# Crop Profile for Potatoes in Wisconsin

**Prepared: September, 2000**

## General Production Information

Wisconsin is a leading producer of fall potatoes in the United States. In 1998, 83,500 acres of potatoes were harvested resulting in Wisconsin being the number 4 potato-growing state in the country. Total yield in 1998 was 30.9 million cwt with a per acre yield of 370 cwt.

Crop value that year was $4.95 per cwt for a total value of $15.3 million. Wisconsin potatoes are grown for the following uses:

| Use | Percentage of Crop |
|---|---|
| Frozen | 44% |
| Table stock | 23% |
| Chipped | 17% |
| Seed | 10% |
| Dehydrated | 6% |

### Production Costs

According to calculations made using the Agricultural Budget Calculation Software in 1997, the cost of production of one acre of irrigated potatoes was $1,500.

### Production Regions

There are three main production regions in Wisconsin. The central sands counties of Adams, Waushara, Portage, Wood, and Waupaca produce the bulk of the state's irrigated crop with northwestern counties including Barron, Dunn, and Menominee, constituting the remainder of the crop. Some of Wisconsin's potato crop is also grown on muck soils in the south central counties of Jefferson and Waukesha. Seed production is centered in the northeast in Langlade and adjacent counties.

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# Cultural Practices

Potatoes are planted in fertile, well-drained soils including sands, sandy loams, or silt loams for best production. Planting occurs from early May through early June in the southern part of the state, mid-April to mid-May in central Wisconsin, and from early May to late May in northern counties when the soil temperature is between 55-60F. Rows are spaced 32-36 inches apart and seed pieces are planted 8-16 inches apart within the row, depending on the variety. The average size of seed pieces are between 1.5-2.0 oz.

Seed potatoes are warmed slowly to 50-55F for several days before handling and cutting. After cutting, they may be planted immediately or stored at the same temperatures for 3-5 days with good air circulation and high humidity of 95-99% to provide optimum wound healing before planting. Whole or cut seed potatoes may be treated with a fungicide to reduce seed piece decay in the soil.

Soil pH is maintained at 5.0-5.6 where scab-susceptible potatoes are grown on organic and mineral soils, 5.6 for scab-resistant varieties on organic soils, and 6.0 for scab-resistant varieties on mineral soils. Generalized recommended rates for phosphorus are shown in the table below. Some research on medium-textured, acid soils in northeastern Wisconsin shows responses to relatively high rates of $P_2O_5$ even on soils testing more than 100 ppm soil test phosphorus. Sandy soils showed few responses when soil test phosphorus was higher than 75 ppm. Potassium should be broadcast in spring on highly leachable sandy and organic soils. Some row-placed starter fertilizer (30-30-30) is recommended even when soils test excessively high for phosphorus.

| Nitrogen -- amount to apply | | | | | Phosphate and potash -- amount to apply | |
|---|---|---|---|---|---|---|
| Percent Organic Matter | | | | | | |
| Yield Goal | <2 | 2.0-9.9 | 10-20 | >20 | $P_2O_5$ | $K_2O$ |
| cwt/a | lb/a | | | | | |
| 250-350 | 115 | 90 | 70 | 30 | 35 | 150 |
| 351-450 | 150 | 125 | 100 | 45 | 50 | 200 |
| 451-600 | 200 | 150 | 125 | 60 | 65 | 260 |

On sandy soils, 25-50% of the supplemental nitrogen is applied at emergence and the remainder is applied at tuberization Alternatively, nitrogen may be applied in multiple split applications. The latter method will improve yield and quality during years with high precipitation. On medium or heavy textured soils, there is no advantage to splitting applications.

Potato cultivars commonly grown for processing in Wisconsin include Gold Rush, Superior, Russet Burbank, Russet Nortoka, Ranger Russett, and Snowden. Frito Lay varieties are grown for chipping and Dark Red Norlands are grown on muck soils.

Weed control practices involve the use of herbicides and timely cultivation. During the second and third weeks after planting, cultivation and herbicide use are critical to keeping weed pressure down. Hilling is another effective weed control method and herbicide applications are timed in such a manner with the hilling operation to optimize weed control. Most of the herbicide applications are made at emergence during the first hilling. Additional herbicides may be applied postemergence as needed for weed control.

Much of the Wisconsin potato crop is irrigated. It is important that plants receive a constant supply of water during tuber formation and growth as moisture stress can reduce both yield and quality of the crop. Many growers utilize an irrigation scheduling software program included with the Wisdom software package.

To enhance the color of red skinned potatoes, 1-2 applications of Riverdale 2,4-D L.V.6 Ester are made at least 45 days before harvest.

Two to three weeks prior to harvest, the vines are treated with Diquat herbicide at a rate of 1 pint per acre. Where vine growth is dense, a second application may be made at the same rate at least five days after the first. Paraquat, endothal, glufosinate, and sulfuric acid are also registered as vine desiccants in Wisconsin but have restrictions as to the soil type and intended crop use. All products may be used according to label rates. Potatoes are dug after vines are completely desiccated - usually 14-21 days after treatment. This is done to reduce tuber infection by early and late blights and to allow the skin to set before harvest to avoid wounding during harvest.

Potatoes are cured while in storage. Curing promotes suberization and prolongs their storability. Potatoes are cured at 50-55F and a relative humidity of 90-95% for 2-4 weeks immediately after harvest. After the tubers are properly cured, they are prepared for long-term storage. The storage temperature is slowly lowered by 1 every 5-7 days to prevent reducing sugar accumulation. The relative humidity remains at 90-95%. Potatoes grown for seed or fresh market use are stored long-term at a temperature of 38F while those that will become fries are stored at a temperature of 45F and chipping potatoes at 50-55F.

Potatoes that will be stored long-term require a sprout inhibitor the can be applied either in the field or in storage, after the tubers have been cured. Before the potatoes are removed from storage, they are gradually warmed to 55-65F for 2-3 weeks.

# Insect Pests

**<u>Colorado potato beetle</u>** (*Leptinotarsa decemlineata*) feeds on the foliage of potatoes. If left unchecked, feeding activity of the larvae and adults can completely defoliate potato plants, resulting in reduced tuber size or plant death. Colorado potato beetles overwinter as adults in the soil, often at field margins. Adults become active in the spring, about the time the first shoots of early season potatoes or volunteer plants appear. Females will lay up to 500 bright yellow eggs in clusters of 15-25 on the lower leaf surfaces before dying. Eggs hatch in 4-9 days and larvae begin feeding immediately. After passing through four instars over the course of 2-3 weeks, larvae return to the soil to pupate. Within 10-14 days, adult beetles emerge. There are 1-2 generations per year in northern states and 3-5 generations in the south.

Cool weather tends to slow insect activity and development, thereby reducing the amount of damage that occurs. Conversely, warm spring weather may accelerate insect growth so that as many as two full generations develop before the end of the season. Both adults and large larvae are voracious leaf feeders. Large holes, larger than inch in diameter, are chewed into potato leaves. Often, entire leaves on the terminal parts of the plants are consumed. Larvae typically feed in groups and may completely defoliate plants. The late larval instars and summer adults do the most feeding damage. Heavy defoliation will severely affect plant yields, particularly if it occurs when potatoes are in bloom.

**Key control strategies**: General predators such as ladybeetles or stink bugs feed on eggs and small larvae but rarely provide economic levels of control Cultural controls can be extremely effective in delaying infestation and reducing populations and should be employed. Distance rotation of potato crops is most effective and rotating new plantings at least 400 meters from the nearest previous crop can reduce infestation by over 75%. Fall trap crops formed by leaving a strip of potatoes unkilled prior to harvest will aggregate large numbers of adults which may then be killed prior to overwintering. Spring trap crops or field edges, which are infested first, can be used to aggregate adults early in the season and spot, or edge treatments with insecticide, vacuum suction, or flaming can then be used effectively to reduce populations. Plastic-lined trenches (18 inches deep) placed between overwintering sites and the emerging crop can also prevent infestation.

Chemical control is the most commonly used management approach but the Colorado potato beetle has developed resistance to all insecticides used against it and resistance management is critical.

**Two approaches exist for chemical control**: systemic treatments applied at planting or emergence and foliar sprays. Systemic control is most effective in early to mid season with Admire (imidacloprid) being most widely used. The persistence of Admire treatment is dependant on application rate. Seed treatments of imidocloprid (Genesis or Gaucho) also provide systemic protection. For resistance management , Admire should not be used repeatedly in the same area.

Foliar sprays have repeatedly resultied in resistance with control failures noted following applications of carbamates (carbaryl, Furadan), organophosphates (Guthion, Imidan), organochlorines (Thiodan), and pyrethroids (Ambush, Pounce, Asana, and Baythroid). To manage resistance selection pressure must be reduced and this is best accomplished by reducing the number of applications. In Wisconsin, this is achieved by carefully timing applications to target the most vulnerable stage of the life cycle - first generation, $1^{st}$ and $2^{nd}$ instar larvae. Avoid treatment of overwintered adults infesting fields or confine treatment to field edges if severe defoliation is occurring. Treat when eggs have hatched and larvae are predominantly in the $2^{nd}$ instar. This stage can be determined by scouting or prediction (250 degree days using a base temperature of 50F from first eggs to $3^{rd}$ instar). If oviposition is prolonged, a $2^{nd}$ application is often necessary 7-10 days after the first. This program will avoid damaging defoliation since small larvae cause little defoliation and kill larvae prior to pupation, thus avoiding $2^{nd}$ generation pressure.

Strict insecticidal rotation by chemical class should be followed to further avoid resistance build up. Bioassay kits are available to test larval susceptibility prior to initial applications.

**Potato leafhopper** (*Empoasca fabae*) is a serious pest of potatoes in most Midwestern production areas. They do not survive in northern states. Populations build up on legumes early in the year in isolated areas of the Gulf states and migrate northward in April and May on warm southerly winds. The first migrants, which are primarily females, reach Midwestern states in early summer. Large influxes of migrants occur in June and early July causing populations to increase rapidly and seemingly 'explode' overnight. White eggs are inserted into the stems and large leaf veins of susceptible crops. Each female lays approximately 3 eggs per day and oviposition typically lasts about one month. Eggs hatch in 7-10 days. Nymphal development involves five successively larger instars and takes 12-15 days. First generation offspring mature in late July with a second generation maturing in early September. There are normally only two generations per year in Wisconsin.

Leafhopper injury develops most rapidly during hot, dry weather. Both nymphs and adults feed by inserting their piercing/sucking mouthparts into the vascular tissue of the plant and extracting sap. Damage is principally to the phloem cells which becomes blocked by salivary products during feeding, preventing translocation of photosynthetic products from the leaves. General symptoms include stunted plants with chlorotic foliage that curls upward at the margins. Early symptoms include triangular, brownish spots at the leaflet tip or at the leaf margins near veinlets. Browning progresses inward from the margins and leaf margins become dry and brittle. Often only a narrow strip of green tissue remains along the midveins. The burned appearance of the foliage is where the term "hopperburn" is derived. Symptoms of feeding injury begin on older foliage and move upward. Pre-mature death of untreated vines causes severe yield reduction. Damage may be more severe in hot, dry years and nymphs cause more damage than adults. Yield loss may occur before obvious hopperburn symptoms develop and the level of yield loss is not directly related to hopperburn.

**Key control strategies**: Biological and cultural controls do not provide effective potato leafhopper control and chemical control is usually required. Plants should be scouted by sweep net (adults) and leaf counts (nymphs) and treatments applied only when thresholds are exceeded: when adults are below 0.5 adults/sweep do not treat until more than 1 nymph/10 leaves is present; if 0.5-1.0 adults/sweep are present, treat if populations persist for 10-14 days or if nymphs are found; if 1.0-1.5 adults/sweep are present, treat in 5-7 days or immediately if nymphs are found; if over 1.5 adults/sweep are present, treat immediately.

A broad range of insecticides provide effective potato leafhopper control including organophosphates (Dimethoate, Pencap-M, Malathion), carbamates (Lannate, carbaryl), and pyrethroids (Ambush, Pounce, Asana, Baythroid). Since the potato leafhopper is a migratory insect with a broad host range, resistance is not a concern, however, insecticides should only be used which will not select for resistance to other key pests such as the Colorado potato beetle. When natural enemy preservation is desirable (eg. for aphid control), low application rates, short persistence materials or early season applications should be used to keep disruption at a minimum.

**Green peach aphid** (*Myzus persicae*) is the most serious pest of seed potato production due to its capacity to transmit potato leafroll virus (PLRV) and potato virus Y. On processing potatoes, tuber symptoms of PLRV (net necrosis) may reduce quality. Heavy infestations may kill vines late in the season with damage typically restricted to small circular patches. The green peach aphid overwinters as black, shiny eggs on the bark of *Prunus* spp: peach, plum, apricot or cherry trees but most aphids migrate into northern areas from overwintering sites in southern states. Overwintering eggs hatch at about the same time *Prunus* spp. are in bloom. After 2-3 generations, winged forms of aphids are produced. The aphids then migrate to susceptible weed and crop plants and begin producing nymphs asexually. Infestations often begin in the field margins and many generations of wingless forms are produced during the summer. A single female can produce 50-100 live young and with a complete generation requiring less than 10 days under ideal conditions. In response to adverse conditions, such as crowding, winged, asexual forms are produced and further dispersal occurs. In the fall, winged sexual forms are produced which mate and lay eggs on trees in the genus *Prunus*.

Heavy rain can rapidly decrease aphid populations as well as produce ideal conditions for the rapid spread of several fungal diseases which can rapidly reduce populations. Green peach aphids possess extremely fine, needle-like, piercing mouthparts which are inserted between plant cells, and into the vascular tissue. Typically, this causes little direct morphological damage. When present in high numbers, enough sap may be extracted to cause plant wilting, particularly on hot, dry days. Eventual plant death may occur under extreme conditions and usually occurs in small circular patches which enlarge as aphids move. Excess sap is excreted as "honeydew" that falls onto leaves, giving them a shiny appearance and sticky texture. Indirect damage is caused by transmission of plant viruses and the green peach aphid is known to transmit several important potato viruses including potato leafroll virus and potato virus Y. Winged forms of the aphid are generally more important in transmission of PVY.

**Key control strategies:** Green peach aphid cannot be managed culturally. However, biological control by predators (eg. lady beetles, syrphids, lacewings) and tiny parasitic wasps can effectively regulate aphid populations in potatoes and these natural enemies should be preserved by avoiding broad spectrum sprays where possible. This approach can only be used in table stock where virus transmission is not a primary concern and should not be used in seed production where extremely low thresholds must be maintained. Chemical control can be achieved by systemic insecticides or foliar sprays. Systemics are most effective in early and mid season with Admire being the most widely used.

Foliar sprays should be employed when aphid populations exceed thresholds (normally in mid-late season) and thresholds vary by end use: in seed -- 1 aphid/10 leaves; in processing for varieties susceptible to net necrosis--3-5 aphids/10 leaves; in table stock--1-4 aphids/leaf. Repeated foliar applications should be avoided since the green peach aphid can rapidly develop resistance. The organophosphate Monitor is the most effective and widely used aphidicide. Fulfill, a reduced risk, specific aphidicide was registered in 1999 and provides an effective alternative particularly in situations where natural control by predators and/or parasites is active.

**Potato aphid** (*Macrosiphum euphorbiae*) is a common pest of potatoes and is primarily important as a vector if virus diseases, particularly potato virus Y. Potato aphids overwinter as black eggs on wild and cultivated roses. Eggs hatch in the spring and several generations are produced asexually on the succulent, developing tissue of the rose before winged forms of the aphid are produced. Winged aphids migrate to susceptible host plants in early summer. On potatoes, aphids give birth to live young asexually and one female may and produce 50 nymphs within a two week period. Aphid nymphs become mature in two weeks. The short generation time, along with the high numbers of offspring, result in rapidly exploding populations. As conditions become adverse or crowding occurs, the aphids disperse to new hosts. In late fall, winged forms return to roses, undergo sexual reproduction and lay overwintering eggs prior to frost.

Heavy rain can rapidly decrease aphid populations as well as produce ideal conditions for the rapid spread of several fungal diseases. Like other aphids, the potato aphid possesses a fine, needle-like stylet that is inserted between plant cells into the vascular tissue. Typically, this causes little direct injury to adjacent tissues. Extremely large populations may extract enough sap to cause leaf curling and wilting or eventual plant death under extreme conditions. Excess sap is excreted as honeydew and falls onto leaves, giving them a shiny appearance and sticky texture. Sooty mold fungi may grow on copious honeydew secretions. The potato aphid transmits some potato virus diseases but it is not as efficient a vector as the green peach aphid.

**Key control strategies:** The potato aphid normally infested potatoes in mid-season (June/July) and is subject to the same control strategies as the green peach aphid. Chemical control can be achieved with a broader range of insecticides (including pyrethroids) and since potato aphids are not as efficient a vector, thresholds may be raised to 3 aphids/10 leaves in seed and 5-10 aphids/10 leaves in processing stock.

**Aster leafhopper** (*Macrosteles fascifrons*) is an occasional pest of potatoes because of its ability to transmit the phtyoplasma that causes aster yellows. On potatoes, this disease is called purple top. Infection of processing potatoes is serious since fried product is dark. The first aster leafhoppers that appear in May to June do not overwinter in the northern states but overwinters in grain fields from Louisiana to Kansas. Northward migration occurs each spring on warm, southerly winds and large influxes of adults may occur in May and June. Southerly winds when temperatures are above 60F in May will increase leafhopper movement which can be predicted by following wind speed and direction in relation to overwintering areas.

Leafhopper feeding does not damage to the plant and this species does not reproduce on potato and thus, nymphal production is not a concern. However, the transmission of the aster yellows pathogen may damage the crop severely. Newly sprouted potatoes are most susceptible while mature plants are almost totally resistant to aster yellows. If young plants become infected, symptoms typically are not expressed for 30 days or more. General aster yellows symptoms on potatoes include yellowing and reddening of mature foliage, and aerial tuber formation. Infected plants are generally stunted and have small tubers. When processed, infected tubers produce a dark-colored product. An infective leafhopper transmits the pathogen to a plant during its feeding activity. The pathogen is carried in the insect's saliva and is transmitted to the phloem vessels when the leafhopper feeds on plant sap. On average, the leafhopper must probe and feed on a host for eight hours before the pathogen is transmitted. The aster yellows organism can multiply in both the plant and in the insect vector.

**Key control strategies:** the aster leafhopper has no effective biological controls and cultural controls cannot reduce infestation. Chemical control is necessary if the Aster Yellows Index (AYI) exceeds 50. AYI is derived from the number of adults/100 sweeps X the % infectivity in the population. Adult numbers are obtained by sweep sampling and a percent infectivity of 2% should normally be used for the migrating population. UW Extension conducts annual surveys of the migration and infectivity and these may be used to predict infestation and adjust the infectivity level. Systemic organophosphate insecticides (Thimet, DiSyston) provide effective control while Admire is less effective. Foliar insecticides (Asana, Baythroid) should only be used if populations exceed the AYI.

**Cutworms** (*Agrotis ipsilon, Peridroma saucia*) There are two species of cutworms that are problematic in potatoes: black cutworm and the variegated cutworm. Larvae of both insects feed at night and hide in the soil during the day. Feeding damage may appear as "window-paning" when newly hatched larvae feed on plant foliage. As the larvae grow, they begin to feed on the older growth resulting in large holes in leaves. Late instar larvae may occasionally "cut" the plant at, or just beneath, the soil surface.

Black cutworms are a greasy, dark grey and about 1 ½ inches long when mature. Variegated cutworm larvae have distinct pale yellow dots on the mid dorsal line of most body segments and frequently have a dark W on the 8th abdominal segment. Adults of both are brownish-grey moths.

In Wisconsin, black cutworm moths migrate from southern states each spring. Mated females lay eggs on low-growing vegetation such as chickweed, mustards or plant residue from the previous crop. There are three generations per year but it is the first generation that is most damaging as it occurs when crops are small.

Variegated cutworms, on the other hand, overwinter in the soil as partially matured larvae or pupae. Eggs are laid in clusters on grass, weeds and vegetables. Larvae are primarily foliage-feeders. There are two generations per year in Wisconsin.

**Key control strategies:** Although cutworms are susceptible to attack by general predators and some parasitoids, these do not provide adequate regulation. Cultural controls such as tillage to remove crop residue and weeds may reduce early season black cutworm problems. Chemical control is effective, but since cutworm defoliation rarely causes yield loss, sprays should only be applied when populations exceed thresholds (4/row foot in early season and 8/row foot late in the season). Systemic insecticides do not provide cutworm control.

**European corn borer** (*Ostrinia nubilalis*) attacks over 200 different plants and is a sporadic pest of potatoes and is typically only a serious problem when the preferred host, corn, is not available. Certain varieties of potato are more susceptible to damage with Norgold, Norchip, and Norkota being the most affected. European corn borer larvae feed on foliage prior to boring inside potato stems where damage is severe. Foliar feeding is characterized by small feeding scars that develop when the larvae remove all but the upper epidermis. Stem damage produces a inch entry hole that is typically surrounded by frass. Secondary bacterial infections may invade the stems and cause stalk death.

European corn borers overwinter as mature 5th instar larvae in corn stalks and stems of weedy hosts. Pupation occurs in the spring with the first moths flying shortly thereafter. Adult moths are nocturnal and spend most of their daylight hours in sheltered areas along field edges. Eggs are laid on susceptible hosts and the young instar larvae feed on leaves and in the midrib of the leaf. Third instar larvae begin to bore into the stem. There are two generations per year but only the first generation is damaging to potatoes.

Weather plays an important role in the survival of the eggs and young larvae. Cool spring weather and drought delay insect development due to the desiccation of eggs and young larvae. Conversely, warm, wet weather accelerates insect development. Excessive heat and drought can cause increased mortality of all life stages.

**Key control strategies:** Biological regulation of overwintering larvae by parasites and predation of eggs by predators (eg. lady beetles, stink bugs) can reduce populations but in years when first generation adult flights are high, insecticidal controls may be necessary if egg masses are found on more than 10% of the leaves. Fields should be scouted during the first generation flights using leaf counts. Flight intensity can be obtained from Wisconsin Department of Agriculture, Trade and Consumer Protection (WDATCP) survey publications listing blacklight trap catches throughout the state and flights can be predicted using degree days.

Baythroid and permethrin (Ambush/Pounce) provide the most effective control.

Cultural controls are not effective in the potato crop although mowing edge grassy areas where moths congregate, may reduce oviposition.

**Potato fleabeetle** (*Epitrix cucumeris*) can normally be found in potatoes but is rarely a serious pest. Potato fleabeetles overwinter as adults in the soil in fields in which they have matured. Beetles become active when temperatures reach 50F. and emerge in spring to early summer. They begin feeding on weeds or volunteer potato plants until the crop emerges. Adult fleabeetles lay eggs in the soil at the base of host plants. The eggs hatch in 7-14 days and larvae feed on the roots of the host plant until fully grown. After feeding for approximately two weeks, the larvae pupate in earthen cells for 11-13 days before emerging as adults. A complete life cycle takes 30-50 days and the second generation adults emerge in mid summer. Adults are typically only present for 2-3 weeks.

Potato fleabeetle populations can be very high, however, it is not known what conditions lead to these outbreaks. Adult fleabeetles feed on both leaf surfaces but usually on the underside where they chew small, circular holes less than inch , through the tissue to the upper cuticle. The circular holes give the plant a shotgun blast appearance which is characteristic of fleabeetle injury. Heavy feeding on young plants may reduce yields or even kill plants in severe cases. Larvae feed on the roots and tubers but do not cause economic injury.

**Key control strategies:** Fleabeetles are not regulated effectively by natural control. Cultural controls such as crop rotation may reduce populations but in severe infestations, chemical control may occasionally be necessary. Pyrethroids (permethrin, Asana, Baythroid) provide effective control but should only be employed if feeding damage is severe during the flowering stage. Systemic insecticides normally provide effective fleabeetle control.

**Tarnished plant bug** (*Lygus lineolaaris*) is an occasional pest on potatoes but its affect on yield and quality have not been determined. Tarnished plant bugs overwinter as adults under leaf mold, stones, tree bark, and among the stubble of clover and alfalfa. Adults begin to emerge in late spring. After feeding for a few weeks, they migrate to various herbaceous weeds, vegetables, and flowers where the eggs are inserted into the stems, petioles, or midribs of leaves. Eggs hatch in about 10 days. There are five nymphal instars requiring 20-30 days to complete. New generation adults begin to emerge in late June to July. There may be 2-3 generations per year with adults entering hibernation in October or November. Appreciable numbers of plant bugs are not seen on potatoes until mid summer.

Weedy fields or fields with a large amount of plant residue may increase the numbers of tarnished plant bugs. The tarnished plant bug causes injury to potatoes by inserting their piercing-sucking mouthparts into the plant and removing sap. In addition to the direct damage caused by feeding, the insect also injects a salivary secretion which is toxic to the plant. This toxin will produce small, circular, brown areas at the point of feeding. Feeding causes leaves to curl, new growth to wilt, and destruction of the flowers.

**Key control strategies:** Tarnish plant bugs are only an occasionally pest of potato and populations are normally controlled by chemical controls for other insect pests. Treatment should only be made if plant bugs exceed 1 per sweep. Effective chemical controls and considerations are similar to those listed for the potato leafhopper.

**White grub** (*Phyllophaga* spp.) larvae attack many plants and are occasional pests of potatoes. These C-shaped larvae with brown heads eat large, circular or irregular, holes in potato tubers. Tuber damage can go undetected until harvest as the above-ground plant parts show no damage. Because white grubs have a 3 year life cycle, damage is most severe two years following peak adult moth flights.

Crops following sod or fields with grassy weeds are favored by the mated female moths as egg-laying sites. Eggs hatch in spring and the grubs immediately begin feeding on the roots and other below-ground parts. They migrate below the frost line seasonally until the third spring when the moths migrate to the subsoil layers to pupate.

**Key control strategies:** No biological controls provide effective regulation. Cultural controls involving crop rotation to avoid fields which have had a grass problem or were sod fields in the previous three years are effective. Where cultural control through rotation is not possible, fields may be treated with a soil insecticide prior to planting. In-furrow applications of Admire or Phorate as a systemic control for other potato pests provide some control but if infestation is heavy, a soil insecticide such as Mocap should be utilized.

**Wireworms** are the thin, yellow to reddish-brown larvae of several species of click beetles. Adult beetles are hard-shelled, brown or black "streamlined" beetles that flip into the air with an audible click. Wireworms have an extended life cycle, taking from 1-6 years to complete a single generation. Larvae live in the upper six inches of the soil and feed on seeds and roots. Adults become active in spring as they fly about searching for a site on which to oviposit. Eggs are laid in grassy areas such as pastures, alfalfa, sod, and grassy row crop fields.

Wireworms feed primarily on grasses including corn and small grains as well as nearly all wild and cultivated grasses. The damage to potatoes by this occasional pest appears as deep, cylindrical tunnels about the diameter of a match stick rendering the tubers unmarketable. Damage is most severe when potatoes are planted into fields previously in sod.

**Key control strategies:** Control strategies are similar tho those described for white grub although rotations may need to be extended to 4-5 years following sod.

## Chemical Controls for Insect Pests in IPM and Resistance Management Programs

In 1996, the Wisconsin Potato and Vegetable Growers Association (WPVGA) in collaboration with the World Wildlife Fund (WWF) and the University of Wisconsin entered into a collaboration with the goal of reducing industry reliance on the eleven most toxic pesticides used by potato growers. Toxicity was based on overall toxicity derived from acute and chronic mammalian toxicity, ecotoxicity, and impact on IPM systems. Insecticides targeted for reduction included the organophosphates azinphos-methyl and methamidophos, the carbamates, carbofuran and oxamyl, the pyrethroid, permethrin, and the organochlorine, endosulfan. These materials were also targeted for review under the Food Quality Protection Act (FQPA) together with other organophosphate (dimethoate, phosmet, ethoprop, diazinon, phorate, malathion, parathion, disyston) and carbamate (methomyl, carbaryl, aldicarb) insecticides. Grower surveys were conducted in 1995 (baseline), 1997, and 1999 (USDA, NASS, http://usda.mannlib.cornell.edu/ to track use of impacted materials. Reductions were achieved by product selection based on toxicity, efficacy and cost and use patterns based on the key control strategies listed under each target pest above. Baseline data were also obtained for 1990-1994 from USDA-NAPIAP Report "Use, target pests, and economic impact of pesticides applied to potatoes in the United States". Insecticides used in Wisconsin potato production and considerations involved in product selection by growers are as follows:

### Soil Insecticides (non-systemic)

**Ethoprop** (Mocap G, L) is an organophosphate soil insecticide for control of soil insects (white grub, wireworm) and nematodes in potatoes. It is applied in the furrow or broadcast at 3-6 lb a.i./A. Some reduction of common scab has also been reported following use in-furrow. Less than 3% or the acreage is treated with ethoprop annually.

**Diazinon** (G, EC, WP) is registered as a pre-plant broadcast, incorporated, soil insecticide for wireworm control in potatoes at 2-4 lb a.i./A. No significant use in Wisconsin.

### Soil Insecticides (systemic)

**Aldicarb** (Temik G) is registered for use on potatoes in the US but is not labeled in Wisconsin due to concerns over groundwater contamination.

**Disulfoton** (Di-Syston G, EC) is a restricted use organophosphate insecticide that controls a wide range of potato insects. Its primary use in Wisconsin has been for control of aphids and leafhoppers as a soil-applied systemic at 3 lb a.i./A. During the 1990-94 survey, disulfoton use was reported on 9% of the Wisconsin potato acreage. Surveys in 1995, 1997, and 1999 reported no use of disulfoton with use switching to imidacloprid after registration in 1995.

**Phorate** (Thimet G, Phorate G) is a restricted use soil insecticide used to control aphids, leafhoppers, flea beetles, and to suppress Colorado potato beetles. It is applied as a band application in the furrow at planting or as a side dress, postemergence application at hilling at a rate of 2.0-3.0 lb a.i./A. There is a 90 day pre-harvest interval. Seventeen percent of the potato crop land received phorate applications during the survey period 1990-94. No use was reported in 1995, 1997, or 1999 surveys following the registration of imidacloprid.

**Imidacloprid** (Admire 2F, Tops-Mz-Gaucho dust, Genesis F) is a nicotinyl sytemic insecticide that controls Colorado potato beetles, aphids, potato leafhoppers, and flea beetles. It may be applied as an in-furrow spray or impregnated on the starter fertilizer at 0.2 to 0.3 lb a.i./A. In 1999, new registrations for seed treatment (Tops-Mz-Gaucho D or Genesis L) were added. Use rates in Wisconsin vary from 0.2 lb a.i./A on table stock and processing potatoes to 0.3 lb a.i./A for seed. Imidacloprid registration was received in 1995 and use in Wisconsin has increased rapidly to 51% in 1997 and 81% in 1999. Imidacloprid use has replaced organophosphate systemic insecticides (Phorate, Di-Syston) and resulted in significant reductions in the use of foliar insecticides used for Colorado potato beetle and aphid control.

With increased acreage, resistance management has become a major concern for this product and growers are advised to avoid repeated use in specific areas through distance rotation and the use of foliar alternatives. This option is however, curtailed by the current lack of effective foliar alternatives. The withdrawal of transgenic Btt potatoes by the manufacturer in 1999 will further contribute to increased imidacloprid use.

## Foliar Insecticides

### Organophosphates

**Azinphos-methyl** (Guthion, Sniper E, Azinphos-M 50W) is a restricted use insecticide for the control of Colorado potato beetle, European corn borer, potato fleabeetle and potato leafhopper. It is applied at a rate of 0.5-0.75 lb a.i./A no less than 7 days before harvest. Crops other than those that have a use label for azinphos-methyl should not be planted in azinphos-methyl treated soil any sooner than 6 months after the last application. No more than 3 applications should be made per season. The USDA NAPIAP

Report "Use, Target Pests, and Economic Impact of pesticides Applied to Potatoes in the United States" indicates that during the survey years between 1990-94, Wisconsin growers surveyed stated they applied azinphos-methyl to 9% of the planted acreage. Surveys in 1995 indicate an increase in use to 40% of acres but subsequent use has declined dramatically with 0% of the acreage treated in 1997 and 1999 reflecting the substitution of imidicloprid as a systemic and increased Colorado potato beetle resistance to azinphos methyl.

**Disulfoton** (Di-Syston EC) is a restricted use organophosphate insecticide which is labeled for general insect control (primarily aphids and leafhoppers) on potatoes at 0.4-1.0 lb a.i./A with a 30 day pre-harvest interval as a foliar systemic. This use pattern has not been used in Wisconsin in the 1990s.

**Diazinon** (Diazinon Ag 500, EC, WP) is an organophosphate insecticide which is labeled for aphids, fleabeetles, and leafhoppers as a foliar spray at 0.25-0.5 lb a.i./A with a 35 day PHI. Diazinon isnot used as a foliar spray in Wisconsin having been largely replaced by organophosphate and pyrethroid alternatives.

**Dimethoate** (EC) is an organophosphate insecticide used as a foliar spray to control primarily potato leafhoppers (with aphid suppression) at 0.25-0.5 lb a.i./A with a 0 day PHI. Dimethoate is an inexpensive and effective leafhopper material which is used widely in fields not treated with a systemic insecticide. Use will vary with leafhopper pressure. In 1990-94, 21% of acreage was treated. Acreage increased to 28% in 1995 and remained high at 59% in 1997 and 45% in 1999.

**Malathion** (Malathion EC, Cylhion EC) is an organophosphate insecticide with short persistence used to control primarily potato leafhoppers (with aphid suppression) as a foliar spray at 0.6-0.9 lb a.i./A with a 0 day PHI. The short residual of this material reduces its negative impact on beneficial organisms but its use in Wisconsin is below 1% of the treated acreage.

**Methamidophos** (Monitor EC) is an organophosphate insecticide used to control aphids and leafhoppers as a foliar spray at 0.75-1.0 .b a.i./A with a 14 day PHI. Efficacy testing has shown that methamidophos is the most effective aphicide registered prior to 2000 and the only material which has not induced resistance in green peach aphids following repeated use. Its importance to the potato industry was emphasized in the 1990-94 NAPIAP survey where it was identified as the pesticide which would cause the greatest economic impact in the US if registration were lost. In Wisconsin, 36% of the acres were treated in 1990-94. Use increased in 1995 to 66% but decreased to 22% in 1997 and 19% in 1999. Use of methamidophos varies with aphid pressure annually but reductions in 1997 and 1999 also reflect the increasing acreage treated systemically with imidacloprid. In late 1999, a new aphicide, pymetrozine (Fulfill F) received registration. This reduced-risk alternative for aphid control has the potential to reduce methamidophos use further in 2000 and beyond.

**Phosmet** (Imidan WP) is an organophosphate insecticide which may be used for control of Colorado potato beetle and potato leafhopper as a foliar spray at 1.0 lb a.i./A with a 7 day PHI. Phosmet resistance in CPB and availability of alternatives has resulted in little use in Wisconsin with no use reported in the

1994, 1995, 1997, or 1999 surveys.

## Carbamates

**Carbaryl** (Sevin WP, S, L, XLR Plus) is a carbamate insecticide used to control cutworms, European corn borers, potato fleabeetles, potato leafhoppers, and tarnished plantbugs at a rate of 0.5-1.0 lb a.i./A. Applications can be repeated as necessary every 7 days for a total of 6 applications. There is a 7 day pre-harvest interval. Carbaryl is a broadspectrum insecticide with high toxicity to natural enemies which is known to flare aphid populations. This, together with widespread resistance in Colorado potato beetles have resulted in little or no use in Wisconsin potatoes.

**Carbofuran** (Furadan F) is a restricted use insecticide used to control the Colorado potato beetle, European corn borer, potato flea beetle, and potato leafhopper. It is applied at a rate of ½ - 1 lb a.i./A no more than 3 times per season. There is a 14 day pre-harvest interval and a 10 month plant back restriction for all crops except those on which carbofuran is registered. According to the PIAP survey, 12% of the acreage was treated with carbofuran during the period 1990-94. Use in 1995 remained moderate at 15% of the acres treated but widespread resistance and the increasing use of imidacloprid resulted in 0% use of carbofuran in 1997 and 1999.

**Methomyl** (Lannate SP, L) is a restricted used insecticide used to control aphids and potato leafhoppers. It is applied at a rate of 0.45-0.9 lb a.i./A no less than 6 days before harvest. Methomyl has not been used in significant amounts in Wisconsin potatoes due to the availability of organophosphate and pyrethroid alternatives and no use was reported in the 1990-94, 1995, 1997, or 1999 surveys.

**Oxamyl** (Vydate L) is a carbamate insecticide which can be applied at a rate of 0.25-1.0 lb a.i./A to control Colorado potato beetles, green peach and potato aphids. There is a 7 day pre-harvest interval and a 4 month rotational plantback restriction. The 1995 Agricultural Statistics Service pesticide use survey indicates that oxamyl was applied to 8% of the potato crop grown in Wisconsin. In 1995, 5% of the acres were treated and availability of imidacloprid in 1997 reduced use to 0%. In 1999, resistance of Colorado potato beetles to pyrethroids and endosulfan resulted in a small increase in use to 4% of the treated acres. The risk of groundwater contamination associated with oxamyl has restricted its use in Wisconsin potatoes and the combination of its overall toxicity and potential for Colorado potato beetle resistance, will likely restrict its use in the future.

## Organochlorines

**Endosulfan** (Thiodan EC, Phaser EC) is registered for control of Colorado potato beetles, potato flea beetles, potato leafhoppers, green peach, and potato aphids. It is applied at a rate of 0.5-1.0 lb a.i./A and may be repeated up to 6 times per season. Endosulfan has been an important component of foliar Colorado potato beetle control programs in Wisconsin with 40% of the acres treated in 1990-94. Increasing resistance to pyrethroid insecticides in Colorado potato beetle populations resulted in an increase in usage in 1995 to 48% but increasing use of imidacloprid in 1997 reduced endosulfan use to 13%.

## Pyrethroids

**Esfenvalerate** (Asana XL) is a restricted use insecticide for control of Colorado potato beetles, European corn borers, potato flea beetles, potato leafhoppers, aphids and tarnished plant bugs. It is applied at a rate of 0.025-0.05 lb a.i./A not to exceed 0.35 lbs a.i./A per season. Some populations of Colorado potato beetles have developed resistance to esfenvalerate resulting in poor control but this material remains the predominant foliar tool for Colorado potato beetle control. Most applications are now tankmixed with piperonyl butoxide (PBO), a synergist that helps control of resistant populations. Esfenvalerate was applied to 44% of Wisconsin acreage in 1990-94. This use has remained high with approximately 45% (3000 lb a.i.), 32% (2000 lb a.i.), and 58% (6000 lb a.i.) of acreage treated in 1995, 1997, and 1999. PBO use as a tank mix with esfenvalerate for increased efficacy in Colorado potato beetle control has increased from 3000 lb a.i. in 1995 to 7000 lb in 1997 to 18,000 lbs in 1999.

**Permethrin** (Ambush, Pounce EC) is a restricted use insecticide labeled to control the Colorado potato beetle, European corn borer, potato flea beetle, and potato leafhopper. It is applied at a rate of 0.05-0.2 lb a.i./A with a 7 day pre-harvest interval. Thirty-three percent of Wisconsin potatoes were treated with permethrin in 1990-94 but with increasing resistance in Colorado potato beetles, permethrin use dropped to 4000 lbs of a.i. in 1995, none in 1997, and 1000 lbs a.i. in 1999. Permethrin use is currently used primarily for control of the potato leafhopper.

**Cyfluthrin** (Baythroid EC), a pyrethroid insecticide, received registration in 1999. This material is registered for control of Colorado potato beetles, leafhoppers, and flea beetles at 0.025 - 0.044 lb a.i./A with a 0 day PHI. No survey data exists for cyfluthrin use after 1999 but it is estimated that cross resistance to other pyrethroids, necessitating tank mixes with PBO, have held use below 5%. Piperonyl butoxide use as a tank mix for pyrethroid insecticides in Colorado potato beetle control has increased from 3000 lbs a.i. in 1995 to 7000 lbs a.i. in 1997 and 18,000 lb a.i. in 1999.

## Other Foliar Insecticides

**Sodium aluminofluoride** (Prokill Cryolite 96, Kryocide) is an insecticide that provides control of the Colorado potato beetle. It is applied at a rate of 10-12 lb a.i./A as needed and its primary usage in the US has been for control of pesticide-resistant Colorado potato beetles where no effective alternatives exist. No use has been reported in Wisconsin for 1990-94, 1995, 1997, or 1999.

**Bacillus thuringiensis var. tenebrionis** (Novodor) is a registered biological insecticide for the control of Colorado potato beetle. It is the most effective against 1st and 2nd instar larvae, therefore the initial application should be made when eggs and small larvae are observed. It can be reapplied as necessary to maintain control. The application rates vary depending on the population pressure and the stage of larval development. For light to moderate populations of early instar larvae (newly hatched up to ¼ inch in length), 1 to 3 quarts/A are applied, while 2 to 3 quarts/A should be applied when heavy infestations are present. There is a zero day pre-harvest interval.

Although Btt is an effective insecticide against Colorado potato beetles, its short persistence normally requires multiple (3-4) applications. To achiever control. Its use in the US has consequently been primarily in areas where no effective alternative for Colorado potato beetle control exists as a result of resistance. No use has been reported in Wisconsin in the 1990-94, 1995, 1997, or 1999 surveys. Btt remains a safe, pest-specific, alternative for biointensive IPM programs, however, and there is potential for increased use in low risk pesticide programs.

**Transgenic Btt potatoes** Btt as a genetically-engineered, plant-produced toxin has been available in Russet Burbank, Atlantic, and Superior varieties for several years. This induced trait provides excellent and very specific Colorado potato beetle control. Concerns over potential risk from genetically-modified plants have restricted the use of transgenic varieties expressing Btt, however, and less than 5% of the acreage utilized this trait before its voluntary withdrawal from production in 2000.

**Spinosad** (SpinTor, Success) Spinosad is a biologically-derived, naturalyte insecticide which received registration in 1999. Applied at 0.062-0.125 lb a.i./A, spinosad has low toxicity and is pest specific, with primary efficacy against the Colorado potato beetle and lepidoptera, and is thus a good fit in biointensive IPM programs where preservation of natural control is important. No survey data is available since its registration but spinosad use has remained below 2-3% of the acreage. The potential for increased use in reduced risk IPM programs in good.

**Imidacloprid** (Provado 1.6F) is the foliar formulation of Admire. Provado is a nicotinyl insecticide with activity against the Colorado potato beetle, aphids, flea beetles, and leafhoppers when applied as a foliar spray at 0.047 lb a.i./A with a 7 day PHI. Twelve month plantback restrictions for crops not on the imidacloprid label, however, restricted its use as a foliar spray prior to their removal in 1999. Since Provado should not be applied to potatoes treated with Admire (to avoid selection for imidacloprid resistance) use in Wisconsin as a foliar spray has been minimal.

**Abamectin** (AgriMek) is a biologically-derived insecticide registered for use on potatoes at 8-16 fl. oz./A with a 7 day PHI. Its primary activity is against Colorado potato beetles but no use has been reported in Wisconsin since its registration.

**Pymetrozine** (FulFill) is a new specific aphicide which received registration in 1999. Pymetrozine is a low toxicity, pest-specific aphicide with activity against green peach and potato aphids when applied as a foliar spray at 2.75 oz/A. The low toxicity and safety to beneficial insects make pymetrozine an excellent alternative to methamidophos in IPM programs. No survey data exist on 2000 usage but its potential to increase in acreage is high.

# Diseases

**<u>Bacterial Ring Rot</u>** (*Corynebacterium sependonicum*) is a highly infections disease that is spread by potato cutters, planters, harvesters, and containers. Losses due to this disease can be high if infected plants rot in the field or in storage.

The bacterium overwinters in tubers or as bacterial exudates on baskets, bags, and equipment. The bacteria enters healthy plants through wounds or through the use of contaminated knives during seed cutting. Once inside the plant, the bacteria invades the xylem tissues.

Symptoms of bacterial ring rot don't appear until late in the growing season. Some infected plants may be asymptomatic. Lower leaves may exhibit interveinal chlorosis or may become pale green with upward-rolling margins. Leaf discoloration is accompanied by a progressive wilting. Eventually, the entire plant may die. When an infected stem is cut, the vascular tissues appear brown and a milky-white bacterial exudate can be squeezed from the base of the infected stem. Infected tubers may have reddish areas near the eyes or the skin may be swollen. When the tuber is cut across the stem end, a creamy, yellow to light brown rot is visible in the vascular ring. The rot is crumbly to cheesy and odorless. If you squeeze a cut tuber, bacterial exudate oozes from the affected part of the ring.

**Bacterial Soft Rot** is another common bacterial disease wherever potatoes are grown and is caused by the bacterium *Erwinia carotovora* var. *carotovora*. Bacterial soft rot often occurs in association with other stem and tuber diseases or injuries such as late blight, sunscald, or freezing injury.

The pathogen may overwinter on crop debris or be present on seed tubers. In the field, the bacterium is spread by splashing rain and irrigation. Rainy weather favors disease development since potato tissues (leaves, stems, and tubers) are covered with a film of moisture. In wet soil, tuber lenticels are enlarged, providing an entrance for the bacteria. On wet stems and leaves, infection often occurs through wounds.

Affected tissues in tubers are typically white to cream-colored, soft, somewhat watery and slightly granular. Later, the infected tissue becomes grey-brown. A black margin often separates diseased and healthy tissues. Infected tubers break down partially or completely, and a watery rot develops. The decay may progress into either a wet rot stage or it may dry up and leave chalky-white lesions. Soft rot affects tubers in storage, but seed pieces and newly-formed tubers in the field can become infected. Stem infections appear as soft-rotted, often dark brown to black lesions several inches above the soil line. Infected tissues collapse and dry, leading to wilting of the foliage or affected vines.

**Blackleg** (*Erwinia carotovora* var. *atroseptica*) is a common bacterial disease wherever potatoes are grown. This disease can cause heavy losses through yield reduction as well as loss of tubers from rot in storage. Loss due to pre-emergence seedpiece decay and pre-emergence shoot infection may also occur.

The bacteria overwinters in the soil or in tubers associated with infected plant debris but does not appear to survive in the absence of host tissue. Infected seed pieces that are planted in the field, decay and release the bacteria into the soil. These bacteria may move with soil water to infect adjacent plants. The disease also appears to be spread in the field by various insects.

Soil temperature and soil moisture markedly affect blackleg at low inoculum densities. When sufficient moisture and cool temperatures prevail, the disease progresses rapidly and the entire plant wilts and dies. Affected tubers decay rapidly in wet soils. The symptoms of chlorosis and severe rolling of the leaves can be recognized even when plants are only a few inches high. As the disease progresses, dark, inky black, and sometimes slimy lesions extend from the seedpiece up the stems for some distance above the ground level. Dissection of infected stems show a black discoloration of the pith and vascular system. Infected plants wilt and finally die as the lower stems are girdled with rotting lesions. An odor characteristic of rotting vegetation is associated with infected plants. When tubers are infected, decay usually begins at the stolon end of the tuber. The lesions produced by this rot are small and dark. Often a small, circular black opening is visible on the tuber surface. Internal tuber tissue may show varying degrees of soft rot.

**Common scab** (*Streptomyces scabies*) is caused by an aerobic, soilborne bacteria. Although the disease doesn't affect the eating quality, surface lesions blemish tubers and reduce their commercial grade and market price. Scabbed tubers tend to shrink excessively during storage and are often invaded by secondary soft-rotting organisms.

The bacterium overwinters in the soil where it can survive indefinitely in the absence of a suitable host. Fields that receive heavy applications of manure are particularly susceptible to the buildup of scab in the soil. Infection occurs through natural openings in the plant such as lenticels and stomata. Soils with a pH between 5.5-7.5 that have been in continuous potato production for several years are likely candidates for losses to common scab.

Symptoms of scab infection appear as brownish spots that are small at first but later enlarge. The resulting lesions may be large, raised and corky or more frequently, they appear as small, russetted areas that occur only on the tuber surface. Thin-skinned potato varieties are more severely affected than varieties with a russetted surface, but surface scab affects russetted varieties as well. Scab shouldn't be confused with enlarged lenticels that are found on tubers grown in excessively wet soils. In severe cases of pit scab, small, circular lesions extend into the flesh several millimeters.

Control is best achieved by maintaining a soil pH between 5.2-5.8. Scab-free seed pieces should be planted on land that is free from scab. Long rotations of 3-5 years out of potatoes are recommended. Treatment of seedpieces with mancozeb dust formulations helps to reduce scab severity.

**Early blight** (*Alternaria solani*) is a common foliage disease of potatoes. When leaf spots are numerous, foliage is prematurely killed and yield may be reduced. In years when environmental conditions favor disease development, disease management costs may exceed $100/acre.

*Alternaria solani* overwinters as spores and mycelium in plant refuse in the soil. In the spring spores are released and spread to other plants by wind, rain, and insects. The fungus penetrates the leaves through natural openings. As the infected plant grows, the infection spreads. Plants that lack vigor are predisposed to attack by this fungus. Plants with nutrient imbalances, virus infections, and insect damage are at increased risk for infection. Many cycles of early blight may occur within one season. Secondary infection occurs when foliar lesions begin to sporulate and spores are carried to nearby, non-infected plants. Early blight may appear slightly earlier in the season than late blight, and is usually first observed in early to mid-summer but often does its greatest damage late in the season if weather is favorable.

Moderate temperatures, high humidity, and prolonged leaf wetness from dews, rain, or irrigation, favor the development of early blight. Rain is not necessary for the development of the disease. Alternating periods of wet and dry weather tend to increase progression of the disease.

Symptoms initially appear on the older foliage and progress upward in the plant. Leafspots are round, oval, or angular and are dark brown to black in color. These necrotic spots usually have concentric rings that produce a bull's-eye or target appearance. There is usually a narrow chlorotic zone around the lesion which fades to the normal green coloration further from the central lesion. As lesions enlarge and coalesce they are often delimited by the large leaf veins. Sometimes the spots coalesce, killing large areas of individual leaflets. Early blight sometimes attacks the tuber. On tubers, the lesions are small, sunken, round or irregular in shape with slightly raised margins. The skin around the margin is slightly puckered. Affected tissue also develops a corky, brown, dry rot. Tissue near the margin of the tuber lesion is yellow to light brown in color initially and may be water-soaked. Wounds are generally necessary for tuber infection to occur.

**Fusarium dry rot, Fusarium tuber rot** (*Fusarium solani, F. roseum*) are widespread and cause heavy losses to potatoes in storage and markets. These diseases reduce market quality and the use of tubers for processing. Factors that contribute to *Fusarium* tuber rot include wounds, high storage temperature and humidity.

*Fusarium* inoculum can remain in the soil for many years, however most infection is likely to be caused by surface contamination of the tubers. Infection occurs via wounds on the tuber during the handling of tubers.

*Fusarium* species live in the soil or on plant debris. *Fusarium roseum* is more prevalent in warm soils with temperatures between 78-89F. *Fusarium solani* is present in cooler soils with temperatures around 77F. The optimum soil temperature for infection of roots is 68-77F, with a minimum temperature of 53F and a maximum temperature of 86F. There is no spread of the disease from infected to healthy tissue during storage, but symptoms may become more intense when tuber are stored at 50F. Wet rot may occur when infected tubers are stored at 60-70F. High storage temperature and humidity favor disease development. At 40F, the disease is checked completely. Tuber dry rot is common on stored tubers which were harvested in fields subjected to long periods of excessively dry weather during the growing season since these tuber are likely to bruise at harvest.

Infected tubers usually develop a dry rot, but a moist rot may occur under warm, humid conditions. The species of *Fusarium* may affect the type of symptoms produced. *F. roseum* causes no external symptoms on potato but does cause an internal discoloration at the stem end of the tuber. The color of the vascular ring in the tuber varies from yellow or brown to black and may extend all the way through the tuber. Sometimes the vascular ring becomes hard and woody. *F. solani* causes a brownish skin discoloration at the stem end, which later becomes sunken or wrinkled and may rot. A white fungal growth is often present on the wrinkled and rotted areas. The vascular ring becomes yellow, brown, or black and may be water-soaked. The discoloration may extend through the tuber. New tubers are affected more by water rot than older tubers.

**Grey mold** (*Botrytis cinerea*) is a common fungal disease with a wide host range that overwinters on crop debris. When temperatures are cool and humidity is high, spores are released and infection begins. Grey mold is often found in fields where an abundance of fertilizer and irrigation is used. It is typically not economically important on potatoes grown in Wisconsin.

Symptoms that appear late in the season are often mistaken for late blight. A greyish-green, wedge-shaped, spreading lesion with concentric rings appears on the leaves, often near an injury or a dried blossom. Lesions begin on the margins or tips of leaves. In severe infections, leaves are blighted and a soft grey rot attacks the stems. Infected tissues are usually covered with a layer of brown spores and fungal mycelium. When potato vines are disturbed, spores billow from them like a cloud of dust. Grey mold normally attacks the lower, senescing leaves that have been weakened by shade or old age. The disease spreads through the plant via the petiole to the stem cortex. Tuber infection, although uncommon, produces a slightly watery and odorless rot of tubers. The tuber surface may become wrinkled.

**Late blight** (*Phytophthora infestans*) is found throughout the world and has been responsible for periodic epidemics when weather conditions favor infection. Late blight can be a very serious disease on potatoes particularly where the weather is consistently cool and rainy in late summer and fall. Late blight is responsible for millions of dollars of losses in the U.S. due to recent epidemics confronting North American growers.

There are two major mating types of late blight fungus, A1 and A2. Originally, both of these mating types were only present in Mexico; however, in 1984 the A2 mating type was reported in Europe and since has become widely distributed throughout the world. The presence of both mating types in a specific area has important implications in control. When only one mating type is present in an area, the fungus reproduces asexually and survives only in association with living host tissue. When both mating types are present, however, sexual reproduction is possible, leading to the production of oospores with thick walls and have the capability of surviving adverse environmental conditions in the absence of living host tissue.

The pathogen survives during winter months in association with potato tubers. Tubers that overwinter in the soil, tubers dumped in cull piles from warehouses in the spring, and infected seed slivers serve as sources of inoculum for neighboring fields. The late blight fungus grows in and on plants which develop from infected tubers. Primary inoculum is produced under moist conditions and the pathogen is disseminated further by wind or water or human activity. The pathogen is most active during periods of cool moist weather. Cool nights with temperatures of 50-60F, and warm daytime temperatures of 60-70F are ideal for late blight development. Fog, rain or heavy dew for four to five consecutive days will also favor disease development.

Symptoms of late blight appear on leaves, stems, and tubers. Leaf symptoms appear as pale green, water-soaked spots that often begin at the edges of leaves or leaf tips where water from rain or dew accumulates. The circular, or irregularly-shaped lesions are often surrounded by a pale yellow to yellow green border that blends into healthy green tissue. The lesions enlarge rapidly and killed tissues turn brown to black. It is not uncommon for leaf lesions to expand in diameter by ¼ to ½ inch per day until the whole leaflet is killed. Often during periods of ideal temperature and abundant moisture, there may be multiple lesions per leaflet. When relative humidity is above 90% and leaves are wet from rain or dew, leaf lesions are bordered by a thin, white covering of the late blight fungus on the lower leaf surface. Wind, rain, machinery, workers, and wildlife can dislodge the sporangia and carry them to other plant parts and neighboring plants. During high temperatures and low humidity, leaf lesions dry and infected leaves die and fall from the plants. These new tissues are not protected by fungicide sprays. Stems and petioles may also be infected by late blight fungus. Infected stems and petioles turn brown to black and entire vines may be killed, depending on the location of the lesions. The edges of stem and petiole infections may be covered with white masses of sporangia during wet weather. Because of a similarity in appearance to bacterial stem rot, *Botrytis* vine rot and even blackleg disease, the stem and petiole lesions may be overlooked or misidentified in the field. It should also be noted that in addition to symptoms appearing on potato, tomato, and hairy nightshade are also susceptible to the late blight fungus.

Tuber infection occurs when sporangia or zoospores, washed into the soil via cracks or crevices in the hill, come in contact with tubers. Moisture in the hill provides an ideal environment for tuber infection. Varieties with shallow-set tubers and plantings where there is a significant hill erosion or cracking experience the greatest risk of tuber infection. Tubers may also come into contact with sporangia when green infected vines are present at harvest. Tuber infection results in a coppery brown dry rot that spreads irregularly from the tuber surface through the outer to ½ inch of the tuber tissues. The boundary between healthy and infected tissues is not well defined and the depth of infection may vary from one variety to another. Later in storage, tuber lesions become sunken as water is lost from infected areas. Tubers infected with the late blight fungus are often infected with soft rotting bacteria and fungi, often leading to a slimy and smelly breakdown of stored tubers. Infected tubers surviving in the field as volunteers or in cull piles serve as overwintering sites for the late blight fungus. Potato cultivars differ in susceptibility to late blight infection.

**Leak** (*Pythium ultimum* & *P. debaryanum*) is caused by one of the soilborne water mold fungi and is most serious in years with heavy rainfall. The fungus infects potatoes through wounds and invades tubers damaged by sunburn or tubers that are allowed to remain in, or on hot soils after being harvested.

Infected tubers of white-skinned varieties often have light to dark brown lesions on the surface. Internally, the affected tissues are creamy at first but as the disease progresses, the tissues soon become tan or slightly reddish, then brown, and finally inky black. The diseased areas are sharply set off from the healthy tissue and often only a shell of sound tissue remains. The flesh of infected tubers is granular, soft, and very watery. Control is cultural and potatoes should not be planted on heavy, poorly drained soils. Only fully mature tubers should be harvested and care should be taken to avoid bruising and injuring the skin. Harvested tubers should be moved to storage as quickly as possible and kept dry and cool. The fungicide mefanoxam provides some control of this disease when applied during mid-season.

**Lesion nematode** (*Pratylenchus penetrans*) damages both the roots and tubers of potatoes. Nematode infestations can reduce plant growth by almost 60% and can cause losses in tuber yields of 20-50%. The feeding of these nematodes may predispose potatoes to other diseases, or the nematodes may act with other pathogens in the development of potato disease complexes.

Eggs are laid in the soil or within the root. Nematodes undergo the first of their molts while still in the egg. Upon emerging from the egg, second instar larvae and subsequent stages penetrate unsuberized areas of the root. Typically, the larvae feed and develop into adults within 40-45 days depending on temperatures and other environmental conditions. It takes between 4-8 weeks to complete one generation.

Lesion nematodes occur in most potato production areas. They are more common and cause more damage in sandy soils, but they may also be abundant in heavier soils with a higher clay content.

Optimum temperatures for reproduction are between 70-85F. Alternate freezing and thawing of the soil tends to kill the nematodes quicker than continuously low temperatures. Lesion nematodes require moderate soil moisture for migration from plant to plant. Some species however, are relatively resistant to drought.

Above-ground symptoms of severely affected potato plants are manifested as poor growth. In the field, affected plants often appear in patches with stunted growth and chlorosis. Sometimes, affected plants may show no obvious above-ground symptoms. Underground symptoms are more obvious. Roots may be girdled at the infection site so that the outer tissue layers will readily slip off from the central cylinder. The nematodes cause root necrosis, often visible externally as darkened lesions. Small feeder roots are often completely destroyed, resulting in a drastically reduced root system. Internally, nematodes tunnel through root tissue as they feed, damaging root cells. This damage causes plants to grow poorly with reduced yields. Where nematodes feed on tubers, bumps appear that later change to black depressions. When infection is severe and bumps and depressions are numerous, tubers are marred and become unmarketable.

**Pink rot** (*Phytophthora erythroseptica*) is a late season disease of potatoes that results in wilting, chlorosis and the development of aerial tubers. Tubers become infected through diseased stolons and the disease progresses through the tuber with the line of demarcation between healthy and infected tissue appearing as a dark black line. Infected tissues are spongy but intact and are salmon pink when exposed to the air.

The fungus that causes pink rot is soilborne and survives from season to season as oospores. Infection occurs when soils are poorly drained and remain wet for a prolonged period. High soil organic matter content also precipitates the disease. Planting in well drained soils and irrigation management to manage the amount of soil moisture present are key in preventing disease development. Fungicide treatment with mefenoxam provides some control of this disease.

**Silver scurf** (*Helminthosporium solani*) is a common and widespread disease of potatoes that is favored by high soil moisture and high humidity. Symptoms are confined to the tubers and appear as light to dark brown, round or irregular, spots that develop on the tuber surface. On wet tubers, the spots are silvery and glassy and easily observed. After prolonged storage under warm, moist conditions, spores form in the diseased spots and make them look sooty or smudgy. The affected skin sloughs off and tubers shrivel and shrink. The color of red-skinned potatoes may be completely destroyed by the disease.

Silver scurf overwinters in infected tubers and other debris in storage and those left in the soil after harvest. Infection of healthy tubers occurs through wounds or lenticels. Cultural controls such at planting disease-free seed pieces and rotating crops will reduce the incidence and severity of the disease.

Fungicides are also available for control.

**Verticillium Wilt** (*Verticillium albo-atrum, Verticillium dahliae*) is a disease that can cause serious losses in potatoes. Severe infections may reduce yield by 20% or more. Wilt severity and yield losses depend on the level of inoculum in the soil, prevailing weather conditions, and cultivar susceptibility.

*Verticillium albo-atrum* overwinters as mycelium in plant debris while *V. dahliae* survives as resting spores called microsclerotia. Infection occurs through natural openings and wounds in roots. Initial outbreaks are typically localized. Severity of infection increases with each subsequent year potatoes are planted in infested fields. Dissemination occurs via infected seed in addition to the movement of infested soil.

The pathogens responsible for verticillium wilt can persist in the soil for 2-7 years. During periods of cool weather accompanied by sufficient soil moisture, typical wilt symptoms do not develop. Wet soils during the period of emergence to tuberization favor infection by the *Verticillium* fungus and dry, hot soils during tuber bulking favor symptom expression. Symptoms can appear as early as flowering. The leaves of the infected plants will wilt from the bottom of the plant upward. The wilted foliage becomes pale yellow and then brown. Sometimes only one stem is affected or possibly all but one stem may escape infection. Plants may either die very quickly or may succumb gradually. Often, on hot, sunny days, plants may wilt but regain turgor after sundown. Some curling and rolling of the leaflets and a tipburn may occur. Often, only the uppermost leaves remain green. The interior vascular tissue of the stems becomes yellow, and later, reddish brown. Infected stems remain upright. All of the fine feeder roots as well as the bark of the main taproot eventually decay. Tubers may exhibit a brown or black discoloration of the veins at the stem end.

## Viruses

There are several viruses that cause problems in potatoes. Three of the most common viruses are described below.

**Potato Virus X - "potato latent virus"**, also known as the "healthy potato virus" since infected plants typically only show mild stunting or deformation of the foliage. The virus doesn't affect the eating quality of the tubers but tuber size and number can be reduced resulting in a yield reduction of 15% or more.

Many potato varieties are symptomless carriers of this virus, however some varieties show an acute reaction such as tip kill. The virus moves up through the plant killing the tip and the plant dies from the top, downward. In these varieties, tubers may not develop. Other varieties produce mottled foliage which can vary from being inconspicuous to very noticeable with a rugose texture to the leaves as well.

Infected plants may or may not be stunted.

**<u>Potato Virus Y</u> - "rugose mosaic virus"** is an important virus because it causes degeneration or "running out" of tubers and is capable of causing complete crop failure. It is most serious when potato virus X is present concurrently. The virus is transmitted from infected plants to healthy ones by aphids, primarily the green peach aphid. Leaf molting caused by potato virus Y infection may not be apparent at high temperatures.

Symptom severity varies with virus strain and potato cultivar and ranges from a wild mosaic to severe foliage necrosis and plant death. The severe symptoms of rugose mosaic make it easy to identify from other mosaics on potato. In the first year of infection, black streaks develop in the veins, leaf stalks, and stems which cause the leaves to shrivel. The leaves are left hanging on the plant by the withered petiole. Some leaves become so brittle they drop from the plant. One or more shoots may be infected in one hill, but by the end of the season, most, if not all shoots from a hill will be affected. Infected plans die prematurely. Plants emerging from tubers infected with potato virus Y are dwarfed. The leaves on these plants are severly mottled, wrinkled, distorted, and reduced in size. The leaf stalks are brittle. Tubers produced on these plants are smaller than those produced on healthy ones. Rugose mosaic is distinct from other mosaics on potato because the mottled areas are numerous, smaller, and more conspicuous.

**<u>Simple mosaic virus</u>** (Potato virus X,M, and S) is the most common of all potato virus diseases. It is found in almost every crop of susceptible potato varieties grown for table stock. The disease complex does not affect the eating or marketing quality of the potatoes. However, tubers with the virus infection cannot be used as seed potatoes. Tubers produced from virus-infected plants are smaller than tubers produced on healthy plants and the reduction in yield is comparable to the reduction in size and vigor of the infected plants. The virus associated with simple mosaic are transmitted by the following aphids: green peach aphid (*Myzus persicae*), potato aphid (*Macrosiphum euphorbiae*), and the buckthorn aphid (*Aphis nasturtii*).

In hot weather, the symptoms are reduced in severity and often masked or very mild. Mottling symptom is most obvious in cool weather. Infected plants are mottled between the veins. Symptoms vary from conspicuous to barely noticeable. The plants may have slightly rugose leaves with an upward roll. Plants may or may not be stunted. Symptom expression may vary with the potato variety affected.

## Other Diseases/Disorders of Potato

There are several tuber disorders that result from unsuitable fertility or cultural practices. Post-harvest storage conditions also affect tuber quality. These disorders are not discussed in this crop profile because there are no pesticides used in their control.

## Chemical Controls for Diseases in IPM and Resistance Management Programs

**Chlorothalonil** (Bravo, Terranil and other formulations) is registered for control of early blight and late blight applied at a rate of 1.0-2.125 pt a.i./A for Bravo 720, Bravo ZN and Terranil 6L. Bravo Ultrex and Terranil 90DF are applied at a reduced rate of 0.8-1.4 lb a.i./A. Applications begin when vines are first exposed to the pathogen and an extended period of leaf wetness occurs and are repeated at 7-10 day intervals. When disease pressure is severe, 5-7 day intervals are recommended. No more than 16 lb a.i./A should be applied per season and there is a 7 day pre-harvest interval that must be observed. Chlorothalonil has a multi-site mode of action that may be used to prevent or delay the development of resistance to single-site fungicides. Chlorothalonil is used on 42% of the Wisconsin potato crop during the survey period 1990-94.

**Copper hydroxide** (Champ, Kocide) is a fungicide that gives fair control of early blight and good control of late blight. It is applied at a rate of 0.75-4.0 lb a.i./A up until the day of harvest. The first application can be made when plants are 6 inches high and repeat applications made at 7-10 day intervals. Tank mixes with maneb, mancozeb or chlorothalonil provide broad-spectrum disease control in potatoes. Copper hydroxide is applied to 20% of Wisconsin potatoes.

**Cymoxanil** (Curzate 60DF) is a curative fungicide that is mixed with other protectant fungicides such as mancozeb, chlorothalonil, triphenyltin hydroxide, or metiram for control of early and late blights. No more than 7 applications per season are allowed and there is a 14 day pre harvest interval. Rotation to an alternative fungicide after 3-4 applications of Curzate is recommended.

**Dimethomorph** (Acrobat MZ 69W) is a new fungicide registered that contains mancozeb used for control of early blight and late blight on potatoes. It is applied at a rate of 2.25 lb a.i./A up to five times per season. Because this fungicide contains and EBDC, it is subject to the EBDC threshold levels described under maneb below.

**Iprodione** (Rovral 50WP, 4F) is a protectant fungicide labeled for the control of white mold on potatoes. Up to four applications are made at 7-10 day intervals when warm wet weather conditions favor disease development. There is a 14 day pre harvest interval and a plantback restriction that must be followed. Less than 5% of the potato acreage in Wisconsin was treated with iprodione in 1999.

**Maneb** (Maneb, Manex) is another fungicide registered for control of early and late blights. It is applied at a rate of 1.5-2.0 lb a.i./A beginning when plants are 2-6 inches high and repeated every 5-10 days as needed. No more than 11.2 lb a.i./A of any EBDC fungicide (maneb or mancozeb) per growing season should be applied and there is a 3 day PHI. Nearly 100% of the potato acreage in Wisconsin is treated with either maneb or mancozeb each year to control potato pathogens.

**Mancozeb** (Dithane, Manzate, Penncozeb) is another EBDC fungicide used to control early blight and late blight. It is applied at a rate of 1.0-2.0 lb ai/A but not within 3 days to harvest. Application timing is similar to that of maneb and is included in the total amount EBDC used per growing season.

**Mefenoxam** (Ridomil) is a protectant fungicide used for the control of tuber rot, pythium leak, and pink rot. Up to three applications can be made at 14 days intervals beginning when the plant is flowering. Twenty-seven percent of the potatoes grown in Wisconsin were treated with mefenoxam during the survey period.

**Metam-sodium** (Busan, Vapam) is a soil fumigant used to control nematodes and the verticillium fungus responsible for the early dying complex. It is knifed into the plow layer or applied through the irrigation system at a rate of 50 gal/A on mineral soils or 100 gal/A on muck soils in the fall while the soil is warm.

**Thiabendazole** (Mertect 340F) is used as a post-harvest treatment to control fusarium tuber rot. Unwashed tubers are misted with 0.42 fl oz Merctect 340F per 2000 lb of tubers before entering storage.

**Triphenyltin hydroxide** (Super-Tin 80WP, Agri Tin 80WP) also controls early blight and late blight. This restricted use pesticide is applied at a rate of 2.5-3.75 oz a.i./A not to exceed 15 oz/A per season. The lower rate of application is used early in the season and the higher rate mid to late season when blight infection is in the area. There is a 7 day pre-harvest interval for Super-Tin and a 21 day PHI for Agri Tin. During the survey years, triphenyltin hydroxide is was applied to 34% of the potato acreage. Typically growers apply the 2.5 oz rate in combination with a low label rate of EBDC material to achieve maximum efficacy and to minimize the risk of phytotoxicity.

## Other Chemicals

Fourteen to 21 days prior to harvest, the vines are killed with herbicides to stop tuber growth and promote skin set. Skin set is essential in reducing the susceptibility to disease. Vine killing is a key practice utilized to prevent further spread of early and late blights and aphid transmission of virus diseases. The following materials are utilized in Wisconsin:

**Diquat** (Des-i-cate) kills vines at a rate of 0.25 lb a.i./A when applied 7 days before intended harvest. If vine growth is dense, a second application is made at the same rate five days after the first application. During the survey years 1990-94, 65% of the potato crop grown in Wisconsin was killed with diquat.

**Endothall** is another option for potato vine killing. It is applied at a rate of 0.78-1.04 lb a.i./A between 10 and 14 days before harvest. It was applied to 8% of the potato acreage in Wisconsin between 1990-94.

**Paraquat** (Gramoxone Extra) is the third vine killer commonly used in Wisconsin. It can only be used on potatoes that are not intended for storage or seed. Rates between 0.5-0.9 lb a.i./A are used with a 5 day PHI. In situations where vine growth is dense, a second application is made at the same rate as the first, five days following the initial application. Paraquat was applied to 9% of the potato acreage in 1990-94.

Maleic hydrazide is used as a sprout inhibitor for stored tubers. Two to three weeks after full bloom, when the smallest tubers that will be required to reach maximum size are 1 ½ - 2 inches in diameter and elongating, 5 lbs Royal MH 3056 is applied in 30 gallons of water. During the survey years, it was used on 8% of the potato crop.

## Alternative Pest Management Strategies

Considerable research has been done on potatoes with regard to pest management strategies that reduce the use of chemical pesticides. Traditional IPM systems utilize cultural activities such as crop rotation with corn, small grains, legumes, and green manure to suppress soilborne diseases and insects. Irrigation scheduling is a cultural practice used to minimize leaf wetness time utilized by most Wisconsin potato growers. Planting only certified seed reduces the risk of viruses and bacterial diseases.

Mitigation strategies have been identified for the primary pests of potato that will either replace or reduce reliance on FQPA-targeted pesticides. These mitigation strategies will only provide a short-term solution for potato growers if used solely as a replacement. This relief would be transitory as pest resistance rapidly negates the effectiveness of the alternatives. Substitution of lower risk alternatives will only be effective if they are integrated with other approaches that seek to reduce pest populations preventatively in biointensive IPM systems. Mitigation strategies are currently being tested for potatoes that utilize a GIS-based system that recognized the variation in spate and time of pest outbreaks. These strategies also utilize alternative, lower risk pesticides as one of the key management strategies in a biointensive IPM program.

Plant breeding efforts have lead to the development of transgenic resistance to the Colorado potato beetle. Resistant varieties also exist for potato virus Y and the potato leafroll virus.

## Critical Pest Control Issues

The five most important pests of potato and the FQPA-targeted pesticides used most frequently to control them are: Colorado potato beetle (phorate, azinphos methyl, phosmet, and carbofuran); potato leafhopper (dimethoate, phorate); aphids (methamidiphos, disulfoton, phorate, and dimethoate); the foliar blights, early and late blight (chlorothalonil, mancozeb, maneb, metiram, and TPTH, and weeds (metribuzin)

The targeting of chlorothalonil, mancozeb, maneb, metiram and TPTH by FQPA is a serious threat to the potato industry in Wisconsin since these are the fungicides that constitute the bulk of our disease control recommendations. Loss of these materials without replacements would jeopardize the future economic production of potatoes in Wisconsin. The recent registration of azoxystrobin (Quadris), a low risk fungicide used at low (0.1-0.25 lb ai per acre), will greatly improve control of foliar diseases such as early blight and will ultimately reduce the use of the FQPA materials. Our recommendations include a strict alternation of Quadris with one fo the FQPA fungicides and this serves as the backbone for our resistance management strategy. Loss of the FQPA materials would jeopardize the future usefulness of azoxystrobin and several other strobilurin materials under development. The need continues for new, safer chemistry with different modes of activity from the strobilurin fungicides. We also need cultivars with greatly improved levels of disease resistance.

### Outlook for New Registrations

New insecticides include thiomethoxam (Adage, Platinum, Actara) which is a highly-active, systemic, newnicotinyl insecticide with broad activity against potato insect pests. It will serve as an alternative to organophosphate and carbamate insecticides but concerns exist over potential cross resistance with imidacloprid.

Fipronil (Regent) is a systemic insecticide with activity against Colorado potato beetles and will provide alternative chemistry for resistance management in foliar spray programs.

There are currently several strobilurin fungicides in various stages of development by BASF, Novartis, and others. In addition, DuPont is developing famoxate for early and late blight control and Rohm and Haas is developing zoxamide for late blight control. Hopefully one or more of these new fungicides will gain registration in the next two years and these registrations will assist growers in achieving control of foliar diseases with less active ingredient, safer fungicides, and fewer applications.

In the herbicide arena, Frontier is a potential replacement for metolachlor that provides good grass weed control. Axiom is a broad-spectrum package mix that will replace the use of metolachlor/pendimethalin combination products. Spartan is a broad-spectrum broadleaf herbicide that provides good control and may be a suitable replacement for metribuzin.

## Weeds

## Annual Broadleaf Weeds

Annual broadleaf weeds that pose a problem in potato production include lambsquarters, redroot pigweed, and common ragweed. Potatoes grown on irrigated land may also be infested with buckwheat, bedstraw, Eastern black nightshade and hairy nightshade.

**Lambsquarters** (*Chenopodium album*) is a very adaptable broadleaf weed that sets thousands of seeds that can remain in the soil for many years. It thrives on all soil types and over a wide range of disturbed habits. Most seed germinates early in the growing season and control should be targeted at this time. Lambsquarter is a vigorous competitor for nutrients.

**Redroot pigweed** (*Amaranthus retroflexus*) is vigorous competitor that produces a very large number of seeds that can survive in the soil for up to 40 years. Fields with a history of redroot pigweed must have pre-emergence or early post-emergence herbicides applied along with early season cultivation to prevent outbreaks in the current season. The plant is easily identified by its reddish taproot and its stiff panicle spikes bearing small, green flowers. Leaves are dull green and about 6 inches long when mature.

**Common ragweed** (*Ambrosia artemisiifolia*) is a problematic weed in both crop land and non-crop land. The plant is shallow-rooted with a rough, hairy stem and finely dissected leaves. In addition to being a major competitor in crop production, ragweed is the bane of many allergy sufferers. Ragweed seeds are viable for a long time and can last up to 40 years in the soil.

**Eastern black nightshade** (*Solanum ptycanthum*) occurs most frequently on rich loamy soils in sun or shade. It is more common in irrigated potato fields. This widely-branched, spreading plant can reach 2 feet in height. Its characteristic berries are green initially, becoming black at maturity. Unripe berries are toxic if eaten. The seeds can remain viable for 5-10 years in the soil.

**Hairy nightshade** (*Solanum sarrachoides*) is an annual, spreading weed with hairy foliage as the name implies. Flowers resemble that of potatoes and are easily recognized by the enlarged green calyx that cups the fruit as it matures. Unlike the black berries of Eastern black nightshade, the berries of hairy nightshade are translucent at maturity.

Hairy nightshade serves as an alternate host for late blight and therefore must be controlled to prevent serious problems associated with late blight. Herbicide use often is ineffective at controlling both species of nightshade and therefore they have become more problematic in recent years.

**Buckwheat** (*Polygonum convolvulus*) is a twining, vine-like weed that climbs over any plants in it's path. Irrigated potatoes may be infested with wild buckwheat. It is distinguished by its arrowhead-shaped leaves with entire margins, membranous sheaths around the stem just above the base of the leaves (called ocreae), and small, greenish petals without flowers. Buckwheat is capable of reducing crop yield and quality. Its triangular seeds are difficult to remove from crop seeds. Wild buckwheat is becoming more difficult to control as herbicide use controls susceptible weeds while reducing competition for the buckwheat.

**Bedstraw** (*Galium aparine*) is another problematic weed found on irrigated potatoes. This broadleaf annual has a taproot and sprawling stems with 6-8 narrow leaves arranged in a whorled fashion at each node. Flowers are borne on branches in the leaf axils.

## Annual Grasses

Annual grasses also pose a problem in the production of potatoes because of their vigorous growth and ability to produce copious amounts of seed. They are also very tolerant of moisture and temperature extremes once they become established. If uncontrolled, grass weeds can root and branch from the lower joints and stems. All annual grasses should be controlled before they set seed. Some of the most problematic grasses in potatoes are the foxtails (*Setaria spp.*) And barnyardgrass. Foxtails germinate in the early spring and throughout the growing season. They have a very rapid life cycle, with an average of 37 days from seedling to 25% flowering. Foxtails are easily identified by their bristly panicle once they flower. The seeds can remain viable in the soil for up to 5-10 years.

**Barnyardgrass** (*Echinochloa crusgalli*) is warm-season annual grass that commonly appears in late summer. It is adapted to wet soil conditions. It responds to short days by quickly flowering. Seeds are borne on panicles that produce compact side branches and can remain viable for 2-4 years in the soil.

## Perennial Weeds

**Yellow nutsedge** (*Cyperus esculentus*) is a perennial monocot with grass-like foliage. It is a serious weed pests on both muck and mineral soils. The plant reproduces by seed and underground tubers called nutlets. The underground tubers can overwinter and survive soil temperatures of -20F. The tubers sprout from May to late July and each sprouting tuber is capable of producing numerous plants.

**Quackgrass** (*Agropyron repens*) is a problematic perennial weed that infests cultivated crops, pastures, and roadsides. It is easily recognized by its thick underground mat of whitish rhizomes, the presence of auricles, and a seed head which resembles that of wheat. Quackgrass seeds can remain viable in the soil for up to 4 years however, it is most readily propagated by cultivation that fragments the rhizomes leading to the production of daughter plants from each fragment.

## Chemical Controls for Weeds in IPM and Resistance Management Programs

Potato crop emergence typically occurs 15-30 days after the seedpieces are planted, depending on soil temperatures and the date of planting. This allows growers to utilize cultural and mechanical weed management techniques. One such cultural practice is the utilization of a narrower row spacing to shade the soil and reduce weed seed germination. However, this technique is seldom used due to the fixed nature of the equipment.

Because potato seed pieces are planted 2-4 inches deep, shallow cultivation over the top of the planted crop is possible. This would include "drag-off" treatments which refers to dragging off the soil from the planting hills with a spike-tooth drag or similar tillage tool such as a rotary hoe. This is done after the seedpiece has sprouted, but before the sprouts emerge so that they are not broken off when the area is tilled. By dragging the hills down, weeds are removed as well as a layer of soil from above the potato seed piece, which will result in faster emergence of the potatoes.

In general, weeds are easiest to control after germination and through the cotyledon stage of growth. As the potato plants grow, they are hilled by moving soil into the row with a cultivator or hiller. This will bury weeds that are in the row where previous cultivation could not disturb them. Hilling occurs until potatoes reach 14-16 inches high at which point it's discontinued to avoid excessive root pruning or vine damage from the cultivator.

Healthy, competitive vines are most effective in providing competition to weed infestations. Provide adequate fertility, disease management and insect control for the crop to insure good competition against weeds.

Many herbicide application options exist, including preplant, drag-off, preemergence, post-emergence, spray-hill and hill-spray applications. Spray-hill refers to applications made at cracking but before emergence. Hill-spray refers to applying the herbicide immediately after hilling when potatoes are beginning to emerge. Any preemergence herbicide can be used for these applications.

Perennial weeds are difficult to control because of their large underground root system. There are very few effective options for perennial weed management in potatoes so it is best to control perennial weeds before the potato crop is planted because selective control in the crop is difficult.

## Grass Herbicides

**Sethoxydim** (Poast) is a grass herbicide that may be applied postemergence to actively growing grasses. It provides excellent control of barnyard grass, large crabgrass, green foxtail, sandbur, and witchgrass. No more than 5 pt/A Poast can be applied in one season and there is a 30 day PHI. Sethoxydim is applied to less than 10% of the potato acreage in Wisconsin annually.

## Broadleaf & Grass Herbicides

**EPTC** (Eptam products) is a herbicide that controls annual grasses and some broadleaf weeds when applied at drag-off, spray hill, or after crop emergence. It is important to immediately incorporate EPTC to prevent loss through volatilization. Rate of application varies depending on the product used. There is a 45 day pre-harvest interval that must be observed. According to the 1996 NASS survey, less than 5% of the potato acreage was treated with EPTC.

**Linuron** (Lorox, Linex) is a preemergence herbicide that provides excellent control of Lady's thumb and Pennsylvania smartweeds, lambsquarter, redroot pigweed, common purslane, common ragweed. It also provides good control of black nightshade, velvetleaf, barnyard grass, large crabgrass, and green foxtail. It is applied at varying rates depending on product formulation and the amount of soil organic matter. Application is timed as a delayed preemergence treatment after planting but just before the potatoes emerge when broadleaf weed are < 6 inches tall and grass weeds < 2 inches. According to the PIAP survey, Linuron was applied to 14% of the potato acreage between 1990-94.

**Metolachlor** (Dual, Dual II, and Dual Magnum) is a preemergence herbicide that provides excellent control of barnyard grass, crabgrass, green foxtail and black nightshade and good control of redroot pigweed and common purslane. Use rates and pre-harvest intervals vary depending on product formulation and the amount of soil organic matter. Metolachlor was used on 21% of the potato acreage during the survey years 1990-94.

**Metribuzin** (Sencor, Lexone) is another preemergence herbicide applied after drag-off or hilling. It is not incorporated and has a 60 day pre-harvest interval. It may also be applied postemergence in fields where white-skinned varieties are planted but is not recommended for use on Atlantic, Shepody, Chip Bell, Bellchip, of Centennial varieties. Metribuzin provides excellent control of carpetweed, Lady's thumb and Pennsylvania smartweeds, lambsquarter, redroot pigweed, common ragweed and velvetleaf. Metribuzin is applied to approximately 80% of the Wisconsin potato fields annually.

**Pendimethalin** (Prowl 4EC) is a herbicide that provides excellent control of crabgrass and green foxtail and good control of lambsquarter and redroot pigweed at a rate of 1.5 - 3.0 pt Prowl/A. The herbicide is applied preemergence after potatoes are planted but before weeds or the crop emerge. It may also be applied as an early postemergence herbicide as long as the crop isn't under stress from extreme environmental conditions. Between 1990-94, Prowl was applied to 22% of the potatoes grown in Wisconsin.

**Rimsulfuran** (Matrix) may be applied preemergence or postemergence to young, actively growing weeds and is incorporated with rainfall or irrigation water. Repeat applications may be made not to exceed 2.5oz/A matrix. There is a 60 day pre-harvest interval. Rimsulfuran was applied to 60% of the potato acreage in 1999.

**Trifluralin** (Treflan 4EC, Treflan MTF) is a preemergence annual broadleaf and grass herbicide that provides excellent control of common purslane, barnyard grass, large crabgrass, green foxtail, and witchgrass. It also provides good control redroot and prostrate pigweeds and lambsquarter. Treflan is applied at a rate of 1-2 pints/A after planting but before emergence immediately following drag-off, or after plants emerge and is incorporated immediately. Treflan was applied to 5% of the Wisconsin potato crop land in 1999.

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