low toxicity to mammals, beneficial insects, and non-target organisms in general makes it a desirable option for cutworm control.

B.t.k. is registered for use and is proven effective, but some growers seem to doubt its effectiveness. Growers' experiences in the effectiveness of *B.t.k.* could vary due to several factors, including but not limited to:

- premature breakdown due to weather factors—some formulations are less subject to degradation in the field. Applied sprays often lose effectiveness within 24 to 48 hours;[12]
- less than ideal application procedures (e.g., spraying in the heat of the day rather than in the evening, pH of spray water is too high—spray water should have a pH of 6.5 to 7, that is, neutral to slightly acidic. Water with a pH greater than 9 (alkaline) will inactivate the *B.t.k.*[52]
- plant growth outstrips plant tissue coverage (*B.t.k.* is a stomach poison and must be eaten; if affected plant tissue is not covered, or insufficiently covered, enough of the toxin may not be ingested to infect the cutworm.)

5. Test strip tilling potatoes into grain stubble. Mulch is known to increase predator populations (e.g., spiders and carabid beetles). Strip tilling potatoes into grain stubble might enhance predator populations, particularly carabid beetles. It also may have beneficial effects on soil moisture retention, wind erosion of soil, and protecting potato seedlings against soil-blasting damage.

6. Test parasitic nematodes as cutworm control agents. Recent studies have shown the parasitic nematode, *Steinernematidae carpocapsae*, significantly reduces black cutworm populations after treatment.[53][54] Beneficial nematodes enter the bodies of cutworm larvae and release an intestinal bacteria (*Xenorhabdus* spp.), paralyzing and killing the worm within 24 to 48 hours. The nematode then completes several generations within the carcass. During the winter, predatory nematodes burrow deep into the soil for hibernation and return near the surface too late to control early-season larvae, so re-application must be made annually.[51] Beneficial nematodes do not work well against above-ground feeders such as the variegated or the army cutworm.

It is not certain how long applied nematodes persist in the field. Some research shows that the nematodes do not last in the field for more than 8 days.[53][54] However, other research (Rick Miller, Product Manager, Biosys, personal communication, January 8, 1997) shows applications may control cutworms for 4 to 6 weeks, an advantage over Sevin applications for cutworm control, which loose effectiveness more quickly. Local soil conditions such as soil moisture, soil structure, and soil ecology no doubt influence the persistence of applied parasitic nematodes in the soil. Depending on persistence, either a single application, or a series of 2 to 4 weekly applications might be required for protection of young potato plants. A banded spray application would conserve material and decrease treatment costs. As with other novel approaches, the economics of this approach would need to be investigated.

The nematode product (BioVector: Biological Insecticide for Fruits and Vegetables) is typically used at rates of 1 billion nematodes per acre (costing roughly $70-80). Rates of 0.5 billion per acre have worked well at times, depending on moisture conditions (Rick Miller, pers. comm., January 8, 1997). Since nematodes perform best with ample soil moisture, they might provide good control of cutworms in potatoes because moist conditions are typical of newly emerging beet fields. Applications may control cutworms for 4 to 6 weeks, an advantage over Sevin applications, which lose effectiveness more quickly.

According to the manufacturer, the ideal application strategy for using beneficial nematodes would be to apply 0.10 to 0.20 inches of water via overhead irrigation to the crop when the cutworms are still small. Then treat with BioVector at the 0.5 billion nematodes per acre rate, wait 5 to 7 days and monitor for damage. Re-treat only if necessary.

There are no regulations in California restricting the use of beneficial nematodes. Trials with these organisms could be done by growers working

on their own, or in coordination with the IPM coordinator and local Extension and experiment station researchers. Use of beneficial nematodes would require approval from the IPM coordinator.

Beneficial nematodes are available commercially from a number of sources (see Useful Contacts and Resources).

7. Investigate the effectiveness of increased irrigation for cutworm control. In some years cutworms may have potential for economic damage. In these years, increased irrigation may be effective. Metcalf[10] notes that the likelihood of problems developing from the pale western cutworm may be high during dry periods and low during wet ones. The rain forces the cutworms from their protective burrows, increasing their exposure to predators. A recent Norwegian[55] study seems to confirm this observation by showing that damage to certain root crops by *Agrotis segetum* (a species closely related to the black cutworm) can be substantially reduced by increased irrigation. This study showed that irrigations decreased cutworm damage to carrots from 48 percent (no irrigation) to 6 percent (three irrigations). One irrigation resulted in 33 percent cutworm damage in carrots.

It should be noted that irrigation, particularly sprinkler irrigation, beyond that required by the crop, may increase incidence of some fungal diseases such as late blight, white mold, and others.

8. Controlling hosts highly attractive to cutworm adults: Certain plants such as milkweed, spider plant and viburnum are highly attractive to black cutworm adults when they are in bloom.[56] It may be worthwhile to investigate which plants on the Refuge are especially attractive to cutworm adults and to consider eliminating them from Refuge areas adjacent to cropland, or using these plants as a trap crop.

Grasshopper

1. Determine the effectiveness of identification, monitoring, and targeting of oviposition sites of grasshoppers for management of this pest. The clear-winged grasshopper generally lays eggs in concentrated areas known as hatching beds (Dr. Mark Quinn, Grasshopper researcher, personal communication, October 27, 1996). These may range in size from less than a 0.25 acre to over 20 acres (during large outbreaks). A grasshopper monitoring program set up on appropriate lands adjacent to the leased lands may be able to note location and time of grasshopper hatching. This information would enable early treatment before the grasshoppers migrate to adjacent croplands and cause economic damage.

Yellowstriped armyworm

☞ **1. Provide habitat to increase predation of cutworms by bats and birds.** See Field Trial Recommendations for cutworms.

2. Test strip tilling potatoes into grain stubble. See Field Trial Recommendations for cutworms.

3. Determine the effectiveness of aluminum sheeting (or other physical barriers) along all borders of a potato field in protecting against armyworms (and voles). Aluminum sheeting, or other physical barriers, could be placed around potato fields to prevent damage by voles, a major pest of potatoes. The populations of armyworms in such a field should be compared to the populations in a field not using physical barriers.

Late blight

(in the event late blight is found in Klamath Basin)

☞ **1. Test using a vacuum seeder for planting potato seed pieces to examine the effect this technology has on infection of seed pieces and seedlings.** This should be done whether or not late blight is found in the basin. The present 'spike' technology is a likely method of inoculating seed pieces with disease organisms just as they are planted.

White mold

☞ **1. Examine the effect of no-tilling potatoes into the fall-planted barley for control of white mold and weeds (nightshade and pigweed)**. Research in Willamette Valley[57] showed that planting snap beans into a fall-planted barley cover reduced the incidence of white mold on snap beans to a level comparable to the conventional plot treated with Ronilan. Planting snap beans in flailed (threshed) barley was more effective in decreasing white mold compared to planting in unflailed barley. It should be noted that eliminating spring tillage reduced early season weed emergence in snap bean production by 87 percent. The barley cover crop residues decreased weed emergence an additional 65 percent. Flailing the barley cover increased plant emergence and crop yield, but also increased weed emergence.

Conversion of conventional till grain drills to no-till drills depends on the type of drill. Little or no welding should be necessary. At the least, it would be a matter of changing out the drag chains for press wheels, and adding slicing colters at the front of the tool bar. There may be conversion kits available that have new opener assemblies complete with press wheels, down pressure springs, and a set of slicing colters. The frame and seed box would be the same (Dr. Preston Sullivan, ATTRA, personal communication, December 10, 1996).

☞ **2. Examine the effect of strip tillage on potato production (with wheat or barley residue present) and the effect this residue would have on development of white mold, other pests, and crop management.** Strip tillage may have beneficial effects on soil moisture retention, wind erosion of soil, and protecting potato seedlings against soil-blasting damage. It may also have an unknown impact (positive or negative) on diseases, since there will be crop residue in close proximity to potato plants. The positive impact would result from less water stress and windblasting of the potato seedling. The potential negative impact might result from possible increased amount of disease inoculum (on the grain

stubble) adjacent to the young potato seedlings. Field trials will provide information about the relative importance of the impacts of strip tillage on disease incidence. Strip tilling potatoes into grain stubble might enhance predator populations, particularly carabid beetles.

☞ **3. Using BioTrek 22G (containing *Trichoderma harzianum*, a fungus parasitic on *Sclerotinia sclerotiorum*) to test the effectiveness of this treatment for control of white mold.** Research[58] showed that *T. harzianum* is an antagonist of white mold and that sclerotia infected by *T. harzianum* did not produce *S. sclerotiorum* or other fungi. BioTrek is registered in California for use as an in-furrow granular treatment for potato seed crops. This practice would require PUP approval.

Rhizoctonia (Black scurf)

☞ **1. Test the effectiveness of *Gliocladium virens* for control of common damping off and root rot diseases, such as pythium and Rhizoctonia. *Trichoderma harzianum*, a fungus parasitic on *Rhizoctonia* spp. should also be tested for control of plant pathogens**. Thermo Trilogy, the biopesticides division of W.R. Grace, has developed a new biofungicide based on the beneficial fungus, *Gliocladium virens*, effective for control of common damping off and root rot diseases, such as Pythium and Rhizoctonia. This should be tested for effectiveness in Klamath Basin. The granular formulation is known as SoilGard 12G. Another new product is BioTrek 22G, containing *Trichoderma harzianum*, a fungus parasitic on *Rhizoctonia* spp. This product may also prove to be effective against not only Rhizoctonia, but other soil diseases as well. It is also sold as a growth promoter under different formulations and tradenames. Research[27] indicates that *Trichoderma* spp. will invade organic debris previously infested with *Rhizoctonia* spp. and reduce the survival of the pathogen on the substrate. This practice would require PUP approval.

☞ **2. Test the effect of new crop rotations/cover crops and conservation tillage on the prevalence of this disease and others. (i.e., the effect of Jupiter rapeseed planted as a cover crop prior to potatoes on rhizoctonia).** The benefits of crop rotation have long been known. Cover cropping is a variation on this theme with an additional consideration: some covercrops such as Sudangrass, rapeseed and some cultivars of canola and mustard, especially if they are incorporated, can have suppressive effects on both weeds and plant pathogens, including nematodes. Many of these cover crops are already being tested by Dr. Carol Shennan.

Table 14.
Possible 3-year rotation with potato using nonhost cover crops

Year 1 Fall	Year 2 Spring	Winter	Year 3 Spring	Fall	Year 4 Spring

Year 1	Year 2		Year 3		Year 4
Harvest potatoes and plant winter wheat as cover crop	Plant poor host (Sudangrass, canola, mustard, cowpea, or rapeseed)	Stubble fallow (prevents wind erosion of soil)	Plant nonhost cash crop such as canola.	After canola harvest, plant winter rapeseed as a green manure crop	Disc under winter rape and plant potatoes in the spring

Adapted from: [59]

Recent research in Maine by the Agricultural Research Service of the USDA has shown that planting hairy vetch, alfalfa or white lupin prior to the potato crop can replace up to a third of fertilizer inputs and also reduce losses to Rhizoctonia.[60]

Blackleg
Soft Rot

☞ **1. Examine seedpiece treatment with some of the new bacterial or fungal-based formulations for effectiveness against bacterial soft rots and other soil-borne pathogens.** Several researchers have investigated the ability of some Pseudomonas bacteria to control soft rot and black leg.[30][31][32] All have reported significant decreases in root rot or decrease in populations of the disease-causing Erwinia around the root. Half of the field plots of Pseudomonas-treated seed pieces in California and Idaho showed yield increases of 14 to 33 percent.[32] There are several commercially available formulations of Pseudomonas now on the market, including Blue Circle and Deny (Stine Seed), and a formulation available from EcoSoil. See Useful Contacts and Resources.

☞ **2. Examine the effect a vacuum-type seeder has on spread and infection of seed pieces by bacterial and fungal pathogens.** The present 'spike' technology is a likely method of inoculating seed pieces with disease organisms just as they are planted. The AireCup planter, that uses vacuum and air pressure to pick up and plant seed pieces, will be less likely to create wounds on the seed piece and inoculate seed pieces with disease.

Pink Rot

☞ **1. Examine the effect of various cover crops/crop rotations on the severity of this disease.** This might be conducted in conjunction with Dr. Carol Shennan's work.

Fusarium Dry Rot
Fusarium Seed Piece Decay

☞ **1. Examine the effectiveness of Mycostop for control of seed piece decay caused by *Fusarium* spp**. Thiabendazole-resistant strains of Fusarium threaten to negate the use of this product for both post-harvest and seed-piece treatment. A commercial product, Mycostop, manufactured by Kemira and AgBio and registered with the EPA is effective in

controlling *Fusarium* spp. It may be effective in controlling other soil-borne pathogens as well. Use of this product would require PUP approval.

☞ **2. Test commercial formulations of *Pseudomonas* as seed treatments for control of Fusarium and other soil-born diseases**. These have been shown to be effective in controlling *Fusarium* dry rot disease.[61] There are several commercially available formulations of Pseudomonas now on the market, including Blue Circle and Deny (Stine Seed), and a formulation available from EcoSoil. It may be worthwhile testing these formulations as seed treatments for control of Fusarium and other soil-borne diseases. This practice would require PUP approval.

3. Examine the effect of adding compost to the soil on losses due to *Fusarium*. Research in Gilroy, California, showed that addition of 2.5 tons of compost per acre decreased *Fusarium* losses in onion 60 percent compared to those fields that received typical ammonium nitrate fertilizer, but no compost. The compost was made from yard trimmings. Poultry compost would not be appropriate for use on the Refuge due to avian disease concerns. The effect of compost on losses due to soil-borne diseases should be investigated in the Klamath Basin. This practice would require approval of the IPM coordinator.

Verticllium Wilt
Potato Early Dying

☞ **1. Examine the effectiveness of plowing in Sudangrass (or sudex) or Jupiter rapeseed for control of Verticillium wilt**. In Idaho, incorporation of Sudangrass as a green manure prior to potatoes decreased Verticillium wilt by 24 to 29 percent and increased marketable tuber yields by 24 to 38 percent compared to potatoes following barley or fallow.[37]

Nematodes:

Northern root-knot
Columbia root-knot
Root-lesion

☞ **1. Large-scale field trial: Refine methods for using rapeseed and/or Sudangrass cover crops/green manures for nematode and weed control.** Rapeseed and Sudangrass green manures grown prior to potatoes at Prosser, Washington, provided 72 and 86 percent control of the root-knot nematode on potatoes.[37] In the same study, on-farm research in western Idaho showed that rapeseed green manures decreased soil populations of root-lesion nematodes to a greater extent than did Sudangrass green manures.

There has been some success in Montana using European radish for control of the sugarbeets cyst nematode, and this might be investigated for effectiveness against the root-knot nematodes (David Koch, researcher of European fodder radish, University of Wyoming, personal communication, July 18, 1996).

☞ **2. Field tests using Ditera ES should be run.** Ditera ES is registered on

root crops, such as potato, and is applied at 5 to 40 gallons per acre as a 12-to-24-inch band to the bed prior to planting or germination.

FURTHER RESEARCH

This section outlines areas of further research that might benefit growers, but are perhaps not yet ready for field trials.

Aphids

Investigate the use of degree day models (available from the U.C. Statewide IPM Project) in monitoring and predicting green peach aphid populations on potatoes. The U.C. system has information available on degree day models of the green peach aphid. This information might be useful in predicting when these aphids are likely to begin entering fields.

Aphid/virus complex

Investigate the possibility of adopting enzyme-linked immunosorbant assay (ELISA) tests to make them 'field friendly.' Test the aphids for the presence/absence of leaf roll virus and virus Y. If the virus is absent from aphids found infesting a field, the treatment thresholds for both seed potatoes and fresh market potatoes possibly could be higher, saving the growers money on chemical treatments.

Silver Scurf

Examine the use of biological antagonists (at planting) for control of silver scurf in conjunction with investigations into other diseases.

Pink Rot

Examine the effect of adding finished compost to soil on the presence of the disease.

USEFUL CONTACTS AND RESOURCES

Beneficial insect habitat/strip cropping

- W.E. Chaney, U.C. Cooperative Extension, 1432 Abbot St., Salinas, CA 93901; (408) 759-7350

  Bill Chaney has done work on enhancing biological control of aphids through the use of insectary plants in fields of vegetables.

Cultural Controls

- Agromac International Inc., P.O. Box 400, Gering, NE 69431; 1-800-488-8085

Biological Controls

The publication*, Suppliers of Beneficial Organisms in North America*, lists 132 commercial suppliers of beneficial organisms including parasites, predators, nematodes, bacteria, fungi, protozoans, and viruses useful for biological pest control.

One free copy of the above document is available from:

- California EPA, Dept. of Pesticide Regulation, Environmental Monitoring and Pest Management Branch, 1020 N Street, Rm. 161, Sacramento, CA 95814-5604; (916) 324-4100

The Directory of Least-Toxic Pest Control Products is updated and published yearly by the Bio-Integral Resource Center (BIRC). It lists over a thousand pest control items including products, services and beneficial organisms. Descriptions and contact information for manufactures and suppliers are given for each product.

Contact BIRC at the following address to request a copy:

- BIRC, P.O. Box 7414, Berkeley, CA 94707; (510) 524-2567

- BioTrek 22G, Wilbur Ellis, PO Box 1286, Fresno, CA 93715; (209) 442-1220, Fax (209) 442-4089)

  BioTrek 22G may provide some control of white mold. BioTrek 22G contains *Trichoderma harzianum*, a fungus parasitic on *Sclerotinia sclerotiorum.*

- Stine Seed Co., 2225 Laredo Trail, Adel, IA 50003; (515) 677-2605; Fax (515) 677-2716

  Stine Seed Co. sells Blue Circle and Deny which are formulations of *Psuedomonas* spp. active against soil pathogens such as soft rot bacteria.

- Tom Quick, Eco-Soil, 10890 Thornmint Rd., Suite 200, San Diego, CA 92127; (619) 675-1660

  EcoSoil also markets a Pseudomonas-based formulation effective against soil pathogens such as soft rot bacteria.

- Soilserve (owned by Mycogen of San Diego); (408) 422-6473 Evette (Contact person)

  Soilserve makes bait formulations for cutworm control.

Books

- Rowe, R.C. (ed). 1993. *Potato health managemen*t. APS Press, St. Paul, MN.

- University of California. 1986. *IPM for potatoes in the western United States.* U.C. Division of Agriculture and Natural Resources, Oakland, CA. Publication # 3316.

Bats/Bat Habitat

- Dr. Steve Cross, Southern Oregon State College, 1250 Siskiyou Blvd., Ashland, OR 97520-5071; (541) 552-6749

  Dr. Cross has done extensive work increasing bat habitat.

- Jim Kennedy, Bat Conservation International, P.O. Box 162603, Austin, Texas, 78716; (512) 327-9721; FAX (512)327-9724

  BCI has a wealth of information concerning bats and bat habitat.

- Rachael Long, Farm Advisor, U.C. Cooperative Extension, 70 Cottonwood St., Woodland, CA 95695; (530) 666-8143

  Rachael Long is working with growers in Yolo County, California, to increase bat populations and study the positive effects on crops of increased bat populations.

Grasshoppers

- Dr. Mark Quinn, 319 S. Monroe, Moscow, ID 83843; (208) 883-8818

  Dr. Quinn is knowledgeable about grasshopper IPM and life cycles. He is doing research in the Klamath Marsh (Klamath Forest NWR) on grasshoppers.

To order the Grasshopper IPM User Handbook:

- USDA-APHIS/PPQ, Stephen A. Knight, Unit 134, 4700 River Rd., Riverdale, MD 20737; (301) 734-8247

- Cliff Bradley, Mycotech Corporation, 630 Utah Ave., Butte, MT 59702; (406) 782-2386

  Mycotech manufactures Mycotrol, a formulation of the fungus *Beauveria bassiana* registered for use against grasshoppers on rangeland.

Loopers/Pheromone Traps

- Phero Tech, 7572 Progress Way, Delta, BC Canada V4G 1E9; (604) 940-9944; Fax (604) 940-9433

  Phero Tech specializes in semiochemical traps (i.e., pheromone traps) and has cabbage looper traps.

Parasitic nematodes

Local suppliers of BioVector Biological Insecticide for Fruits and Vegetables:

- United Horticulture Supply, 100 S. Central, Medford, OR 97501; (541) 779-0121

For further information about the use of beneficial nematodes for cutworm control contact:

- Rick Miller, product manager, Biosys, 10150 Old Columbia Rd., Columbia, MD 21046; (410) 381-3800

Potatoes

- John P. Helgeson, Plant Disease Resistance Research, Madison, WI; (608) 264-5276

  Dr. Helgeson is working to develop PVY-resistant potato varieties.

- Mary L. Powelson, Department of Botany and Plant Pathology, Oregon State University, Corvallis, OR 97331-2902; (541)737-5309; E-mail powelsom@bcc.orst.edu

  Dr. Powelson has done much work on Verticillium wilt on potatoes and is an expert on potato disease management.

- Jeff Stark, College of Agriculture, Research and Extension Center, University of Idaho, P.O. Box AA, Aberdeen, ID 83210-0530; (208) 397-4181; Fax (208) 397-4311

  Dr. Stark and his colleagues have researched many aspects of sustainable potato production in the Pacific Northwest.

LITERATURE CITED

1. Burton, V.E. 1995. *Potato pest management guidelines*. U.C. Pest Management Guidelines, University of California, Statewide IPM Project, Davis, CA. Web site: http://axp.ipm.ucdavis.edu/PMG/r607300611.html

2. Mahr, S., J. Wyan, E. Radcliffe, C. Hoy, and D. Ragsdale. 1995. Potatoes. In *Vegetable insect management with emphasis on the Midwest*. Foster, R. and B. Flood, eds.

3. Wyman, J.A. 1996. WISDOM, IPM Program for Potatoes. University of Wisconsin, Cooperative Extension Service. Computer program.

4. Shields, E. J., D. I. Rouse, and J. A. Wyman. 1985. Variegated cutworm (Lepidoptera: Noctuidae): Leaf-area consumption, feeding site preference, and economic injury level calculation for potatoes. Journal of Economic Entomology. October 1985. 78:5:1095-1099.

5. Burton, V.E. 1989. *Flea beetles on potatoes*. U.C. Pest Management Guidelines, University of California, Statewide IPM Project, Davis, CA. Web site: http://www.ipm.ucdavis.edu/PMG/r607300311.html

6. Carlson, H. 1994. *Potato pest management guidelines.* U.C. Pest Management Guidelines, University of California, Statewide IPM Project, Davis, CA. University of California Statewide IPM Project. Web site: http:// www.ipm.ucdavis.edu/PMG/r607101211.html

7. Radcliffe, E.B., D.W. Ragsdale, and K.L. Flanders. 1993. Management of Aphids and Leafhoppers. In *Potato Health Management*. R.C. Rowe, ed. St. Pileups Press.

8. Andaloro, J.T., and A.M. Shelton. 1996. Cabbage looper - *Trichoplusia ni* (Huebner) Web site: http:// gopher.cce.cornell.edu/CGI/scripts/library.cgi/vegpestslib/menu /menu4

9. Hutchison, W.D., H. Hoch, P. Bolin, and R. Hines. 1997. Cabbage looper. The Veg Edge. University of Minnesota Extension Service. Web site: http://www.mes.umn.edu/ vegipm/vegpest/colecrop/looper.htm.

10. Metcalf, C.L., W.P. Flint, and R.L. Metcalf. 1962. *Destructive and useful insects*. New York: McGraw-Hill.

11. Berry, R.E. 1978. *Insects and mites of economic importance in the Northwest.* Oregon State University Bookstores, Inc., Corvallis, OR.

12. Flint, M. L. 1990. *Pests of the garden and small farm*. University Of California. Oakland, CA. Hoffman, M.P., C.H. Petzoldt, and A.C. Frodsham. 1996. *Integrated Pest Manatementfor Onions.* Cornell University. Cornell, NY.

13. Hoffman, M.P., Petzoldt, C.H., and Frodsham. A.C. *Integrated Pest Management for Onions*, Ithica, NY: Cornell Cooperative Extension, p. 19

14. Buhler, W.G., and T.M. Gibb. 1994. Persistence of *Steinernema carpocapsae* and *S. glaseri* (Rhabditia: Steinernematidae) as measured by their control of black cutworm (Lepidoptera: Noctuidae) larvae in bentgrass. *Journal of Economic Entomology.* Vol. 87, No. 3. p. 638-642.

15. University of California. 1986. *IPM for potatoes in the western United States.* U.C. Division of Agriculture and Natural Resources, Oakland, CA. Publication # 3316. p. 79.

16. Summers, C.G., L.D. Godfrey, and R. Long. 1996. *Sugarbeet: Empoasca leafhoppers*. U.C. Pest Management Guidelines, University of California Statewide IPM Project, Davis, CA.

17. Rugen, C., and R. Dufour. 1995 and 1996. Interviews with growers who lease land from the Service in Klamath Basin. May and June

(respectively).

18. Davidson, R.G., and W.F. Lyon. 1979. *Insect pests of farm, garden, and home*. 7th edition. New York: John Wiley & Sons.

19. Long R. 1996. Personal Communication (Rachael Long is a farm advisor with the U.C. Cooperative Extension in Yolo County, CA.)

20. Peet, M. 1996. Sustainable practices for vegetable production in the South. (http://www2.ncsu.edu/ncsu/cals/sustainable/peet/profiles/pppotato.html)

21. Rowe, R.C. (ed) Potato Health Management. APS Press, St. Paul, MN.

22. Rich, A.E. 1983. Potato Diseases. Academic Press, San Francisco, CA. 238 p.

23. Stevenson, W.R. 1993. Early blight and late blight. In *Potato Health Management.* R.C. Rowe, ed. APS Press, St. Paul, MN.

24. Easton, G.D., and M.E. Nagle. 1985. *Lack of economic benefits by fungicides applied through center-pivot irrigation systems for control of "alter naria solani" on potato.* Plant Disease. 69:152-153.

25. Carlson, H. 1994. *Potato pest management guidelines (Fusarium).* U.C. Pest Management Guidelines, University of California, Statewide IPM Project, Davis, CA. UNIVERSITY of California Statewide IPM Project. Web site: http://www.ipm.ucdavis.edu/PMG/r607100711.html

26. Beagle-Ristaino, J.E., and G.C. Papavizas. 1985. Biological control of Rhizoctonia stem canker and black scurf of potato. Phytophathology. 75:5:560-564.

27. Jager, G., and H.Velvis. 1986. Biological control of *Rhizoctonia solani* on potatoes by antagonists. 5. The effectiveness of three isolates of *Verticillium biguttatum* as inoculum for seed tubers and of a soil treatment with a low dosage of pencycuron. *Netherlands Journal of Plant Pathology*. 92: 231-238.

28. Lewis, J.A., and G.C. Papavizas. 1987. Reductions of inoculum of Rhizoctonia solani in soil by germlings of Trichoderma hamatum. *Soil Biol. Biochem.* 19:2:195-201.

29. Howell, C.R. 1987. Relevance of mycoparasitism in the biological control of *Rhizoctonia solani* by *Gliocladium virens*. *Phytopathology*. 77: 992-994.

30. Voland, R.P., and A.H. Epstein. 1994. Development of suppressiveness to diseases caused by Rhizoctonia solani in soils amended with composted and noncomposted manure. *Plant Disease*. May 1986. pp. 461-466.

31. Rhodes, D.J., and C. Logan. 1986. Effects of fluorescent pseudomondads on the potato blackleg syndrome. *Annals of Applied Biology*. 108:511-518.

32. Kloepper, J.W. 1983. Effect of seed piece inoculation with plant growth-promoting rhizobacteria on populations of Erwinia carotovora on potato roots and in daughter tubers. *Phytopathology*. 73:2:217-219.

33. Burr, T.J., M.N. Schroth, and T. Suslow. 1978. Increased potato yields by treatment of seed pieces with specific strains of *Pseudomonas fluorescens* and *P. putida*. *Phytopathology*. 68:1377-1383.

34. Powelson, M.L., K.B. Johnson, and R.C. Rowe. 1993. Management of diseases caused by soilborne pathogens. In *Potato Health Management*. R. C. Rowe, ed. St. Paul: APS Press.

35. Merida, C.L., and R. Loria. 1994. Effects of potato cultivar and time of harvest on the severity of silver scurf. *Plant Disease*. February 1994. pp. 146-149

36. Rich, A.E. 1983. *Potato diseases*. San Francisco: Academic Press.

37. Hodgson, W.A., Pond, D.D., and Munro. J 1974. *Diseases and pests of potatoes*. Canadian Department of Agriculture publication # 1492.

38. Stark, J.C. 1995. *Development of sustainable potato production systems for the pacific northwest*. SARE Final Report.

39. Banttari, E.E., P.J. Ellis, and S.M. Khurana. 1993. Management of diseases caused by viruses and viruslike pathogens. In *Potato health management*. R.C. Rowe, ed. St. Paul: APS Press.

40. DiFonzo, C., D. Ragsdale, and E. Radcliffe. 1993. Red River Valley research leads to virus Y control. *Valley Potato Grower*. June 1993. pp. 17-19

41. MacGuidwin, A.E. 1993. Management of nematodes. In *Potato Health Management*. R.C. Rowe, ed. St. Paul: APS Press.

42. Forge, T. A., R.E. Ingham, and D. Kaufman. March 1995. Winter cover crops for managing root-lesion nematodes affecting small fruit crops in the Pacific Northwest. *Pacific Northwest Sustainable Agriculture*. pp. 3-5.

43. Luna, J. 1993. Crop rotation and cover crops suppress nematodes in potatoes. Pacific Northwest Sustainable Agriculture. March 1993. pp. 4-5.

44. Dietrick, E.J., J.M. Phillips, and J. Grossman. 1995. *Biological control of*

insect pests using pest break strips. Nature Farming Research and Development Foundation. Santa Rosa , CA. (booklet)

45. Hickman, J.M., and S.D. Wratten. 1996. Use of *Phacelia tanacetifolia* strips to enhance biological control of aphids by hoverfly larvae in cereal fields. *Journal of Economic Entomology*. August 1993. pp. 832-840.

46. Bugg, R.L., and R.T. Ellis. 1990. Insects associated with cover crops in Massachusetts. Biological Agriculture and Horticulture. Vol. 7. pp. 47-68.

47. Grossman, J., and W. Quarles. 1993. Strip intercropping for biological control. *The IPM Practitioner*. April 1993. pp. 1-11.

48. Lowery, D.T., and M.B. Isman. 1996. Inhibition of aphid (Homoptera: Aphididae) reproduction by neem seed oil and azadirachtin. *Journal of Economic Entomology*. June 1996. pp. 602-607.

49. Pottinger, L. 1994. Improve your pest-control batting average. *Farmer to Farmer*. December 1994. p. 5

50. Morris, O. 1995. Profitmakers: Caffeine jolts worms. *The New Farm*. January 1995 . p. 42.

51. Ellis, B.W., and F.M. Bradley. 1992. *The organic gardener's handbook of natural insect and disease control*. Emmaus: Rodale Press.

52. Nardozzi, C. 1989. Bt....or not Bt. *National Gardening*. June 1989. pp. 44-47.

53. Buhler, W.G., and T.J. Gibb. 1994. Persistence of *Steinernema carpocapsae* and *S. glaseri* (Rhabditia: Steinernematidae) as measured by their control of black cutworm (Lepidoptera: Noctuidae) larvae in bentgrass. *Journal of Economic Entomology*. 87:3:638-642.

54. Levine, E., and H. Oloumi-Sadeghi. 1992. Field evaluation of steinernema carpocapsae (Rhabditida: Steinernematidae) against black cutworm (Lepidoptera: Noctuidae) larvae in field corn. *Journal of Entomological Science*. 27(4):427-435.

55. Kobro, S. 1991. Irrigation against cutworm. *Gartneryrket*. 81:321:22-23

56. Zhu, Y., A.J. Keaster, and K.O. Gerhardt. 1993. Field observations on attractiveness of selected blooming plants to noctuid moths and electroantennogram responses of black cutworm (Lepidooptera: Noctuidae) moths to flower volatiles. *Environmental Entomology*. 22(1):162-166.

57. Peache, E., and R. William. 1994. Influence of grain cover crops on rowcrop pests. *Pacific Northwest Sustainable Agriculture*. October 1994. pp. 4-5.

58. Knudsen, G.R., D.J. Eschen, L.M. Dandurand, and L. Bin. 1991. Potential for biocontrol of *Sclerotinia sclerotiorum* through colonization of sclerotia by *Trichoderma harzianum*. May 1991. pp. 466-470.

59. Cardwell, D. , R. Ingham, and R. William. 1996. Management of practices to suppress Columbia root-knot nematode. *Pacific Northwest Sustainable Agriculture*. September 1996. p. 6-7.

60. Honeycutt, C.W. 1996. Potato farmers could save on fertilizer—and cut yield losses from a fungus—by rotating their potato crops with one of these nitrogen-fixing legumes: Hairy vetch, alfalfa, or white lupin. *ARS Quarterly Report*. July to September 1996.

61. Schisler, D.A. and P.J. Slininger. 1994. Selection and performance of bacterial strains for biologically controlling Fusarium dry rot of potatoes incited by *Gibberella pulicaris*. *Plant Disease*. 78:3.

62. Zehnder, G., A.M. Encill, and J. Speese III. 1995. Action thresholds based on plant defoliation for management of Colorado potato beetle (coleoptera: Chrysomelidae) in potato. *Journal of Economic Entomology*. Vol. 88, no. 1.

63. Northwest Coaltion for Altenrative Pesticides. 1997. Comment letter of Draft IPM Plan.

COPYRIGHT PERMISSIONS

Inc. Used with permission.

69. Table 12: *Integrated Pest Management for Potatoes in the Western United States* (Publication 3316). Oakland, CA: University of California, Statewide Integrated Pest Management Project, Division of Agriculture and Natural Resources. Copyright: 1986, University of California Board of Regents. Used with permission.

70. Figure 13: *Plant Pathology* (3rd edition), by George N. Agrios. San Diego, CA: Academic Press, Inc. Copyright: 1988, Academic Press, Inc. Used with permission.

71. Figure 14: *Plant Pathology* (3rd edition), by George N. Agrios. San Diego, CA: Academic Press, Inc. Copyright: 1988, Academic Press, Inc. Used with permission.

72. Figure 15: *Plant Pathology* (3rd edition), by George N. Agrios. San Diego, CA: Academic Press, Inc. Copyright: 1988, Academic Press, Inc. Used with permission.