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Introduction

This BioIPM Workbook is written for growers and the vegetable industry. It is organized seasonally to provide a comprehensive, year-round self-assessment tool and reference on pest management and cultural practices of the snap bean production system. The workbook is organized into five chapters— preplant, planting, in-season, harvest/postharvest, and an appendix with individual pest profiles. Each chapter is further divided into pertinent topic sections with self-assessment statements followed by information on standard recommended practices as well as advancements to a biointensive production system.

This workbook is intended as a practical tool for growers' use throughout the entire production cycle. The workbook will help growers learn how to move toward a more biologically-based production system that is ecologically sound and economically profitable.

At the beginning of each topic there is a set of statements about the farm's current production practices. This self-evaluation section is formatted on a scale, with Category A being the minimal practices that could be used and Category D describing advanced, sometimes experimental, approaches. For most topics, the biointensive approach utilizes all categories. By checking all the statements that apply, growers can use the section to assess where their systems fall on various topics, such as selecting resistant cultivars or managing a certain pest. Growers can use the statements when making plans for the year ahead or to document practices or inputs used.

After each statement set, there is specific information expanding on the practices described in the categories A through D. Look to these paragraphs to learn how or why to implement specific activities and practices during various times of the year. The authors encourage growers to read about and consider the biologically based practices that may not currently be part of their growing system.



This information is specific to Wisconsin.

Please visit the Nutrient and Pest Management program's website at ipcm.wisc.edu for more IPM and nutrient management publications.

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Resistance Management in Rotational Years

Preplant



Resistance management is essential to maintain the efficacy of available pesticide chemistries in the potato system. The goal is to avoid consecutive use of products with similar modes of action, against the same target pest over successive generations or years.



Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A.** Resistance is considered when managing pests in rotational crops.
- ☐ **B.** During rotational years, herbicides are chosen with a different chemical site of action from the potato herbicides.
- ☐ **C.** Insecticide and fungicide chemistries are alternated on an area-wide basis.
- ☐ **D.** BiolPM strategies are implemented including cultural control methods to manage potato pests in rotational crops.

A. Resistance Management for the Entire Potato System

Pesticide resistance is a significant decrease in the sensitivity of a pest population to a pesticide. It results in control failures in the field and often serious economic consequences. Growers need to consider resistance management strategies in the rotational cropping years, both in other crops and between the previous year's potatoes and the current year's potato fields. Do not expose insect, disease, and weed pests to the same chemistry in consecutive applications, whether the exposure takes place within or between years.

General resistance management strategies which should be used in rotational cropping years include:

- ▶ Only applying chemicals when pest levels are at or above threshold levels, or when disease forecasting models determine applications are appropriate
- ▶ Alternating chemical classes between applications
- ▶ Controlling known potato pests in rotational years by using pesticide chemistries not registered in potatoes, but labeled for the rotational crop
- ▶ Utilizing BiolPM strategies (e.g. cultural, biological) which decrease reliance on pesticide use

Potato pests to watch for resistance development

Insects: Colorado potato beetles, green peach aphids

Diseases: early blight, late blight, fusarium, silver scurf

Weeds: giant foxtail, green foxtail, velvetleaf, pigweed, large crabgrass

B. Herbicide Rotation

There are few herbicides registered for potato weed control and maintaining their efficacy is important. Rotational

resistance management strategies can be very effective during the non-potato years. Problem weeds, such as nightshade or **pigweed**, may be difficult to control in potatoes.

However, they can be controlled in the rotational crops because more herbicide options with different modes of action are labeled for these crops. Limiting the weeds which are contributing to the seed bank will also reduce populations in the following potato crop.

Look in Appendix C for the EPA resistance management groups for herbicides applied to potatoes and rotational crops. When possible, select herbicides from chemical groups which are not available for the potato crop and alternate chemical groups between years.



Pigweed seedhead

C. Area-wide Resistance Management

Insecticides

Insecticides with the same EPA resistance management designation code (see Appendix C for listing) should not be used to control insects consecutively. The **Colorado potato beetle** has been shown to develop resistance quickly, and it is important to maintain the susceptibility of insecticides available for their management.

Adult Colorado potato beetles exit fields in the fall, overwinter in areas on field edges, and then emerge in the spring to infest nearby potato fields. Therefore, any adult beetle that was exposed to a certain insecticide class the previous fall should not be exposed to that same class in the current season. For example, if chloronicotines (EPA Group 4A) were used in adjacent fields the prior

season, a different insecticide class should be considered for the current cropping season.

An exception to spatial resistance concerns are **potato leafhoppers**. Potato leafhoppers migrate from the southern Gulf States each spring and reach Wisconsin when winds carry them north. Since new potato leafhoppers migrate into Wisconsin each year, there is less chance of resistance development, and concerns over rotational resistance management are minimal.



Quick Note

General Rule for Colorado potato beetle Area-wide resistance management:

When a group 4A systemic (neo-nicotinyl) is used in the soil, group 4A systemics **SHOULD NOT** be used on the next year's potato crop unless it is located $\frac{1}{4}$ mile or more from the previous use site.

Fungicides

Fungicide chemistries with single site modes of action have a high probability of developing resistance. Limiting pathogen exposure to these chemistries in the rotational years will delay the onset of resistance and maintain the compound's efficacy. Pathogens that are showing signs of reduced control and increased disease pressure should be monitored for baseline levels of resistance. If populations are shown to be sensitive to resistance, continued exposure to the same chemistries will worsen the problems.

The most serious resistance concerns to fungicides are found with the newer, reduced-risk, single site chemistries such as the strobilurin fungicides (EPA Group 11 in Appendix C). If sensitivity to Group 11 fungicides was observed in the previous year's potato crops, steps should be taken to reduce disease pressure in the current crop while also alternating



Some fungicides have a high relative risk of developing resistance

fungicide classes to reduce exposures to these materials.

For example, **Early blight** spores overwinter in plant refuse. Wind, rain, or insects can move the spores into fields during the current cropping season. Selecting fields that are farther away from the previous year's fields would limit early blight infections. If the previous year's potatoes showed signs of early blight sensitivity (building resistance) to strobilurins, the Group 11 fungicides should be managed for resistance in the current crop. If fungicides are applied during the rotational year, consider alternating multi-site and single-site fungicides and limit the strobilurin fungicides to not more than three applications.



Early blight

Common Potato Fungicides with a High relative risk of developing resistance

EPA Group 1: Benzimidazoles

Tops (thiophanate methyl)

Mertect (thiabendazole)

EPA Group 4: Acylamines

Ridomil (metalaxyl)

Ridomil Gold (metalaxyl/mefenoxam)

EPA Group 11: Strobilurins

Gem (trifloxystrobin)

Headline (pyraclostrobin)

Quadris/Amistar (azoxystrobin)

D. BiolPM Techniques

The alternative BioIPM techniques for specific pests are discussed in the next topic section – *Pest Management in Rotational Crops*. General strategies include:

Disease

Use proper BioIPM strategies such as managing weed hosts and utilizing disease forecasting models to schedule fungicide applications.

Consider long-term cropping systems with grains to reduce the number of *Verticillium* propagules in the soil.

Insect

Incorporate bioIPM strategies such as spot treatments, trap cropping, and biological controls whenever possible.

Weed

Use proper cultural, mechanical and other bioIPM practices to limit weed populations.

Notes:

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.

Pest Management in Rotational Crops

Preplant



Pest populations in the potato cropping season can be greatly limited if proper management strategies are utilized in the non-potato years. Applying a variety of BioIPM strategies during the non-potato crop will reduce in-season pest pressures. Proper planning and implementation of these strategies will greatly enhance pest management programs during the potato season, and could decrease pest populations and limit pesticide usage.



Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A.** Cull piles, potato remnants, or other possible sources of late blight inoculum are eliminated.
- ☐ **B.** BioIPM techniques are used to manage crucial pest problems (such as *Verticillium*, early blight, Colorado potato beetle, European corn borer, nightshades and other hard to control weeds) in rotational crops.
- ☐ **C.** Field maps of pest population levels are maintained for long-term comparisons and evaluation of management strategies.
- ☐ **D.** GPS/GIS mapping of pest pressures are used to identify problem foci or areas with recurrent management issues.

A. Eliminating Late Blight Innoculum Sources

Reducing **late blight** inoculum sources will limit disease outbreaks during the potato season. Cull piles, volunteer potatoes, and alternate weed hosts (such as hairy nightshade) can all serve as potential sources of late blight spores. Late blight can be severely limited by eliminating these infection sources prior to the potato production year.



Late blight on nightshade

By law, cull piles must be destroyed by May 20th each year. The safest disposal method is to thinly spread cull potatoes on fields during the winter months. Only spread cull potatoes on fields not intended for potato production the following spring. Freezing destroys late blight infected tubers and late blight spores. Frequently check the cull potatoes for vegetative growth. If they sprout, the plants should be immediately killed with a herbicide or by mechanical control.

Cull piles may also be hauled to commercial landfills or buried on-site at least 3 feet below the soil surface. Feeding culls to livestock is acceptable as long as the tubers are completely consumed, and the manure is not returned to fields used for potato production.



Quick Note

For Cull Pile Removal: If cull piles are found beyond May 20th, contact: Wisconsin Department of Agriculture, Trade and Consumer Protection
2958 Church Street
Stevens Point, WI 54481 Phone: 715-342-2640

B. BiolPM Techniques

Disease

To help control **Potato early dying**, utilize cover crops or rotational crops which are not hosts to *Verticillium* or root lesion nematode. These crops include grains, brassica species, and white mustards. More management specifics can be found in the Preplant/Early Dying Management section.



Field with potato early dying (PED)

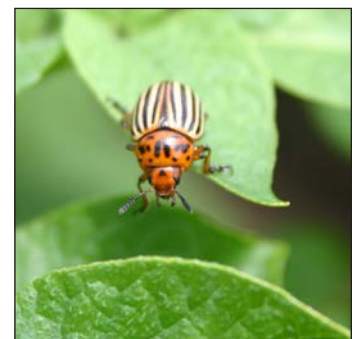
For **early blight**, control volunteer potato and host plants to limit spore formation and disease spread. Early blight overwinters as spores and mycelium on crop residue and is distributed by wind during the cropping season. Therefore, field selection and long distance rotations are appropriate cultural control strategies for early blight management.



Early blight

Insects

Colorado potato beetles overwinter as adults, burrowing 6-8" deep in the soil adjacent to field edges. Habitat disruption focuses on lowering soil temperatures and increasing frost penetration to increase winter mortality and reduce emerging spring populations. It is most successful during the coldest period of the year, typically during the month of January. Consider these factors when using this control strategy:



Adult Colorado potato beetle

- Snow and mulch at the field margins keep the soil temperatures around 32°F, which is fa-

avorable for beetle survival.

- Where possible, remove the snow and mulch in Colorado potato beetle overwintering sites when temperatures are below 23°F.



Snow-covered potato field

European Corn Borer

(ECB) commonly overwinters in field and sweet corn stubble, although there are many non-crop hosts as well. The European corn borer overwinters as mature 5th instar larvae in corn stalks and the stems of weedy hosts. Pupation occurs in spring with the first moths emerging shortly thereafter, usually in late May and June. Plow down or chop corn stubble in fall to destroy overwintering habitats, especially in areas that are known or expected to have high ECB populations.



ECB life cycle

As adults, European corn borer moths rest in weedy, grassy areas at field edges during the day and then fly into nearby crops to lay eggs at night. Cleaning up weedy, grassy areas around fields can reduce borer pressure as well.

In any field recently rotated from sod or pasture, soil sample for **wireworms** before planting potatoes. Where high populations are detected or anticipated, production of potato in the first year following grass or pasture may pose considerable risk. Rotation with a non-grass crop preceding potato can limit further damage. Wireworms have an extended life cycle that lasts from 1-6 years. Larvae live in the upper six inches of the soil. The adult females migrate only short distances and look for grassy areas to lay their eggs.



Wireworms

If wireworm pressures are expected to be high, dig into the soil to check for worms. Sampling should be done in the fall before first frost or in the spring after the soil has warmed to 45°F. If wireworms are present in high numbers, potatoes should not be planted in that field. If potatoes need to be planted on that field, a soil insecticide should be applied in-furrow, at-planting.

Beneficial Insects

Managing beneficial insect habitats and augmentative releases of beneficial insects could help maintain beneficial populations that reduce pests during the following potato year. General beneficial predators, such as **lady beetles**, **stink bugs**, and **lacewings** remain in the area as long as there is prey available for them to eat and broad-spectrum insecticides are limited in use. Developing diverse habitat areas, either in field corners, along windbreaks, or in field edges allows generalist predators to thrive. Establishing plantings of multiple species and types enhances beneficial habitat. If areas are established, augmentative releases of beneficial insects (for example, dumping a cup of lacewings) may be useful to increase beneficial populations in and around the field. Do not attempt augmentative releases if there are no prey for the predators because the beneficials will not stay in the area.

Growers and researchers need more knowledge of the predator and parasitoid species and their potential for controlling pests. For example, lacewing and lady beetle populations are most effective as biological control agents in their larval stages. Timely releases are necessary to maximize their populations in larval stages during the times when vulnerable prey populations are present in fields. The strategies of managing beneficial habitat and species in potato systems are the subject of ongoing research.

Weeds

Control volunteer potatoes in rotational crops to limit the onset and spread of many diseases including late blight. Volunteer potatoes can be managed through tillage or chemical control methods.

Use mechanical, physical, biological, or cultural practices in the non-potato years to limit the number of weed seeds entering the seed bank. Tillage, burning, or other operations around field edges should occur before weeds reach the seed formation stage to ensure that weeds do not contribute more seeds to the weed seed bank.



Using tillage to control volunteer potatoes

Spot spraying of weed patches in and around fields, and mowing or tilling operations on field edges during the non-potato years are effective strategies if implemented prior to seed formation.

Some herbicides applied to small grain and field crops can be biologically active at extremely low rates and residues are found in the soil for a long time. There are various plant-back restrictions for most herbicides, so read the labels closely to ensure the herbicides fit in the potato system.

Crop rotation is an important part of any weed management program. Certain weeds naturally become associated with particular crops because of similar life cycles or similar growth requirements. If a single crop is grown continuously, weeds associated with that crop (such as nightshades in potatoes) tend to dominate and proliferate year after year. A diverse crop rotation discourages domination by any one group of weed species and provides the opportunity to control troublesome species.



Lambsquarters is a common weed in potatoes

C. Field Maps of Pest Pressure

Field maps designating areas where insect, disease and weed populations are found should be kept for long-term comparisons of pest populations. Mapping can assist growers in becoming better managers by focusing on key concerns within fields, and by avoiding pests in the potato cropping system when possible. Maps can also assist producers in locating 'hot spots' for diseases, insects, and weeds that can be targeted early with perimeter or spot spraying.

Draw field maps by hand or create them on a computer. Indicate areas infested by insects, weeds, or disease. Mark Colorado potato beetle overwintering sites, cull pile burial locations, and potential volunteer potato areas. Maps can also be used to track pesticide use, soil fertility, or yield of previous crops.

Field maps should be used as a resource during field selection and when planning crop rotations. To create field maps follow these steps.

- 1) Draw an overview of the entire farm. Include all the farm's fields.
- 2) Record what was planted in each field, including varieties.
- 3) Mark insect infestations from the previous year with X's or another symbol. Be sure to differentiate between different pests.
- 4) Mark disease infestations from the previous year with stripes or another symbol. Be sure to differentiate between different diseases.
- 5) Record what chemicals were used in each field and the rate of application.
- 6) Record weed patches, perennial weeds or weed escapes on the map.
- 7) Record fertilizer programs.
- 8) Record production (quality & yield).

D. GPS/GIS Mapping

The past decade has seen advances in agricultural uses of GPS (Global Positioning System) and GIS (Geographic Information Systems) technologies. GIS is the process whereby geo-referenced data is analyzed to interpret (patterns in) spatial data. GIS includes an organized collection of computer hardware, software, geographic data and personnel designed to efficiently capture, store, update, analyze and display all forms of geographically referenced information.



An ATV marks field boundaries with GPS

GPS use satellite signals to geo-reference data (yield, fertility, or pest density) to specific points within the field. GIS is used with GPS to link spatial information with graphic and numerical data.

These technologies allow for quantification of sub-field similarities and differences like crop yield or quality, yield limiting factors including pests, soil fertility or pH, and inputs such as pesticides or fertilizer applications.

Successful implementation of precision agricultural methods has been limited in potato and other production systems. In part, the lack of successful precision agriculture applications is due to the current lack of understanding of how multiple factors influence yield and/or quality. Therefore, current limitations in our ability to predict outcomes makes it challenging to optimize inputs and maximize net revenue. Research and on-farm testing continues, and the technology will likely prove useful and profitable to growers in the future.

How to get started with a GPS unit & data logger and GIS based software:

GPS field boundaries are taken at any time in the fall or early spring to provide a general overview of the entire farm. Scouting points are marked anytime from planting time to plant emergence. Scouting points provide specific information within each field and are used the entire growing season.

Procedure:

1. Mark individual field boundaries using a GPS unit.
2. Mark all scouting points that will be used for management information throughout the year.
3. Enter field boundaries and scouting sites into the GIS based software.
4. Organize farmview and fieldview in the database by crop year.
5. Create maps according to present and future farming needs.
6. Analyze data to obtain pest control information and evaluate cost effectiveness of control practices and possible effects of production practices on pest distributions and dynamics.
7. Incorporate all crop year information into the GIS database.

Soil Sampling

Preplant



Soil sampling is a valuable management tool for proper and efficient nutrient management sustainability. Soil samples should be collected and analyzed before planting potatoes into a field for the first time. Soil sampling should be conducted at a minimum of every four years. . If there are other high value, high nutrient demand crops in rotation, then more frequent sampling (i.e. every year or every other year) may be beneficial.



Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A.** Soil samples are taken to determine soil nutrient, pH, and organic matter levels.
- ☐ **B.** Soil samples are taken in a manner recommended by UWEX.
- ☐ **C.** Fertilizer rates are decided upon using results from soil tests.
- ☐ **D.** Organic matter levels are monitored, and practices that increase the organic matter content are implemented.
- ☐ **E.** Soils are sampled for soil borne pathogens.

A. How to sample soil

Taking accurate soil samples is the first step in determining nutrient needs, soil pH, and soil organic matter levels. The following is detailed information on how to sample soil and submit the soil for testing.

When to sample

Soil samples should be collected in the fall after harvest or in the spring before planting, whichever is most convenient, and never after an application of fertilizer or manure. For potatoes, a fall sampling time may be necessary to ensure soil test results and fertilizer recommendations are received well before the planting date. Whichever sampling time you choose, you should attempt to be consistent from year to year.

Sampling equipment

Use a stainless steel soil-sampling probe if you have one. These insert easily into the soil, bringing up a soil “core”. You may be able to borrow a soil sampling probe from your county extension office. You can also use a shovel and trowel. Dig into the soil with the shovel and carefully bring out a vertical slice of the soil, then use the trowel to take a slice off the desired sampling depth. Be sure the tools are clean and free from rust. Do not use galvanized steel or brass equipment because they may contaminate the soil samples with metals.



Use a stainless steel soil probe when sampling soils

You will need a bucket to collect samples into. A plastic or stainless steel bucket is recommended; rubber or galvanized steel buckets are not recommended as they may contaminate the soil sample.

How to take soil samples

One composite soil sample should be taken for every five acres within the field. A composite sample is a collection of 10-20 soil cores that are mixed together in a bucket. The more soil cores you collect, the more representative the soil sample will be.

Walking in a W-shaped sampling pattern is a good technique to use to ensure that you are collecting samples that represent the entire five acre area.

If manure or crop residues are on the soil surface, push them aside before sampling. Insert the probe or trowel to plow depth, which is generally considered to be the top 6 to 8 inches of soil. Sample to the same depth from year to year so that soil test values can be compared accurately over time. Sampling deeper than the tillage layer can result in an underestimation of organic matter and some crop nutrients.

After all of the cores for a five acre area have been collected, mix the soil thoroughly to obtain a composite soil sample. Collect at least two cups of soil into a clean plastic or paper bag. Sealable plastic bags work the best if samples need to be stored cold or frozen prior to analysis. Paper bags allow for more efficient drying of soil, but the bags can fall apart when soil is wet. Heavier duty paper bags are recommended.

If you are growing many different crops in an area of five acres or less, you may want to consider altering your sampling protocol and dividing your fields into smaller management zones. Each management zone would represent an area of the field that is managed differently than other parts of the field in any year. One composite sample should then be collected for each management zone. This type of soil sampling protocol is especially beneficial if the management zones differ with respect to the type and intensity of tillage and use of manure or cover crops.



Quick Note

Send your samples to a Wisconsin DATCP certified soil and manure testing laboratory. Certification guarantees that analytical procedures used and nutrient recommendations are based on procedures and guidelines approved by the University of Wisconsin. To find a list of DATCP certified labs go to: datcp.wi.gov/Farms/Nutrient_Management/Planning/index.aspx.

What to do with the soil samples

Routine soil analysis includes soil pH, soil test phosphorus (P), soil test potassium (K), and soil organic matter content. It should be noted that soil test P and K are not a measure of the total amount of P and K in the soil but instead are chemical measurements of extractable P and exchangeable K in the soil. Soil tests can also be requested for sulfate, calcium, magnesium, boron, manganese and zinc. Other soil measures such as texture analysis, cation exchange capacity, and total nitrogen can be requested to learn more about your soil.

B. Interpreting the soil test

The soil testing lab will send you a soil test report for each of the samples you submit. Most of these reports will include three sections: the soil analysis, the test interpretation, and the nutrient or fertilizer recommendations.

Nitrogen recommendations are based on results of field trials in Wisconsin and bordering states and the organic matter percentage of the soil. Soils with lower organic matter will have less natural supply of N and require larger fertilizer inputs compared to soils with greater organic matter. Soil test P and K values are converted into fertilizer recommendations by placing each value into a soil test category. The soil test category (low, medium, optimum, high, very high, extremely high) along with the crop demand level are used to determine the fertilizer recommendation. Potatoes have been designated their own nutrient demand category, which means that potato has a much greater P and K demand than any other crop. Soil test categories have also been developed for calcium, magnesium, boron, zinc, and manganese. Sulfur (S) requirements are determined from a Sulfur Availability Index (SAI), which utilizes soil test sulfur (as sulfate) and organic matter, as well as other estimated S components. For a detailed description of soil test levels see *Optimum Soil Test Levels for Wisconsin* (UW-Extension A3030) and *Nutrient application guidelines for field, vegetable, and fruit crops* (UW-Extension A2809).



Quick Note

Use the information provided in your soil test to plan your fertility program. Soil test reports from WI DATCP certified labs will provide all nutrient recommendations, which are based on guidelines reported in UWEX A2809.

Finally, the soil test report will include nutrient or fertilizer recommendations. The recommendations are based on the crop demand for nutrients in a single season and are calculated to tell you how much (if any) of a particular nutrient is needed for optimum crop growth.

C. Fertilizer Considerations

Fertilizer decisions need to be made before the field season has begun. Types of inorganic fertilizers (often called chemical or commercial fertilizers because they are produced in an industrial manufacturing process) include: urea, ammonium sulfate, ammonium nitrate, triple super phosphate, potassium chloride (muriate of potash), and potassium sulfate (sulfate of potash). An advantage of using inorganic fertilizers is that they are concentrated in nutrients, and the nutrients are water-soluble and thus are immediately available for plant uptake. However, if inorganic fertilizers are not applied in synchrony with plant demand or applied in excess of plant demand, nutrients can be lost to the environment and become a water quality contaminant.

Organic fertilizers are fertilizer sources that originate from animal waste or plant material, such as animal manures, compost, or green manures (legume cover crops). An advantage of organic fertilizers is that nutrients are not all immediately available and thus are released throughout the growing season. An additional advantage is that they provide soil quality benefits as well; additions of organic material can improve soil structure, water holding capacity, and biological activity of the soil. A disadvantage of organic fertilizers is they are not as nutrient-rich as inorganic fertilizers and greater amounts of material will need to be applied.

Potato Early Dying Mgmt

Potato early dying can cause a tremendous yield loss to susceptible varieties. Since fumigation is expensive and destructive, it should only occur when *Verticillium* and the root lesion nematodes are found at or above the following recommended threshold levels:

- ▶ 10 microsclerotia per cubic centimeter without nematodes present
- ▶ 7 microsclerotia per cubic centimeter when nematodes are present
- ▶ 1 nematode per cubic centimeter of soil

The instructions for *Verticillium* and nematode soil sampling are in this handbook's next section (**Preplant/Potato Early Dying Management**).

For certified organic growers, the Organic Materials Review Institute (OMRI) provides guidance on which fertilizer products are allowable in accordance with National Organic Standards. Examples of OMRI-approved fertilizers are blood meal, composted animal manure, fish emulsion, feather meal, cottonseed meal, and alfalfa meal. Rock phosphate and bone meal are common organic fertilizers used to supply additional phosphorus. Amending soil with compost, legume cover crops, or crop residues also supplies significant plant nutrients in organic form and are allowable for organic farming.

Organic products must be decomposed by soil microorganisms before the nutrients become available to plants. Because it is a microbial process, decomposition depends on the type of material, the fineness or coarseness of the material, the temperature, and the moisture level. Sometimes the decomposition process isn't fast enough to provide enough nitrogen for a rapidly growing crop. Since decomposition is a function of many factors, some of which are controlled by the environment, the rate of decomposition will vary from year to year and as a result, so will the benefit of the

organic fertilizer source. Therefore, it is always a good idea to keep records of the organic (animal, green, OMRI) materials you use and how the crop responds to them.

D. Building the organic matter content of the soil

A soil which receives regular additions of organic materials will have good nutrient- and water-holding capacity, will have good aeration for root development, will require less chemical fertilizer and water, and is easier to cultivate. Organic matter stabilizes soil particles, helping soil to resist compaction. It supports an active soil biota that competes with and suppresses soil-borne pathogens.

Utilize your routine soil analysis to monitor to soil organic matter status over time. Implement practices in your IPM program that maintain or increase the organic matter content of the soil. Regular additions of manures and composts, planting and incorporating cover crops and green manures, reducing tillage, and practicing crop rotation are all practices that will achieve this. Even small increases in organic matter can have a beneficial effect.

E. Sampling for soil borne pathogens

Additional soil samples and screens for soil-borne pathogens may be warranted if concern is high. Long-term field comparisons should be kept to document year to year changes in disease pressures. Screening procedures exist for these potato pathogens:

- ▶ *Verticillium dahliae*
- ▶ *Pratylenchus penetrans* (root lesion nematode)
- ▶ *Streptomyces scabies* (scab)
- ▶ *Pythium*
- ▶ *Rhizoctonia*
- ▶ *Phytophthora* root rot

Potato Early Dying Management

Preplant



Growers must consider managing the early dying complex, a potentially damaging problem in the potato cropping system. Practices which enhance soil quality and limit the onset of the potato early dying complex should be implemented to reduce the need for fumigation.

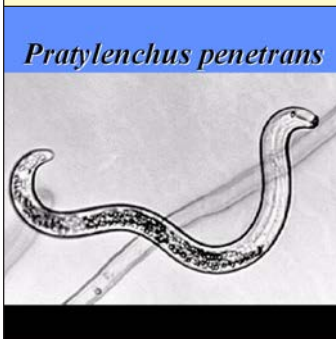


Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A. Fields which have a history of early dying, Verticillium, or nematode damage are fumigated.**
- ☐ **B. Fields are sampled prior to each potato crop to assess the level of nematodes and Verticillium in the soil. Fields above threshold levels are fumigated.**
- ☐ **C. Cover crops and non-host crop rotations are added to the potato system.**
- ☐ **D. Additional BiolPM practices, such as cultivar selection, potato vine removal and site specific sampling, are used.**

General Information

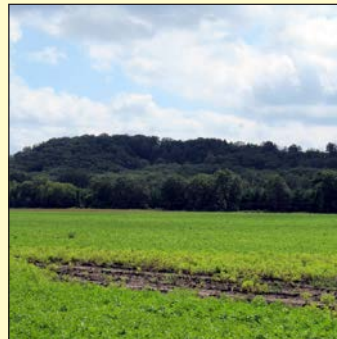
Early dying is associated with two components, the **Verticillium fungus** and the **root lesion nematode**. The fungus survives as microsclerotia which germinate in the presence of growing roots of susceptible host plants. The fungus penetrates root hairs and the presence and feeding of root lesion nematodes enhances the fungal infection. As the plant dies, the fungus grows throughout the dying tissue and releases more fungal structures into the soil. Dissemination of the fungus and the plant parasitic nematodes occurs via infected seed pieces, tubers, tillage equipment, and infested soil moved by wind and water erosion or other means.



Root lesion nematode



The small spot on the penny's letter "I" is a verticillium proagule



Potato field with PED complex



Potato plant exhibiting PED symptoms

A. Fumigation

Fumigants are non-specific, gaseous chemicals that are injected into the soil to control soil borne pests. Fumigants are lethal to many soil organisms, including weed seeds, but may also cause unintended side effects such as the loss of beneficial soil fungi and nematodes.

Fumigation is the most effective under the following conditions:

- ▶ The optimal soil temperature for fumigation is between 50-70°F. Do not fumigate when soil temperatures are below 45°F since the gas will not disperse properly in cold soils.
- ▶ For best results, fine-textured soils should contain 65-75% of available soil water, and coarse textured soils should contain a slightly higher percentage.
- ▶ Fumigation should occur at depths of 2-4 inches for fungi and greater than 4 inches for nematode control. Make sure that the fumigant is evenly distributed throughout the correct depths. Read the pesticide label for specific requirements.

- ▶ Because most fumigants are toxic to plants, a waiting period is required between application and planting the crop. Usually two to three weeks between fumigation and planting allows time for the fumigant gases to dissipate.
- ▶ Fumigation is usually done after tillage, because good soil preparation and proper application procedures are important to achieve the desired results. Before a soil-injected fumigant is applied, the soil should be in good condition. It is important that clods are broken up and crop residues are finely chopped and thoroughly incorporated. If this is not done, target organisms may survive, because they are not exposed to lethal levels of the fumigant.



Soil fumigation

Verticillium and Nematode Soil Sample Analysis

1. 20 core samples per 5 acres are recommended although more intense sampling provides more accurate information.
2. Combine all core samples & mix well.
3. Remove 1 pint (2 cups) of soil from mix.
4. Place sample in a plastic bag.
5. Seal plastic bag to maintain soil moisture. **The sample should not dry out!**
6. Do not leave samples in the sun or hot areas.
7. Send samples to an appropriate testing service. The University of Wisconsin has the ability to test the soil.

For UW analysis, send samples to:

**UW-Madison Plant Pathology Dept.
c/o Ann MacGuidwin, 1630 Linden
Drive, Madison, WI 53706**

Phone: (608) 263-6131

FAX: (608) 263-2626

B. Soil Sampling for Early Dying Pathogens

Soil sampling to determine root lesion nematode and *Verticillium* levels should be done before deciding if fumigation or other appropriate management is necessary. The best time to sample is late July or early August in the year prior to planting potatoes. Samples may also be taken to coincide with soil testing samples taken in the fall prior to potatoes.



Quick Note:

Thresholds to implement a management control program for the potato early dying complex. The threshold for **Verticillium** control is: 10 microsclerotia per cubic centimeter of soil when nematodes are not present; 7 microsclerotia per cubic centimeter of soil when nematodes are present. The threshold for nematode control is 1 nematode per cubic centimeter of soil.

C. Cover Crops and Crop Rotation

Cover Crops

Cover crops have many benefits such as increasing soil organic matter, improving soil structure, reducing soil erosion, providing weed management, and attracting beneficial insects. Some cover crops can be grown specifically as green manure crops to aid in



Kohout millet is an effective green manure crop for PED

control of the potato early dying complex. Certain cover crops like rapeseed release a chemical similar to the chemistry from conventional fumigants, providing a “biological fumigant” response.

Cover crops also benefit the soil by adding organic matter resulting in better overall soil quality. The improvements to the physical properties of the soil benefit the microbial community which exists in the soil. The activities of this microbial community have many benefits and may limit detrimental organisms, including *Verticillium* and root lesion nematodes.

Cover crops can be incorporated in the fall or spring prior to potatoes. Research is currently being conducted to provide specific recommendations on the best choices, seeding rates, incorporation time, and biomass potential.

Crop Rotation

Since microsclerotia of *Verticillium dahlia* persist in the soil up to 7 years, one of the best cultural strategies to limit potato early dying is to lengthen potato rotations. Three year rotations are a minimum to reduce inoculum levels and can be effective in limiting the fungus when populations are low (below 10 microsclerotia per cubic centimeter). Long-term rotations are recommended in heavily infested fields, with rotations as long as possible.

When implementing these long-term rotations, choose crops which are not hosts to either *Verticillium* or the root lesion nematode. Non-host crops include snap bean, peas, sweet corn, field corn, small grains, and alfalfa.

D. BiolPM Techniques

Resistant and/or Tolerant Cultivars

There are some tolerant varieties which may be planted to limit the onset of potato early dying. These cultivars include Ranger Russet, Russet Nugget, Bannock Russet, Frontier Russet, and NorKing Russet. Growing resistant cultivars in the long term rotational system may reduce *Verticillium* populations in the soil over time.

Russet Norkotah is an extremely susceptible cultivar to potato early dying. When the pathogens are present, disease symptoms can commonly be found on this cultivar early in the growing season.

Vine Removal

Vine removal can help mitigate the effects of potato early dying. This takes *Verticillium* spores present throughout the living plant tissue off the field, reducing microsclerotia movement into the soil as vines die. Vines removed with a forage chopper can be composted along field edges or in large, open areas. Be sure that vines are composted in areas which will not spread microsclerotia through wind or water erosion. Vines can be actively composted by adding external carbon sources and turning the pile frequently throughout the winter months. Temperatures in the compost pile should reach high levels to kill microsclerotia (113° F for one hour). Properly composted vines can be reapplied to fields to increase soil quality. This option

may be ideal for some production systems, but not all. Removal of vines may impact integrity of the hill and wind erosion and exposure can result.

Site Specific Fumigation

Grid soil sampling on a 1 to 5 acre grid can be useful in locating potential early dying “hot spots.” Intense soil sampling for root lesion nematodes and *Verticillium* levels within a field can locate specific sites for fumigation. This method decreases the amount of fumigant applied to the entire field which limits fumigation's negative effects. Site-specific fumigation is promising in Wisconsin potato production systems.

Another fumigation method designed to reduce total amount of pesticide applied is use of in-line applications. With the use of such methods only potato rows are treated, eliminating need for pesticides in furrows. GPS-assisted farm tools are necessary for this approach.

Maintaining good field records of potato early dying locations and effects from year to year will help decide if grid sampling and site-specific fumigation is likely to be profitable. Site-specific fumigation can be cost effective when a small percentage of the field needs to be fumigated. In this case, the savings from limited fumigation overcomes the increased cost of soil sampling. However, if the field is heavily infested and the majority of the field needs to be treated, the cost of the increased number of soil samples (which can exceed \$1200 for a 100 acre field) is quite expensive. When this cost is combined with the cost of fumigation (>\$150 per acre), this approach is not economical.

Soil Solarization

Soil solarization successfully limits *Verticillium* and nematode populations and may be useful in reducing potato early dying. Solarization is a tactic which may be used either as a standalone strategy or in combination with other practices such as fumigation, cover cropping, or vine removal. The idea behind soil



Soil solarization trials

solarization is to lay transparent polyethylene covers on top of the soil to trap heat under the plastic. This raises soil temperatures to kill *Verticillium* and plant pathogenic nematodes. Studies have shown that heating the soil to levels of 140° F for a few minutes is adequate to kill *Verticillium* propagules. Similar results can also be seen from cumulative exposures of *Verticillium* and the nematodes to soil temperatures as low as 100° F for several hours.

Using soil solarization as a fumigation alternative is currently being researched in Wisconsin potato production systems. The application of these techniques to the state's conditions is not yet known. Specific recommendations will be made once field data has proven that solarization is effective and economically feasible.



Soil solarization may be an alternative to fumigation

Fumigation Alternative Planning Checklist:

- | | | |
|--|------------------------------|-----------------------------|
| 1. Did you sample for <i>Verticillium</i> and nematodes site specifically? (e.g. half pivots, quarter pivots, entire fields—preferably in multiple locations where you can maintain and track your sites from year to year, using GPS when applicable) | YES
<input type="radio"/> | NO
<input type="radio"/> |
| 2. Did you plan your rotations to limit PED complex buildup? (used cover crops, planted resistant varieties, planned long term rotations, etc) | YES
<input type="radio"/> | NO
<input type="radio"/> |
| 3. Did you plant crops that break the cycle of increase for nematodes and/or <i>Verticillium</i> ? (short-season vegetables like pea, snap bean, peppers) | YES
<input type="radio"/> | NO
<input type="radio"/> |
| 4. Did you incorporate plant residues or add organic amendments to build soil organic matter? (cover crops, sweet corn residue, paper mill residuals) | YES
<input type="radio"/> | NO
<input type="radio"/> |
| 5. Did you plant cover crops known to suppress <i>Verticillium</i> and/or nematodes? (forage pearl millet, sorghum-sudangrass, biofumigant mustards or rapeseed) | YES
<input type="radio"/> | NO
<input type="radio"/> |
| 6. Did you plant PED tolerant varieties of potatoes? | YES
<input type="radio"/> | NO
<input type="radio"/> |
| 7. Did you use soil solarization? | YES
<input type="radio"/> | NO
<input type="radio"/> |
| 8. Did you use site specific fumigation? | YES
<input type="radio"/> | NO
<input type="radio"/> |
| 9. Did you remove and discard potato vines before harvest to reduce <i>Verticillium</i> inoculum for future potato crops? | YES
<input type="radio"/> | NO
<input type="radio"/> |
| 10. Did you track your fields long term to see “hot spots” of PED? | YES
<input type="radio"/> | NO
<input type="radio"/> |

If you said YES to the majority of the questions, you are adequately working toward limiting your fumigation use by using multiple strategies to combat PED. It is recommended that you still sample to determine PED thresholds in your fields.

If you said NO to the majority of the questions, you can look at these practices as future strategies to incorporate into your practices for combatting PED in your fields.

Field Selection

Preplant



Potato management begins with selecting the appropriate planting site. Field placement and selection should be based on pest and crop management considerations that assure a healthy crop.



Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A.** Potatoes have not been grown in the field for at least three-years.
- ☐ **B.** Potatoes are rotated spatially, keeping a 1/4 mile distance from last year's potato fields.
- ☐ **C.** Field maps or records of past pest pressure are consulted.
- ☐ **D.** Soil qualities and field characteristics are considered in the selection process.

A. Temporal Rotation

Potatoes should not be grown on fields where they were planted the previous year. Temporal (or time in years) rotations should be increased for as long as possible. A rotation of at least 3 years is recommended. Longer rotations have benefits for disease suppression, insect control, weed management, soil quality characteristics, and soil biodiversity. Long-term rotations are among the most effective cultural control strategies for pest populations.



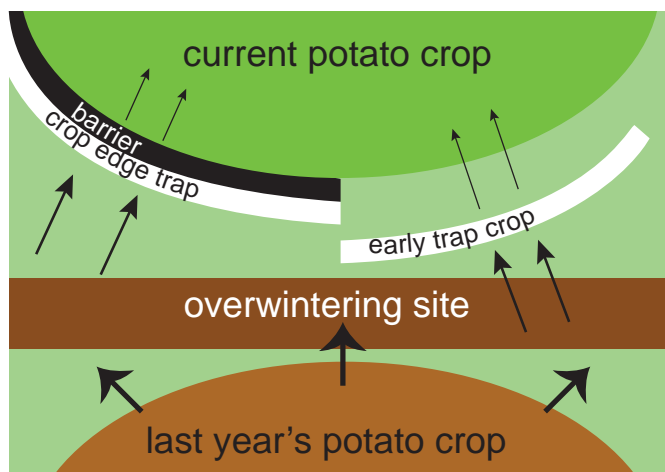
Quick Note

Temporal rotation: refers to the number of years since potatoes were planted. A rotation of potatoes-snap beans-sweet corn-potatoes is a 3 year rotation.

Spatial rotation: refers to the distance from the current potato field to last year's potato fields.

B. Spatial Rotation

The distance between the current season's potatoes and the previous year's crop can have an effect on the current pest pressures. Considering the spatial dynamics of Colorado potato beetle migration is essential for managing beetle populations. Adult beetles usually walk into fields from overwintering sites. By increasing the distance between



overwintering sites and newly planted potato fields, the colonization by Colorado potato beetles is delayed. A distance of at least 1/4 mile between the previous year's potatoes and the current year's field significantly reduces beetle infestations in the spring.

Early blight spores can move via air and water and longer distances between the previous year's and current year's potato crops can help in limiting infections.

C. Past Pest Pressure

Pest management and production practices are influenced by previous crops and rotational histories. Growers can be better managers by keeping field records of cropping history, pest populations, and management practices. Field mapping systems should be used to designate possible problems.

Field maps provide an overview of a particular farm. These maps should designate areas infested by insects, weeds, or disease in previous years. Field maps can help in decision-making. For example, if the field had soil-borne pest problems, rotate to a non-host crop to reduce the pest populations. Field mapping methods are described in the **Preplant/Pest Management in Rotational Crops** section.

Problem pests and concerns to record in rotational years include:

- **Insects:** wireworm and white grub
- **Disease:** Rhizoctonia, scab, nematodes and *Verticillium*
- **Weeds:** quack grass, hairy nightshade, and Eastern black nightshade
- **Production information:** yields, quality, and marketability

D. Soil Quality and Field Characteristics

Enhanced soil quality can result in better production (see the Preplant/Soil Sampling section for more details). The following characteristics may be considered as field selection criteria.

- ▶ Compaction can decrease drainage thus causing water to pool, increasing disease and tuber deformities.
- ▶ Organic matter is an important factor in soil quality. It helps to retain water and allows for optimal crop growth.
- ▶ Controlling wind erosion keeps the soil and nutrients in place and prevents crop damage.
- ▶ Damaging pesticide residues may occur when some herbicides that have active ingredients in the sulfonylurea and imadazolinone families are used. These herbicides can remain at levels toxic to potatoes for several years following application.

Spray Equipment

Growers should consider how they will apply crop protectants when deciding field locations. These factors should be taken into account:

Aerial spraying: windbreaks, building and power lines can interfere with aerial applications of potato pesticides. Apply backup spray with ground equipment to field borders and other areas that are not well covered.

Ground spraying: odd shaped fields are difficult to treat with large sprayers.

Colorado Potato Beetle Area-wide Management

If high populations of Colorado potato beetles are expected, plant potatoes at least 1/4 mile from fields that were planted with potatoes the previous year. If small populations are expected, closer rotations may be considered.

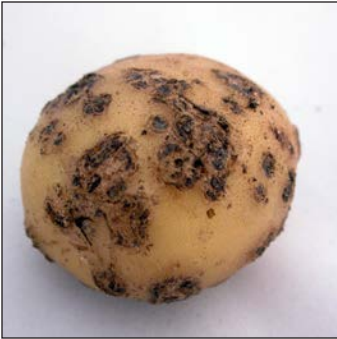
Field isolation can be difficult for one farm, but more easily achieved if a cooperative approach is followed by adjacent landowners. Since a 1/4 mile is needed to optimize management, growers collaborating on an area-wide basis can plan rotations over time and location, and discuss insecticide applications. This will maximize Colorado potato beetle management in the area.

To utilize an area-wide management strategy, consider each of the following questions prior to determining field locations.

1. Where were the previous year's fields?
2. How large was the Colorado potato beetle population exiting the previous year's potato crop?
3. Where are the beetle overwintering sites?
4. What was the control method used in the previous year's field?
5. Are there obstacles (such as roads or streams) in the way of the beetles' migration?
6. Can long distance rotations be used to manage beetle populations?

Cultivar Selection

Preplant



Consider factors beyond market demand when selecting cultivars. Criteria to consider include disease tolerance, certification system, seed source and availability, field factors, and previous pest pressures.



Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A. Potato cultivars are selected according to region, quality and marketability of the crop.**
- ☐ **B. Certified seed is purchased.**
- ☐ **C. Seed production practices are reviewed with the seed producer prior to purchase and delivery.**
- ☐ **D. Pest susceptibility is considered in cultivar selection.**

A. Potato Marketability

Potato marketability is a key component in growers' varietal selection. Market analysis should take place over the winter to determine what the crop will be used for, where it will be marketed, and what varieties suit these marketing criteria. Trends in fresh, processed, specialty, and seed markets should be watched carefully and tracked from year to year.



Quick Note

Remember that field selection criteria (soil type, draining, yield potential, type of sprayer) as well as pest concerns should also be taken into consideration when selecting cultivars. Refer to the previous Field Selection section in this Preplant chapter for more information.

B. Certified Seed

Planting certified seed potatoes is the foundation of any management program for a productive potato crop. Planting healthy seed is a basic component for disease management and may also help control insects and weeds. Once appropriate cultivars have been selected, a supply of high quality, certified seed potatoes must be obtained.



Certified seed

Seed potato certification programs were started to reduce the incidence of tuber-borne pathogens and to provide seed stock clones of improved cultivars free from varietal mixing. Certified seed potatoes are produced under stringent standards and must meet baseline field and winter test tolerances.

Wisconsin seed potatoes are classified as "Certified" or "Foundation" depending on disease and

varietal mixing levels. Foundation seed meets much stricter tolerances required to protect the integrity of the seed industry.

Seed quality is difficult to define, but it is generally accepted that a healthy seed lot should be:

- ▶ Free of cultivar or clonal mixtures
- ▶ Within established certification tolerances for certain diseases and pests
- ▶ Free of bacterial ring rot
- ▶ Physically sound, with minimal mechanical and cold injury
- ▶ Properly sized and classed A-size or B-size:
 - ▶ A-sized tubers, which will be cut into seed pieces, weigh between 4-10 ounces and are between 1-1/2 to 3-1/4 inches in diameter
 - ▶ B-sized tubers (single drop), which will be planted whole, generally weigh less than 4 ounces and are between 1-1/2 to 2-1/4 inches in diameter
- ▶ True to grade, with few knobs and second growth
- ▶ Free of excess soil, stones and other debris
- ▶ Of the desired physiological age
- ▶ Properly inspected and certified

Examine the records for all seed lots and discuss the reasons for rejection of any lot with the seed grower. The seed grower should have certification records for specific seed lots readily available.

C. Communication with Seed Suppliers

Maintaining positive communication between the seed producer and seed buyer is important. When contracting to buy seed, visit the seed producer in the year prior to purchasing the seed to inspect the crop before buying the seed. Communicate to the seed producer any comments or observations on the performance of the given seed lot, both positive and negative. The seed producer is an important partner in commercial production, and two way communications should be maintained.

D. Pest Susceptibility of Cultivars

Potato leafhoppers

are one of the most damaging insects of Wisconsin potatoes. Variety selection plays a role in the susceptibility of potatoes to leafhoppers. Although it is not commonly grown in Wisconsin, the potato variety Delus is highly resistant to potato leafhoppers. Wisconsin varieties and their level of susceptibility include:



Potato leafhoppers

- ▶ **Highly susceptible to potato leafhoppers:** Norland, Norchip, Atlantic, Superior
- ▶ **Moderately susceptible to potato leafhoppers:** Goldrush, Snowden, Norgold Russet, Kennebec, Red Pontiac
- ▶ **Least susceptible cultivars to potato leafhoppers (but NOT resistant cultivars):** Ranger Russet, Russet Norkota, Russet Burbank, Ontario, Red LaSoda

The **early blight** pathogen overwinters as spores in the soil or on plant debris. In the spring, spores are released and spread to other plants by wind, rain, insects, and other wildlife. The fungus penetrates the leaves through natural openings causing characteristic brown lesions with concentric rings. As leaves age, they become more susceptible to the early blight fungus. Stress caused by nutritional deficiency, air pollution and weed competition can increase susceptibility to early blight.



Early blight

Cultivars differ greatly in their susceptibility to **early blight**, but all cultivars currently grown in Wisconsin exhibit symptoms at some point during each growing season. Resistance levels are as follows:

- ▶ **Highly susceptible to early blight** (early and mid-season cultivars): Norland, Redsen, BelRus, Norchip, Norgold Russet, Early Gem, Superior, Monona, LaChipper, Atlantic
- ▶ **Moderately susceptible to early blight** (late season cultivars): Russet Burbank, Kennebec, Katahdin, Rosa
- ▶ **Lowest susceptibility to early blight** (very late cultivars): Butte, Nooksack, Ontario

Common scab is caused by the bacterium *Streptomyces scabies* and can be a serious tuber pest. The organism causes raised corky lesions, russet scab and pitted scab. All of these lesions cause economic losses in fresh market potatoes and to a lesser degree in processing stock. The scab organism is usually introduced by infected seed pieces and can survive indefinitely in the soil on decaying plant material. Scab bacteria can also survive passage through an animal's digestive tract and be distributed in manure.



Common scab

Resistance to scab is related to the tuber's ability to form corky tissue that walls off the pathogen and prevents further infection. Susceptible and moderately resistant cultivars are listed below.

- ▶ **Susceptible cultivars to common scab:** Centennial Russet, Chippewa, Denali, Elba, Hampton, Irish Cobbler, Jemseg, Kanona, Katahdin, Red Pontiac, Rosa, Shepody, Steuben, White Rose and Yukon Gold.
- ▶ **Moderately Resistant Cultivars to common scab:** Atlantic, BelRus, Conestoga, Crystal, Islander, Kennebec, LaRouge, Monona, Norchip, Norgold Russet, Norland, Onaway, Ontario, Pungo, Rideau, Russet Burbank, Sebago, Superior and Viking.

Seed Preparation

Planting



Seed selection and careful handling ensures vigorous seedling growth while limiting seed piece and seedling diseases.



Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A. Certified seed is purchased.**
- ☐ **B. Seed tubers are carefully stored, handled, and warmed prior to cutting.**
- ☐ **C. Proper sanitation and cutting practices are used.**
- ☐ **D. Cut seed is carefully stored and allowed to cure and suberize for at least 7 days.**

A. Certified Seed

Planting certified seed is a crucial phase in the potato BioIPM system. Non-certified seed may contain high levels of virus or other pathogens which will cause problems during the season.

An important step is meeting with the seed producer before the season begins. Growers should discuss seed production practices, scouting numbers and certification with their certified and/or foundation seed potato producers. Make every effort to ensure that clean, non-infected seed is purchased and seed-borne problems are avoided.



Use only certified seed

B. Storing & Warming Seed Tubers

When seed arrives, the shipment should be thoroughly inspected to detect disease or other disorders. To minimize bruising, the seed should never drop more than six inches during the handling, storing and cutting operations.

Before cutting the seed, it should be stored in cool (38-40°F), well ventilated bins at 90-95% relative humidity until it is time to cut.

Seed tubers should be allowed to warm to 50-55°F before handling. Begin warming the tubers very slowly, about 0.5-1.0°F per day, seven to ten days prior to cutting. Warming the seed before cutting serves three purposes:

- ▶ Reduces bruising during handling
- ▶ Promotes rapid healing after cutting
- ▶ Initiates sprouting before planting

C. Proper Seed Cutting

Careful seed handling and cutting are important steps in a healthy potato management program. Improper seed cutting has the potential to spread diseases or lead to planting and emergence problems.



Seed potato

Cut seed tubers in a clean, relatively humid area, preferably indoors. The flow of seed potatoes into the cutters should be adjusted so that they are not more than one tuber deep.

Mechanical cutters should be set to provide seed pieces of 2-3 ounces with 1-2 eyes on each seed piece. Smaller seed pieces may result in weak plants, while seed pieces above three ounces produce plants with excessive numbers of stems, possibly leading to higher tuber numbers and lower yields. A wide variation in size results in problems with planting and a higher number of skips and doubles in the field. Keep the blades sharp and adjusted to deliver seed pieces in the appropriate size range.

Regardless of the type of mechanical cutter used, it is essential that the equipment be thoroughly cleaned and sanitized prior to each season. Cutters with water-impermeable sponge rollers are recommended since open-cell rollers may harbor ring rot bacteria and other decay pathogens.

To reduce disease spread, clean and disinfect the equipment before cutting each new seed lot and whenever possible during the cutting operation. In addition, disinfect the conveyers and other equipment used to transport the tubers between each seed lot. Provide workers with disinfectants and washing facilities to minimize potential infection spread during



Disinfect equipment prior to seed cutting

the cutting operation. It is also advisable to provide workers with new plastic disposable boots and gloves each day.

D. Cut Seed Storage Prior to Planting

Seed pieces need to be handled with care. Optimum stands are more likely when disease exposure is minimized, mechanical and physiological damage to seed piece reduced, and favorable conditions for rapid plant development are provided.



Seed pieces need to be handled with care

After cutting, it is critical that cut seed be stored in an environment that favors rapid wound healing. Some growers use pallet bins or boxes to hold cut seed, while others place seed in piles no more than 4-6 feet deep over air ducts. Air movement must be adequate to provide oxygen and prevent the accumulation of high levels of carbon dioxide.

Storage temperatures should be between 50-55°F. Keep the relative humidity high at 90-95% (but no free water). Because cultivars and local storage conditions may vary, monitor the humidity carefully. Do not humidify the storage during the first 24-48 hours after cutting if there is condensation and surface moisture on the seed pieces.

Warm seed pieces or tubers before planting. Ideally, the difference in temperature between seed and soil should be no more than 5°F at planting time. However, warming seed for periods longer than 2 weeks or to temperatures higher than 55°F can result in excessive sprouting and physiological aging. This can lead to lower yields and reduced quality.

Wound Healing and Suberization

Immediately after cutting seed, a natural wound healing process begins. The healing process benefits from abundant fresh air, high relative humidity (95-99%), and temperatures at 55-60°F (the healing process takes approx 4-7 days). Maintaining humidity above 90% is critical to prevent death of cells on the cut surfaces and allows proper healing.

Although high humidity is required, the formation of free water (condensation) must be avoided, because water film on cut surfaces acts as an oxygen barrier to cells on the cut surface. Free water on seed pieces interferes with wound healing and may allow soft rot bacteria to become established. When wound healing is completed, the suberized layer and wound periderm prevents both moisture loss and infection of the cut surfaces by bacteria and fungi.

The cut surface of a potato tuber heals in two phases. The first phase is suberization: cells just below the cut surface produce a waxy, fatty compound called suberin. This seals the wound, prevents water loss, and blocks infection by pathogens. Suberization begins 1-3 days after cutting and is complete in 4-7 days.

The second phase of healing is the formation of wound periderm. The periderm is a permanent, protective layer of cells that replaces the tuber's skin when it is destroyed. The new periderm is a corky layer, which serves as the final covering to prevent infection and desiccation. Periderm formation begins shortly after suberization and is complete in about 1-2 weeks.

Field Preparation

Planting



Fields should be prepared properly to maintain soil moisture and allow for root penetration and water infiltration. Field preparation includes tillage, proper soil moisture levels at planting and the optional practice of incorporating green manures or other composted materials. Keeping good field records of the previous year's rotational crop and pest pressures improves planning for field operations.

Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A. Preplant tillage is adequate for potato planting and weed control, but not excessive.**
- ☐ **B. Soil moisture levels are monitored and are near field capacity at planting.**
- ☐ **C. Cover crops and/or composts are incorporated to add biomass and increase the soil's organic matter content.**
- ☐ **D. The field's rotational and pest history is documented and considered before field preparation.**

A. Tillage

Tillage is necessary for loosening the soil prior to planting, managing plant residues, and warming the soil early in the season. Avoid excessive tillage as it increases the cost of production, the likelihood of wind erosion, and the amount of soil compaction.



Preplant tillage machinery

Pre-plant tillage is often an important part of a potato pest management program. Tillage effectively controls emerged annual weeds and when combined with herbicides, can also manage perennial weeds and volunteer potatoes. However, tillage can increase some perennial weed problems if underground storage organs are spread by tillage. Tillage can also interfere with herbicide uptake by perennial weeds if herbicides are sprayed too soon after a tillage operation.

Water infiltration is influenced by crusting, organic matter, soil aggregation, and macro-pore formation (earth worm tunnels). Tillage can have both positive and negative effects on these factors. Tillage can improve water infiltration by disrupting surface seals or crusts. Deep tillage (> 8-10 inches) disrupts compacted areas formed by field traffic and natural laying pans. Tillage can also break up clods if done at the appropriate time, but may promote clod formation in excessively wet, heavy soils.

Generally, tillage negatively influences soil aggregation, macro-pore formation, and organic matter.

Follow these general guidelines for pre-plant tillage:

- ▶ Do not till if soil moisture is greater than 80 percent
- ▶ Clean tillage equipment of all soil and plant residue when moving from field to field to prevent the spread of weeds and plant pathogens between fields.

- ▶ Vary tillage depth from year to year to prevent the buildup of a hardpan just below the tillage level. Occasionally, deep tillage operations (deep ripping to 18") may be done if hardpans are a concern.
- ▶ When using heavy equipment, distribute the weight over multiple tires and axles to spread the load over as large an area as possible. Adjust speeds, ballast, and tire pressure to minimize tire slippage.

B. Soil Moisture and Irrigation

Soil moisture level at planting is an important factor contributing to seed piece decay. Plant when the soil moisture is at 70-80% of available soil water. Planting in soil wetter than this promotes bacterial seed piece decay regardless of the temperature. Planting into hot, dry soil often leads to excessive seed piece decay as well. If the soils are excessively dry, irrigate prior to planting. Avoid irrigation between planting and emergence as this can contribute to seed piece decay.

An easy method to estimate soil moisture levels is to use the ball test. To do this, simply take a handful of soil and try to form it into a ball. Then consult the **Feel Chart for Estimating Soil Moisture** in this section.

Get a clean start on weeds

Controlling weeds prior to planting can be a critical component of an integrated management program. Pre-plant tillage often controls existing early-season annual weeds. Some non-residual herbicides are also labeled for pre-plant application and can be useful for controlling perennial weeds but be sure to check rotational restrictions prior to use. If the planting schedule allows, utilizing the stale seedbed approach can reduce in-season weeds by up to 40%. In this approach, the field is tilled for planting and then allowed to rest for up to 3 weeks to allow for weed germination. Existing small weeds are then removed as part of the normal field preparation and potato planting process.

C. Organic Matter Incorporation

When using manure or cover crops in your system, it is important to thoroughly incorporate the material into the soil to prevent runoff of nutrients from manure and to aid in decomposition of plant material. For incorporating cover crop plant material, you will need to consider your method of killing and method of incorporation. You can choose to kill plants chemically and then incorporate or simply till the living biomass into the soil. Use of a moldboard plow will work the best for complete incorporation of living plant material, but also cause the greatest soil disturbance. Reduced tillage implements such as a chisel plow or disk will lead to only partial incorporation of plant material into the soil, but will also leave more soil cover to prevent erosion. Selection of killing method, killing timing,

and soil incorporation should be based on erosion potential of the soil and timing of planting. Potatoes should not be planted sooner than two weeks after incorporation of cover crop plant material or manure. Planting within two weeks may favor the development of Pythium seed piece decay.

D. Rotational Field History

Keeping and checking accurate field records is important so that problems can be corrected or prevented before planting takes place. An accurate field history can point toward controlling perennial weeds or correcting a drainage problem related to a hardpan. The record of the previous year's potato fields pinpoints field borders to scout for Colorado potato beetles.

Feel Chart for Estimating Soil Moisture Percent (%):

	Sand or loamy sand soil texture	Loam, silt loam, clay loam soil texture
Below 20%	No ball forms. Single grained soil flows through fingers with ease.	Powdery, dry, will not form a ball; if soil is crusted, easy to break into powdery condition.
35-40%	Forms weak brittle balls. Finger print outline not discernible. No soil sticks to hand.	A ball can be formed under pressure, but some soil will fall or flake away when hand is opened. The ball is very crumbly and hardly holds its shape.
50%	Forms very weak ball. If soil is well broken up, it will form more than one ball upon squeezing. Fingerprint outline barely discernible. Soil grains will stick to hand.	Forms a ball readily, holds its shape. No moist feeling is left on hand nor will any soil fragments cling to palm. Ball is very brittle and breaks readily. Soil falls or crumbles into small granules when broken.
60-65%	Forms weak, brittle ball. Fingerprint outline not as distinct. Soil particles will stick to hand in a patchy pattern.	Forms firm ball; finger marks imprint on ball. Hand feels damp but not moist. Soil doesn't stick to hand. Ball is pliable. When broken, ball shatters or falls into medium-size fragments.
70-80%	Forms weak ball. Distinct fingerprint outline on ball. Soil particles will stick to palm. Optimum for planting.	Damp and heavy; slightly sticky when squeezed. Forms tight plastic ball. Shatters with a burst into large particles when broken. Hand is moist. Optimum for planting.
100%	Upon squeezing, no free water appears on ball but wet outline of ball is left on hand. Ball has some stickiness and a sharp fingerprint outline is left on it.	Wet, sticky, doughy, and slick. A very plastic ball is formed, handles like stiff bread dough or modeling clay; not muddy. Leaves water on hand. Ball will change shape and cracks will appear before breaking.

Cultural Pest Management Options

Planting



Cultural control practices at planting are important to the BioIPM production system. Key practices include eliminating sources of disease inoculum, preventing pest introductions to clean fields, and assuring a healthy potato canopy develops.



Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A.** Cull piles, storage wastes and seed cutting remnants are buried or destroyed before planting begins.
- ☐ **B.** Machinery is cleaned when leaving a field and before entering new fields.
- ☐ **C.** Practices to assure a healthy crop and canopy development are followed. These include: proper seed and row spacing, proper canopy development, and following University fertility recommendations.
- ☐ **D.** Cultural control strategies are implemented. Some examples include spring trap crops for Colorado potato beetle control or smother crops for weed management.

A. Limiting Disease Inoculum Sources

Eliminating inoculum sources is a proven strategy for limiting disease development in the potato system. Several effective strategies for this are described below.

Late blight: Cull potatoes that are not properly disposed of often initiate late blight epidemics. Tubers from warehouses dumped in cull piles or seed slivers serve as sources of inoculum for neighboring potato fields. The late blight fungus develops on the plants growing from these infected tubers.



Cull piles

Bury cull piles or seed slivers from the seed cutting operation with a minimum of 3 feet of soil over the top of the potatoes. Do not bury cull potatoes or slivers in fields which will be planted to potatoes during the season. Frequently check fields which were used to bury potato waste for vegetative growth above ground. If the potatoes sprout, they should be immediately killed.

Early blight: Early blight can be limited by controlling its alternate hosts. Plants such as hairy nightshade, eastern black nightshade and other solanaceous plant species serve as fungal reproductive and overwintering sites. Early blight can also overwinter on dead potato vines. Control the weeds, specifically nightshades, by cultivation or with herbicides to limit these hosts of early blight.



Early blight

Potato Early Dying: cultural management tactics are described in this handbook's *Preplant/Potato Early Dying Management* section.

B. Preventing Pest Dispersal by Machinery

If weeds, nematodes, or other soil borne pests are not yet present in a field, preventing their introduction is a cost effective strategy. Soil that is left on equipment traveling from field to field introduces weeds and pathogens to new areas. Thoroughly wash equipment before working in potato production fields and if possible, between fields.

In most cases, the introduction of weeds and/or plant pathogens occurs at the field entrance and tillage then spreads them through the field. Clean tillage equipment before leaving a field. After removing all soil from the implement and tires, spray all equipment parts coming in contact with the soil with a disinfectant. Disinfectant applications can be made with a simple hand sprayer and do not take more than a few minutes between each field.

C. Plant Health and Canopy Development

Weeds and crops have the same requirements for normal growth, development, and reproduction and therefore are in constant competition. Growers can apply management strategies (proper seed and row spacing and proper plant nutrition) to improve the crop's competitive advantage and reduce negative effects of weeds.

If weeds are controlled early in the season before the potato canopy develops, the potato crop easily competes with weeds later in the season. The options for potato weed management include chemical, mechanical, and cultural control, or more often some combination of the three. Herbicides are typically used pre-emergent to the potato crop, but will only give between seven to nine weeks of control. Weed control from herbicides can be enhanced with cultivation; however, excessive cultivation may reduce herbicide efficacy and may reduce yields through root pruning.

Most potato cultivars reach maximum canopy at six to seven weeks after emergence. Once maximum canopy is reached, weed control is provided

by the potato crop until the canopy begins to break down later in the season. Some early harvested cultivars such as Superior and Dark Red Norland only shade the soil at about the 90% level which allows for some weed growth. Russet Burbank on the other hand provides shade at 96% or higher. This should prevent any mid-season weed growth.

Crop canopy development and maintenance depends on the general health of the potato plant. The canopy may be reduced by water stress, nutrient deficiencies, insect and disease infestation, and other environmental factors.

Field scouting is a critical component of this integrated control program. If the crop canopy is damaged, it may be necessary to apply a post emergent herbicide so weeds can be controlled until the crop is able to recover.

D. BiolPM Techniques

Insects

Colorado potato beetles are vulnerable to various cultural strategies at planting since they walk into the field from overwintering sites in the spring. This limited migration pattern allows for border and trap crop techniques to be used as control methods. Keep scouting and monitoring beetle populations in the field even when these strategies are used since these will not provide 100% beetle control.

Planting **trap crops** can be an effective method for controlling Colorado potato beetles. In Wisconsin, trap crops work by congregating adult beetles as they exit overwintering sites and enter newly emerged potato fields.

The beetles which congregate in the early planted stand of potatoes are then killed by chemical, physical, or cultural methods. By limiting overwintering adults, fewer beetles will enter the main potato crop, fewer eggs will be laid, and ultimately fewer chemical applications will be necessary,



Planting trap crops is an effective method for controlling Colorado potato beetles

reducing the adverse effects of pesticides.

To implement a trap crop, plant a strip of early-planted potatoes, anywhere from 12-48 rows, along the field's edge. The remainder of the field can be planted at a later date. Once the beetles have congregated in the trap crop area, control them physically or chemically.

Physical control methods that are commercially available include **vacuum suction** and **propane flaming**. Propane flamers are highly effective for Colorado potato beetle control when potatoes are up to 4 inches tall. Two burners per row of potatoes should be directed at an angle at the base of the plants. Adjust the nozzle distance, angle, and tractor speed so that the young foliage is not heavily injured while ensuring that Colorado potato beetles are killed.



Vacuum suction of CPB

Chemical border treatments along field edges may also be used as a cultural control strategy. This method is similar to a trap crop but a systemic or foliar insecticide treatment is applied to a strip of potatoes planted along the field edge where Colorado potato beetles are expected to enter. The chemical border method should limit Colorado potato beetle infestations of the main field area. The strip of potatoes can be planted earlier than the rest of the field, or it can be planted at the same time. If beetle populations are expected to be low, border treatments of 24 rows should be sufficient. However, if large beetle populations are expected, a border treatment of greater than 48 rows is needed.

Barriers, either natural or artificial, found in or along field edges will limit Colorado potato beetle infestations as well. Barriers are physical obstructions that delay beetle movement into potato fields. Streams, windbreaks, and weeds are among the many natural barriers that already exist. Artificial barriers, such as wheat or grasses, can be planted along field edges prior to beetle emergence to confuse beetle migration.

Trenches can be dug along field edges to “trap” beetles in the ground where they can be killed before entering the potato fields. Trenches can be an effective, yet costly control measure. Trenches may be used if heavy beetle populations are found or as a resistance management strategy where concerns over beetle resistance are high. Trenches are popular in Long Island due to the beetles’ development of resistance to all chemical control options in that area.



Trenches may be used during heavy beetle infestation

To use trenches for Colorado potato beetle control, follow these steps.

- ▶ Check pest pressure and field maps from previous years. Locate the most highly populated areas where trenches will be the most effective.
- ▶ Dig trenches along field edges approximately 2-1/2 ft. wide x 1 ft. deep.
- ▶ Line the trenches with plastic to create a slippery surface that the adult beetles cannot climb.
- ▶ Once beetles have congregated in the trenches, control them physically or chemically. Several physical control methods are commercially available including vacuum suction machines.

Few cultural strategies are effective to prevent **potato leafhopper** infestations, but selecting less susceptible potato varieties may help. A list of the highly to least susceptible varieties can be found in this handbook’s *Preplant/Cultivar Selection* section. When possible, avoid planting potatoes near alfalfa. Alfalfa is a primary source of potato leafhoppers. Leafhoppers will migrate out of alfalfa to other, nearby crops when the alfalfa is cut.



Potato leafhoppers

Growers may be able to completely avoid aphid concerns at the end of the growing season by

altering the timing of planting or the variety planted. Early potato varieties or potatoes which are planted early enough to be harvested by mid-August can avoid aphid problems by being harvested prior to aphid infestations. Since aphids usually infest in mid to late August, varieties which are harvested by that point can be utilized, even if they are susceptible to aphid and viral infections.



Pea aphids on potato

Weeds

Mechanical, physical, biological, or cultural practices should be utilized in and around the field in the non-potato years to limit the number of weed seeds entering the seed bank.

Minimizing weed competition is critical to improve yield and quality. Potential economic benefits associated with reduced herbicide applications have stimulated interest in alternative and integrated weed management strategies. Smother crops seeded at or near the time of potato planting may provide an alternative to conventional weed management by providing a competitive suppression of early season weed growth.

Smother crops are specialized cover crops selected for their ability to suppress weeds. They compete aggressively for light, nutrients, and moisture with the weed species infesting an area. Any highly competitive crop that is well adapted to an area may be suitable for use as a smother crop. If weeds are suppressed during the 4 to 6 weeks after emergence, potato yield reductions are not usually seen.

The fundamental challenge to effectively using smother crops is timely establishment. Smother plants must germinate and grow rapidly to gain a competitive advantage over weeds. Several species have potential for quick establishment and weed suppression. Examples of annual smother crops include rye, buckwheat, and millet. Examples of perennial smother crops include sweet clover and cowpeas.

A photograph of a field of yellow mustard flowers. The flowers are in various stages of bloom, with some showing the characteristic four-petaled structure. The stems are green and leafy. The background is a clear blue sky with a few wispy clouds. The overall scene is bright and sunny.

- ▶ Seed the smother crop at or within 2 weeks of potato planting.
- ▶ Suggested seeding rates for mustard are 5-7 lbs/acre for small-seeded cultivars, 10-12 lbs/acre for large-seeded cultivars.
- ▶ Seed 3/8 to 3/4 inches deep.
- ▶ Drill mustard before planting potatoes or broadcast seed it after planting.
- ▶ Mustard species and fast growing plants either die quickly during the potato season or can be easily killed with potato herbicide programs.

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Resistance Management

Planting



Resistance management is a critical part of an overall bioIPM program and needs to be considered in all aspects of the production system. Good resistance management strategies should be employed to maintain the reduced-risk, lower toxicity chemistries now available for potatoes.



Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A.** Resistance management strategies are considered before applying pesticides.
- ☐ **B.** Herbicide classes are rotated between seasons/crops as well as within the season.
- ☐ **C.** Insecticide chemistries for Colorado potato beetle control are rotated throughout the farm.
- ☐ **D.** Additional BioIPM strategies (cultural options, biological controls, and barriers) are utilized whenever possible to reduce reliance on pesticides.

A. Resistance Management for the Current Year's Potato Crop

Resistance of diseases, insects, and weeds to registered pesticides is found in an increasing number of pest species found in potatoes. Resistance concerns for Wisconsin potatoes include Colorado potato beetles, green peach aphids, early blight, late blight, and several weed species including giant foxtail, green foxtail, velvetleaf, pigweed, and large crabgrass.

Resistance develops through a genetic alteration in the pest allowing it to overcome the toxic effect of pesticides. These resistant genes are transferred through reproduction ultimately increasing the resistant population. Maintaining susceptible populations which will breed with the resistant population is a key to limiting the onset of resistance.

Once resistance occurs, it may be permanent, although occasionally, populations revert back to susceptible levels. These populations, however, have a high probability of quickly becoming resistant again. Therefore, it is still important to practice proper resistance management strategies to prevent the development of resistance. General resistance management strategies should be employed at all times during the production cycle to prevent the onset of resistance by pest species.

General resistance management strategies which should be used include:

1. Avoid consecutive use of a product or other products with similar modes of action against the same target pests. This includes:
 - ▶ Alternate chemical classes and modes of action within a cropping season.
 - ▶ Alternate chemical classes and modes of actions between years in the rotation.
2. Only apply pesticides when needed (when problems are seen in a field, when thresholds are met, when forecasting models indicate, when susceptible stages are present, etc.)
3. Incorporate various BioIPM techniques when possible to limit pest infestations. This will

reduce the exposure of pest populations to pesticides, ultimately reducing the chance of resistance development.



Quick Note

Remember, there is no chance for resistance developing if pests are not treated with pesticides.

Look in Appendix C for the EPA resistance management groups for insecticides, fungicides, and herbicides. The EPA list is based on the pesticide's mode of action and will help growers determine their pesticide rotational strategies. Resistance management on potatoes can be a challenge because so many of the new, reduced risk chemistries are grouped together. Good resistance management strategies need to be utilized to maintain efficacy for all of the chemistries within the groupings.

B. Herbicide Class Rotation

Resistance of weed species in Wisconsin is becoming an increasing concern in vegetable production systems. It is important to rotate herbicide chemistries from year to year to limit resistance development by weeds. The key to managing potential weed resistance is to not apply the same herbicide class for the same weed species consecutively whether within a season or between seasons. Herbicide class rotation requires good record keeping from year to year and is complicated by the small number of herbicides that are labeled for vegetable crops.

Look in Appendix C for the EPA resistance management groups for herbicides applied to potatoes and rotational crops. There are few herbicides registered for potato weed control and maintaining their efficacy is important. Additional guidelines for herbicide resistance management are covered in this handbook's *Preplant/Resistance Management in Rotational Years* section.

C. Colorado Potato Beetle Control

The **Colorado potato beetle** is known for its extraordinary capacity to develop insecticide resistance and has already shown resistance to every class of insecticide available. In the Midwest, problems with insecticide resistance are localized, but are increasing and should be monitored.

A good resistance management strategy is to apply insecticides with different modes of actions spatially around the farm. Planting is the time to consider these choices since the systemic insecticides (the chloronicotinyls) used at planting are at a high risk for resistance development. If resistance management is not practiced, the Colorado potato beetle is likely to develop resistance to these insecticides.

Avoid using the same insecticidal control strategy on all the potato fields on the farm. If only chloronicotinyl insecticides are used for Colorado potato beetle control on all fields on the farm, the chance of a resistant beetle being selected greatly increases. This beetle may then breed with susceptible beetles with little consequence, but may also breed with another resistant beetle which could lead to a larger resistant population. However, if multiple insecticidal classes are applied spatially around the farm, the beetle which may be resistant to the chloronicotinyls, could still be susceptible to other insecticides (such as anthranilic diamides's) and could be killed in a nearby field with that insecticide.

See Appendix C for a listing of EPA resistance management groups.

More information on area-wide resistance management is found in this handbook's *Preplant/Resistance Management in Rotational Years* section.



The Colorado potato beetle has shown resistance to every class of insecticide



Quick Note

Resistance normally develops by allowing rare individuals that overcome a particular mode of action to survive. Growers “select” these individuals by spraying the same pesticide repeatedly. These resistant species (in our example insects) then mate, and if they mate with another resistant individual, their offspring may all be resistant. This process multiplies if the same insecticide, or similar modes of action, is continually applied.

D. BioIPM Techniques

Implementing various BioIPM techniques to limit pest populations will reduce pesticide applications, therefore decreasing the possibility of resistance developing. Specific BioIPM techniques are discussed in the handbook's *Planting/Cultural Pest Management* section or are found in the pest profiles in Appendix B. Examples include:

Disease

- **Late blight:** destroy cull piles
- **Early blight:** track populations from nearby fields and determine if sensitivity to fungicides may have occurred in populations the previous year. This may be noticed if early blight infection greatly increased toward the end of the previous year's potato growing season. If so, select fungicide options carefully.
- **Soil borne pathogens:** clean machinery between fields to prevent spread of inoculum
- **Others:** utilize resistant cultivars when applicable

Insects

- **Colorado potato beetles:** implement an area-wide rotational scheme
- **European corn borer:** destroy areas where larval populations can survive and infest potatoes. These locations include corn and snap bean stubble in neighboring fields.

Weeds

- Till or mow field edges to prevent weeds going to seed
- Clean machinery between fields to prevent weed seed spread

Planting Process

Planting



A good stand of potatoes is essential to minimize the effect of plant pathogens and pests. Environmental conditions at planting, accurate equipment and careful planting processes all contribute to the health, quality and emergence of the crop.



Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A.** Planter and other transfer equipment are calibrated to reduce the chance of bruising seed pieces.
- ☐ **B.** Seed temperatures and soil temperatures are within 5 degrees of each other at planting. Soil is at or below field capacity during the planting period.
- ☐ **C.** Planter is calibrated and field checks are taken to ensure accuracy in planting depth, in-row spacing, and fertilizer/pesticide placement.
- ☐ **D.** A cup or air planter is used instead of a pick planter. The planter is disinfected many times during the planting process.

A. Equipment Calibration

Before planting begins, check for proper operation of the planting equipment by measuring the drop distance and checking for planter skips. At all stages of the planting operation, seed should not drop from heights greater than six inches. Greater seed drops may cause bruising and infection sites for disease. Bruised seed may also alter the physiological age of the seed piece leading to increased stem number. Higher stem numbers increase tuber set and can reduce yields.



To prevent bruising, seed pieces should not drop from heights greater than six inches

B. Seed and Soil Conditions

Proper seedbed conditions, especially soil temperatures and moisture, are essential in developing a healthy stand of potatoes. Planting in soils which are too hot and too moist may result in a poor stand, excessive seed piece decay, bacterial decay or physiological disorders.



Proper seedbed conditions are essential in developing a healthy stand

Planting should not occur when soil temperatures are below 50° F. The difference between seed and soil temperatures should be no more than 5°F to prevent condensation forming on the seed piece which can lead to increased seed piece decay.

Soil moisture should be at 70—80 % of available soil water. This provides good planting conditions and adequate soil water for sprout and root development. If the soil is dry, consider irrigating before planting. Do not irrigate between planting and emergence as this increases the likelihood of seed piece decay. A simple method for estimating soil moisture level is described in the **Field Preparation** section.

Seed and Row Spacing

Appropriate spacing of rows and seed pieces depends on several factors, including cultivar, fertilization, irrigation, soil type, and intended market. General guidelines are given here.

- ▶ Row widths generally range from 30-36 inches.
- ▶ In cultivars that generally produce a heavy set, seed pieces should be spaced farther apart in the row, up to 15-18 inches in some areas. If cultivars produce a smaller set, plant seed closer together.
- ▶ The row spacing and seed spacing affect the production potential of the crop:
 - ▶ Generally, seed pieces planted closely together will yield smaller tubers and lower quantities.
 - ▶ Conversely, seed pieces planted farther apart will yield larger tubers and greater quantities.

C. Field Checks

As planting progresses, conduct field checks to ensure that seed is placed at the desired depth and spacing. Also monitor the fertilizer placement as well as the position of any in-furrow pesticide. It is important to check multiple planter rows and multiple spots in the field to be certain that the planter is operating correctly. Take time to make checks continuously through the planting operation.



Field checking

D. Planters

The type of planter used can have an effect on the health of potato plants. A pick planter produces seed piece wounds that can provide entry points for pathogens and increases the likelihood of seed piece decay.



Pick planters can produce seed piece wounds

Pick planters may also spread viruses from one seed piece to another. Using a cup or air planter is preferable as seed piece damage is reduced and the likelihood of spreading pathogens is lessened. Regardless of the type of planter, disinfect the planter periodically during the planting process and clean soil from the planting equipment before moving between fields.

IMPORTANT POINT:

Use proper fertilizer placement and seed spacing as required for specific varieties. This manual does not designate specific variety recommendations, so check with the University Extension service or your seed dealers to determine specific variety recommendations.

Notes:

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Soil Fertility and Plant Nutrition

Planting



There are 16 essential plant nutrients. Hydrogen, oxygen, and carbon are supplied by the atmosphere and water. The rest are supplied in full or in part by the soil. However, several nutrients are needed in bulk amounts to produce optimal yields. These are typically nitrogen (N), phosphorus (P), and potassium (K), but can also include secondary nutrients such as sulfur (S), calcium (Ca), and magnesium (Mg). Other nutrients are referred to as micronutrients because they are only taken up in small quantities and are rarely needed to be supplied to obtain optimal yields. These micronutrients include: boron (B), chlorine (Cl), copper (C), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn).



Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A. Nutrient applications are based on University of Wisconsin-Extension recommendations (UWEX A2809) and in accordance with nutrient management planning rules.**
- ☐ **B. Starter fertilizer is applied in a manner (placement and rate) that is not harmful to the seed.**
- ☐ **C. Surfactants are used.**
- ☐ **D. If variably applying fertilizer or lime, decisions are made based on grid soil sampling and computer software.**
- ☐ **E. Credit nitrogen from manure, legume forage crops in rotation, and green manure.**

A. Plant Nutrition and Fertilization 101

Fertilizer applications should be based on soil test results and guidelines described in A2809 *Nutrient Application Guidelines for Field, Vegetable, and Fruit Crops in Wisconsin*. Nitrogen management for potato can be difficult because it is a high N demand crop. Split applications of N may be necessary to reduce nitrate leaching losses, especially on sandy soil. Potato is also a high P and K demand crop and these fertilizers can be applied broadcast prior to planting, as starter fertilizer at planting, or both. On sandy soil, it is beneficial to apply some N fertilizer (~30 lb/ac) at the time of planting. Adequate nutrient application at planting is crucial for vigorous early season growth for potatoes. Vigorous early season growth decreases the potential for disease and insect damage and improves the crop's competitiveness with weeds.



Soil sampling

The University of Wisconsin has produced research-based fertilizer recommendations for potatoes. University of Wisconsin guidelines for P and K applications on potatoes are based on soil test P and K levels and expected yield (which is variety dependent). The University of Wisconsin guidelines for N applications are based on soil organic matter concentrations and expected yield. There has yet to be a reliable soil test for N that provides insight into how much N fertilizer is required. The soil organic matter concentration provides a general indication of how much N the soil will supply. Nitrogen recommendations are provided for four categories of organic matter concentrations (<2%, 2-10%, 10-20%, and >20%) with less N recommended with greater organic matter concentrations. Routine soil analysis will also provide a measure of pH and a recommendation for lime application if necessary.

B. Fertilizer Recommendations

pH and Lime

The target pH for potato depends on if the variety is scab resistant or not. For scab-resistant varieties, the target pH is 6.0 on mineral soil and 5.6 on organic soil (organic soil is soil with organic matter greater than 10%). For varieties that are not scab-resistant, the target pH is 5.2 across all soil types. The lime requirement will be reported on the soil test report along with recommended adjustment to this requirement based on plow depth. Further adjustments may need to be made based on the type and quality of liming material. The amount of lime recommended is the amount that will reach the target pH during the next four years. Coarse-textured soils such as sands and loamy sands are less buffered against changes in pH and thus, may need to be limed more frequently. Timing of lime application is critical when growing low pH sensitive crops in rotation with potato. It is recommended that lime be applied after potato harvest to reduce the liming effects on soil by the time potato occurs again in rotation.

Nitrogen

Nitrogen is often the most limiting nutrient for potato production, especially on sandy soils. University guidelines suggest basing N applications based on yield goal and organic matter percentage, with higher yielding varieties receiving greater amounts of N, and soils with higher organic matter concentrations requiring less N inputs. There are no current soil tests for N to predict N application need. It is also important to credit N applied as manure or green manure cover crops. Split application of N on sandy soil is recommended. On sandy soil, a common management practice is to apply some N at planting (30-50 lb/ac), one-third to one-half the remaining N at emergence, and the remainder (typically one-half to two-thirds of the total N) applied at tuber initiation. Nitrogen fertilizer technologies such as polymer coated urea products and nitrification inhibitors may also be used to reduce nitrate leaching losses, and in the case of polymer coated urea, can be applied entirely at plant emergence.



Quick Note

For more details, look for the following Extension Publications:

- ▶ *Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin* (A2809)
- ▶ *Understanding Plant Nutrients: Soil and applied nitrogen* (A2519)
- ▶ *Nitrogen management on sandy soils* (A3634)
- ▶ *Understanding Plant Nutrients: Soil and applied phosphorus* (A2520)
- ▶ *Understanding Plant Nutrients: Soil and applied potassium* (A2521)
- ▶ *Choosing between liming materials* (A3671)
- ▶ *When and how to apply aglime* (A2458)

Phosphorus and Potassium

Phosphorus and potassium applications for potato are based on soil test P and K values, soil type, and yield goal. Since potato is such a high P and K demand crop, it has its own P and K demand category. UW fertilizer guidelines for P and K are based on many years of field trials to optimize potato yield quantity and quality. There are six soil test category levels: very low, low, optimal, high, very high, and excessively high. The goal is to manage your soil in the optimal soil test level category; if less than optimal, extra P or K is recommended to build the concentration and if above optimal, less P or K is recommended to draw down the concentration. The P and K fertilizer recommendations are reported in terms of lb/ac of P_2O_5 or K_2O . Sandy soils have lower P and K recommendations at below optimal soil test values compared to non-sandy soils because soil test P and K is more responsive to fertilizer applications. However, they are also more likely to decrease in soil test values if fertilizer is not applied.

Phosphorus can also be a contaminant for surface water quality if lost via runoff or erosion. Practices to incorporate applied P into the soil or reduce erosion losses should be enacted to limit the environmental impact of P applications. The Wisconsin Phosphorus Index (wpindex.soils.wisc.edu) is a planning and assessment tool that can be run as part of the SNAP-Plus nutrient management planning software to estimate P losses from your farming system. It can also help identify which management practices can be implemented to reduce your P loss. However, runoff losses on sandy soils rarely occur.

Nitrogen (N) Rate Guidelines (Table 6.3, UWEX A2809)

Potato	Yield range per acre	Soil organic matter content (%)			
		< 2.0	2.0–9.9	10.0–20.0	> 20.0
-----lb N/a to apply*-----					
	250–350 cwt	145	120	100	60
	351–450 cwt	180	155	130	75
	451–550 cwt	220	180	150	85
	551–650 cwt	250	210	175	95

* This is the total amount of N to apply including starter fertilizer. Reduce nitrogen rate by 25% if petiole nitrate test is used to guide in-season N applications.

Phosphorus (P) and Potassium (K) Fertilizer Application Rate Guidelines (Table 7.4, UWEX A2809)

Potato	Yield goal (per acre)	P ₂ O ₅ rate guidelines					K ₂ O rate guidelines					
		VL	L	O	H	EH	VL	L	O	H	VH	EH
		-----lb P ₂ O ₅ /a to apply ^a -----					-----lb K ₂ O/a to apply ^b -----					
	250–350 cwt	185	135	65	50	30	245	225	180	120	75	30
	351–450 cwt	200	150	80	55	30	295	275	230	145	90	30
	451–550 cwt	210	160	90	60	30	345	325	280	170	100	30
	551–650 cwt	220	170	100	65	30	395	375	330	195	115	30

^a This is the total amount of P₂O₅ to apply, including starter fertilizer.

^b This is the total amount of K₂O to apply, including starter fertilizer.

Secondary and micronutrients

Potato is considered a medium demand crop for sulfur, zinc, and manganese and a low demand crop for boron and copper. However, response to applied nutrients may be likely on sandy soils which have inherently low concentrations of these nutrients. Potatoes are often responsive to application of calcium, in terms of increased yield and quality. Also, calcium need in concordance with large application rates of potassium, as the potassium can limit calcium uptake. A reduction in tuber defects such as internal brown spot and a decrease in soft rot occurrence during storage have been linked to calcium applications. If you want to apply calcium without altering the soil pH, calcium sulfate (gypsum) or calcium nitrate can be used. Apply 200 lb/A of calcium for soils in the very low soil test category, and 100 lb/A of Ca for soils in the low soil test category.

C. Starter Fertilizer & Surfactants

Starter fertilizer enhances early season crop growth and helps the crop compete against early weed infestations. Banding at planting is the most common method of application of starter fertilizer. The fertilizer can be placed two inches to the side and two inches below the seed piece. On sandier soils, the starter fertilizer can be applied above the seed piece after the seed is covered with a layer of soil. If the fertilizer touches the seed piece, injury may result. Starter fertilizer can also be applied

during row marking operations before planting as broadcast applications. An ideal starter fertilizer would contain some N, P, and K, with the remaining P and K needs supplied pre-plant and the remaining N needs supplied post-plant. Micronutrients can also be applied in the starter fertilizer.

Surfactants are products that improve the wettability of the soil by allowing more rainfall or irrigation water to infiltrate into the soil hill. Applying surfactants in furrow can keep the area around the seed piece from drying out and can help reduce nitrate leaching.

D. Precision-applied Fertilizers

On fields that have not been cropped uniformly or have variations in soil type, drainage or topography, it may be profitable to site-specifically soil sample and precision apply lime, phosphorus or potassium. Take composite soil samples on a 2-3 acre grid, using GPS to mark the central location for each composite sample. Once the samples are analyzed, computer software can generate maps of the nutrient and pH levels and the grower can determine if it would be economical to variably apply a nutrient or lime. While it is more expensive to conduct this type of testing, it may save money if nutrient or pH imbalances exist across a field. For more information on grid soil sampling for variable rate applications, see UWEX A2100 *Sampling Soils for Testing*.

E. Nitrogen credits

Nitrogen should be credited from animal manure, legume forage crops in rotation, and green manures. It is highly recommended that all animal manures be sampled and analyzed for nutrient content. Not all of the N from animal manures is plant available for the subsequent crop. Table 9.1 in UWEX A2809 provides estimations on percent availability of various manure sources along with method of application. If you have not analyzed the manure that was applied, Table 9.2 in UWEX A2809 provides average values of nutrient concentrations of various manure types. It is also estimated that only 80 of the P and K in manure is plant available in the first year after application. The second-year nitrogen credit (from all manures) is 10% and the third-year credit is 5%.

Nitrogen Applications

Of all essential plant nutrients, nitrogen is often the most limiting to potato production on sandy soils. Plants normally contain between 1-5% nitrogen (N) by weight. Nitrogen helps to build proteins and the main cellular components of the potato. In addition, nitrogen is an integral part of chlorophyll, which is the primary absorber of light energy needed for photosynthesis.

An adequate supply of N is associated with high photosynthetic activity, vigorous vegetative growth, and a dark green color. If a plant lacks N, the entire plant may turn light green, and its leaf margins will roll upward. Young leaves remain green and older leaves turn yellow to light brown as nitrogen moves from the older to the younger.

Estimated Nutrient Availability for Various Manures (Table 9.1, UWEX A2809)

	Nitrogen (N)			P ₂ O ₅	K ₂ O	S
	Time to incorporation					
	> 72 hours or not incorporated	1 to 72 hours	< 1 hour or injected			
First-year availability	% of total					
Beef: liquid (≤ 11.0% DM) ^a	30	40	50	80	80	55
Beef: solid (> 11.0% DM)	25	30	35	80	80	55
Dairy: liquid (≤ 11.0% DM) ^a	30	40	50	80	80	55
Dairy: solid (> 11.0% DM)	25	30	35	80	80	55
Goat	25	30	35	80	80	55
Horse	25	30	35	80	80	55
Poultry (chicken, duck, and turkey)	50	55	60	80	80	55
Sheep	25	30	35	80	80	55
Swine	40	50	65	80	80	55
Veal calf	30	40	50	80	80	55
Second-year availability	% of total					
All species	10	10	10	0	0	10
Third-year availability	% of total					
All species	5	5	5	0	0	5

^a If dry matter (DM) is < 2.0% and NH₄-N is > 75% of total N, the following equation for first-year N availability may be used in an effort to better account for the high concentration of NH₄-N that may be found in these manures: first-year available N = NH₄-N + [0.25 x (Total N – NH₄-N)], assuming manure is injected or incorporated in < 1 hour.

^a If dry matter (DM) is $< 2.0\%$ and $\text{NH}_4\text{-N}$ is $> 75\%$ of total N, the following equation for first-year N availability may be used in an effort to better account for the high concentration of $\text{NH}_4\text{-N}$ that may be found in these manures: first-year available $\text{N} = \text{NH}_4\text{-N} + [0.25 \times (\text{Total N} - \text{NH}_4\text{-N})]$, assuming manure is injected or incorporated in < 1 hour.

Typical Total Nutrient Content of Manures Tested In Wisconsin from 1998-2012 (Table 9.2, UWEX A2809)

	Dry Matter (DM)	N	P₂O₅	K₂O	S
Solid manure	%	-----lb/ton-----			
Beef	29	13	8	12	1.9
Dairy: semi-solid (11.1–20.0% DM)	15	8	4	6	0.8
Dairy: solid (> 20.0% DM)	33	9	4	7	1.2
Goat	43	13	7	10	2.0
Horse	33	10	6	8	1.3
Poultry: chicken	57	49	44	33	3.0
Poultry: duck	36	12	10	9	1.8
Poultry: turkey	59	51	44	31	3.8
Sheep	34	19	9	24	2.2
Swine	19	18	13	10	2.0
Liquid manure	%	-----lb/1,000 gal-----			
Beef	3	16	7	15	1.6
Dairy: liquid (< 4.0% DM)	2	14	4	14	1.1
Dairy: slurry (4.1–11.0% DM)	6	24	8	21	2.2
Goat	4	17	8	19	1.7
Poultry	2	12	7	9	1.3
Swine: finish (indoor pit)	5	43	18	28	3.2
Swine: finish (outdoor pit)	2	18	7	10	1.0
Swine: (farrow-nursery, indoor pit)	2	21	8	13	1.0
Veal calf	1	9	3	16	0.6

If legume forage crops were grown prior to the potato growing year, N credits can be taken and are based on plant height and density at time of killing and the soil texture. The UWEX has guidelines established for alfalfa, red clover, birdsfoot trefoil, and vetch. The amount of N supplied by the killing of an established forage legume crop can be substantial, so it is highly recommended that growers not forget to take this credit.

Green manures are crops grown exclusively to be killed and supply N to the soil. These can include alfalfa, red clover, sweet clover, and vetch. With a minimum of 6 inches of growth, these green manures can supply 40 lb/ac of N to the subsequent crop. With greater than 6 inches of growth, a range in N credit is provided by UWEX A2809.



Quick Note

Calculating nitrogen credits: Nutrient credits from animal manures, compost, green manures, leguminous crops, and other organic amendments can and should be calculated and your fertilizer rates reduced accordingly. Estimates of green manure nitrogen credits can be found in the UW Extension publication A2809 Nutrient Application Guidelines for Field, Vegetable, and Fruit Crops. Soil testing labs can also make these calculations for you if you supply them with information on the cropping history and soil amendment applications you have made to your field.

Forage Legume Nitrogen (N) Credits (Table 9.4, UWEX A2809)

Crop/stand density	Medium-/fine-textured soils		Sands/loamy sands	
	> 8" regrowth	< 8" regrowth	> 8" regrowth	< 8" regrowth
First-year credit	-----lb N/a to credit-----			
Alfalfa				
Good (70–100% alfalfa, > 4 plants/ft ²)	190	150	140	100
Fair (30–70% alfalfa, 1.5–4 plants/ft ²)	160	120	110	70
Poor (0–30% alfalfa, < 1.5 plants/ft ²)	130	90	80	40
Red clover, birdsfoot trefoil	-----80% of alfalfa credit for similar stands-----			
Vetch	160	90	110	40
Second-year credit	-----lb N/a to credit-----			
All crops, good or fair stand	50	50	0	0

Green Manure Nitrogen (N) Credits (Table 9.5, UWEX A2809)

Crop	< 6" growth	> 6" growth	
	-----lb N/a to credit-----		
Alfalfa	40	60–100 ^a	^a Use the upper end of the range for spring-seeded green manures that are plowed under the following spring. Use the lower end of the range for fall seedings.
Clover, red	40	50–80 ^a	
Clover, sweet	40	80–120 ^a	^b If top growth is more than 12 inches before tillage, credit 110–160 lb N/a.
Vetch	40	40–90 ^{a,b}	

Field Crop Legume Rotational Nitrogen (N) Credits (Table 9.6, UWEX A2809)

Crop	Medium-/fine-textured soils	Sandy soils
	-----lb N/a to credit-----	
Soybean ^a	20	0
Leguminous vegetables: pea, snap, lima, or dry bean	20	0

^a Soybean credit does not apply to corn or wheat grown after soybean.

Potassium Applications

Plant requirements for available potassium (K) are quite high. The concentration of potassium in vegetative tissue usually ranges from 1 to 4% on a dry matter basis.

Potassium plays an important role in enzyme activation and water regulation. Plants that are K deficient are less able to withstand water stress, mostly because of their inability to make full use of available water. K also controls the loss of water. K can affect the rate of transpiration and water uptake through regulating the opening and closing of tiny holes on the leaf surface.

Since K is mobile in the plant, visual deficiency symptoms such as stunted growth usually appear first in the lower leaves, progressing toward the top as the severity of the deficiency increases. Young leaves develop a crinkly surface, and their margins roll downward. Leaves have slightly black pigmentation. Marginal scorching with necrotic spots may occur on older leaves.

K stress can increase the degree of damage by bacterial and fungal stress, insect infestation, and nematode and virus infection.

Water transports potassium very slowly through the soil profile. Applications may be broadcast prior to planting or potassium may be banded below and to the side of seed pieces at planting. Banding near seed pieces ensures more rapid access for the growing roots and improved uptake under adverse conditions. Broadcasting distributes the nutrients more completely throughout the root zone. In general, a greater yield response can be obtained from banded fertilizer than from the same amount applied broadcast.

Use soil test results to determine K application rates as considerable amounts may remain in the soil.

Phosphorus Applications

Phosphorus (P) occurs in most plants in concentrations between 0.1 and 0.4%. The most essential function of P in plants is energy storage and transfer. Phosphate compounds store energy obtained from photosynthesis or carbohydrate metabolism for subsequent growth and reproductive processes.

A good supply of P is associated with increased root growth and raised tolerance to diseases, especially those affecting the root system. Phosphorus deficient plants are stunted with dark green leaves and upwardly rolled leaf margins with some purpling. Leafroll severity increases as the deficiency increases.

Water transports phosphorus very slowly through the soil profile. Applications may be broadcast prior to planting or banded below and to the side of seed pieces at planting. Banding near seed pieces ensures more rapid access for the growing roots and improved uptake under adverse conditions. Broadcasting distributes the nutrients more completely throughout the root zone. In general, a greater yield response can be obtained from banded fertilizer than from the same amount applied broadcast.

Phosphorus must usually be applied for potato production. Use soil test results to determine P application rates as considerable amounts may remain in the soil.

F. Managing organic soil amendments

Manure and composts

Cow, sheep, horse, goat, swine, and poultry manure and compost of various kinds can be added to soil for their nutritional and soil-building qualities. Most organic soil amendments are a good source of N, P, and K, as well as micronutrients. Even more significantly, these materials feed and support the soil biota, which in turn increases the nitrogen mineralization (release) rate of the soil. The soil therefore becomes more fertile.

The nutrient contribution of organic amendments can and should be calculated towards the total nutrient budget for potatoes. Keep in mind, however, that if manures and composts are supplied in the amounts needed to supply enough N to the crop each year, the phosphorus levels may become excessive. These materials should therefore be considered as soil amendments to improve the soil and supplement the nutrient needs of the crop. Also be aware that manures and composts can contain weed seeds. If obtaining composts or amendments from off the farm, ask the supplier about the potential for weed seeds or pathogens.

The nutrient content and availability of manures depends on the animal species, bedding, manure storage, and whether or not the manure was applied to the surface or incorporated into the soil within three days of application. It's best to incorporate the manure as soon as possible so that nutrients aren't lost by volatilization or run-off. Estimates for first-year available nutrient content of various manures can be found in the UW Extension publication A2809. You can also send a sample of the manure, compost, or other soil amendment to the soil testing lab for nutrient analysis or have the UW Soil Testing lab make these calculations for you. For detailed information on applying manure to cropland, see the University of Wisconsin Extension publication A3392 *Guidelines to applying manure to cropland and pasture in Wisconsin*.

Cover crops and green manure

Green manuring is the practice of planting a cover crop, often a legume, in the spring, summer, or fall

and plowing it under the next spring. It was once the conventional method of supplying nitrogen to crops and was widely practiced before inexpensive commercial nitrogen fertilizer became available. Consider the cover crop to be as valuable as the vegetable crop, with attention to when and how to plant, plant establishment and weed control, and how the crop will be harvested or incorporated into the soil.

Sweet clover was the traditional green manure crop in Wisconsin. Red clover (*Trifolium pratense*), hairy vetch (*Vicia villosa*), annual medic (*Medicago* spp.) and berseem clover (*Trifolium alexandrinum*) are other legume cover crops well-adapted to Wisconsin conditions. Grass and grain crops such as winter rye, ryegrass, or oats are productive soil builders as they grow quickly to provide ground cover and have an extensive root system. They can also be used as a "catch" crop for residual soil nitrates following corn or wheat harvest. However, these crops will not lead to an N credit to the subsequent crop because of the relatively high C:N ratio of their plant biomass.

The amount of nitrogen and organic matter added to the soil from a legume or other cover crop depends on how long the crop has grown. A summer- or fall-seed legume will have had little time to grow in comparison to one that is seeded in the spring or early summer. Growth of more than six inches provides the most nitrogen, ranging from 40 to over 100 lb/a depending on the plant species.

Incorporate cover crops and organic amendments at least two weeks before planting to permit the decomposition of the cover crop.

Growing Legume Cover Crops

Red clover (*Trifolium pratense*), hairy vetch (*Vicia villosa*), sweetclover (*Melilotus officinalis*), annual medic (*Medicago* spp.), and berseem clover (*Trifolium alexandrinum*) are examples of legume cover crops well-adapted to Wisconsin conditions. When evaluating a new legume for use on your farm, start small.



Red clover in bloom

A given legume may or may not perform satisfactorily under your soil conditions and management. It may take a couple of years to find which legume will work for you.

Some guidelines for growing legumes for green manure are:

- ▶ Inoculate the seed with the proper strain of *Rhizobium* bacteria. Different legumes require different strains, and many commercial products contain strains for several species. Inoculation is an inexpensive way to ensure adequate nitrogen fixation will occur.
- ▶ Use common seed, but with a high germination rate. Low germination will reduce yield and may lead to a weed problem the following year. You do not need to plant an improved variety, however. The improved varieties have been bred for persistence—a trait unnecessary for legumes used as green manures.
- ▶ Provide good seed-to-soil contact. Legume seed needs good seed-to-soil contact to germinate rapidly. Cover seed when possible. This is especially true for large-seeded species such as hairy vetch.
- ▶ Minimize competition from weeds. Small-seeded legumes germinate and grow very slowly initially, making them poor competitors with weeds. Anything you can do to reduce or suppress weed competition will improve the chances for legume success.

Soil Test and Nutrient Recommendations

Inorganic (or commercial) and organic fertilizers (or manures) can be used for potato production. Inorganic fertilizers are sometimes called chemical fertilizers because they are produced in an industrial manufacturing process. They often contain higher concentrations of nutrients compared to organic fertilizers, meaning that much less fertilizer material needs to be applied compared to organic fertilizers. Nutrients in inorganic fertilizers are water-soluble and immediately available for plants, while organic fertilizers require soil microorganisms to convert nutrients into plant-available forms. Animal manure is the most commonly used organic fertilizer, but the amount of nutrients that are available will vary based on form (solid or liquid), method applied (surface or injected), and animal species (see A2809). Furthermore, application of animal manure can provide nutrients for the crop grown in the second year after application. For certified organic farming, other approved fertilizers include blood meal, bone meal, fish meal and powder, and feather meal. To learn more about fertilizer and plant nutrients, go to:

<http://www.soils.wisc.edu/extension/>

General IPM

In-season



Integrated Pest Management is a long-term approach to managing pests by combining biological, cultural, mechanical, physical, and chemical tools to combat pests in the most economically and environmentally effective manner.



Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A. Basic IPM approaches are understood.**
- ☐ **B. Fields are scouted. Economic thresholds, weather conditions and resistance management are considered in chemical management decisions.**
- ☐ **C. Life cycles and ecology of insects, weeds and diseases and economic thresholds for potatoes are reviewed and understood.**
- ☐ **D. Biologically-based preventative IPM strategies are used. These include cultural methods, biological controls, physical and mechanical controls, variety selection, and chemical controls. Pest management is considered in spatial (space) and temporal (time) contexts.**

A. IPM 101

Integrated Pest Management (IPM) involves various strategies to combat pests, including cultural, physical, mechanical, biological, host-plant resistance, and chemical control methods. Implementing a variety of these strategies is the basis for any biologically based pest management program (BioIPM). Resistance management strategies to maintain chemical classes are also an important component of IPM programs. The principal components of IPM programs are:

- ▶ Understanding the ecology and dynamics of the crop, pests, and natural enemies in the system
- ▶ Use of decision making tools, scouting and economic thresholds
- ▶ Utilization of all available pest management strategies
- ▶ Year round implementation of preventative pest measures
- ▶ Looking at the cropping system as a whole, not just single season pest species management

This section focuses on the general IPM principals. Other sections detail specific IPM strategies for implementation at various times throughout the production year.

B. Chemical Management Decisions and Scouting

Chemical control measures are an important component to an IPM program, but pesticides are not the only control option. IPM programs use economic threshold levels (when pest damage exceeds the cost of control) to determine when chemical measures are warranted. They utilize IPM tools, such as disease forecasting, to provide adequate information on when to initiate spray programs.

Scouting, the regular examination of the crop to determine the pest pressures, is the key to determine when chemical applications should occur. See the **Scouting Section** in this workbook for proper techniques and pest thresholds to trigger chemical application.

When selecting chemical control measures, proper resistance management strategies are also needed. For more information, read the handbook's resistance management sections in the Preplant, Planting, and In-Season chapters and check Appendix C for the EPA resistance management groups for potato insecticides, fungicides and herbicides.

C. Pest Life Cycles and Ecology

Proper implementation of an IPM program requires grower knowledge of pest life cycles, control tactics, and general production practices. Advanced BioIPM systems call for a more extensive understanding of pest life cycles and targeting control measures to specific times during a pest's vulnerable stages. A combination of control techniques including available biologically based pest management tools should be incorporated when possible.

General pest life cycles for key pests in Wisconsin potatoes are described below. See the **Pest Profiles in Appendix A** for more information.

Weeds

The term **broadleaf weed** pertains to dicot weeds with broad leaves and 2 cotyledons, or seed leaves. Seed leaves or cotyledons are usually the first pair of leaves to appear as the plant emerges through the soil and generally have a different shape and appearance than true leaves.

One key that aids in the identification of broadleaf weeds is the leaf arrangement. Some broadleaf weeds have leaves arranged alternately on the stem, some have leaves arranged opposite each other, and some have leaves arranged in a whorl about the stem.

Both annual and perennial broadleaf weeds affect potato production. Annual species live only a single year and reproduce by seed. They die naturally at the end of the season after they have produced their seed crop. Perennial species live several years and reproduce by various types of vegetative structures in addition to seed. Perennials can regenerate shoots each year using food reserves

stored in vegetative structures in the soil, and thus they are not dependent on seed germination for their survival. They can also re-sprout when their top growth has been removed mechanically or by other means, as long as the underground storage organ is intact.

Grass weeds are monocots and most **annual grasses** have narrow leaves with parallel veins. To ensure proper control measures, it is important to correctly identify grasses found in the field. Seedling grasses are more difficult to identify than seedling broadleaf weeds, but as grasses grow, they develop distinguishing features that aid in proper identification. The four basic parts of the grass plant leaf that are commonly used for identification are described here. More information is contained in the **Pest Profiles (Appendix A)**.

The leaf of a grass plant is composed of four basic parts:

- ▶ The **blade** is the flattened portion of the leaf.
- ▶ The **collar** or **auricle** is the junction between the blade and the sheath.
- ▶ The **sheath** is the portion of the leaf surrounding the stem.
- ▶ The **ligule** is a short tube that extends out of the collar. Not all grasses possess this structure.

D. BioIPM Systems

Biologically-based IPM systems include numerous components based on the potato system's ecology and incorporate more than field-level IPM programs. Progress along the Integrated Pest Management (IPM) continuum toward biointensive IPM is made possible by greater reliance on pest management skills and practices that are inherently **prevention-oriented**. This will ultimately reduce

the reliance on pesticides or practices that are primarily reactive and designed to kill pests when populations exceed prescribed thresholds.

Field data on crop status and pest population levels are the backbone of IPM systems. In making day-to-day operational decisions, it is critical to incorporate the use of scouting data with knowledge of the pest life cycle, economic damage, other pest complexes, and beneficial species to make informed decisions and properly design the pest management strategy. A challenge for all IPM systems is accurately recognizing and responding to changes in the status of crops, pests, and beneficial insects triggered by agronomic systems, weather patterns, and a range of living and non-living factors.

In general, as IPM systems become more complex and prevention-oriented, pest managers will need routine access to both more kinds of data and greater data resolution in time and space. Several tactics which are commonly found in biologically based IPM programs include:

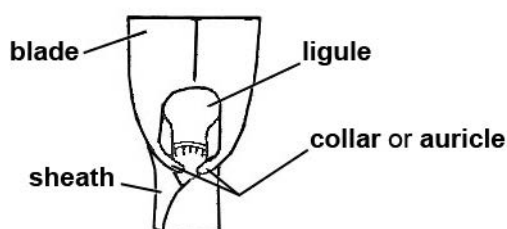
- ▶ Information management systems for long-term assessment of pest, crop and production systems
- ▶ Resistance management strategies to maintain reduced-risk, low toxicity compounds in the production system
- ▶ Area-wide management strategies (multi-field and multi-grower pest control)
- ▶ Prevention based strategies using cultural, host plant resistance, physical, mechanical and other non-chemical strategies
- ▶ Beneficial species management

IPM Components*

IPM is a long-term approach to managing pests by combining biological, cultural, and chemical tools in a way that minimizes economic, health and environmental risks; there are five essential components to an IPM program.

1. Understanding the ecology and dynamics of the crop. It is important to gather all of the available knowledge about the crop we are growing.

Monocot Anatomy



Most, if not all, pest problems can be directly related to the condition of the crop. The more we know about the ecology of the crop, the better pest management decisions we can make.

2. Understanding the ecology and dynamics of the pest(s) and their natural enemies. It is not only important to know what pests are present but also to know the details of their life cycles, what makes their populations change, whether any natural controls are present, and what effects these may have on the pests. By knowing as much about the pest as possible we may find some weak point that we can exploit.

3. Instituting a monitoring program to assess levels of pests and their natural enemies. It is vitally important to continually monitor the pest levels in the field. This is a crucial aspect of the IPM approach. By knowing how many pests are present we can make the best decision about how much damage they might cause to the crop. If natural enemies are present we need to know how many are present as well because they may take care of the pest problem for us.

4. Establishing an economic threshold for each pest. Effective monitoring and use of economic thresholds make up the core of any IPM program. What is an economic threshold? It is the level of a pest population above which, if a control action is not taken, the amount of damage caused by the pest will exceed the amount it costs to control that pest. In other words it is the level of the pest population at which the control measure used pays for itself.

5. Considering available control techniques and determining which are most appropriate. A wide range of control techniques are available for crop pests. They can be divided into 5 broad categories: chemical controls, such as pesticides; cultural controls, such as controlling plant vigor or rotations; biological controls, such as natural enemy releases or conserving natural enemies; behavioral control, such as the use of insect pheromones; and genetic control, such as the use of resistant varieties.

It is very important to choose the right control technique based on the economic nature of the pest problem, the cost of the particular control technique, and the effects of this technique on the environment and people's health.

IPM is an 'Approach' and Changes with Time

IPM is not a technique or a recipe, but rather an approach to identifying and solving pest problems. Particular techniques for pest management may vary from field to field, year to year, crop to crop, and grower to grower but the overall approach is always the same, using the 5 essential components of an IPM program. It is important to point out that an IPM program is not a cookbook approach. It would be nice if we could tackle a pest problem the same way every time, but history has shown us that this will not work.

An IPM program is never complete and is a process of continuous improvement. The reason for this is that over time we learn more about our crop, our pests and their natural enemies, and refine our monitoring programs. We also improve our economic thresholds, and develop new control strategies. Furthermore, we periodically get new pests. As we gain more knowledge, we need to use it to refine our IPM programs to make them more effective and to ensure they will work in the long-term. This is the best way to minimize the economic impacts of pests and minimize the risks to our health and to the environment.

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Key Insect Pests of Potato

These are the main insect pests of potato that you and your scout should be able to recognize. Detailed information on scouting, disease cycles, and management are in the following chapters and in the **Pest Profiles section of the Appendix**.

Colorado potato beetles



Colorado potato beetles overwinter in Wisconsin about 6-8" underground in areas adjacent to fields. They begin to infest potato fields in the spring by walking into the fields. Females lay up to 500 bright yellow eggs on the lower leaf surface and larvae hatch in 4-9 days, depending on temperatures. There are 4 larval stages of the beetle, with the large larval stage (3rd and 4th instar) being the most damaging. Fourth instar populations burrow into the ground and pupate for 7-10 days and then emerge as adults. Summer adults can be damaging when present in high numbers. In the fall, adults head out of the field toward overwintering sites adjacent to field edges.

Potato leafhoppers



Potato leafhoppers do not survive the winter in Wisconsin. Populations are found in the Gulf Coast States and migrate northward in April and May on warm southerly winds. Large migrations of potato leafhoppers into Wisconsin occur in June and early July. Damage occurs through the sucking of the plant sap. Damage occurs when the phloem movement of plant nutrients and water is limited.

Potato aphid



Potato aphids overwinter as eggs on wild and cultivated roses. Eggs hatch in the spring and several generations live on plants in the rose family before winged aphids develop. Winged aphids migrate to susceptible plants in late June and July. Potato aphids are primarily important as vectors of viruses, particularly Potato Virus Y (PVY).

Potato aphids have an elongated body with a long pointed tail. The body color is usually pale green to yellow green and sometimes pink. Adult potato aphids are two to three times the size of adult green peach aphids, and when disturbed are highly mobile.

Interesting Fact

Female, non-winged aphids have the ability to give birth to 50-100 live young with 5-10 generations per year.

Green peach aphids



Green peach aphids are the most serious pest of seed potato production because they transmit the Potato Leafroll Virus and Potato Virus Y. The green peach aphid overwinters in Wisconsin as eggs on the bark of peach, plum, apricot, or cherry trees. Some green peach aphids migrate in from southern states. Nymphs hatch when the fruit trees are in bloom and reproduce parthenogenetically, giving birth to live young for 2-3 generations. Winged green peach aphids then develop and migrate to susceptible weeds and crops where they once again reproduce parthenogenetically.

Green peach aphids have an egg-shaped body that has a plump, rounded back abdomen. They are usually creamy white to light peach in color with an almost translucent appearance.

European corn borer



The **European corn borer** (ECB) is a sporadic pest of potatoes. In years when the first generation of the ECB occurs early, the preferred egg-laying sites in corn are not yet available and the pest moves to potatoes. Damage in potatoes occurs when ECB larvae feed on potato foliage. ECB larvae rarely occur in numbers substantial enough to cause economic damage, but if ECB larvae exist at high enough levels, feeding may cause enough defoliation to warrant a control. Additionally, stem damage may open up the plants to secondary disease infection.

Looper and Cutworms



Cabbage looper

The **looper and cutworm complex**, which are commonly known as “worms”, are not serious pests of potatoes but may cause problems if they are present in high numbers. **Black cutworms** migrate into Wisconsin in late May and lay their eggs on low-growing vegetation such as chickweed, curly dock, mustards, or plant residue from the previous year. **Variegated cutworms** overwinter in the soil as mature larvae or soil encased pupae. Adults emerge in June. Cutworms are large larvae that characteristically curl up into a tight C-shape if disturbed.

Cabbage loopers have a greenish body that tapers at the head with a thin white line along each side. They overwinter in Wisconsin in small numbers but the majority migrate in from the south in mid-July through September.

Tarnished plant bugs



Tarnished plant bugs are occasional pests of potatoes in Wisconsin. Tarnished plant bugs overwinter as adults under leaf mold, stones, tree bark, and among clover and alfalfa. Adults begin to emerge in late April to early May. After feeding for a few weeks, they migrate to lay eggs in a variety of hosts, including potatoes.

Tarnished plant bugs cause 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 bug 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.

Adults are $\frac{1}{4}$ inch long and half as broad. Coloration is variable, but they are generally brown with splotches of white, yellow, reddish-brown, and black. There is a clear yellow triangle tipped with a smaller black triangle on the posterior end of the abdomen.

Flea Beetles



Flea beetles are commonly found in Wisconsin potatoes but are rarely a serious pest. Potato flea beetles overwinter as adults in the field soil. Beetles become active when temperatures reach 50°F and emerge in late May and June. They begin feeding on weeds or volunteer potato plants until the crop emerges. Eggs are laid in the soil and larvae feed on potato roots and tubers. The adults are small, shiny black beetles with enlarged hind legs, which allow them to jump from foliage when disturbed. The second-generation adults emerge in July-August.

Adult flea beetles feed on both sides of the leaf, but usually on the underside where they chew small, circular holes through the tissue. The circular holes give the plant a shotgun appearance, which is characteristic of flea beetle feeding. Heavy feeding on young plants may reduce yields. Larvae feed on the roots and tubers but do not cause economic damage.

Aster leafhoppers



Aster leafhoppers are occasional pests of potatoes because of their ability to transmit a phytoplasma-like organism that carries Aster Yellows. Infected plants are generally stunted and have small tubers. Infected tubers will be dark in color when fried. The aster leafhopper must probe and feed on a host for eight hours before passing its phytoplasma-like organisms into the salivary glands where they are able to be transmitted.

The adult aster leafhopper is olive-green, wedge-shaped, and about $\frac{3}{8}$ inches in length. They have three pairs of spots on their head. Nymphs are similar in shape to adults, but are cream-colored and lack fully developed wings.

Aster leafhoppers do not overwinter in Wisconsin but migrate from the Gulf States on warm southerly winds. Early migrants are female and arrive in May and early June. Infestations may occur in June and July as local populations develop.

White grubs



White grubs are white-bodied larvae, $\frac{1}{2}$ - $1\frac{1}{2}$ inches in length, with brown heads and six prominent brown legs. Adults are June beetles seen in the spring and early summer. Most species have a three-year life cycle in Wisconsin. Adults emerge and mate in late May to early June. Females search out grassy areas, burrow into the soil and deposit eggs. Eggs hatch in 2-3 weeks and grubs begin feeding on roots and underground plant parts. With the onset of cold weather, the grubs move beneath the frost line.

It is during the second year that the most damage is done. Therefore damage is most severe in years following peak adult flights and continues throughout the growing season. In potatoes, the grubs eat large, shallow circular holes in the tubers. The above ground portions of affected plants do not reveal the injury. As a result, serious tuber damage can occur before the grower realizes there is a grub problem.

Armyworm



The **armyworm** is generally not a problem on vegetable crops; it prefers grasses and grains. However, grass weeds in potato fields will attract moths. Outbreaks are more common following cold, wet, spring weather. The moths usually appear in late April and early May. Grasses and small grains are the preferred host and blades are often folded and sealed to protect the eggs. There are 3 generations per season, with each generation lasting 5-6 weeks. The first generation is small and does little damage, however the success of the first generation produces later, more injurious generations of armyworms. The second larval generation which appears in July is the largest and most damaging generation to Wisconsin crops. The fall generation is typically not injurious and is often heavily parasitized by beneficial insects, fungi and viruses.

Key Diseases of Potato

These are the main diseases of potato that you and your scout should be able to recognize. Detailed information on scouting, disease cycles, and management are in the following chapters and in the **Pest Profiles** section of the **Appendix**.

Early Blight



Early Blight is a common foliar disease of potatoes. The pathogen overwinters in crop debris, infected tubers, and on other solanaceous plants. Spores are carried primarily by wind and infect potatoes under wet and warm conditions. Most disease development occurs during periods of alternating wet and dry weather conditions accompanied by periods of high relative humidity.

Germinating spores penetrate susceptible tissue directly or through wounds. Lesions are typically small and sunken with slightly raised margins. Early blight is more prevalent on older, senescing tissue and infection increases when plants have been predisposed by injury, poor nutrition, insect damage or other types of stress. Tuber infections occur mostly through wounds inflicted during harvest.

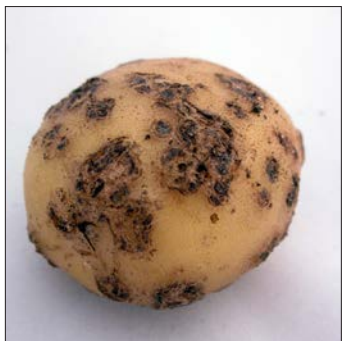
Late Blight



Late Blight is a serious disease on potatoes. There are two mating types of the fungus, the A1 and A2 strains that are found worldwide. If only one mating type is present, the fungus spreads through asexual reproduction by sporangia. When both mating types are present, sexual reproduction may occur resulting in oospores. Oospores have thick walls and are able to overwinter in Wisconsin in association with potato tubers and germinate using a germ tube that grows directly into mycelium (a fungal mass).

In spring, late blight grows on plants which develop from infected tubers, including cull piles, volunteer potatoes, and infected seed. The fungus is prevalent under moist conditions and it is dispersed by wind, water, machine, or human activity. During wet periods, zoospores (fungal spores mobile via water) are formed that increase infection. High humidity conditions (91-100%) and temperatures between 37-79° F (with optimal temperatures from 64-72° F) favor development of late blight. Temperatures above 86° F are not favorable for late blight development.

Common Scab



Common scab overwinters in the soil and survives indefinitely. Scab infection occurs through natural openings in the plant such as through lenticels and stomata, as well as through wounds. It is distributed to infected tubers by wind and water or through animals' manure. Warm, dry soils and early season stress favor scab development.



Rhizoctonia infection occurs when cool wet weather is encountered. *Rhizoctonia* overwinters in the soil as sclerotia on plant debris. Spores germinate in the spring and infect potatoes through wounds. High moisture, cool soil temperatures, pH less than 6, and high soil fertility levels favor *Rhizoctonia* development.

Powdery Scab

Powdery scab was first found in Germany in 1841 and in North America between 1911-1913. Although it is widespread and occurs in most potato producing areas, it was first found in Wisconsin in 2003. The disease develops best under cool, moist conditions. Powdery scab symptoms occur only on belowground parts of the plants. Symptoms on tubers are raised purplish brown lesions. Mature lesions on tubers have a scab like appearance and are filled with fine, brown colored resting spores. In storage, powdery scab infection sites also serve as entry points for other tuber rotting organisms.

Infection can occur on roots and stolons and first symptoms are small lesions or necrotic spots. These infection sites develop into milky white to tan galls. As galls mature they turn dark in color and eventually break down releasing resting spores into the soil. Powdery mildew infection sites often serve as entry points for other pathogens.

Powdery scab survives in the soil in the form of resting spores which can survive for up to six years and can survive passage through animal digestive tracts. Inoculum can be transported from field to field through the spread of infected seed, soil, and manure and perhaps on wind-borne particles. Soil temperatures of 52-64°F and alternating periods of wet and dry soil favor disease development. Powdery scab is often associated with poorly drained soils.

Few cultivars have true resistance to powdery scab, but russet-skinned varieties have more resistance to tuber infection though they still may be susceptible to root infection.

Guidelines for Powdery Scab Management:

- ▶ Ensure a powdery scab free seed source
- ▶ Avoid planting tubers infected with powdery scab
- ▶ Avoid fields with a history of scab infection
- ▶ Rotate out of infested fields for 3-10 years
- ▶ Control weed hosts of powdery scab
- ▶ Carefully manage irrigation

Scouting

In-season



Effective scouting during the growing season will ensure that pests are controlled only when they reach economically damaging levels, will ensure efficacy of the applied control measure, and will provide information regarding pest population changes over time and space.



Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A. Fields are occasionally scouted during the growing season**
- ☐ **B. Fields are scouted weekly for insects, diseases, and weeds starting at crop emergence and continuing until harvest. Fields are scouted utilizing the university recommended methods (sweeps, plant counts, leaf counts, etc.).**
- ☐ **C. Management strategies are monitored for their effect on target pests and non-target organisms. Information gathered from this monitoring is used to alter and/or improve management decisions in the future. Written records are kept for long-term comparisons of pest pressures. Pest pressures are tracked over time to check for changes in each field.**
- ☐ **D. Field maps of pest "hot spots" are created to observe general patterns of changes in pest populations over time within a field. These should maintained in a geo-referenced manner so that management plans can be implemented site specifically.**

A. Crop Scouting 101

Scouting is the regular examination of the crop condition and is the backbone of a successful IPM program. Scouting involves walking through a field and stopping at a number of locations to observe crop growth and check for the presence or signs of insect pests, beneficial insects, diseases and weeds. Accurate and timely scouting may prevent unnecessary pesticide treatments, and it helps you to identify potential problems before they become less manageable. The recorded information is also useful to prevent problems in the future.

The number of scouting locations should be determined by field size. One scouting site per 10 acres is recommended. To ensure that the entire field is represented in the scouting process, a W-shaped pattern should be followed across the field. If that is not feasible, the scout should walk the pivot tracks, and should make sure that a reasonable amount of the field is scouted, including the edges. Increasing the number of scouting locations provides better information to the crop manager for more informed management decisions.

Specific areas of the field should be scouted to look for certain pest problems. For example, scout the field's edge for early season Colorado potato beetles as the beetles leave overwintering sites. Completely inspect areas prone to disease development as well. These areas include locations near windbreaks, woodlots, low spots in the field, near irrigation pivots, or areas where fungicide applications are difficult to make such as underneath power lines or utility poles and near highways or residential areas. Scout these disease-prone areas throughout the growing season until harvest is completed.

Individuals who are interested in becoming scouts should take the University of Wisconsin Vegetable Crop Scouting class. Crop scouts must be able to properly identify pests, scout using the proper techniques, and provide an accurate analysis of field pest concerns and overall crop health. Crop managers should employ certified crop scouts or IPM trained farm employees to scout fields and provide accurate information for decision making. The University of Wisconsin IPM program offers a

Vegetable Crop Scouting class. Contact the IPM Coordinator, Bryan Jensen, at 608-263-4073 for more information.

B. Crop Scouting Calendars and Methods

Implementing the University of Wisconsin recommended scouting procedures will help growers receive an accurate account of pest populations found in their fields. Complete and accurate field diagnosis also provides information to improve the timing of chemical treatments. Specific instructions for scouting the important potato pests are provided in the tables at the end of the section. Scouting should occur at least weekly from emergence to vinekill, and pests should be noted on scouting form. Scouting methods include plant counts, sweep net samples, and general visual observations.



Quick Note

Scout weekly from emergence until vines are completely dead.

Weed Scouting

- ▶ Begin scouting when the potatoes emerge and continue until harvest.
- ▶ At each sampling site, note any weed infestations.
- ▶ Properly identify the weed species since this will dictate the control method.
- ▶ Record the numbers of weed species present and their locations within the field.
- ▶ If GPS is available, map weedy areas within a field by walking around the weed patch for long-term monitoring.

Horsfall-Barratt Disease Rating System

Foliar disease infections can be monitored using the Horsfall-Barratt disease rating scale. This scale, which runs from 0 to 11, takes into account the percentage of the field which exhibit disease symptoms. The scale should be recorded on the scouting form.

0= no infection

1=2-3% infection

2=3-6% infection

3=6-12% infection

4=12-25% infection

5=25-50% infection

6=50-75% infection

7=77-88% infection

8=88-94% infection

9=94-97% infection

10=97-100% infection

11=all foliage infected

C. Information Gathering and Management

Field scouting has many advantages beyond the simple determination of pest species and numbers. Scouting can provide information on the effectiveness of current management programs (including cultural, biological, mechanical and chemical control methods) and can aid in future management decisions. By tracking scouting data with management information, growers can determine the most effective, economical, and environmentally sustainable control method. It is recommended that pest population numbers and control strategy information be kept for 10 years for long-term analysis.

If data is discarded, the information cannot be used to guide better management strategies in the future.

D. Field Maps of "Hot Spots"

Long-term pest averages and numbers should be kept by the grower to watch the trends and changes in pest populations. Usually, there are areas within a field which are prone to pest infestations, especially with weeds and diseases. These areas of the field are known as "hot spots" and geo-reference mapping of such areas could provide valuable information from year to year. Mapping these areas using GPS can be done to assess the patterns and changes in these pest "hot spots" over time. Specifics on using GIS and GPS technologies can be found in the **Preplant/Rotational Pest Management** section.

Aphid Scouting

Take leaf samples from the middle of the potato plant to ensure an accurate account of the aphid populations. Potato aphids reside toward the upper portion of the plant, while green peach aphids reside toward the lower portion of the plant.

Leafhopper Scouting

Sample for both nymphs and adults. Do not treat if fewer than 0.5 adults per sweep are detected unless there are more than 2.5 nymphs per 25 leaves. If means estimates of adults range between 0.5 – 1.0 per sweep, treat if they remain at this level for > 10 days or if nymphs become present. If you observe mean adult numbers between 1.0 – 1.5 per sweep, treat within a week, or immediately if nymphs are present. When adult counts exceed 1.5 adults / sweep, treat immediately.

Scouting Key Diseases of Potato

These are the main diseases of potato that you and your scout should be able to recognize. Detailed information on scouting, disease cycles, and management are in the following chapters and in the **Pest Profiles** section of the **Appendix**.

Early Blight



Scouting should occur when weather conditions are favorable for early blight development - at 300 P-days (P-day calculations begin at crop emergence). Scout at least weekly throughout the growing season until the vines have completely died. Pay specific attention to older, senescing leaf tissue where early blight symptoms tend to appear first. Assess early blight incidence based on the Horsfall-Barratt disease rating system.

Late Blight



Scouting should occur just before crop emergence in sites where overwintering inoculum (such as near cull piles) may be present. After emergence, scouts should record disease symptoms at each scouting site weekly throughout the growing season until vines are completely dead. Scouts should look for late blight lesions as they are casually walking through the field as well. Scout additional sites which could be prone to late blight infections weekly. These include areas near windbreaks, woodlots, near the irrigation pivot, or near power or utility lines. Assess late blight incidence based on the Horsfall-Barrett disease rating system.

Scouting Key Insect Pests of Potato

These are the main insects of potato that you and your scout should be able to recognize. Detailed information on scouting, disease cycles, and management are in the following chapters and in the **Pest Profiles** section of the **Appendix**.

Colorado potato beetle



Begin scouting in early May when adults emerge from overwintering sites along field edges. Start scouting for bright yellow egg masses by looking at the lower surfaces of all leaves on a plant. Record numbers of adults, eggs, small larvae (1st and 2nd instars), large larvae (3rd and 4th instars), and estimate the percentage of defoliation per 10 plants at each site.

Colorado potato beetle are most vulnerable during the 1st to 2nd instar stages, and chemical controls should be applied when they are in these developmental stages. Growth and development is dependent on heat unit accumulations. Colorado potato beetle larvae can cause significant damage and defoliation, and the degree day model should be used for precise, accurate timing for larval control.

Threshold: Adult threshold levels of defoliation are as follows:

Plant Stage (Allowable Defoliation)

- ▶ Pre-flowering (20 -30% defoliation)
- ▶ Flowering (5-10% defoliation)
- ▶ Tuber bulking (30% defoliation)

Economic threshold levels for Colorado potato beetle adults

- ▶ 1st generation 4 adults/ plant
- ▶ 2nd generation 3 adults/ plant

Potato leafhoppers



Scout for potato leafhoppers by taking 25 sweeps per sample site and generate a mean abundance from samples collected at 5 sites. Record the number of adult PLH found in the net. Potato leafhopper nymphs are less mobile and are best scouted by leaf samples. Carefully turn over 15 leaves per sample site. Select the leaves from the middle portion of the plant. Record the number of nymphs found on the leaves.

Potato leafhoppers feed on plants using their piercing/sucking mouthparts resulting in stunted plants with yellow, triangular-shaped burned areas on leaf tips called “hopperburn”. Severe yield reductions have already occurred when this symptom appears in the field. Therefore, proper scouting needs to be done to ensure management at established threshold levels. Therefore, proper scouting needs to be done to ensure management at the threshold levels.

Threshold:

- ▶ Potato leafhopper adults: 25/25 sweeps
- ▶ Potato leafhopper nymphs: 1.5/15 leaves

Aphids



Aphids can be sampled by sweeping, but if aphids are found in the sweep net, then leaf counts should be taken to ensure the proper analysis of aphid numbers. Sample for aphids by examining 25 leaves at each sampling site. Leaves should be taken from the middle of the plant. Record the total number of adults and nymphs per leaf. Potato aphids tend to reside on the upper, newer leaves of the potato plant.

Threshold:

Fresh Market or Processing:

- ▶ Early season — more than 50 wingless aphids per 25 leaves (all species)
- ▶ After bloom — 100 wingless aphids per 25 leaves (all species)
- ▶ 50 aphids of any species per 25 leaves

Seed Potatoes:

- ▶ 2.5 green peach aphids per 25 leaves on virus susceptible varieties
- ▶ 5.0 potato aphids per 25 leaves on virus-susceptible varieties
- ▶ 7.5 green peach aphids per 25 leaves on virus resistant varieties

European Corn Borer



Begin scouting procedures at 500-degree days (around mid-June) and continue through 700-degree days (based on a developmental base 50°F threshold for degree day accumulation). Since the ECB is a sporadic pest, monitoring should be done before beginning any control program. To detect potentially damaging levels of egg-laying; adult moth flights can be monitored using a black light trap.

Pheromone traps are another way to monitor male moth activity. These traps are specific to individual moth species, which makes identification easier. Contact your local UW-Extension agents who have access to statewide monitoring programs for plant trap numbers.

Once adults are found in field, scouting for ECB egg masses and larval damage should occur. To scout, look for white eggs that overlap like fish scales on the lower leaf surface. There can be as many as 30-40 eggs in each mass.

Threshold: If European corn borer counts exceed 25 moths per trap per night, egg laying in potatoes may be high enough to result in sufficient larval feeding to cause economic damage. European corn borers prefer corn, and therefore, there is no need to treat unless egg masses and/or European corn borer larvae are present within the potato field. Spot treatments may be effective in localized areas within a field and damage is often more prevalent on specific varieties (e.g. Russet Norkotah).

Use degree day accumulation to determine peak flights (for more information the individual pest profile in the **Appendix**).

Looper and Cutworms



Sample by shaking the foliage of a five-foot row section into the furrow and counting the larvae on the soil surface. Worm populations (combining loopers and cutworms) can also be sampled using the sweep net method and counting the number of worms per 25 sweeps.

Threshold:

Prior to July 25: 20 larvae/5 foot section. Minimal defoliation will not cause yield losses.

After July 25: 40 larvae/5 foot section. Larger plants can sustain more defoliation without the threat of yield losses.

Tarnished Plant Bugs



Scout using a sweep net beginning in early to mid-July. Take 25 sweeps per site and count the total number of tarnished plant bugs in the sample.

Threshold: No formal thresholds are available.

Flea Beetles



Scout using a sweep net beginning early in the season when flea beetles are the most active. Look for damage on smaller plants where defoliation will likely be more prevalent. Flea beetles are not a pest later in the season.

Threshold: No established thresholds are available.

Aster leafhoppers



Scout when plants are newly sprouted in the spring and the leafhoppers begin infesting Wisconsin.

Threshold: No established thresholds are available.

Disease Management

In-season



An integrated disease management program which incorporates cultural, physical, mechanical, biological, and chemical control strategies should be utilized during the potato growing season.



Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A. Fungicides are applied according to a calendar schedule.**
- ☐ **B. Protectant fungicide applications begin at 300 P-days and/or 18 disease severity values (DSVs).**
- ☐ **C. Good growing practices produce a healthy crop that limits disease infections.**
- ☐ **D. Cultural control strategies are added to the potato disease management system. Growers and neighboring home gardeners control late blight as a community-wide disease.**

A. Calendar Applied Fungicides

Traditionally, fungicide applications for potato disease control began early in the growing season and continued at least weekly until harvest. Regular, frequent fungicide applications were the basis of many disease management programs. Today, new BioIPM techniques, including disease forecasting models and cultural, biological and reduced-risk chemical options, have advanced disease management strategies. Using these new strategies will assure a more effective fungicide program.

Disease Forecasting Model

“Blitecast”, developed at Penn State University, is a program module that has been adapted for Wisconsin and is part of the WISDOM and SureHarvest software systems. Currently, several private companies which support environmental collection systems also offer Blitecast and P-day packages. The model uses the duration of high relative humidity along with the corresponding range of temperatures to calculate severity values. Severity values represent the extent to which the daily environment has been favorable for disease development and sporulation. Calculation of severity values begins at crop emergence, and when 18 DSVs are accumulated, environmental conditions are favorable for disease development and fungicide control measures should be initiated. There is an approximate two week window from the time 18 DSVs are accumulated and the anticipated onset of disease symptoms.

B. Disease Forecasting Models

Disease forecasting models are useful tools to predict when disease incidence may occur as a result of weather and environmental conditions. The predictive models alert crop managers to start

protectant fungicide applications. Disease forecasting models for early blight and late blight are an integral part of the disease management programs for Wisconsin potatoes.

Annual Disease Forecasting

To view current season’s P-day and severity value accumulations at various locations throughout Wisconsin, visit the UW Vegetable Pathology website at <http://www.plantpath.wisc.edu/wivegdis/>

Calculations from data collected at monitoring sites in Antigo, Grand Marsh, Hancock and Plover can be found there.

For more accurate values, on-farm weather stations can be used and models can be run in the WISDOM or SureHarvest software systems, or other systems currently available.

Early blight infections are forecast with predictive models that calculate the physiological age of potatoes. Physiological days (P-days) calculate the age of potatoes using high and low temperatures. When 300 P-days accumulate, sporulation of the pathogen (*Alternaria solani*) is likely to increase, potatoes become vulnerable to the disease, and protectant fungicide sprays should be initiated.



Early blight on potato foliage

Calculations for P-day values are based on potato developmental temperatures. The potato plant grows at temperatures above 45° F and below 86° F (optimal potato growth occurs at 70°F). Outside this range no P-day accumulations occur. The maximum P-day accumulation in one day is 10, and that occurs with a continuous temperature of 70° F for 24 hours.

Severity Value Accumulations based on Environmental Conditions

Average

temperature range*

	0	1 (trace)	2 (slight)	3 (moderate)	4 (severe)
45 - 53°F	15 hours	16-18 hours	19-21 hours	22-24 hours	25-27 hours
54 - 59°F	12 hours	13-15 hours	16-18 hours	19-21 hours	22-24 hours
60 - 80°F	9 hours	10-12 hours	13-15 hours	16-18 hours	19-21 hours

*Average temperature of period when relative humidity > 90%

At 45-53°F and >27 hrs of relative humidity >90%, total severity values = ((Total hours- 1)÷3) - 4

At 54-59°F and >24 hrs of relative humidity >90%, total severity values = ((Total hours- 1)÷3) - 3

At 60-80°F and >21 hrs of relative humidity >90%, total severity values = ((Total hours- 1)÷3) - 2

Late blight infections are forecast using the disease severity value model. Fungicide sprays should be initiated when 18 disease severity values (DSVs) have accumulated. Historically, 18 DSVs accumulate in Wisconsin between mid-June and mid-July. The early accumulation of 18 DSVs usually predicts a high risk of late blight infection if there is a local inoculum source.



Late blight on potato foliage

Disease severity values are numbers that can be calculated each day based on two factors:

The number of hours the relative humidity is at or above 90%

High and low temperatures during the high humidity period

Calculations of severity values begin at crop emergence and continue throughout the growing season.



Quick Note

Protectant fungicides applications should begin when 300 P-days and/or 18 DSVs have accumulated. Fungicides should be applied with the correct equipment, nozzles, and pressure to ensure complete plant coverage. If aerial applications occur, field edges should be ground sprayed to provide adequate coverage.

C. Reduce Plant Stress and Increase Potato Health

Many pathogens are opportunistic and attack plants that are already stressed by malnutrition, water, heat, or by insects, weed competition or other diseases. Good healthy potatoes will aid in the reduction of disease pathogen infestations.

Early blight is more prevalent on older, senescing tissue and particularly when plants have been predisposed by injury, poor nutrition, insect damage or other types of stress.

Tuber infection does not occur before harvest because the spores do not percolate in the soil. Most tuber infections occur when the periderm is damaged during harvest operations. The spores will not penetrate intact periderm.



Early blight on tubers

D. BiolPM Techniques for Disease Management

Alternate host species provide reproductive and overwintering sites for late blight and early blight pathogens and commonly serve as inoculum sources for both the early and late blight pathogens. These hosts include tomato, eggplant and most plants in the *Solanaceae* (nightshade) family. Volunteer potatoes, cull piles and other waste tu-

Notes:

This image shows a full page of a document template designed for handwritten notes. It features a series of evenly spaced, light blue horizontal lines across the entire width of the page. The lines are thin and consistent in color, providing a guide for writing without being distracting. There are no margins, headers, footers, or other markings present on the page.

Since late blight is a community disease discuss disease control strategies with neighboring growers and home gardeners. Neighbors can have a direct effect on the late blight pressure on nearby farms, and therefore, growers should ensure that their neighbors are properly applying fungicides when models indicate, and that they remove plants which exhibit symptoms.



Late blight on hairy nightshade

If late blight is found in a field, apply fungicide to the uninfected portion of the crop first, and then apply fungicide to the infected area. Exercise caution when re-entering the uninfected portion of the field and sanitize all equipment completely before entering the uninfected portion of the field and again before entering the next field. Vine desiccate the infected potatoes and include dessicant on a 20 foot border from each edge of the infected patch. Once vines are desiccated, reapply fungicides until no green tissue remains. Plow down the infected areas and monitor the plants for any regrowth or lesions. If regrowth or lesions are found, reapply vine desiccant and fungicide. Continue monitoring areas near the infected sites (within the field and neighboring field) for the entire growing season.

Summary of IPM Strategies for Potato Diseases

Summary of IPM Strategies

Disease	Preplant	Planting	Inseason and Harvest
Late Blight	<p>Eliminate Cull Piles</p> <p>Limit seed source infection</p> <p>Seed treatments with some fungicides limit seed to seed spread of late blight</p>	<p>Do not plant new crop in field neighboring an infected crop</p>	<p>Begin protectant fungicide program at 18 DSV</p> <p>Manage solanaceous weeds in and around potato fields</p> <p>Scout early and often</p> <p>Ensure adequate vinekill prior to harvest</p>
Early Blight	<p>Crop rotation, field sanitation</p>		<p>Maintain preventative fungicide program starting at P-Day 300</p>
Fusarium	<p>Start with healthy seed</p>	<p>Avoid deep planted seed</p>	<p>Harvest after appropriate maturity and skin set, avoid bruising</p>
Silver Scurf	<p>Start with healthy seed</p>	<p>Promote good soil drainage</p>	<p>Harvest after appropriate maturity and skin set, avoid bruising</p>
Soft Rot	<p>Start with healthy seed</p>	<p>Plant into warm, well drained soil</p>	<p>Harvest after appropriate maturity and skin set, avoid bruising</p>
Viruses	<p>Start with healthy seed</p>		<p>Apply horticultural oils when appropriate to deter feeding of insects vectoring virus</p>
Powdery Scab	<p>Ensure a seed source free of powdery scab.</p> <p>Avoid fields with a history of scab infection.</p> <p>Rotate out of infested fields for 3-10 years.</p>	<p>Avoid planting tubers infected with powdery scab.</p> <p>Control weed hosts of powdery scab.</p> <p>Carefully manage irrigation</p>	<p>Do not store powdery scab potatoes</p>

Insect Management

In-season



An integrated insect management program that incorporates cultural, physical, mechanical, biological, and chemical control strategies should be utilized during the potato growing season.



Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A. Insecticides are applied according to a calendar schedule.**
- ☐ **B. Insecticides are applied when populations reach economically damaging levels.**
- ☐ **C. Cultural control strategies such as spot treatments, crop rotation, or targeted scouting are also used for insect management.**
- ☐ **D. Management decisions consider beneficial insects and beneficial species as part of the pest control strategy.**

A. Calendar Spray Program

In traditional pest management systems, insecticides were the sole means of insect control and these chemicals were applied according to a calendar schedule. Field scouting rarely occurred and the actual number or species of insects present was not taken into consideration.

Current insect management programs include both scouting and precise timing of insecticide sprays targeting the vulnerable stages of the pest's life cycle. Using insect threshold levels assures more effective insecticidal sprays and less adverse environmental impact.

B. Threshold Program

Control strategies should only be used when insect populations have reached or exceeded economic threshold levels. Threshold levels are set to limit yield loss from insect damage to the potatoes. The control strategy managers wish to employ is their choice, and does not necessarily have to be a chemical application. Cultural, biological, physical, and chemical options are available to combat insect pests. For specific control options, see the pest profile area in Appendix A or try one of the bioIPM strategies discussed throughout this handbook.

C. Cultural Management Strategies

Advances in bioIPM techniques for insects, including cultural, biological, mechanical, and host plant resistance strategies provide many ways to combat pests in an integrated insect management program. Various cultural management strategies which limit or prevent pest levels should be included in the insect management program. Some of these strategies are described in the following paragraphs.

Spot treatments (only chemically treating the part of the field where pests are located) can be very effective for insect control. Spot treatments greatly limit the amount of pesticide used. This

limits the adverse effects of pesticides and impacts on beneficial insect populations can be lessened or preserved in non-treated areas. Spot treatments can be effective at preventing full field infestations. Spot treatments are most effective for insects that are not greatly mobile. Unlike highly mobile or flying pests, insects that walk or are in larval (e.g. worm) stages are more likely to remain in the area where they originate.



Spot treatments can be very effective

Examples of insects where spot treatments can be very effective include Colorado potato beetle control along field edges in the spring and spraying localized infestations of European corn borers as well as green peach aphid.

Flaming using propane torches can be an effective cultural control for **Colorado potato beetles** and provides more than 75% control of adult beetles. Propane flammers are especially effective for early season control of adults on plants up to 4 inches tall. Use flaming as an edge treatment to kill adult beetles when they are exiting overwintering sites and moving into the field early in the season.



Propane flamer

Flaming should occur daily during the first 2 weeks of beetle infestations and can be done by placing two burners on a rig on either side of the potato row and directing the burners at an angle toward the base of the plants. Adjust the nozzle distance, angle, and tractor speed so that the young plant foliage is not seriously injured but Colorado potato beetles are killed. The potato plants' stunted growth and appearance caused by flaming is temporary and will not adversely affect potato growth or yield.

Potato leafhoppers are found extensively in alfalfa fields. Once the alfalfa is cut, potato leafhoppers

Summary of management options for insect pests of potatoes

Pest	Cultural control	Mechanical control / Exclusion	Host plant resistance	Biological control
Colorado potato beetle	<ul style="list-style-type: none"> ▶ Long distance rotation ▶ Trap crop ▶ Chemical border treatment 	<ul style="list-style-type: none"> ▶ Adjacent Field Trenches ▶ Cold overwintering sites ▶ Vacuum suction or propane flaming ▶ Physical barriers 		<ul style="list-style-type: none"> ▶ Some general species of insects
Potato leafhopper	<ul style="list-style-type: none"> ▶ Avoid planting near alfalfa 	<ul style="list-style-type: none"> ▶ Determine timing of arrival from winds and pest updates 	<ul style="list-style-type: none"> ▶ Trichome varieties 	
Aphids	<ul style="list-style-type: none"> ▶ Grassy trap areas or early planted crop placed around fields to attract aphids 	<ul style="list-style-type: none"> ▶ Reflective mulches ▶ Altering planting and harvest timings 		<ul style="list-style-type: none"> ▶ Look for aphid mummies to see if parasitic wasps are parasitizing population

** FOR ALL: Spot Treatments in field to target only sites where insects are present and over thresholds can reduce insecticide applications and be extremely effective at managing insect pests.

rapidly migrate to the nearest host crop, including nearby potatoes. A cultural management strategy for potato leafhoppers in alfalfa stands is to cut the alfalfa prior to leafhopper damage. If your potato crop is near an alfalfa field, be aware of when the alfalfa is cut and scout the potato field immediately after cutting to determine if potato leafhoppers reach threshold levels.

Cultural controls for **loopers and cutworms** can be successful and greatly help in keeping looper populations down. To control overwintering looper larvae, spring plow debris. Keep weeds controlled in and around fields to reduce egg laying environments.

D. Beneficial Insects

Beneficial insect and fungal species within a field can greatly decrease pest populations. General insect predators may feed on the larval stages to reduce populations. Biological control will not

entirely suppress these populations, but may aid in an integrated control program.

Aphid species usually sustain high levels of mortality from natural enemies. **Parasitic wasps** frequently attack aphids. The wasps (which are microscopic and not seen by the human eye) lay their eggs in the aphid's body. The wasp's larva grows by feeding on the aphid and after it is done feeding, it breaks away and leaves an aphid mummy. An **aphid mummy** looks like a petrified aphid body and is usually stuck to the underside of leaves. To determine if parasitic wasps are located in a field, scout and note the number of aphid mummies found in the field. If high numbers of aphid mummies are seen, insecticide applications may not be necessary, as wasps



Aphid mummies

To maintain both predatory and parasitic beneficial insect populations, use low toxicity insecticides which do not damage the beneficial species. Certain materials, such as the systemic neo-nicotinyls, spinosad, and spinetoram compounds and other low risk insecticides are not detrimental to beneficial species and will allow beneficial populations to reproduce increasing the overall number of beneficials in the field. Traditional chemistries, such as OP's, carbamates, and pyrethroids usually are detrimental to beneficial species. When these compounds are applied, growers may want to reinvigorate the beneficial populations by releasing beneficial species.



Preserve beneficial insects by using a pest specific insecticide that won't kill the beneficial insects. Use of a broad spectrum foliar insecticide will kill the beneficial populations.



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Colorado potato beetle degree days accumulations

Degree days provide a means of predicting an insect's development and activity by monitoring time and temperature. Since insects are cold blooded, their body temperature is related to the temperature of the surrounding environment. As a result, the physiological activity of many insects is determined by environmental temperatures. Degree day calculations of Colorado potato beetle growth and development help to determine the most effective timing of pesticide applications.

Below 50° F, Colorado potato beetle growth is limited. In the Colorado potato beetle degree day accumulation model, growth starts at a base temperature of 52° F. Calculation of degree days begins when the first egg mass is found in the field and continues according to the following equation.

Calculating degree days for Colorado potato beetle growth and development.

Use the high and low temperatures for the day to calculate an average temperature, and subtract 52.

Example: High temperature = 80° F

Low temperature = 60° F

Average temperature: $(80 + 60) \div 2 = 70^{\circ}\text{F}$

$70 - 52 = 18$

The degree days for this particular example are 18.

If the average daily temperature is below 52° F, no degree days are accumulated

Degree day accumulations for the Colorado potato beetle are as follows:

Life Stage	Degree Day	Cumulative Degree Days
*Egg	120	120
*First Instar	65	185
**Second Instar	55	240
**Third Instar	60	300
Fourth Instar	100	400
Pupae	275	675

* the most susceptible life stage for novaluron foliar applications

**the most susceptible life stage for most foliar insecticide applications.

Important point to remember - do not treat fields unless scouting reports **verify** that Colorado potato beetles are present at or above economically damaging levels.

Weed Management

In-season



An integrated weed management program which incorporates cultural, mechanical, biological, and chemical control strategies should be utilized during the potato growing season.



Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A. Weeds are controlled solely by chemical means.**
- ☐ **B. Herbicides are applied at reduced rates where possible, and herbicide modes of actions are rotated. Tillage practices are timed for weed control.**
- ☐ **C. Overall plant health is encouraged through proper fertility, insect and disease control. Weeds are controlled prior to canopy closure.**
- ☐ **D. Advanced cultural management strategies are utilized when possible. These include the use of smother crops, tilling and mowing field edges, and controlling weeds during fallowing periods and in rotational crops.**

A. Chemical Weed Control

Traditionally, weeds were controlled solely through the use of herbicides and often no other cultural or mechanical control methods were used. With the advancement of BioIPM strategies, growers can now manage weeds in a more comprehensive, year-round program.

Benefits and Disadvantages of Tillage

Benefits:

- ▶ Not restricted by windy weather
- ▶ Does not increase toxicity values
- ▶ Aerates the soil
- ▶ Effectively controls annual weeds

Disadvantages:

- ▶ May damage potato roots and foliage
- ▶ Increases soil compaction and erosion potential on sloped ground
- ▶ May require repeated operations
- ▶ Only effective early in the season

In addition to reducing the herbicide rate, think about what herbicides are available later in the season to control weed escapes not controlled by tillage. Postemergent herbicide applications should include chemical classes not used in a preemergent application. For example, if metribuzin is used in a pre-emergent application, it should not be applied in a postemergent application unless it is tank mixed with a chemical from a different herbicide class that will augment metribuzin's efficacy. For help in rotating herbicides, refer to Appendix C which lists all the potato herbicides by their chemical class.

B. Reduced Rate Herbicides and Tillage Practices

Reducing the herbicide application rate can significantly diminish the potential for ground-water contamination. Reduced rates provide good weed control when coupled with timely tillage operations. Tillage, such as during potato hilling, is very effective in controlling small, shallow rooted annual weeds early in the season and less effective later in the season when weeds are larger. Don't cultivate in overly wet soil or irrigate after cultivation, as wet conditions allow weeds to re-root. Don't reduce herbicide rates to the point where weed control is compromised and weed seed production occurs as this can lead to selection for resistant weeds.



Cultivating weeds in potatoes

Annual broadleaf seedlings are generally very susceptible to uprooting by cultivation. They are also susceptible to specific soil and foliar herbicides that provide excellent control when properly applied. Optimal application timing is important in controlling annual broadleaf weeds with foliar sprays as many of these herbicides will not control larger annual weeds. Annual broadleaves that reach larger size are generally more difficult to manage.

As with broadleaf weeds, annual and perennial grasses infest potato fields. Young grass seedlings are easily controlled with cultivation, but as they get older, they may re-root after a cultivation.

Most annual grasses are easily controlled with preemergent herbicides. Emerged annuals and perennials can also be controlled to varying degrees with postemergent herbicides, but do not rely solely on these herbicides as resistance selection may occur. Perennials can also resprout when the top growth has been removed as long as the storage organ is intact. Avoid planting into fields heavily infested with perennials.

Herbicide resistance in weeds

To be effective, herbicides must come into contact with and be absorbed by plants. Once in the plant, the herbicide must travel to a specific site of action which disrupts some critical growth process resulting in weed death. The term “mode of action” refers to the specific growth process that is disrupted by the herbicide. The mode of action also dictates how the herbicide is applied.

An understanding of how herbicides kill weeds is necessary for selecting and applying the correct chemical for a given weed problem and for preventing herbicide resistance.

In general, herbicides fall into three different types depending on how the weed uptakes the herbicide and how the weed is killed.

- ▶ Soil-applied herbicides are taken up by the weed as it germinates and begins to grow
- ▶ Foliar- applied herbicides act as a contact and "burns" the foliage to kill the plant
- ▶ Foliar-applied systemic herbicides in which the chemical travels into the plant tissue and is transported to its site of action

Some chemicals can be used in more than one way. For instance, metribuzin can be used preemergent or it can be used as a postemergent foliar spray (on select potato varieties and types; others can be severely injured).

The repeated use of herbicides with similar modes of action on the same site over a period of years has resulted in weed biotypes that are resistant. Weed resistance occurs when a weed that is normally controlled by the applied herbicide dose survives the herbicide application in the absence of abnormal application or environmental conditions that may affect control.

Characteristics of herbicides or herbicide families that contribute to the development of herbicide resistance are:

- ▶ Specific mode of action with a single target site
- ▶ Effective in killing a wide range of weed species
- ▶ Long soil residual activity
- ▶ Frequent use in season and from year to year without rotating, alternating or tank mixing with other herbicide classes

Prevention is important to avoid the development of herbicide resistant weed populations. Preventative measures are designed to break the cycle of constant pressure that selects for herbicide resistance.

- ▶ Rotate crops and herbicide modes of action among years
- ▶ Plan a 4 - 5 year crop rotation that addresses herbicide rotation
- ▶ Avoid sequential applications of high risk herbicides (ALS, ACCase)

Within years

- ▶ Use multiple modes of action and integrate with cultural and mechanical control
- ▶ Choose herbicide families that pose a low risk of developing resistance
- ▶ Follow all label instructions
- ▶ Control escaped weeds prior to seed production
- ▶ Use scouting information to determine the location of weeds
- ▶ Tank mix herbicides with different modes of action when allowed by the herbicide labels

C. Canopy Closure for Weed Management

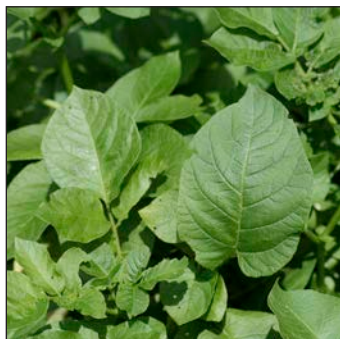
Utilizing early-season potato emergence and canopy closure can drastically reduce competition from weeds and optimize yield. Maximum shading from the canopy will occur at approximately 7-8 weeks for most cultivars depending on row and seed spacing. At that time full season cultivars like Russet Burbank will provide approximately 97-100% reduction in light reaching the soil surface which is enough shading to prevent growth of most weeds. Earlier maturing varieties such as Superior will only provide approximately 90% shade which greatly slows, but does not stop weed growth. Full season cultivars will typically maintain that shade until late in the season which prevents weeds from growing and limits the need for any further herbicide application. Weed growth that occurs with early maturing varieties is usually not enough to interfere with potato growth or harvest.

The key to understanding the canopy in weed control is knowing that a combination of herbicides and cultivation is needed for only 7-8 weeks (when maximum canopy shading occurs).

An important factor to remember in utilizing the canopy is that the plant's overall health must be maintained through proper fertility and irrigation as well as insect and disease control. Any canopy breakdown can allow weed growth. Therefore, selection of disease-resistant varieties is an important choice in managing weeds.



Measuring light prior to canopy development



Canopy closure is an important factor for weed control

D. Advanced Cultural Management

Advanced cultural or mechanical weed management methods should be used when possible and when the situation dictates. These alternative strategies will help in weed control and may limit the need for herbicide application.

One of these methods is to inter-seed **smother crops** between the potato rows. This technology provides a rapidly growing crop that will shade between the rows providing weed control before the potato crop is able to fully shade the soil surface. Crops that have been used as smother crops include dwarf brassica and some of the mustard crops. Ensure that the inter-seeded crop does



Mustards are a good smother crop

not act as a weed itself, competing with the potato crop. Provide the potatoes with adequate nutrition and water and use only short-lived smother crops which will die before competing with the potatoes.

Weeds need to be controlled in and around the field as well and in areas adjacent to but not in the potato crop. This prevents the spread of weed seeds, decreases the weed seedbank and controls alternate plant hosts for disease and insect pests. **Mow ditches** and corners of pivots and till headlands or any other bare soil where weeds are growing.

Controlling weeds during fallow periods and in rotational crops will improve weed control in the potato season. Agronomic crops grown in rotation with potatoes often have more integrated weed control options and are more competitive with weeds. Crops such as field corn and soybean can reduce the weed seedbank prior to the potato season. Perennial weeds are also easier to control in other crops grown in rotation with potatoes.

Plant Nutrition

In-season



In-season applications of nutrients to potato should focus on split-application of N or other leachable nutrients and utilizing petiole sampling to guide the need for supplemental N later in the growing season.



Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A. Nitrogen should be applied following University guidelines and split applied on sandy soils**
- ☐ **B. Consider using controlled release fertilizers or enzyme inhibitors**
- ☐ **C. Petiole nitrate samples are taken to justify supplemental nitrogen**
- ☐ **D. Hill shape is modified to ensure optimal water and nitrogen use efficiency**

A. Split Application of Nitrogen

After N is applied at planting, the remaining N applied should be split over at least two applications. The guidelines for N fertilizer rate in UWEX A2809 Table 6.3 include the amount applied as starter (see **Planting: Soil Fertility and Plant Nutrition**). A typical in-season application system would have 1/3 to 1/2 of the N applied at emergence and 1/2 to 2/3 applied at tuber initiation. A three-split program would apply N every 7 to 10 days starting at emergence. However, there are many different possibilities for timing, rate, and source of each N application. Each grower will have to experiment with their system to find the right combination for their field and crop. It is important to note that excess N applications to potato, especially when applied well after emergence, may stimulate excessive vine growth, leading to delayed tuber maturity and lower solids content in the tuber.

B. Controlled Release and Enzyme Inhibitors

Polymer coated urea

Polymer coated urea products are those where each granule of urea is coated in a plastic polymer coating. Water is able to move through the coating to dissolve the granule in place and the dissolved nitrogen diffuses back through the coating and into the soil environment. The release of N from the coating is a temperature dependent process, so the N will stay protected during colder periods of the growing season, when there is little plant uptake. Recent research in Wisconsin and Minnesota has shown that these products can be applied as a single application and maintain potato yield and reduce nitrate leaching losses on sandy soils. However, it should be noted that this product will be more expensive than regular urea and reduces the N concentration of the fertilizer to 44% (compared to 46% N in urea). Growers are encouraged to test these products out on a small scale and evaluate their effectiveness over several growing seasons.

Urease and nitrification inhibitors

Urease inhibitors are fertilizer additives that chemically inhibit the soil enzyme urease in a zone

around the urea granule. The urease enzyme is responsible for promoting urea hydrolysis, the first step in the conversion of urea into plant available N. If the breakdown of urea occurs on the soil surface, N can be lost from the soil system due to volatilization, the loss of N in the gaseous form of ammonia (NH_3). Inhibition of urease will protect surface applied urea from volatilization up to 14 days depending on weather conditions. Hot, wet conditions will promote the resupply of urease around the urea granule. The greatest benefit from using this product is when urea is surface applied and not incorporated or watered into the soil (through rain or irrigation) for three days. If urea is incorporated, such as with hilling, there is little value of this product. Urease inhibitors should not be used with non-urea containing fertilizers.

Nitrification inhibitors

Nitrification inhibitors are fertilizer additives that inhibit or kill the soil bacteria responsible in the first step of the nitrification process, which is the conversion of ammonium (NH_4^+) to nitrate (NO_3^-). Nitrification is a two-step process, where ammonium is first converted into nitrite (NO_2^-) by the soil bacteria *Nitrosomonas*. The second step is where nitrite is converted into nitrate by the soil bacteria *Nitobactor*. The delay in converting ammonium to nitrate can be valuable for keeping plant available N in the root zone. Once plant available N exists as nitrate it can be lost from the soil system via leaching or denitrification. The greatest value with using nitrification inhibitors have been found with fall applied fertilizers, tile drained soils, and on wet or poorly drained soils (where loss to denitrification can be high). Nitrification inhibitors are only valuable when applying ammonium based fertilizers (e.g. urea, ammonium sulfate) and are less effective when applied with fertilizers that contain nitrate (e.g. UAN solutions, ammonium nitrate) because much of the applied N already exists in the nitrate form. It is unclear how well nitrification inhibitors work on sandy soils.

C. Petiole Nitrate Sampling

For potato, visual estimates of crop health are not adequate to determine additional crop needs. Petiole sampling for potato is a diagnostic tool used to determine nutrient status. For potato, the

petiole is used rather than the leaf because it is more responsive to indicate nutrient stress in the plant. This is of particular value when it comes to detecting nitrogen stress or deficiency. The petiole nitrate concentration can be used to guide rescue N applications later in the growing season. Petiole sampling should be started approximately 30 days after emergence and continue at 7-14 day intervals until approximately 65 days after emergence. Potatoes absorb little or no nitrogen after 70 days, so continued sampling is unwarranted.

Samples should be taken before noon because petiole nitrate concentrations can fluctuate greatly as plants grow throughout the day and internal moisture levels change. Sample only from the newest fully mature leaf, which is typically the fourth or fifth leaf down from the growing point. Older or younger leaves will not accurately represent the plant's nutritional status. Sample forty to fifty petioles from a given area and take samples following the same pattern used for soil samples. Sample field areas that differ in soil type or in cropping history separately. If the samples are going to be sent to a lab for dry tissue analysis, the petioles can be put into a paper bag and be "sun dried" before sending to the lab.

When analyzing nitrate-N in the petiole sap, the test should be conducted immediately. However, samples can be stored on ice or in a refrigerator for 24-48 hours without affecting the results.

Samples should be stored as cold as possible in airtight zip-lock bags to avoid moisture loss and incorrect readings.

The tables below list optimum petiole nitrate levels for several varieties and stages of growth. If levels are below optimum and the crop has at least 45 days to vine kill, apply 30-50 lb N/a. Early season supplemental N rates should be reduced by 25-30% if N levels will be monitored through petiole nitrate testing to gain the most economic value out of testing.

D. Hill Shape

Hill shape can influence water and nitrogen use efficiency. When hills are round-topped or pointed, more water runs off into the furrow than percolates through the hill and root zone. These hill types do not hold nitrogen well because the water carries nutrients into the furrow. Implements that create flat topped hills with a small ridge on either side have recently become available. Hills formed in this manner allow better water use efficiency by forcing more water to flow through the hill rather than running off the side of the hill. These flat topped hills also provide better nitrogen use efficiency as less of the nitrogen is washed down the side of the hill. It is possible that the improved water use efficiency may result in improved nitrogen use efficiency and reduce the loss of nitrogen to the groundwater.

Optimum Petiole NO₃⁻ N Levels for Several Potato Varieties at Different Growth Stages (Table 6.4, UXEX A2809)

Stage of growth (days after emergence)	Dry weight basis			Sap basis		
	Norkota, Norland, Atlantic, Kennebec	Shepody, R. Burbank, Snowden	Onaway, Superior	Norkota, Norland, Atlantic, Kennebec	Shepody, R. Burbank, Snowden	Onaway, Superior
	----- % NO ₃ ⁻ N -----			----- ppm NO ₃ ⁻ N -----		
30	2.5–2.8	2.0–2.3	2.3–2.5	1,900–2,100	1,600–1,800	1,800–1,900
40	2.3–2.5	1.7–2.2	2.0–2.3	1,800–2,000	1,600–1,700	1,600–1,800
50	1.8–2.3	1.2–1.6	1.5–1.9	1,400–1,800	1,000–1,300	1,200–1,500
60	1.3–1.9	0.8–1.1	0.9–1.2	1,100–1,500	700–900	500–1,000
70	0.8–1.1	0.5–0.8	0.4–0.6	700–900	500–700	400–600

Irrigation

In-season



Irrigation management strategies which provide adequate water without over watering should be used to ensure proper growth and development of the potato crop.



Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A. Irrigation is applied to ensure proper water to the crop.**
- ☐ **B. Irrigation scheduling tools are used to determine irrigation timing and amounts.**
- ☐ **C. Disease management and stress concerns play a key role in irrigation decisions.**
- ☐ **D. Water is applied efficiently throughout the crop cycle to reduce physiological stress and adverse environmental effects.**

A. Irrigation

The goal of water management is to maintain adequate soil moisture throughout the growth of the crop, while avoiding extremes and excessive fluctuations. Water constitutes approximately 90-95% of the foliage and 75-85% of the tubers. For potatoes, the soil moisture status becomes critical when water levels reach 60-65% of available soil water. Plants become stressed when only 35-40% of the available soil water is used. At the other extreme, excessive soil water can cause plant stress as well as leach nutrients.

Available Soil Water

The **available soil water** is the difference between a soil's field capacity (total amount of water that can be held by a soil) and the permanent wilting point (point at which plants wilt and die). As potatoes show stress and loss of yield and quality before the permanent wilting point is reached, there is a critical amount of available soil water that can be depleted. That critical depletion amount is called the **allowable depletion**.

The maximum allowable depletion for the potato crop is at 60-65% of available soil water. Although the allowable depletion is 60-65% of the available soil water, most growth stages of the potato crop require at least 70-75% ASW for optimal growth. See section D for further explanation of water use efficiency. If the field is allowed to go below the allowable depletion, significant stress will occur and yield and quality will suffer.

The majority of Wisconsin growers use center pivot overhead irrigation systems but some of the crop is irrigated with traveling gun or linear systems. A small percentage of the crop is irrigated through solid set systems. Regardless of the system used, it is critical that the application rate be matched to soil infiltration rate and crop use.

Advantages of overhead irrigation include uniform water distribution, good control of the amount of water applied, and the capacity to apply fertilizer and pesticides without making additional trips across a field. A major disadvantage of overhead irrigation is the high energy required to pressurize the systems. Energy costs can be reduced by using low pressure nozzles which also increase water use efficiency.



Irrigating potatoes

Some smaller-scale, fresh market growers use drip irrigation systems. The high cost of equipment and the labor required to lay drip tubes prohibits this technology's use on larger commercial fields.

B. Irrigation Scheduling Tools

Whatever the type of irrigation system, use irrigation scheduling to balance crop use with irrigation and rainfall. The simplest tool to use is a check-book method to track water use and irrigation needs. In this approach, crop water use is calculated using evapotranspiration. When calculations show that the allowable depletion is reached, irrigation is applied to bring the available soil water back to desired levels

The amount of available soil water can be derived from the WISDOM or SureHarvest computer irrigation scheduling tools, which are based on the Wisconsin Irrigation Scheduling Program (WISP). The irrigation-scheduling module requires the input of the following parameters for successful and effective operations:

- ▶ Allowable depletion value for the soil
- ▶ Initial allowable depletion balance at crop emergence
- ▶ Amount of rainfall and irrigation applied to the field
- ▶ Daily evapotranspiration estimate

Evapotranspiration (ET)

Irrigation schedules are based on an estimation of the amount of water the plants require each day. Crop water use is referred to as **evapotranspiration**. This is the sum of two forms of water loss, evaporation from the soil surface and transpiration from the plants.

Evapotranspiration (ET) is affected by several climatic factors and plant characteristics. It increases as sunlight, temperature, and wind increase and as the size of the plant canopy increases. It decreases as the relative humidity increases and as stomata on the leaves close in response to water stress.

Various methods have been developed for estimating daily ET. ET numbers for production areas in Wisconsin and Minnesota can be viewed by accessing the WI-MN cooperative extension agricultural weather page at <http://www.soils.wisc.edu/wimnext/weather.html>. The Wisconsin Irrigation Scheduling Program (WISP) is a part of the WISDOM and SureHarvest programs. It uses daily ET to determine the current percentage of available soil water, the frequency of irrigation, and the amount of water to be applied.

- Percent canopy cover to adjust the ET when the crop is less than full cover

These inputs are used in a simple checkbook-like accounting format in which water deposits and water withdrawals are used to derive the allowable depletion balance. The allowable depletion balance reflects the current amount of soil water storage and can be used to determine irrigation frequency and amounts.

C. Disease Management

Irrigation often plays a crucial role in managing various diseases and physiological disorders. For instance, late blight development is favored by long periods of uninterrupted leaf wetness. During times of late blight concern, keeping leaves drier is preferred. On the other hand, water stress can also lead to disease concerns. Stressed plants are vulnerable to certain diseases, such as potato early dying.



Late blight on potato foliage

D. Efficient Water Use

The following guidelines describe optimum water management at various stages of the potato crop.

Growth Stage I: Vegetative

Irrigation management should be moderate and designed to promote optimal plant stands and canopy development. If the field is very dry before planting, the field should be pre-irrigated to field capacity before planting. After emergence, keep the field at 75-85% available soil water (ASW). By keeping the soil below field capacity, some soil water storage holding capacity is available to absorb rains. Early applied nitrogen could leach if rains fall on a soil at field capacity.

Growth Stage II: Tuber Initiation

Irrigation should again be moderate with the goal of preventing moisture fluctuations. Irrigation should maintain soil water levels from 75-85% ASW. Avoid excess irrigation that can lead to nitrogen leaching. Increasing ASW to 80-90% during tuber initiation and early bulking is important for reducing scab on susceptible cultivars.

Growth Stage III: Tuber Bulking

Soil water should be maintained at 75-85% ASW during early tuber bulking to minimize hollow heart and nitrogen leaching. As tuber bulking continues,

increase the soil moisture to 80-90% ASW to help reduce the potential for scab. Care must be taken during this period as excessive moisture can result in disease problems such as hollow heart. Minimize soil moisture fluctuations if possible.

Growth Stage IV: Tuber Maturation

Irrigation should reflect declining water use by the crop and declining canopy. As the canopy senescences, irrigation management should lower to 60-65% ASW. This will help weaken vines and aid in vine kill.

Harvest:

If soils become excessively dry after vine killing but before harvest, irrigate to bring the ASW back to the 65-70% range. Apply this irrigation about one week prior to harvest. This will allow the tuber to rehydrate and become more resistant to blackspot bruising. Avoid over irrigating as this may enlarge lenticels and increase storage problems and tuber decay from several different pathogens.

Plant Stress		
Growth Stage	Excess Soil Moisture	Deficient Soil Moisture
I - Vegetative	Stands will be reduced from increased seed piece decay. <i>Rhizoctonia</i> infection may be a problem especially if soils are also cold.	Can result in poor stands from the decreased healing of seed pieces. Will increase susceptibility to soft rot decay especially if the soil temperature is 10 or more degrees higher than the seed piece.
II - Tuber Initiation	Shown to result in increase in brown center, hollow heart and <i>Verticillium</i> .	Inhibits plant growth and fertilizer uptake. Soil water deficits increase tuber susceptibility to scab.
III - Tuber Bulking	Hollow heart may increase from fluctuations in soil water. Excess irrigation will increase diseases such as early and late blight and may leach nitrogen leading to nutrient deficits.	Slows tuber development and reduces yield. Knobs and other tuber malformations will increase. Premature plant senescence may occur which leads to increased problems with early blight and early dying.
IV - Tuber Maturation	Leads to enlargement of lenticels which may increase bacterial infection. Also favors development of pink rot, <i>Pythium</i> leak and late blight in tubers.	Dry soils will dehydrate tubers and increase likelihood of stem-end vascular discoloration. May also hinder skin set.
Harvest	Increases susceptibility to shatter bruise. Soil clings to tubers and may increase likelihood of tuber rot in storage.	Increases blackspot bruising during harvest. Increases clods in soil which will increase bruising.

Resistance Management

In-season



Resistance is simply a genetically controlled decrease in susceptibility of a population to a control measure. The occurrence of resistance to insecticides has been documented in well over 500 species resistant to one or more insecticides. Resistance can also take the form of adaptation to pest resistant crop varieties as well as adaptation to crop rotation. Resistance of pest populations to pesticides is an increasing problem in Wisconsin potato production. Proper resistance management strategies should be used to maintain the efficacy of available pesticide chemistries in the potato production system.

Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A. Pesticide resistance is considered when choosing a pesticide.**
- ☐ **B. Pesticides with different modes of action are used within a growing season and among rotation years. Pesticides are only applied at pest threshold levels or when weather conditions dictate that controls measure should be utilized.**
- ☐ **C. If systemic insecticides are applied at planting, foliar versions of that chemistry or similar chemistries are not used later in the season.**
- ☐ **D. The resistance management program considers the field's past history and future crops.**

A. Pesticide Modes of Action

Pesticides have a specific way in which they control pests known as the pesticide's mode of action, or target action site. Growers need to know these modes of actions so they can implement proper resistance management strategies. Ultimately, applying these strategies will minimize selection pressure and the likelihood that resistance to the various chemistries will occur and will further maintain more options for potato pest management.

The Environmental Protection Agency (EPA) and the Fungicide, Insecticide and Herbicide Resistance Action Committees (FRAC, IRAC, HRAC) have developed a voluntary pesticide labeling proposal that groups pesticides with similar modes of action and designates them with a group number. Look in **Appendix C** for the EPA resistance management groups for insecticides, fungicides, and herbicides.

Pesticide resistance develops in pathogens, insects and weeds in a variety of ways. In general, the pest species become resistant through natural selection of phenotypes exposed to a particular family of pesticides over a period of years. These pests have the genetic potential to pass along the resistant traits through reproduction. Many times the resistant traits are irreversible in the populations, and once resistance occurs, the pesticide will never work in the system again. Occasionally resistance is lessened in successive populations when the pesticide is not used for a length of time. For example, certain fungal populations may exhibit a form of "resistance" in one growing season, but become susceptible to the fungicides in the following years.



Mixing pesticides

Herbicide Resistance

The development of herbicide-resistant weed species is an increasing problem in Wisconsin. Most weed species contain a tremendous amount of genetic variation that allows them to survive under a range of environmental conditions. Resistance

develops through selection pressure imposed by repeated, often nearly continuous use of a herbicide, or several herbicides that have the same mode of action. Long residual preemergence herbicides, repeated application of postemergence herbicides, or application rates that are too high or too low relative to the amount needed for weed control, will further increase selection pressure.

Complete reliance on herbicides for weed control can greatly increase the likelihood of herbicide resistant weeds. This can be especially true for no-till or reduced till systems. Weeds that are most likely to develop resistance are annual weeds with high seed production and high germination rate; especially those that produce more than one generation in a year, or that are extremely sensitive to a particular herbicide.

B. Non-consecutive Spray

The genetic alterations that create resistant populations occur most rapidly when growers repeatedly apply pesticides with similar modes of action in consecutive sprays. Therefore, it is essential to not spray the same product or similar products against the same target pest in consecutive applications.

Single-site fungicides, including the new, reduced-risk Group 11 strobilurin fungicides, are prone to the development of resistance by pest populations. Recommendations for Group 11 fungicides are to completely avoid consecutive sprays of any Group 11 fungicide. This includes pre-mixed products which include a Group 11 material and tank-mixed applications with other, non-Group 11 materials.

Resistance management programs should incorporate BioIPM approaches which limit pest infestations, limit the number of applications needed, time the products appropriately, and target the vulnerable life stages. Specific strategies are listed in the text box at the end of the section, *Strategies to prevent resistance development*.



Herbicide application

Strategies to prevent resistance development

Growers should consider the following resistance management strategies and evaluate all chemical applications (fungicides, insecticides, and herbicides) as part of a comprehensive IPM program.

Fungicides

- ▶ For the strobilurin group of fungicides (Group 11 in Appendix C):
 - ▶ Always alternate any Group 11 compound with another mode of action, specifically a multi-site compound group, do not apply Group 11 compounds twice in a row, even if they are tank mixed with combinations of other fungicide classes
 - ▶ Do not exceed six applications of strobilurin fungicides per crop per acre per year. In Wisconsin, three applications are recommended
- ▶ Use disease forecasting programs and IPM approaches to target fungicides to when control is most needed
- ▶ Integrate lower risk fungicides into a season-long, seed to market disease management program
- ▶ Use BioIPM strategies which limit inoculum sources and disease potential whenever possible

Herbicides

- ▶ Rotate crops
- ▶ Rotate herbicide families and use herbicides with different modes of action in the growing year and between years
- ▶ Use herbicide mixtures with different modes of action
- ▶ Control weedy escapes and practice good sanitation to prevent the spread of resistant weeds
- ▶ Integrate cultural, mechanical, and chemical weed control methods

Insecticides:

- ▶ Rotate crops and select field locations to avoid high, early season pest pressure
- ▶ Scout pests using the correct method to get an accurate count
- ▶ Treat only at economic thresholds or vulnerable stages of insect development (see below).
- ▶ Time applications to target the most vulnerable life stages (e.g. eggs plus 1st and 2nd instar Colorado potato beetle larvae)
- ▶ Obtain good spray coverage and ensure that spray equipment is properly calibrated.
- ▶ Spot treat when feasible
- ▶ Take all pests into consideration to maximize sprays
- ▶ Preserve natural controls by using selective insecticides (e.g. spinosad, spinetoram) and by using selected uses of materials (timings, rates)
- ▶ Use cultural control to reduce populations
- ▶ Rotate potatoes 1/4 mile from previous crop
- ▶ Treat edges as trap crop in spring and fall
- ▶ Do not tank mix insecticides

C. Systemic and Foliar Insecticides

To limit the possible exposure of Colorado potato beetles to chloronicotine (neonicotinoid) active ingredients (Group 4A materials), it is recommended that these products only be used as a systemic (at-planting or seed treatment) OR foliar treatment. Do not use a Group 4A insecticide both systemically and as a foliar application in the same year. Products in this class include the active ingredients acetamiprid (Assail), clothianadin (Belay, Poncho), dinotefuran (Scorpion, Venom), imidacloprid (Admire, Alias, Brigadier, Gaucho, Genesis, Leverage, NuPrid, Provado, , etc.) and the thiamethoxam (Actara, Cruiser, Endigo, Platinum, Voliam Flexi). Refer to **Appendix C** for insecticide resistance management classifications.

Monitoring for pesticide resistance

Early detection is important if resistance is developing in a population of insects or weeds. Scout fields and be on the lookout for patterns that would indicate resistance. For weeds, look for patches in fields, escapes scattered in no particular pattern throughout the field, or patches of dense populations of weeds with some radiating out from the central patch. Whole fields infested with weeds or strips of weeds do not typically indicate resistance. If you are concerned that a particular insect or weed is becoming resistant, you can have it tested. University laboratories and private companies have procedures to test for resistant populations. Check with your county extension agent for further information about specific labs and how to take a sample.

D. Rotational Resistance Management

Successful resistance management programs incorporate an area-wide management approach and consider the field's pesticide history and pest populations from previous years as well as future plans and projections. The movement of pest populations, specifically for Colorado potato beetles from overwintering areas and early blight spores from the previous year's field, can have a major impact on the resistance management program. If localized populations develop resistance, using the chemistries where resistance is found will only increase the problems. Therefore, if there are resistance concerns, alternating different chemical classes with different modes of actions is extremely important.

Rotational resistance management strategies are most effective when field maps with locations of pest populations and the types of management strategies are kept from year to year. Growers should think of their programs in an area-wide framework and alternate chemical classes on adjacent fields one year to the next. Growers should also consider the projected applications for following years. More information on resistance management in rotational crops can be found in the **Preplant** chapter.



Colorado potato beetle adults and eggs

Biological Control

In-season



Strategies that promote beneficial species should be utilized whenever possible. Conservation and augmentative releases of beneficial species may have an effect on limiting pest populations within the field.



Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A. Beneficial insects and biological controls are considered part of the potato production system.**
- ☐ **B. Insecticides that are safe to beneficial insects are selected when possible.**
- ☐ **C. Beneficial habitat is maintained and beneficial insects and/or fungi are occasionally released.**
- ☐ **D. The potential for pest control by beneficial insects is known and considered in management decisions.**

A. Biological Control

Insect

Biological control uses naturally occurring organisms to control pests. Using biological control methods as part of a comprehensive IPM program can reduce the adverse environmental and public safety hazards of pesticides.

Beneficial organisms, also called “natural enemies”, fall into three categories: general predatory insects, parasitic insects, and insect pathogens (fungi, bacteria or nematodes). To implement biocontrol strategies, it is critical to first properly identify beneficial populations and then determine if biological control is a feasible control option for the field area and crop.



Lacewing larvae eating an aphid

For biological control to be effective, adequate prey (food) is required to be present at all times. If pest populations are too low, the beneficials may starve to death or leave the field. If pest populations are too high, the natural enemies may be unable to act quickly enough to protect the crop.

Maintenance of habitat in or around the field may increase beneficial species and may aid in biological control. Maintained areas may include non-agricultural areas which are ecologically diverse and have multiple species with a diversity of floral resources that include a range of color, shapes and sizes. These areas attract beneficial species and also serve as an area for them to reside when little prey (food) is available in the field.



Assassin bugs are an example of predatory insects

Pathogen/Disease

Biological controls of soilborne fungal or bacterial pathogens such as the white mold fungus, *Sclerotinia sclerotiorum*, and the common scab bacterium, *Streptomyces scabics*, are beginning to gain commercial adoption.



Biological control can help control crop pests

Biological fungicides are often soil-incorporated prior to planting or applied in-furrow at planting. These bio-fungicides can become a successful part of a multi-faceted disease management program over time.

Contans (*Coniothyrium minitans*) can limit white mold in susceptible crops including potato. Serenade Soil (*Bacillus subtilis*) can aid in common scab control of potato.

Remember that these materials have biological activity and rely on many environmental cues such as temperature and moisture for activity.

Conserving the natural enemies in your fields

- ▶ Avoid the use of broad-spectrum insecticides and fungicides.
- ▶ Reduce the impact of insecticide sprays by spot-treating, banding, timing treatments carefully, and choosing compounds with low toxicity and short persistence
- ▶ Maintain plantings that provide nectar, pollen, alternate hosts, and humid resting places in or near the field. Sweet alyssum, cilantro, and goldenrod are particularly attractive to adult syrphid flies and parasitic wasps but any non-invasive mix of plants that includes flowering plants and will be competitive with weeds will be beneficial.

Maintain overwintering sites for beneficials on the border of fields

B. Pesticide Selection

The choice of pesticides may have a large effect on beneficial populations. Broad spectrum insecticides and fungicides kill or eliminate pest species, as well as potential biological control agents found in or around fields. Therefore, carefully select pesticide options to protect biological control organisms. New, reduced-risk options which adequately match pesticide applications to pest species should be used when possible because these materials do not adversely affect beneficial populations. The pesticide toxicity calculation found in **Appendix B** includes in its scoring system each chemical's effect on beneficial organisms. Review this section to determine the reduced-risk options that do not adversely affect beneficial species.

Scouts should properly identify and count beneficial populations during normal scouting activities. If few to no beneficials are found, biocontrol will not be effective. If many beneficial species are detected, it is critical that only pesticides which do not harm beneficials are chosen.

C. Beneficial Insect Management

If beneficial populations are found, growers can maintain them by protecting or enhancing their habitats. To conserve beneficial species in and around fields, maintain the overwintering areas and field edges for natural enemies. To improve habitats, plant a variety of plant species that attract both beneficial organisms and non-pest hosts of the beneficial insects. Providing a variety of floral resources and plant types also aids in survival of beneficials.

Augmentative releases of biological control agents may be utilized. Biocontrol companies routinely sell predatory insects, such as lady bugs and lacewings, which can be put directly in the field. These agents may be effective if large quantities are released and the appropriate lifestages are present, normally the larval stages.

D. Biocontrol Potential

When insecticides are used which do not adversely affect beneficial species, many microscopic parasitic wasps are able to survive. These parasitic wasps feed extensively on aphid populations and it is possible for these natural enemies to control aphid populations. Broad spectrum insecticides will kill the parasitic wasp populations, but certain specific, targeted materials will not harm the wasps. To determine if natural enemies are attacking aphids, look for aphid mummies stuck to the leaf undersides. Parasitic wasps feeding on aphids result in the mummies. If a high number of aphid mummies are seen, insecticide applications may not be necessary.



Aphid mummies

Certain pathogens also have biocontrol potential. *Beauveria bassiana* is a naturally occurring fungi which can attack insect populations in the field. However, necessary protectant fungicide sprays usually limit its effectiveness in insect control. If you find Colorado potato beetles which are dead due to a fungal infection, this means that *B. bassiana* is present in the field and providing biological control.



Quick Note

When selecting pesticides choose insecticides that preserve natural enemies. Pesticides that are pest-specific help to maintain beneficial populations whereas broad-spectrum pesticides eliminate both pests and beneficial insects.

Specific Predators of the Colorado potato beetle

Predatory stinkbugs are voracious and can kill a large number of Colorado potato beetle larvae and other pest species in a short time. However, they are rarely present in numbers great enough to be of much practical value.

The **carabid beetle** is an aggressive predator and can cause high levels of mortality in Colorado potato beetle eggs. Larvae of the beetle feed exclusively on Colorado potato beetle larvae. This beneficial insect is very sensitive to most insecticides commonly used in potato fields and therefore may be of little value in commercial fields.

Parasitic flies can cause up to 80% mortality in the prepupal stage of the Colorado potato beetle, especially in second generation pests. This beneficial insect is a strong flier and appears able to rapidly colonize new potato fields at the same time as Colorado potato beetle adults.

The **ten-spotted ladybird beetle** is a generalist predator. It can cause as much as 35% mortality in first-generation Colorado potato beetles larvae and up to 60% in the second generation larvae. Both larvae and adults ladybird beetles also feed on aphids. Adult ladybird beetles overwinter in undisturbed habitats around the edges of fields.

Notes:

Common Predators of Insect Pests

Most predatory insects are called generalist predators because they feed on a wide variety of insects, rather than on a few specific species. Aphids, moth eggs, larvae, and pupae, are just some of the important prey for generalist predators.

You and your scout should learn to recognize the presence of these beneficial insects. Note that some of them are active in both the larval and the adult stages.

Lady beetles

Hippodamia convergens and other species



Lady beetle adult



Lady beetle larvae

Lady beetles are a large group of well-known beneficial insects. The convergent lady beetle, *Hippodamia convergens*, is one of the most common species in the upper Midwest. Other common species include the twelve-spotted lady beetle, *Coleomegilla maculata*, and the seven-spotted lady beetle, *Coccinella septempunctata*. All are important aphid predators in both the larval and adult stages.

Learn to recognize the lesser-known larval stage of the lady beetle as well as the adult. Larvae are active, black, elongated insects with bright red or orange spots and long legs and resemble tiny alligators.

Availability for release: Lady beetles are available commercially, but their use has been limited by their tendency to disperse. The best time to release is when prey is abundant.

Ground beetles

Many species, including Lebia grandis



© Gyorgy Csoka, Hungary Forest Research Institute

Ground beetles are probably the most numerous predatory insects in crop fields. There are hundreds of species of ground beetles, most of which are dark, shiny, and somewhat flattened. They live in cracks and burrows in the soil and debris and are fierce predators of caterpillars, larvae of other beetles, and seed maggots. They can consume their body weight in food daily.

Conserve ground beetles by reducing tillage to a minimum and not using broad-spectrum soil insecticides. Their survival will be enhanced by providing refuges and overwintering sites such as hedgerows or mulch.

Availability for release: Not available commercially

Syrphid or hover fly

Many species in the family Syrphidae



Hover fly adult



Hover fly larvae

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Syrphid or hover flies, also called flower flies, are common and important natural enemies of vegetable pests. The larvae of many common species of the syrphid fly feed on aphids and caterpillar larvae in snap bean. The pale green to yellow maggots have a slug-like appearance and can consume 400 aphids each during their development.

The adult flies resemble bees or wasps and are often seen visiting flowers. There are many different species that range in size from less than one-fourth of an inch long to more than three-fourths of an inch long. Many have the typical black and yellow stripes on the abdomen that give them a bee-like appearance.

The adults need flowers as nectar and pollen sources. They are attracted to weedy borders or mixed plantings that are also infested with aphids. Some flowers that are especially attractive include wild carrot or Queen Anne's lace, wild mustard, sweet alyssum, coriander, dill, and other small-flowered herbs.

Availability for release: Not available commercially.

Green lacewings

Chrysoperla spp.



Green lacewing adult



Green lacewing larvae

The adult lacewing is easily recognized as a slender flying insect with veined gauze-like wings, but it is the larvae, called aphid lions, that are the important predators. Aphid lions resemble little green alligators with mouthparts like ice tongs. They are voracious feeders that will consume more than 200 aphids a week, as well as insect eggs, thrips, and small caterpillars. They can detect the larvae of leafminers within the mines and will pierce the leaves in order to feed on the miners within.

Availability for release: Green lacewings are available from many commercial suppliers and can be extremely effective under certain conditions. Two or three successive releases at two-week intervals are usually better than a single release. Ask the supplier to recommend the most appropriate species and stage for your pest management needs.

Lacewings are usually supplied as eggs, but larvae and adults are also available. Eggs are shipped in a carrier material, which makes it easier to distribute them onto infested plants. Lacewings released as pre-fed adults ready to lay eggs can fly away immediately, so take care to provide adequate food and habitat to encourage them to stay and reproduce in the crop. They must have a source of nectar or pollen. A sprayable food supplement can be applied to the crop to encourage lacewings and other predators to remain in the crop.

Spined soldier bug

Podisus maculiventris



The spined soldier bug is reddish brown with two short spines sticking out from the middle edges of its shield-like body. It is a common predator of caterpillars and caterpillar eggs in snap bean. The nymphs look similar to the adults and are also active predators. One nymph may consume as many as 360 host eggs during its development.

Availability for release: The spined soldier bug is available commercially. The suggested release rate is five nymphs for every foot of row. Release when caterpillar larvae are peaking.

Damsel bugs, Big-eyed Bugs & Minute pirate bugs

Nabis spp., Geocoris spp., and Orius spp.



Damsel bug

Damsel bugs, big-eyed bugs, and minute pirate bugs are common and active predators in crop fields.

Damsel bugs, *Nabis* spp., are one-half inch long tan or black bugs with wings. The nymphs are similar but do not have wings. The piercing mouthparts curve down from the head. Both the young nymphs and the adults are active predators that feed on important crops pests such as aphids and caterpillars.



Big-eyed bug

© Bradley Higbee

Big-eyed bugs, *Geocoris* spp., are very small, only one-sixteenth inch and usually brown or black. Both adults and nymphs consume numerous aphids, flea beetles, small caterpillars, and spider mites. Big-eyed bugs are common in agricultural fields, especially when broad-spectrum insecticides have not been used.

Minute pirate bug adults, *Orius* spp., are black, about one-fourth inch long with distinctively patterned black and white wings. The nymphs are yellow to light brown. Both nymphs and adults have prominent beaks and are active predators of thrips, mites, aphids, and caterpillar eggs. Minute pirate bugs are common in pastures, crop fields, and field margins, especially where broad spectrum insecticides are not routinely used.



Minute pirate bug

© John Ruberson, University of Georgia

Availability for release: *Orius* spp. and *Orius tristicolor* are available commercially. They are supplied as adults in a carrier material along with a food source. Shake the carrier onto the plants, and the bugs will readily disperse and locate prey. Ask your supplier for suggested release rates for your crop and pest situation.

Pest Management Decisions

Harvest



Pest management changes throughout the growing season. Late in the season, there is little economic benefit to be gained from controlling insects. It is essential, however, to maintain a proper disease management program until stems and leaves are completely dead.

Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A.** The late blight pathogen is controlled by utilizing protectant sprays until the potato vines are completely dead. Other diseases are monitored late in the season.
- ☐ **B.** Insect pests such as aphids and Colorado potato beetles are not controlled late in the season.
NOTE FOR SEED POTATO PRODUCERS: aphids are controlled until vine kill and the haulm is completely dead.
- ☐ **C.** Cultural control strategies, such as a fall trap crop for Colorado potato beetle, are utilized.
- ☐ **D.** Fields are mapped to record the number of Colorado potato beetles entering overwintering sites. Other pest “hot spots” are mapped for future potato seasons.

A. Late Blight Control Measures

Vine killing prevents the spread of early and late blight spores from foliage to tubers at harvest. After applying the desiccant, continue fungicide applications until the vines are completely dead. This minimizes the development of late blight which can infect tubers in the ground by movement of spores through soil and during harvest, causing serious storage disease problems.

Tubers should be harvested only after the skins are well set (see the **Environmental Conditions** section for more discussion of skin set). Handle tubers gently at all times during the harvesting process to avoid damage and abrasions. Any damage to the potato skin opens the tuber to infection by pathogens including late blight, pink rot, and bacterial soft rot.



Quick Note

Maintain a preventative fungicide program until potato stems and leaves are completely dead. This includes treating any vine regrowth that may occur during warm periods after vine kill.

B. Late Season Insect Control Considerations

Late in the season, many insect pests found in the field at or above threshold levels may not need to be treated. Insecticide applications close to vine kill or harvest may not be beneficial because insect populations found in high numbers at vine kill will not severely limit yield. The vine kill operation immediately stops tuber bulking; therefore, insecticide applications may be an unnecessary expense.



Vine-killed potatoes

Insects which may not need to be controlled include aphids, potato leafhoppers, and Colorado potato beetles. The potential damage done by these insects will not severely limit yields since the vine kill operation will kill living tissue anyway. For example, mature potato plants can withstand up to 30% defoliation without a yield loss, and the beetles can aid in the plant destruction process by feeding on green foliage and vines. Consider the following recommendations when determining late season insect control.

- In fresh market or processing potatoes, insecticides are not needed for leafhopper or aphid control anywhere from 2 weeks prior to vine kill. Control beetle populations only if heavy defoliation is found. There is no need to treat for beetles within 3 days of vine kill.
- For seed potato production, continue insecticide applications for aphid control through the vinekilling period and until the canopy is completely dead to prevent viral transmission. Stop insecticide applications for potato leafhoppers 1 week prior to vinekill. Control beetles only if significant defoliation is found. No application is needed within 3 days of vinekill.

White grubs can cause damage to the tubers and should be carefully monitored during harvest operations. White grubs are distinctive, C-shaped, fat, white larvae, approximately 1/2 to 1-1/2 inches long, with brown head capsules and six prominent brown legs. The adult stages of white grubs are commonly known as June beetles. These are seen in the spring in Wisconsin, but do not damage potato plants.

In general, white grubs are only occasional pests in potatoes, and chemical control is rarely recommended. However, if white grubs are present in a field during harvest, keep accurate records and implement cultural control strategies to reduce populations in the next potato cropping season (see **Cultural Pest Management** section).



White grub damage to tubers

C. Cultural Control Strategies

Insects

Colorado potato beetles exit fields in the fall to enter overwintering sites. A fall trap crop should be used to attract adult beetles moving toward overwintering sites. Fall trap crops are strips of non-vine killed potatoes.



Fall trap crop in field

These sections can be in the middle of the field or along one of the field edges. Colorado potato beetles congregate in the area of living potato plants where the insects can be easily killed before they move to overwintering sites.

- ▶ Leave approximately 24 rows of non-vine killed potatoes along the field's edge or as a single strip anywhere in the field
- ▶ Manage late blight in the trap crop potatoes
- ▶ Once the beetles have congregated into the trap crop area, control them chemically or physically.

Usually beetle feeding will be extensive and no further vine killing is needed. However, if the trap crop remains vigorous, apply a desiccant with the insecticide.

The use of flaming strategies and propane torches at the end of the season may also reduce any remaining Colorado potato beetles while also providing another method for vine desiccation.

Weeds

Continue late-season weed control measures to limit weed populations before seed formation increases the weed seed bank. Chemical or mechanical vine-killing procedures should be targeted to kill weeds along with potato vines.



Monitor green weeds in vine-killed potatoes

After vine desiccant application, monitor weeds along with potato vines to see how the dying is proceeding. Harvest operations are more difficult if green weeds or vines are moving with potatoes through the harvesting chains and equipment. Therefore, all weeds and vines should be dead before harvest begins.

D. Development of Field Maps for Colorado Potato Beetle and Other Pest Populations

Harvest is the ideal time to map pest populations within potato fields. Use the maps to determine rotational sequences, control measures, and BiolPM strategies for the following years.

Map Colorado potato beetle populations to record which field edges have the highest number of adult beetles entering the adjacent overwintering sites. Simply take a field map and mark beetle populations on a scale of high, medium, or low. Use the maps to more accurately predict where high beetle populations will be found the following spring. Use this information in an area-wide rotational strategy, determining the following year's field locations and selecting management strategies for beetle control.

During harvest note other pest populations (specific weed species, wireworm or white grub populations, and disease concerns) that were seen in the field. Use the information gathered during harvest to plan rotational cropping systems and consider pesticide and cultural options to manage these pests during the non-potato cropping years.

Environmental Conditions

Harvest



Conditions during the harvest operations can have a great impact on potato storability as well as quality characteristics. Careful handling and optimum environmental conditions can reduce potato damage and the potential for storage problems.



Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A. Potatoes are harvested with proper skin set.**
- ☐ **B. Potatoes are harvested at the correct temperature and soil moisture.**
- ☐ **C. Tarps are used on trucks and wagons during transportation to prevent tuber heating, cooling or sun burning.**
- ☐ **D. Care is taken to limit bruising throughout harvest and transportation operations.**

A. Harvest Considerations

Harvest is a busy time of year, yet proper harvesting decisions can prevent damage to the crop during the storage and handling process. Harvesting normally occurs after an efficient vinekill and once there is an assurance that the tubers have formed the proper skin set.

Killing potato vines before harvest aids in tuber maturation and skin set. Mature tubers with well-set skin prevent tuber injuries which may lead to infection from bacteria and fungi. Vine killing should occur at least two weeks prior to harvest to allow proper skin set. Avoid vine killing during hot, dry periods because a rapid kill can cause stem end browning in tubers. To prevent the spread of early and late blight, continue fungicide applications after vine killing until no green tissue remains.



Vine-killed potatoes

Proper vine kill will:

- ▶ Stop the spread of foliar disease
- ▶ Help to separate vines from tubers during harvest
- ▶ Protect the tuber from skinning and bruising
- ▶ Help to prevent infection by disease organisms

Skin setting is an essential part of controlling diseases and maintaining tuber viability and quality. Bruising and skin breaks may occur if tubers are harvested too soon after vine kill or the skin is not properly set. Damaged tubers are susceptible to infection by many disease pathogens including late blight, early blight, bacterial soft rot, and *Pythium* leak.

For best skin setting:

- ▶ Vine kill at least 14 days prior to harvest.
- ▶ Make sure vines are completely dead prior to harvest.

Dig up a few hills to check for tuber size and skin setting before harvesting. The skin should not move when it is rubbed with a finger.

Harvest at 60-65% soil moisture levels and when tuber pulp temperatures are between 50-65 ° F. When soil moistures are too high or pulp temperatures are too low, skin set can be delayed.



Check for skin setting prior to harvesting

Skin Set Biology

The periderm is critical for protecting the tuber from storage diseases. The periderm is the specialized layer of cells that lies just under the tuber surface. It prevents the entrance of pathogens, regulates gas exchange and water loss, and protects against chemical damage.

The skin of the potato tuber is the phellem layer of the periderm. The phellem consists of a tough, brick shaped matrix of cells with no intercellular spaces. Cultivars vary in the number of layers and other phellem characteristics.

Tubers become more resistant to wounding as the phellem matures because it is bound more tightly to adjoining tuber tissue. This maturation process produces a sturdy skin set. Skin set cannot occur until the potato tuber stops bulking. Immature potatoes have a loose skin for tuber expansion and growth. As potatoes begin to senesce, the skin thickens and suberin is deposited inside the periderm, forming a much "tougher" skin.

B. Temperature and Soil Moisture

Environmental conditions during harvest are critical for maintaining a quality product through the storage and marketing season. Do not harvest potatoes with any free water on the surface or with pulp temperatures above 70°F. High temperatures and free water promote infections by fungi and bacteria and can lead to large areas of decay in storage.

Harvest potatoes with a pulp temperature between 50-65° F. Potatoes harvested with pulp temperatures above 70° F are very susceptible to breakdown in storage. Potatoes harvested at temperatures below 50° F are susceptible to shatter bruise.



Quick Note

Quick Note: Optimal conditions for harvest are when tuber pulp temperatures are between 50-65° F and when the soils contain 60-65% available soil water moisture levels.

Moisture content of the soil directly relates to moisture content of the potato. Maintain soil moisture 65-70% of available soil moisture (ASW). Soils wetter than 70% ASW carry large amounts of soil onto the harvester which may increase bruising and result in excessive soil being carried into storage. Wet soils may also increase lenticel size and predispose tubers to infections by fungi and bacteria. Dry soils will lead to dehydrated potatoes and an increase to blackspot bruising.

During harvest skip any areas that were infested with late blight to prevent infection of healthy tubers. Also skip low wet spots in the field as these areas may be predisposed to



Moisture content of the soil is directly related to the moisture content of the potato

decay. Harvest these areas last and store them at the end of the building. If any decay does occur, these tubers are more easily removed from storage to prevent further decay.

C. Transportation Conditions

Sometimes potatoes are transported long distances from the field to storage which increases the risk of tuber damage. To avoid harmful temperatures during transport, trucks and wagons should be covered with a tarp.

On warm sunny days pulp temperatures can increase rapidly during transport which may lead to problems removing that heat in storage. Increasing pulp temperatures above 70° F can lead to decay in the pile and problems later in the storage season.

Exposed tubers can also be sunburned in a short period of time. Sunburn interferes with wound healing in storage which may promote disease infection and decay. During cool weather, tubers become chilled which will increase susceptibility to bruise.



Cover harvested tubers with a tarp to prevent sunburn

D. Minimizing Bruising During Harvest

Maintaining a quality bruise free product starts with the harvester and continues through all equipment that comes in contact with the tubers. General guidelines for harvesting equipment are described below.

To prevent bruising, keep the amount of tubers and soil at capacity on all harvester chains and conveyers. Less material leads to excessive bouncing and bruising of the tubers as they roll along the chains. Overfilling chains leads to increased bruising from excessive rollback. As the yield changes

across a field, adjust the ground and chain speed to keep the harvester at capacity. When filling trucks or wagons, do not drop tubers more than six inches except when the steel is adequately padded.



Quick Note

The chain speed is equal to the chain length (in feet) divided by the time for one revolution (in seconds). To express the speed in miles per hour, multiply the number of feet per second by 0.68. Using this formula will help keep harvesting equipment at its appropriate capacity.

Inspect bulk trucks and repair or pad any rough or jagged areas. Equip the trucks with tarps or mechanical covers to protect potatoes from wind, rain, or sunburn during transport. Low temperatures may increase bruising. Sun exposure during transport may warm tubers excessively or cause sunburn.

Conveyors and pilers can contribute significantly to tuber bruising. As with all other equipment, repair or pad rough or jagged edges and limit any drops to six inches. The piler angle should not exceed 45° F to prevent rollback of tubers. Use a stepped bin piling procedure to minimize rollback on the pile face.



Conveyors can contribute to tuber bruising

Bruising: Description and Conditions

There are two types of tuber bruising.

► Blackspot bruise results in discolored areas about 1/4 inch below the skin and is detectable only by peeling the potato. These internal bruises do not develop immediately. It takes from 6-8 hours for symptoms to occur and up to 24 hours for full development.

► Shatter bruise can penetrate deeply into the tuber depending on the severity of the injury. The tuber tissue ruptures and discolored flesh forms on the edges of the damage.

To minimize bruising, aim for the optimum handling conditions described below:

► Maintain soil moisture at 65-70% available soil moisture to properly hydrate the tuber. Higher soil moistures result in more soil carried on the harvester and this can lead to increased shaking and bruising. Lower soil moisture dries out the tuber which may increase the tuber's bruise susceptibility.

► Tuber condition is important at harvest. Vines should be killed two weeks before harvest for proper skin set (three weeks may be required for certain varieties). Proper hydration of the tuber is important as well. Hydrated tubers are susceptible to shatter bruise but resistant to blackspot bruise. Dehydrated tubers are resistant to shatter bruise but susceptible to blackspot bruise.

► Ideal tuber temperature is about 60° F. For tubers dropped six inches bruising increases 1% for each degree of temperature drop below 60°F. For example, a 10% increase in bruising will occur when the tuber temperature drops from 60° to 50° F.

► During harvest and transport all drops should be less than six inches unless steel is adequately padded. Keep maximum volume on all chains and conveyers to prevent tubers from bouncing and rolling.

Storage Conditions

Post-harvest



The proper environmental conditions should be utilized to optimize potato storability.

Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A. Conditions are monitored during the storage period.**
- ☐ **B. The crop is stored at the optimal temperatures and relative humidity levels during curing, storing and removal.**
- ☐ **C. Sprout inhibitors are appropriately applied to maintain tuber dormancy.**
- ☐ **D. Storage records are kept to document storage conditions, disease, quality and shrinkage.**

A. Storage Conditions

Potatoes need to be stored in an environment that keeps their internal and external quality from deteriorating. Because tuber quality does not improve once potatoes are placed in storage, use optimum production and harvest practices to assure that high quality potatoes enter the storage phase.

Proper storage conditions for maintaining tubers will enhance their storability, maintain their quality, and will aid in the disease management during the storage period. Monitor temperatures, humidity, quality, and disease characteristics in each bin. Assess the bin's conditions to determine which tubers and which bins should be cleared out first due to various storage concerns.

B. Temperature and Humidity

The potato tuber is a living organism that uses oxygen and gives off heat, moisture and carbon dioxide. Proper conditions are necessary to control respiration, water loss and sprout inhibition. Maintaining proper storage conditions is crucial in promoting tuber health and wound healing while preventing pressure bruise, disease and the accumulation of sugars. The storage operation is divided into three stages; curing, holding and removal. Optimum conditions for each stage are described below.

Curing

Curing promotes suberization (healing of bruises, cuts and skinned surfaces) over a 2-4 week period immediately after harvest. Cure potatoes at 50-55°F and a relative humidity of 90-95%. Cure tubers that are stressed from disease at slightly lower temperatures and at 85% relative humidity. Maintain proper airflow during this period to provide the oxygen needed for wound healing. Avoid free water on the potato surface because this interferes with oxygen exchange and promotes the development of bacterial soft rot.

Holding

Long term storage temperatures are based on the intended use of the potato as follows:

- ▶ Seed and table stocks: 38-40°F
- ▶ Frozen and dehydration stocks: 42-45°F
- ▶ Chip stock and potatoes stored 3 months or less: 50°F

Once the curing phase is completed, slowly lower the temperature 1° every 5-7 days to prevent accumulation of reducing sugars. Relative humidity should be maintained at 90-95% to minimize weight loss and pressure bruising.

Monitor temperatures at both the top and bottom of the pile. The top of the pile should be 1-3°F higher than the temperature at the bottom of the pile. If the temperatures are the same, too much air is moving through the pile.

Monitor relative humidity as well. A drop in outside temperature can cause condensation on the ceiling that then drips on the potatoes. This surface moisture increases the potential for tuber breakdown by soft rot bacteria.



Tubers infected with bacterial soft rot

Long term storage of potatoes requires using a sprout inhibitor. The current sprout inhibitors are applied either in the field (MH30) or in storage after curing has been completed (CIPC).

Removal from Storage

As the tubers are being removed from storage, continue to monitor and manage conditions. Rough handling of tubers under unfavorable conditions can result in a high incidence of shatter bruise or internal blackspot. It may also cause potatoes to accumulate significant quantities of reducing sugars within a few hours, resulting in an unmarketable product. General guidelines are given below.

- ▶ Gradually raise pulp temperatures to 55-65°F over a period of two to three weeks. This is essential for reconditioning potatoes for quality chips and french fries. Warming also reduces the possibility of tuber injury. Cold potatoes are easily bruised. Use some fresh air to keep carbon dioxide levels low.

- Clean and sanitize all the handling equipment to prevent the spread of bacterial infections
- Keep the dumping heights of hoppers and trucks to 6 inches or less
- Maintain the flow of potatoes at capacity on all conveyors. Pad sharp and rough surfaces on all equipment

C. Sprout Inhibitors

Sprout development in storage significantly decreases tuber quality, accelerates water loss, and may make tubers unmarketable. If potatoes are going to be stored for long periods of time, a sprout inhibitor will be needed. The two commonly used sprout inhibitors are maleic hydrazide (MH) and chlorpropham (CIPC). MH is used during the season and translocates into the tubers. CIPC is applied in storage to control sprouting.

The chemical CIPC interferes with cell division so it should only be applied after all wound healing is complete. If applied before wounds are healed, excessive losses will occur from water loss and disease. CIPC is applied as an aerosol through the plenum into the air ducts and up through the pile. When CIPC is applied to storage, residues can remain up to a year after application. Do not store seed potatoes in treated buildings until the chemical residue is thoroughly cleaned from all surfaces including fans, ducts and plenum and the building is allowed to air out for at least six months.

D. Storage Records

Maintain records of temperature, relative humidity and potato condition while storages are being loaded and throughout the storage process. This can aid in diagnosing storage related problems. Proper documentation of environmental conditions during the growing season can also help determine what field conditions or practices used on the field during the growing season may have led to storage problems.

When storages are initially being filled, record which fields and which field areas are being placed in specific storage areas. Lines on the walls and streamers from the ceiling work well to designate areas in the storage. As the storage is emptied, keep records on tuber quality. Keeping good records of temperatures, relative humidity and any problem areas will assist in correcting the problems during the non-storage months. If problems in storage can be traced to problems in the field, good storage and field records can be used to diagnose and correct the problem in future years.



Potato storage facility

General Recommendations for CIPC Applications to Stored Potatoes

- Only store potatoes for long-term storage in structures insulated to withstand outside temperature extremes
- Ensure all potatoes in the storage have had adequate time to heal by waiting 14 to 21 days (depending on the storage temperature and the potato variety) after the last potatoes are placed into storage before treating with CIPC
- Follow the commercial applicator's pretreatment storage preparation requirements
- CIPC should not be applied after potatoes have broken dormancy and started to sprout
- Do not store potato seed in a building treated with CIPC within the previous year until it is thoroughly cleaned, or in a structure near a storage that will be treated with CIPC

Pest and Soil Management Decisions

Post-Harvest



An Integrated Pest Management program which utilizes cultural, biological, and mechanical methods should be used during the winter season to minimize pest population survival for the following season.

Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A.** Potential late blight sources are eliminated.
- ☐ **B.** Cover crops are planted for weed and disease management and erosion control.
- ☐ **C.** Colorado potato beetle overwintering site management and winter mortality rates are considered as a pest management option.
- ☐ **D.** An IPM storage program is utilized whenever possible.

A. Late Blight Sources

During harvest, storage, and removal from storage, waste potatoes and cull piles can accumulate and become potential sources of the late blight pathogen. Proper removal and disposal of these tubers should occur as soon as possible. Winter disposal can help eliminate late blight sources since the pathogen does not survive the harsh, cold temperatures of severe Wisconsin winters.

To properly dispose of waste and culled potatoes, spread them sparingly during the winter months on the surface of fields not intended for potatoes the following spring. Spread potatoes so they are exposed to several cycles of freezing and thawing throughout the winter months. Tubers exposed to temperatures below 28°F, even briefly, are killed. However, at temperatures above 30°F, tubers will survive. Do not till tubers into the ground in late fall or early winter months since burying protects them from the freezing process.



Tubers infected with late blight

Culled potatoes and waste potato products may be fed to livestock during the winter months as long as the tubers are completely consumed. Do not apply the livestock manure to fields where potatoes may be grown since the manure can contain late blight spores and the scab organism.

B. Cover Crop Considerations

Cover crops or other green manures (rye, wheat, barley, oats, forage grasses) should be planted soon after the harvesting operations so that the crops have enough time to establish themselves before the winter begins. Cover crops provide many benefits including improving crop and soil productivity, reducing disease potential, adding organic matter, reducing soil erosion, and providing a competitive weed control strategy.

To provide soil cover during the winter, a cover crop is usually planted within one week after har-

vesting in late summer or fall. In Wisconsin, the crop selected needs to possess enough cold tolerance to survive hard winters. Rye is one of the few selections that meet this requirement. The cover crop can be established by aerial seeding into maturing cash crops in the fall, or by drilling or broadcasting seed immediately following harvest.



Winter wheat drilled as a cover crop

Winter-annual legumes established in the fall usually produce most of their biomass in the springtime. In many regions, winter-annual legumes must be planted earlier than cereal crops in order to survive the winter.

For more information about which cover crops can be used in your cropping systems, use the Cover Crop Decision Tool (mcccddev.anr.msu.edu). This tool allows cover crops to be selected based on county, cropping system, and cover crop attribute.

C. Colorado Potato Beetle Overwintering Mortality

Winter mortality of adult, overwintering beetles can be enhanced by habitat disruption. These practices kill beetles by decreasing the soil temperature where the Colorado potato beetles are overwintering. The adult beetles overwinter in underground sites adjacent to field edges. If temperatures in these overwintering areas are reduced to 23°F at the depths that beetles are overwintering (about 6-8 inches), the adults will die, reducing the emerging spring populations.



Adult Colorado potato beetles overwinter in soil conditions around 32 degrees F

Habitat disruption will be most successful during the coldest period of the year, typically during

January. Remember that snow and mulch remaining on the soil surface keep the soil temperatures around 32°F, which suits beetle survival. Removing the snow and mulch when the temperature is 23°F or colder can decrease the soil temperatures and may allow temperatures at the beetles' depth to be cold enough to cause death.

D. IPM Storage Program

IPM strategies, especially for disease management, should continue until potatoes are sold and off the farm. Implementation of IPM strategies in storage will greatly aid in storage disease management. To maintain healthy tubers in storage:

- ▶ Inspect, repair, and sanitize the storage facility and storage equipment before putting potatoes in storage
- ▶ Properly dispose of waste potatoes, do not put cull piles near the storage facility.
- ▶ Ensure bruise-free potatoes by not dropping potatoes from heights of more than six inches
- ▶ Install padding on all potential bruise sites and maintain padding through harvest and storage operations
- ▶ Remove as much mulch, soil, and debris as possible during loading of storage bins.
- ▶ Isolate damaged or diseased lots in separate bins for immediate grading, marketing or processing
- ▶ Monitor carbon dioxide levels in storage, because carbon dioxide buildup slows healing, favors bacterial soft rot, and in the most severe cases, causes blackheart

Cover Crops

Cover crops may be a non-legume, a legume, or a combination grown together. Most of the commonly used non-legume cover crops are grasses. These include:

- ▶ Annual cereals (rye, wheat, barley, oats)
- ▶ Annual or perennial forage grasses such as ryegrass
- ▶ Warm-season grasses like sorghum-sudangrass

Commonly used legume cover crops include:

- ▶ Winter annuals, such as crimson clover, hairy vetch, field peas & subterranean clover
- ▶ Perennials like red clover, white clover and some medics
- ▶ Biennials such as sweetclover
- ▶ Summer annuals (in colder climates, the winter annuals are often grown in the summer)

Growers should determine which cover crop works best in their production system. To find a suitable cover crop or mix of covers, consider these steps:

- ▶ Clarify the primary needs of the potato system
- ▶ Identify the best time and place for a cover crop in the system
- ▶ Test a few options
- ▶ Determine the cost of cover crops and economics of the system, but also estimate the cost benefit they may provide (such as reduced disease management costs)

Identification of Common Wisconsin Weeds

Annual Broadleaves

BUCKWHEAT FAMILY

Wild buckwheat (51)*

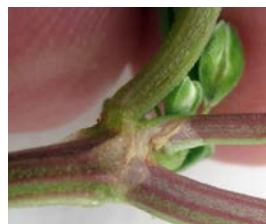
Polygonum convolvulus

- Cotyledon:** oblong oval with granular waxy surface
Ocrea: at leaf axils; small
Stems: trailing vines
Leaves: heart-shaped with pointed tips
Flowers: greenish-white, small and inconspicuous
Seeds: 3-sided

* indicates the page in *Weeds of the North Central States* that describes the plant



Wild buckwheat seedling



Wild buckwheat ocrea



Wild buckwheat plant

BUCKWHEAT FAMILY

Pennsylvania smartweed (52)

Polygonum pensylvanicum

- Cotyledon:** lanceolate to oblong, rounded tips
Ocrea: at leaf axils; smooth top
Stems: reddish, branched swollen nodes
Leaves: rounded at base; pointed at tip
Flowers: pink, terminal flower clusters
Other: seed black, shiny, flattened, circular with pointed tip



Penn. smartweed ocrea



Penn. smartweed seeds



Pennsylvania smartweed flowering plants

BUCKWHEAT FAMILY

Ladysthumb smartweed (52)

Polygonum persicaria

- Cotyledon:** lanceolate to oblong, rounded tips
Ocrea: at leaf axils; hairy top
Stem: reddish with swollen nodes branched
Leaves: pointed at both ends, often have "thumb print"
Flowers: pink, terminal flower clusters
Other: seeds black, most triangular



Ladysthumb ocrea



Ladysthumb seeds



Ladysthumb smartweed plants

GOOSEFOOT FAMILY

Common lambsquarters (57)

Chenopodium album

- Cotyledon:** linear, small
- Leaves:** often whitish, 'mealy'
- Covering:** shape is triangular or "goosefoot" shaped
- Stems:** have reddish streaks, branched
- Seed:** shiny, black, disk-shaped, 1/16 inch in diameter
- Other:** many biotypes, some resistant to herbicides



Lambsquarters seedling



Lambsquarters leaves



Lambsquarter flowers

PIGWEEED FAMILY

Redroot pigweed (65)

Amaranthus retroflexus

- Cotyledon:** linear, smooth
- Root:** often reddish-pink taproot
- Leaves (stems):** notch in tip of first leaves; finely pubescent; reddish-purple color on underside of leaves
- Seedhead:** somewhat spiny, small, black, shiny seeds
- Other:** also called rough pigweed



Redroot pigweed seedling



Redroot pigweed stem



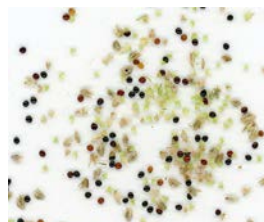
Redroot pigweed seedhead

PIGWEEED FAMILY

Smooth pigweed (64)

Amaranthus hybridus

- Cotyledon:** linear, smooth
- Root:** often reddish-pink taproot
- Leaves (stems):** generally smooth
- Seedheads:** longer than redroot pigweed; rarely branched
- Other:** resistant biotypes



Smooth pigweed seeds



Smooth pigweed stem



Smooth pigweed seedhead

PIGWEEED FAMILY

Waterhemp (67)

Amaranthus tuberculatus

- Cotyledon:** linear; egg-shaped
- Leaves:** nick in tip of first leaves; long-petioled; 3 to 6 in. long; somewhat shiny
- Stems:** smooth, often with colored stripes
- Inflorescence:** small greenish flowers, male and female flowers on separate plants
- Other:** several species of waterhemp in the region; resistant biotypes



Waterhemp seedling



Waterhemp young plant



Waterhemp inflorescence

PURSLANE FAMILY

Purslane (71)

Portulaca oleracea

- Cotyledon:** linear or oblong, smooth
- Leaves:** fleshy, rounded, opposite
- Stems:** fleshy, prostrate, reddish, branched
- Flowers:** 5 yellow petals; small; numerous
- Seeds:** small, flattened, oval, glossy black
- Other:** plants can establish from stem pieces



Purslane seeds



Purslane flower



Purslane plant

MUSTARD FAMILY

Wild mustard (89)

Brassica kaber

- Cotyledon:** heart or kidney-shaped; smooth
- Leaves (stems):** few bristly hairs
- Lower leaves:** large, triangular and lobed (not to midrib)
- Upper leaves:** reduced in size; no petioles
- Flowers:** 4 bright yellow petals
- Seed pods:** "beak" of seed capsule 1/3 length of whole capsule; open to release round seeds



Wild mustard seedpod



Wild mustard stem



Wild mustard flowers

MUSTARD FAMILY

Wild radish (100)

Raphanus raphanistrum

- Cotyledon:** heart or kidney-shaped, smooth
- Lower leaves:** rounded lobes often reach to midrib
- Leaves (stems):** stiff, scattered hairs
- Flowers:** 4 yellowish-white petals; sometimes with purplish veins
- Seed pods:** form constrictions and break into small segments with seed inside
- Other:** fruits contaminate oats and barley grain



Wild radish lower leaf



Wild radish stem



Wild radish flowers and seedpods

MUSTARD FAMILY

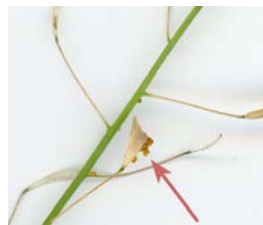
Shepherd's purse (91)

Capsella bursa-pastoris

- Cotyledon:** ovate to rounded
- Rosette leaves:** starlike branched hairs on upper surface; leaf lobes point to leaf tip
- Stalk (stems):** elongated stalk; leaves clasp stem
- Flowers:** small with 4 white petals
- Seed pod:** small, triangular-shaped



Young plant



Seed pods



Shepherd's purse plant

MUSTARD FAMILY

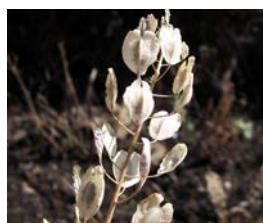
Field pennycress (104)

Thlaspi arvense

- Cotyledon:** round, bluish-green
- Leaves:** rosette and stem leaves; ear-like lobes that clasp stems on upper leaves
- Flowers:** flowers with 4 white petals; in clusters
- Seed pod:** notch in top of pod and flat wing around edge
- Other:** garlic-like odor in crushed leaves and stems



Young plant



Seed pods



Field pennycress flowers

MALLOW FAMILY

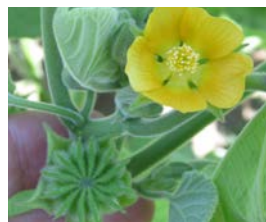
Velvetleaf (122)

Abutilon theophrasti

- Cotyledon:** round or heart-shaped
- Leaves:** very large, heart-shaped, softly hairy
- Stem:** pubescent
- Flowers:** yellow with 5 petals
- Seed capsules:** 13-15 segments; resembles "butterprint"



Velvetleaf seedling



Flower and seed capsule



Velvetleaf leaf and flower

NIGHTSHADE FAMILY

Jimson weed (157)

Datura stramonium

- Cotyledon:** lanceolate, smooth
- Leaves:** ovate (egg-shaped) with pointed tip lobes; wavy margins
- Stems:** hollow, purplish, and smooth
- Flower:** white tubular flowers
- Seed capsules:** spiny, golf ball sized with many seeds
- Other:** strong, foul odor in leaves and stems; poisonous



Jimson weed flower



Seed capsule



Jimson weed plant

NIGHTSHADE FAMILY

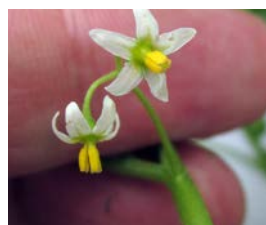
Eastern black nightshade (162)

Solanum ptycanthum

- Cotyledon:** ovate, smooth, small
- Leaves:** purplish color on underside; often with "shot holes"
- Stems:** erect or spreading; widely branched
- Flowers:** 5 white reflexed petals
- Fruits:** green, turning black at maturity; contaminate harvested products



Seedling



Black nightshade flower



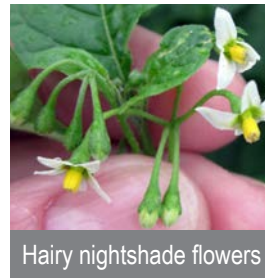
Black nightshade fruit

NIGHTSHADE FAMILY

Hairy nightshade

Solanum physalifolium

- Cotyledon:** ovate, hairy
- Leaves:** ovate to nearly triangular; finely hairy, especially veins & margins
- Stems:** finely hairy
- Flowers:** 3-9 flowers on short stalk; 5-petaled; white or tinged with purple
- Fruit:** turns yellowish brown when ripe



Hairy nightshade flowers



Hairy nightshade stem



Hairy nightshade fruit

GOURD FAMILY

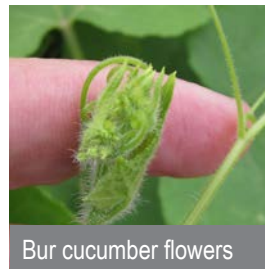
Bur Cucumber (178)

Sicyos angulatus

- Cotyledon:** large; spoon-shaped, thick with dense short hairs
- Stems:** long, ridged vines; sticky-hairy; branched tendrils allow plants to climb over crops
- Leaves:** 3 to 5 shallow lobes (pentagon-shaped), alternate, petioled
- Flowers:** male and female flowers arise at separate axils; 5 greenish-white fused sepals and petals
- Fruits:** in clusters of 3 to 20 egg-shaped, barbed, prickly pods; each pod with one seed



Bur cucumber seedling



Bur cucumber flowers



Bur cucumber plant

COMPOSITE FAMILY

Common ragweed (181)

Ambrosia artemisiifolia

- Cotyledon:** oval to spatulate, thick
- Leaves:** lacy, finely divided, opposite initially, then alternate; first leaves with 5 lobes
- Stems:** rough, hairy and branched
- Flowers:** male flowers in terminal clusters; female flowers in leaf axils



Seedling



Flowers



Common ragweed plant

COMPOSITE FAMILY

Giant ragweed (183)

Ambrosia trifida

- Cotyledon:** oval to spatulate
- Leaves:** opposite, large and 3-5 lobed; upper leaves often simple; roughly hairy
- Stems:** woody and 1-2 inches thick; tough, hairy; 6-14 feet tall
- Flowers:** male flowers in terminal clusters; female flowers in leaf axils



Giant ragweed seedling



Giant ragweed leaf



Giant ragweed flowers

COMPOSITE FAMILY

Horseweed (204)

Conyza canadensis

- Cotyledon:** round to ovate
- Leaves:** many leaves, no petioles; hairy; entire or toothed
- Stems:** covered with bristly hairs; branched at top
- Flowers:** many small flowers on axillary branches
- Other:** also called marestail; common in no-till sites



Horseweed leaves



Horseweed flowers



Young horseweed plant

COMPOSITE FAMILY

Smallflower galinsoga (210)

Galinsoga parviflora

- Cotyledon:** oval to squarish, hairy; abruptly tapered at base
- Leaves:** opposite, toothed
- Stems:** branched, hairy
- Flowers:** 4-5 white ray flowers surrounding yellow disk flowers



Galinsoga flowers



Young galinsoga plant



Galinsoga plants

COMPOSITE FAMILY

Prickly Lettuce (224)

Lactuca serriola

- Cotyledon:** ovate to spoon-shaped
- First leaves:** rosette of pale green leaves; no spines
- Later leaves:** lobed with spiny edges and spines on midrib of underside of leaves; leaf bases clasp the stem
- Stems:** hollow; top very branched when mature
- Flowers:** pale yellow flower heads that release seeds attached to a pappus
- Other:** leaves and stems with milky sap



Prickly lettuce stem



Prickly lettuce leaf



Prickly lettuce flowers

COMPOSITE FAMILY

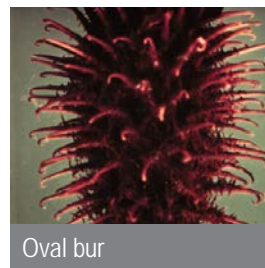
Cocklebur (240)

Xanthium strumarium

- Cotyledon:** lanceolate, thick
- Leaves:** large, triangular and lobed; 3 prominent veins
- Stems:** rough texture, dark purple spots
- Leaves (stems):** sandpaper-like textured surface
- Flowers:** small, male and female separate but borne together in clusters in axils of upper leaves; two female flowers are enclosed in each oval bur



Cocklebur seedling



Oval bur



Cocklebur leaves

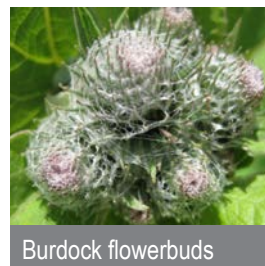
Biennial Broadleaves

COMPOSITE FAMILY

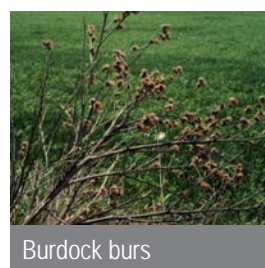
Burdock (187)

Arctium minus

- Taproot:** large, thick, and fleshy
- Rosette leaves:** huge with heart-shaped base; white-woolly below
- Leaves:** alternate, prominent veins
- Stems:** tough; much branched
- Flowers:** red-violet color; 3/4 - 1 inch across
- Fruit:** a bur with hooked spines



Burdock flowerbuds



Burdock burs



Burdock young plant

COMPOSITE FAMILY

Musk thistle (199)

Carduus nutans

- Leaves:** smooth, waxy; grey-green margin with a white, hairless midrib; spiny edges that extend down stem
- Stems:** spiny from leaf bases except right below flower head
- Flowers:** 1-1/2 to 2 inches in diameter; rich pink color; head often tips downward



Musk thistle flowerbud



Musk thistle leaf



Musk thistle flower

COMPOSITE FAMILY

Plumeless thistle (198)

Carduus acanthoides

- Leaves:** leaves deeply divided; hairy esp. lower surface midrib; decurrent
- Stems:** spiny from base to flower head due to decurrent leaves
- Flowers:** ¾ to 1 ½ inches in diameter; pinkish



Plumeless thistle rosette



Plumeless thistle flowerbuds



Plumeless thistle flower

COMPOSITE FAMILY

Bull thistle (202)

Cirsium vulgare

- Leaves:** deeply cut, spiny margins with a wrinkled surface; hairy
- Spines:** prominent; needle-like
- Stems:** spiny with decurrent leaves (extend down the stem)
- Flowers:** 1-2 inches in diameter; are flask-shaped; pink to pink-lavender



Bull thistle rosette



Bull thistle stem



Bull thistle flower

Perennial Broadleaves

HORSETAIL FAMILY

Horsetail (11)

Equisetum arvense

- Spreads:** by spores and rhizomes
- Fertile stems:** stems hollow, not branched; easily separated joints
- Vegetative stems:** "leaves" in whorls at joints; looks like small pine trees
- Other:** most common in wet areas



Horsetail roots



Horsetail seedheads



Horsetail plants

BUCKWHEAT FAMILY

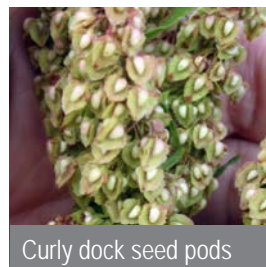
Curly dock (55)

Rumex crispus

- Taproot:** fleshy, branched, and yellow
- Ocrea:** long; prominent
- Basal leaves:** 6-12 inches with wavy edges
- Stems:** smooth, erect, reddish
- Flowers:** small greenish becoming reddish brown at maturity, found in dense clusters on branches at tip of stem



Curly dock leaf



Curly dock seed pods



Mature curly dock flowers

PINK FAMILY

White cockle (74)

Lychnis alba

- Leaves:** hairy and opposite, with no petiole; softly hairy
- Stems:** softly hairy
- Flowers:** white; male & female parts on separate plants (dioecious)
- Fruit:** seed pods with 10 short teeth



White cockle stem



White cockle flower



White cockle seed pod

MUSTARD FAMILY

Yellow rocket (86)

Barbarea vulgaris

- Rosette leaves:** pinnate with large terminal lobe
- Stem leaves:** smooth with waxy surface
- Upper leaves:** clasp stem
- Flowers:** 4 yellow petals, similar to wild mustard but smaller



Yellow rocket leaves



Yellow rocket seed pods



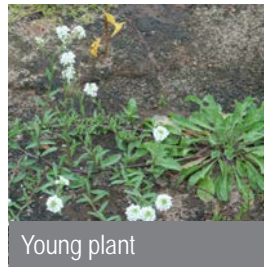
Yellow rocket flowers

MUSTARD FAMILY

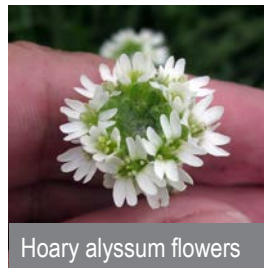
Hoary alyssum (87)

Berteroa incana

- Leaves (stems):** grey-green in color; rough hairs on whole plant
- Flowers:** white with 4 deeply-divided petals
- Fruit:** seed pods small with short "beak"



Young plant



Hoary alyssum flowers



Hoary alyssum-upper part of plant

SPURGE FAMILY

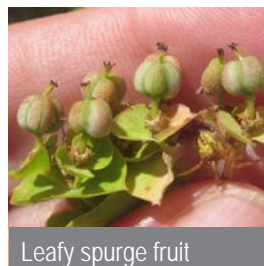
Leafy spurge (118)

Euphorbia esula

- Roots:** deep and spreading
- Stems:** smooth
- Leaves:** alternate, strap-shaped, ¼ inch wide, usually drooping
- Flowers:** small and borne above greenish-yellow bracts
- Fruit:** explode when ripe, shooting 3 seeds, from parent plant
- Other:** all plant parts have milky sap



Leafy spurge leaves



Leafy spurge fruit



Leafy spurge plants

DOGBANE FAMILY

Hemp dogbane (134)

Apocynum cannabinum

- Roots:** deep and branched
- Leaves:** opposite, narrow and pointed tips
- Stems:** smooth, reddish
- Flowers:** 5 greenish white petals that are slightly longer than green sepals
- Fruits:** long, slender pods; occur in pairs
- Other:** all plant parts have milky sap



Hemp dogbane leaf



Hemp dogbane flowers



Hemp dogbane plant

MILKWEED FAMILY

Common Milkweed (137)

Asclepias syrica

- Roots:** deep and branched
- Leaves:** opposite, thick, oblong, rounded tips, prominent veins
- Flowers:** pink to white in large many-flowered ball-like clusters at tip of stem and in axils of upper stems
- Other:** all plant parts have milky sap



Milkweed seed pods



Milkweed flowers



Milkweed plant

MORNINGGLORY FAMILY

Field bindweed (139)

Convolvulus arvensis

- Roots:** deep and spreading
- Stems:** trailing or climbing
- Leaves:** "arrowhead"-shaped leaves with 3 "points"
- Flowers:** white or pink, funnel-shaped, 1 inch or less in diameter, found in axils of leaves
- Other:** flower stalks have 2 stipules below flowers



Flower & stalk



Field bindweed flowers



Field bindweed leaves

MORNINGGLORY FAMILY

Hedge bindweed (140)

Convolvulus sepium

- Roots:** deep and spreading
- Stems:** trailing or climbing (similar to field bindweed)
- Leaves:** "arrowhead"-shaped leaves with 5 "points"
- Flower stalks:** no stipules below flowers
- Flowers:** large, 1 ½ to 2 inches, white or pinkish



Hedge bindweed bud



Hedge bindweed flower



Hedge bindweed plants

PLANTAIN FAMILY

Blackseed plantain (171)

Plantago rugelii

- Roots:** fibrous, tough
- Leaves:** in rosette, broad, ovate with 3 to 5 prominent veins; smooth; petioles purplish; egg-shaped, wavy margins
- Flowering stems:** leafless with many small inconspicuous flowers
- Other:** broadleaf plantain similar but lacks purple petioles and has smaller leaves



Young plantain plant



Blackseed plantain seeds



Blackseed plantain plant

NIGHTSHADE FAMILY

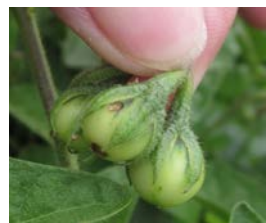
Horsenettle (160)

Solanum carolinense

- Root:** spreading, deep with adventitious buds
- Leaves:** with yellow prickles on the petioles, veins and midribs; hairy; oblong with wavy edges (like oak leaf)
- Stems:** with sharp, stout spines; simple or branched
- Flowers:** potato-like with 5 fused white to purple petals; prominent anthers
- Fruits:** smooth green berries to 0.5" diameter, becoming yellow; become wrinkled and hang on plants most of winter
- Other:** plants poisonous



Horsenettle flower



Horsenettle fruit



Horsenettle stem

COMPOSITE FAMILY

Canada thistle (200)

Cirsium arvense

- Roots:** deep and branched
- Stems:** smooth
- Leaves:** crinkled edges and spiny margins; smooth
- Flowers:** pink to purple, flash-shaped rarely white, $\frac{3}{4}$ inches wide; male and female flowers on separate plants



Canada thistle stem



Canada thistle leaf



Canada thistle flowers

COMPOSITE FAMILY

Perennial Sow Thistle (234)

Sonchus arvensis

- Roots:** spreading; shoots arise from buds
- Leaves:** prickly toothed, lobed; milky sap
- Stems:** milky juice; hollow; branch near top
- Flower heads:** branched with yellow ray flowers
- Seeds:** ribbed; with feathery pappus



Perennial sow thistle leaf



Perennial sow thistle stem



Perennial sow thistle flowers

COMPOSITE FAMILY

Dandelion (237)

Taraxacum officinale

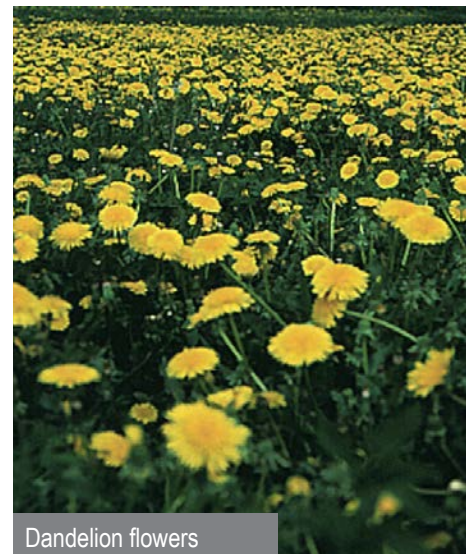
- Roots:** deep taproot with many buds
- Leaves:** lobes point to base of plant; watery, milky juice
- Flowers:** bright yellow with many seeds
- Seeds:** ribbed with barbs to aid in soil penetration; pappus aids in seed spread



Dandelion young plant



Mature flower head



Dandelion flowers

Bacterial Soft Rot

Erwinia carotovora var. *carotovora*

peak activity

April

May

June

July

August

September

October

Bacterial soft rot is common wherever potatoes are grown. It is very wide-spread and often follows late blight, sunscald or freezing injury. Bacterial soft rot is favored by rainy weather when potato tissues are moist and the lenticels enlarge, providing an entrance for the bacteria. The disease often spreads from infected to healthy tubers in storage.

Erwinia carotovora var. *carotovora* has a wide host range which includes most fleshy vegetables such as asparagus, bean, beet, carrot, celery, crucifers, cucurbits, lettuce, onion, pepper, potato, spinach and tomato.

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 mostly affects tubers in storage, but seed pieces and newly-formed tubers can also become infected.

Soft rot bacteria are primarily transmitted through infected tubers. Contamination of seed lots is common. High soil temperatures favor disease development with the optimum temperature range between 77-86°F. In the field, the bacterium can spread by splashing rain and irrigation, gaining entrance to stems through wounds. Frost-injured tubers are commonly invaded by soft-rotting bacteria. Once the bacteria gain entry to plant tissue, they multiply rapidly and liquefy all surrounding tissue. Severe losses can be avoided if the disease is identified quickly and steps are taken to prevent spread.



Bacterial soft rot is characterized by soft, moist, slightly granular appearance of the plant tissue. The decay can become slimy and foul smelling.

Scouting

When walking fields, look for signs of soft rot. Monitor closely during periods of disease outbreaks, insect feeding, or if mechanical injury or freezing weather has occurred as these can provide the wounds needed for the bacteria to enter plant tissue.

The first indication of bacterial soft rot is a moist, mushy appearance on the stem or tuber. The affected tissue often turns brown, and there can be a definite foul odor associated with the rot. Remove any plants with sign of soft rot. Monitor crops in storage areas regularly for signs of soft rot and remove any infected produce.

Threshold

There is no treatment for soft rot once the disease is present.

Management

Cultural control

- ▶ Planting certified disease-free seed is an important management strategy for soft rot.
- ▶ Limit bacterial entrance by controlling insects such as the European corn borer and avoiding stem injury by equipment.
- ▶ Irrigate carefully to avoid maintaining a film of moisture on the vines.
- ▶ Cultivars seem to differ in susceptibility to bruising and the incidence of infection by the soft rot bacterium.
- ▶ Handle the potato crop carefully during harvest to decrease the number of wounds, cuts, cracks or bruises.
- ▶ Harvest potatoes in dry weather if possible, to promote rapid drying and healing of wounds.

Continued on next page...

- ▶ Closely monitor irrigation prior to harvest to lower soil moisture levels. Tubers left in the soil for 7-10 days after vine kill will develop a skin which is less susceptible to wounding.
- ▶ Harvest tubers when soil temperatures are between 50-65°F to prevent bacterial development, should wounding occur.
- ▶ Avoid sunscald of tubers. Exposure of tubers to direct sunlight for as short a period as one hour increases their susceptibility to soft rot.
- ▶ Use spray jets for washing potatoes; never soak tubers in water for long periods. Do not reuse wash or rinse water.
- ▶ Dry tubers immediately after they are washed. Hot air dryers hasten drying.
- ▶ Do not pack tubers in air-tight containers, such as unperforated plastic bags. Provide good air circulation.
- ▶ During the first week or ten days, store tubers at 60°F with adequate ventilation to promote rapid healing of wounds. Afterward, tubers may be stored at cooler temperatures below 39° F.
- ▶ Practice good sanitation in storage facilities. Remove all debris from the warehouse and disinfect walls and containers.

Chemical control

- ▶ If wash water is used, maintain 25 ppm chlorine in the wash water (1 tablespoon of Clorox®, 5.25% sodium hypochlorite bleach per 8 gallons of water). Make sure that the wash water is not cooler than the vegetable temperature, or bacteria will move into the fruit or stem end.

Common scab

Streptomyces scabies

present in soil

April

May

June

July

August

September

October

Common scab is a serious soil-borne disease of potato tubers found throughout the world. Although the disease does not affect eating quality, the surface blemishes caused by the pathogen reduce their commercial grade and market price. The organism that causes potato scab has a limited host range. Besides potatoes, it can infect turnips, sugar beets, garden beets, parsnips, rutabagas and radishes.

A second scab disease, powdery scab, occurs occasionally in Wisconsin. See UW Extension publication A3833 *Potato Disorders: Common Scab and Powdery Scab* for a complete description of powdery scab diseases.

Common scab infects tubers causing 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, russeted areas that occur only on the tuber surface. Common scab mainly affects potato quality and marketability. Scabbed tubers tend to shrink excessively during storage and are often invaded by secondary soft rotting organisms.

The organism responsible for common scab can live indefinitely in the soil. Infection occurs through natural openings in the plant such as the lenticels and stomata. Once the periderm develops on the tubers, the pathogen can only enter through wounds.

The pathogen spreads on infected tubers and in soil movement between fields. It can survive passage through the digestive tract of animals and is distributed in manure. For this reason, manure applied to soil may favor scab infection. The organism persists for many years in fields that receive heavy applications of manure or in old barnyard sites. Scab is most common on potatoes grown in soils with a pH between 5.5 - 7.5 which have been in continuous potato production for several years. Scab rarely occurs in soils with a pH below 5.3 or above 8.0. Warm, dry soils and early season stress favor the development of the disease.



Classic symptoms of scab include scab-like raised or slightly sunken, rough, corky patches on tuber or root surfaces.

Scabby potato tubers, while unsightly, are still edible. Infected potatoes need only be peeled before use.

Scouting

Symptoms of scab are typically evident at harvest and vary widely depending upon potato variety and environmental conditions during tuber development. Scab should not be confused with enlarged lenticels that are found on tubers grown in excessively wet soils. Scab does not develop on tubers in storage.

Management

Cultural Control

- ▶ The best control of common scab is through prevention. Always plant certified, scab-free seed potatoes.
- ▶ Avoid planting in fields infested with the scab pathogen. If scab is present, practice long rotations of 3-5 years, preferably with legumes. Rotations should avoid potatoes, sugar beets, garden beets, radishes, and turnips in the rotational sequence.
- ▶ Plow down cover crops.
- ▶ Plant resistant varieties. Although no variety in commercial production is immune to common scab, several varieties are available with a relatively high tolerance to this disease.
- ▶ Maintain good soil moisture, especially during tuber initiation and early growth. Early season stress favors scab.
- ▶ Soil pH should be tested before planting potatoes and adjusted to a pH of 5.2 to 5.8. Even tolerant varieties of potatoes may be infected with scab when grown in slightly acid or alkaline soils. Choose proper fertilizers which help maintain the soil pH. Avoid the excessive use of lime, manure, and wood ashes.
- ▶ Store tubers with scab in a cool, dark, dry place to reduce the possibility of scabby areas becoming infected by soft rot bacteria that will totally decay tubers.
- ▶ Scabby potato tubers, while unsightly, are still edible. Infected potatoes need only be peeled before use.

Chemical Control and Biological Control (none available)

Early Blight

Alternaria solani

peak activity

April

May

June

July

August

September

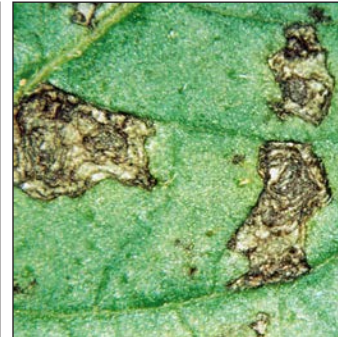
October

Early blight is a common foliage disease of potatoes, tomatoes and eggplant. The early blight fungus causes leaf spots that can be numerous enough to kill foliage and reduce yield. Moderate temperatures, high humidity, and prolonged leaf wetness from dews, rain, or irrigation, favor the development of early blight, but rain is not necessary for the development of the disease. Alternating periods of wet and dry weather tend to increase this disease.

Symptoms appear on the older foliage initially and progress upward in the plant. Sometimes the spots coalesce, killing large areas of foliage. In years when the environmental conditions favor disease development, disease management costs may exceed 10% of the total cost of production.

The early blight fungus will sometimes infect 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 green in color and water-soaked. Wounds are usually necessary for tuber infection to occur.

Alternaria solani overwinters as spores and mycelium in plant debris 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. Many cycles of early blight can 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 mid-summer but often causes its greatest damage late in the season if the weather is favorable. Plants that lack vigor have an increased risk of infection.



Leaf spots caused by the early blight pathogen are round, oval, or angular, dark brown to black in color. The spots usually have concentric rings that produce a target effect.

Scouting

Early blight infestations are forecast with predictive models that calculate the physiological age of potatoes, called **P-days**. Calculations for P-day values are based on temperatures that affect potato development. The potato plant grows at temperatures above 45° F and below 86° F (optimal potato growth occurs at 70°F). Outside this range no P-day accumulations occur.

To view current season's P-day values at various locations throughout Wisconsin, go to the University of Wisconsin Vegetable Pathology website at www.plantpath.wisc.edu/wivegdis. When 300 P-days accumulate in your area, conditions are favorable for sporulation of the pathogen. Monitor fields weekly to determine the level of infection. Sample 5-10 sites per field following a 'W' pattern across the field.

Threshold

If fungicides will be used, apply protectant formulations when 300 P-days have accumulated.

Management

Cultural Control

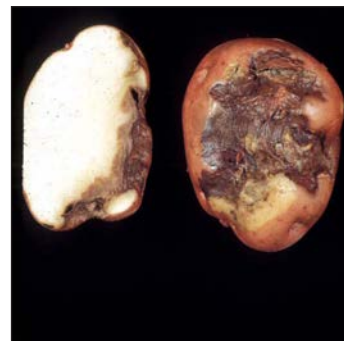
- ▶ Crop rotation is an important control measure for early blight. Fields infested with early blight the previous year are likely to have large overwintering populations of spores. However, because the spores are wind-blown, crop rotation will only delay, not completely prevent, the onset of the disease.
- ▶ Practices which encourage vigorous plant growth and reduce plant stress will reduce disease severity.
- ▶ Avoid excessive irrigation and frequent irrigation that keeps foliage wet for prolonged periods.
- ▶ Provide adequate control of other diseases and insects to avoid predisposing the plants to infection.

Continued on next page...

- ▶ A 7-14 day delay between vine killing and digging reduces the risk of tuber infection.
- ▶ Cultivars differ greatly in their susceptibility to early blight, but all cultivars currently grown in Wisconsin exhibit symptoms of early blight at some point during each growing season. Short season cultivars tend to be more susceptible than longer season cultivars.
- ▶ Destroy or bury dead vines after harvest to reduce overwintering spores.

Chemical Control

- ▶ Fungicides are available to slow disease spread. Refer to A3422 *Commercial Vegetable Production in Wisconsin* for labeled products.
- ▶ Disease management software is available to help growers determine when sprays are needed and the rates of application. Visit www.plantpath.wisc.edu/wivegdis for more information.



The early blight fungus will sometimes infect 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.

Early Dying Complex

Verticillium albo-atrum, Verticillium dahliae and nematodes

	peak activity						
	April	May	June	July	August	September	October

Early dying is a soil-borne disease that can cause serious losses in potatoes. The soil fungus *Verticillium* and a nematode, *Pratylenchus penetrans*, interact synergistically to cause potato early dying. The fungus interferes with water transport in the stems, so injury is most severe during periods of hot weather when plants are stressed for water. There are two types of *Verticillium* that can cause early dying, *Verticillium albo-atrum* and *Verticillium dahliae*.

Verticillium enters the plant through young roots and then grows into the water conducting vessels of the roots and stem. As the vessels are plugged and collapse, the water supply to the leaves is blocked. With a limited water supply, leaves begin to wilt on sunny days and recover at night. The process may continue until the entire plant is wilted, stunted, or dead. Plants may either die very quickly or may succumb gradually. Severe infections may reduce yield by 20% or more.

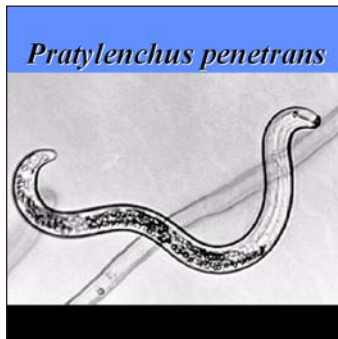
Verticillium albo-atrum overwinters as mycelium in plant debris while *V. dahliae* survives as microsclerotia (hardened overwintering structures). Both fungi can survive in the soil for up to seven years. Fungal infection occurs through natural openings and wounds. Early dying is more severe when the lesion nematode, *Pratylenchus penetrans*, is present. Symptoms may develop even when population densities of *Verticillium* and *P. penetrans* individually are too low to cause significant disease. Once established in a field, the pathogens are spread by soil cultivation and movement of soil by wind or water, and disease severity tends to increase each year. The pathogens are moved longer distances in infested planting stock.

Biological Control

- ▶ *Verticillium* is known to be susceptible to microbial antagonism and competition in soil. Commercial products containing specific beneficial soil microbial products have recently become available.

Chemical Control

- ▶ Soil fumigation may be an option. Refer to A3422 *Commercial Vegetable Production in Wisconsin* for currently labeled products.
- ▶ Soil fumigants will lower populations of non-target beneficial soil microorganisms and their activities of microbial antagonism and competition, which can lead to increased pathogen populations and soil-borne diseases.



Early dying is caused by a soil fungus, *Verticillium*, and a soil nematode. The disease causes wilting and yield losses, sometimes severe. Both pathogens can persist in soil for a long time.

Scouting and Threshold

Soil sampling the fall before anticipated planting is useful in determining the level of *Verticillium* and nematodes present. Samples should be obtained in the standard soil-sampling method which collects multiple samples along a "W" pattern across the field. If the soil test results indicate the level of *Verticillium* is greater than 10 microsclerotia per cubic centimeter of soil, the field should not be planted with potatoes.

Symptoms can appear as early as flowering. Initial outbreaks are typically localized. The leaves of the infected plant 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. Infection is favored by cool weather, but symptom development is favored by high temperatures.

Management

Cultural Control

- ▶ Sample soil in the fall before anticipated planting to determine the level of inoculum present. If the soil is infested, practice a three to four year rotation including a cereal crop or hay, but not strawberries, raspberries, tomatoes, peppers, eggplants or members of the cabbage family.
- ▶ Avoid planting infected seed pieces or planting clean seed pieces into infested soil.
- ▶ Control weeds such as velvetleaf which may serve as a host to the fungus.
- ▶ Plant wilt-tolerant varieties.

Fusarium Wilt

Fusarium species

peak activity

April

May

June

July

August

September

October

Fusarium are common fungi that cause a variety of potato problems. *Fusarium* wilt is the most serious disease. *Fusarium* fungi also cause tuber rots, dry rot of tubers in storage, jelly end rot or soft rot of tubers, and seed piece decay. *Fusarium* fungi infect many other crops in addition to potato, including asparagus, Jerusalem artichoke, carrot, cucumber, lettuce, onion, pepper, sweet potato, and tomato.

Wet, cool soil early in the season favors infection by the *Fusarium* fungus which may cause the underground stems to rot. On older plants, lower leaves wilt, turn yellow and die and the entire plant may be killed. *Fusarium* wilt is difficult to control and is often confused with *Verticillium* wilt (early dying disease).

The fungus that causes *Fusarium* wilt is long-lived in soil and in plant debris. The fungus enters the plant through the roots, progressing through the root tissue into the water-conducting tissues. Seed pieces which are infected with *Fusarium* may transmit the disease to the developing plant. The pathogen is moved from field to field by any means that soil is moved.



In many cases a single shoot wilts before the rest of the plant shows symptoms or one side of the plant is affected first.

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Scouting

Look for signs of *Fusarium* wilt during field visits, especially when weather is warm and dry. The rate or type of symptom expression on potato is controlled by weather conditions and the species of *Fusarium*. Usually there is a yellowing of the lower leaves followed by rapid wilting, but sometimes plants develop symptoms slowly and succumb gradually. The underground stems may decay and brown flecks appear in the stem pith. The woody stem tissues are yellow to brown from the base well into the top. Vascular ring discoloration of roots and tubers may develop.

Threshold

There is no treatment once plants are infected.

Management

Cultural Control

- ▶ Plant certified, disease-free seed pieces.
- ▶ Handle cut seed pieces carefully to avoid bruising. Allow cut tubers to suberize before planting if possible, or plant small, whole seed potatoes.
- ▶ Because *Fusarium* and *Verticillium* fungi are widespread and persist many years in soil, a long crop rotation (4-6 years) is necessary to reduce populations of these fungi. Avoid using any solanaceous crop (potato, tomato, pepper, eggplant) in the rotation, and if *Verticillium* wilt is a problem, also avoid the use of strawberries and raspberries, which are highly susceptible. Rotate with cereals and grasses whenever possible.
- ▶ Follow good soil management, including the use of proper irrigation practices.
- ▶ Susceptibility varies between cultivars but differences are not well documented.
- ▶ Keep rotational crops weed-free (there are many weeds hosts of *Verticillium*).
- ▶ Whenever practical, remove and destroy infested plant material after harvest.

Chemical Control and Biological Control (none available)

Late Blight

Phytophthora infestans

peak activity dependent on weather conditions

April

May

June

July

August

September

October

Late blight is a destructive disease of potatoes and tomatoes that can kill mature plants and make tubers inedible. Late blight is caused by the fungus *Phytophthora infestans*, the same pathogen responsible for the Irish potato famine. Late blight does not occur each year, but when it does, it is one of the few plant diseases that can destroy an entire crop, causing 100% loss. Because a large amount of the pathogen is required to cause an epidemic of late blight, sanitation is the first line of defense against this disease.

If weather conditions are cool and wet, entire plants can collapse and die from late blight in seven to ten days. Tubers infected with the late blight pathogen will rot in storage.

There are several variants of the late blight fungus. Some variants cause disease on potatoes, others are more of a problem on tomatoes. *Phytophthora infestans* spreads by the movement of sporangia, spore-like structures that survive only in living host tissue such as cull potatoes. These are often the original source of infection that initiates a major outbreak of the disease. Once released, sporangia can easily be carried by rain splash and wind. Cool, wet

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Leaf symptoms first appear as pale green water-soaked lesions at the tips or margins. The lesions become brown or purplish-black as they develop.

Scouting

A disease forecasting system called DSV (disease severity value) has been developed to help growers predict when weather and environmental conditions are favorable for late blight development. The DSV index is similar to a degree day model in that it is based on the minimum/maximum air temperatures, as well as the duration of relative humidity periods above 90% for each 24 hour period. A field begins to accrue DSVs at time of emergence or transplant and an individual day can accrue up to 4 DSVs. Research has shown that when 18 DSVs have accumulated, environmental conditions are favorable for late blight. Historically, 18 severity values accumulate in Wisconsin between mid-June and mid-July.

DSVs are computed for several potato and tomato cropping areas in Wisconsin and posted on the UW Vegetable Pathology website at <http://www.plant-path.wisc.edu/wivegdis/>.

Scout the crop for signs of late blight, especially after extended periods of wet or humid weather. If you suspect late blight, be sure to confirm the diagnosis immediately with a crop consultant or UW extension personnel, as quick action is required to contain the disease. Look-alike diseases that are often confused with late blight are Septoria leaf spot, early blight and Verticillium wilt.

Late blight may appear on leaves, stems, and/or tubers. Leaf symptoms first appear as pale green water-soaked lesions at the tips or margins. The lesions become brown or purplish-black as they develop. During humid conditions a white fungal growth can be seen on the underside of the leaves and decay occurs rapidly. Lesions appear on the petioles and stems as black, greasy areas which may girdle the stem and kill the foliage above the lesion. Potato tubers with late blight develop a reddish-brown discoloration, almost like a bruise, under the skin. The lesions may become sunken. The boundary between healthy and infected tissue is not well defined and depth of infection may vary from one variety to another.

Threshold

Research has shown that when 18 DSVs have accumulated, environmental conditions are favorable for late blight and if fungicides will be used, they should be applied at this time.



Cull piles can be a overwintering site for the late blight pathogen.

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Management

Cultural Control

- ▶ Sanitation is an important management strategy. Avoid piling and leaving culls. Culled potatoes should be disked, buried, composted, or otherwise disposed of before the new crop emerges. Cull piles should be as far away from new production fields as possible.
- ▶ Growers who have the option of planting several small, separated fields may have an advantage in containing outbreaks.
- ▶ Practice crop rotation, especially where volunteer potatoes are a problem. Tomato, pepper, and eggplant are all hosts to late blight and should be avoided in rotation and as neighboring crops.
- ▶ Plant certified disease-free seed potatoes.
- ▶ Volunteer potatoes, solanaceous (potato family) weeds, and any infected plants should be destroyed as soon as they occur.
- ▶ Early planting and early harvest may reduce the risk of late blight.
- ▶ Plants showing symptoms of late blight cannot be saved and should be disposed of immediately to limit spread of *P. infestans* to other plants.
- ▶ Kill the infected plants together with plants in a 20-foot border from each edge of the infected patch. Vines should be killed by burning in a burn pile or barrel. For large numbers of plants, place vines in a small pile, cover with a dark-colored plastic tarp, and leave in the sun for a few days. This will create high heat in the pile and kill the plants destroying the pathogen (the late blight pathogen requires living plant tissue to survive). Once dead, vines can be shallowly incorporated into the soil, preferably in an area that won't be planted to potatoes or tomatoes for 2 or 3 years. Do not compost infected plant material. Continue monitoring areas near the infected sites (within the field and neighboring field) for the entire growing season.
- ▶ To prevent tuber infection during harvest, completely kill or remove the vines to prevent spores from coming in contact with tubers. Wait three weeks after vine kill before harvesting to promote good skin set which minimizes skinning and damage to tubers during harvest and handling. Any damage to the potato skin opens the tuber to infection by pathogens including late blight, early blight, bacterial soft rot, and Pythium.
- ▶ Be sure to screen tubers thoroughly going into storage. Infected tubers should be destroyed as they are not fit for storage or sale. Late blight will continue to spread in storage along with the likely onset of bacterial soft rot. Do not eat potatoes that have symptoms of late blight.
- ▶ Small volumes can be burned in a hot fire (be sure they get thoroughly burned). Larger volumes can be spread out on the soil surface and covered with dark plastic and cooked in the sun until completely dead. Do not put late blight-infected tubers on the compost pile, as the tubers may survive the winter and sprout in spring, producing spores that will immediately begin the disease cycle.
- ▶ Check stored potatoes regularly for signs of disease development and remove problem tubers. Even if tubers entering storage do not show symptoms, it does not mean that late blight is absent. Late blight tuber infection can be latent, meaning infection has occurred, but symptoms are not yet visible.

or humid weather favors the production and germination of sporangia. Late blight is commonly introduced into a new area on infected potato tubers or tomato seedlings that are brought in for sale.

Potato tubers become infected when the pathogen grows down infected stems into the tuber. Tubers can also become infected when spores from infected leaves and stems are washed into the soil and come in contact with tubers. Varieties with shallow-set tubers and plantings where there is significant hill erosion or cracking have the greatest risk of tuber infection. Tubers may also come in contact with spores when infected vines are present at harvest.

P. infestans does not survive over the winter in Wisconsin soils, but it can survive on infected plant material that remains alive through the winter. Common overwintering sites include infected plant debris or fruits kept warm in compost piles, infected potato tubers that remain in the soil after harvest, volunteer potatoes, and infected potatoes stored in a warm place.

- ▶ Since late blight can spread so quickly, discuss these disease control strategies with neighboring growers and home gardeners.

Chemical Control

- ▶ Fungicides can be used to reduce the impact of late blight. However, fungicide applications must be made prior to the onset of disease or they will not be effective. Fungicides are most likely to be useful during periods of cool, wet weather. Use the DSV system to determine the best time for application. Note that if weather conditions are excessively cool and wet, even properly-timed fungicide applications may not provide adequate late blight control. Refer to A3422 *Commercial Vegetable Production in Wisconsin* for currently labeled products.
- ▶ Fungicide applications are not needed during periods of hot, dry weather as *P. infestans* will not be active under these conditions.
- ▶ Certain but not all copper-containing products can be used for organic vegetable production. Check with the Organic Materials Review Institute (OMRI) for approved copper products.
- ▶ Be sure to follow all label instructions to ensure that the product that you select is used in the safest, most effective means possible.
- ▶ If late blight is present in a field, apply fungicide to the uninfected portion of the crop first, and then apply fungicide to the infected area. Sanitize all equipment completely before entering the uninfected portion of the field and again before entering the next field.
- ▶ Fungicides resistance is a serious threat to effective chemical control of *P. infestans*. Highly aggressive strains of the fungus, many of which are no longer sensitive to popular synthetic fungicides, have been found in recent years. Apply fungicides only when needed. Always rotate fungicides with different classes and modes of action.

Potato leafroll virus

	seed piece infection		aphid virus transmission				
	April	May	June	July	August	September	October

Potatoes are a vegetatively propagated crop, and many disease organisms, particularly viruses, can be spread in tubers. The important role that tubers play in virus spread is recognized by the strict requirements for foundation or certified seed production. It is almost impossible to eliminate all pathogens from a potato crop, but maintaining strict limits on the acceptable incidence of disease means that a crop grown from certified seed potatoes is much less likely to have disease problems. Planting certified seed potatoes is the best method to reduce the risk of all potato virus diseases

Potato leafroll virus (PLVR) is one of many viruses which infect potatoes, and one of the most serious. Potato leafroll virus (PLRV) causes an important disease of potatoes affecting the quantity and quality of production and may cause a crop to be ineligible for certification. At the present time, there are several known strains of the virus which may occur naturally. All strains are transmitted by aphids. The host range of potato leaf roll virus is restricted to potato, tomato, jimsonweed, groundcherry and a few other weeds in the potato family. Other viruses spread by aphids are potato virus Y, potato virus X, cucumber mosaic and alfalfa mosaic virus.

The appearance of a growing potato crop, or the harvested tubers, is not a reliable guide to the pathogen level in the tubers. If plants are infected shortly before harvest, no symptoms will develop, but virus incidence in the harvested crop can be very high.

Many of the viruses that affect potatoes are transmitted by aphids, which do not over-winter in Wisconsin. The aphids may not arrive in Wisconsin until late summer, but once they arrive they can quickly spread viruses through a potato field. The winter test in Florida, part of the certification process, is designed to detect late-season viral infections.

Leaf roll is one of the most serious virus diseases of potato, capable of

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When a tuber infected with potato leaf roll produces a plant, the plant is very stunted and rigid. Leaves are stiff, dry, and leathery. When crushed in the hand, the leaves crackle. Lower leaves roll and may be pink or dead at the margins.

with net necrosis may result from plants without visual symptoms.

Secondary infection occurs when an infected tuber is planted, giving rise to an infected plant. In this case, initial symptoms become noticeable about one month after plants emerge. Lower leaflets roll up at the edges and become papery, brittle, and leathery to the touch. Affected leaves will "rattle" when shaken. The rolled leaves are lighter in color than normal. As the plant grows, the rolling appears on the upper leaves and may eventually affect the whole plant. Plants are often stunted. Plants are most likely to show symptoms when temperatures are moderate (at or below 77° F).

Tubers produced from plants infected during the current growing season do not always show the net necrosis at harvest. Storage conditions may favor development of tuber symptoms. Maximum development of the net necrosis occurs when tubers are stored at temperatures near 50° F for 2 or 3 months. Net necrosis may also increase during transit and marketing if tubers are maintained near 50°F and are shipped early after harvest.

Management

Cultural Control

- ▶ Planting certified seed potatoes is the best method to prevent all potato virus diseases. For nearly 100 years, Wisconsin seed potato growers have had their seed potato crops certified by the Wisconsin Seed Potato Certification Program (WSPCP). <http://www.plantpath.wisc.edu/wspcp/>
- ▶ Potato varieties differ in their susceptibility to viruses. Check with your seed supplier for current varieties with virus resistance. .
- ▶ Grow potatoes in isolated fields - away from prevailing winds coming from other potato fields. This will help reduce the numbers of aphids entering the field. Read the Green Peach Aphid profile for other aphid management strategies.
- ▶ Rogue all plants showing symptoms of virus infection throughout the season.

Biological Control

- ▶ The green peach aphid has many natural enemies, including ladybeetles,

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syrrhid flies, and parasitic braconid wasps, and insect-infecting fungi. Natural enemies are often numerous enough to keep aphid populations in check, depending on environmental conditions. Be sure to evaluate predator and parasite populations when making treatment decisions. A surge in aphid populations can sometimes be caused by applications of insecticides that have killed natural enemies.

Chemical Control

- ▶ Viruses can't be managed with pesticides, but spot spraying can be an effective way of reducing aphid numbers while maintaining predator populations. Refer to A3422 *Commercial Vegetable Production in Wisconsin* for labeled products.
- ▶ Choose products to manage aphids with Colorado potato beetle resistance in mind. Rates used to control aphids will likely be sub-lethal for Colorado potato beetle, increasing the development of resistance.

causing a 30-50% reduction in yield. Infected tubers develop a network of brown strands throughout the tuber flesh, called net necrosis, especially near the stem end. The appearance of the strands varies with the angle that the tuber is cut. In cross sections, they show up as dots or streaks; lengthwise cuts show the network of brown strands. Tubers produced from plants infected during the current growing season do not always show the net necrosis at harvest. The severity of symptoms produced in potatoes depends on which virus strain infects the plant.

Potato virus Y can interact with other viruses such as potato virus X and potato virus A to result in yield losses. Potato virus X is one of the most widely distributed viruses of potatoes because no symptoms develop in some varieties, so the full extent of damage is not recognized.

Transmission of potato viruses occurs mainly by the green peach aphid (*Myzus persicae*) and through infected seed potatoes. Once an aphid has fed on an infected plant, it remains capable of transmitting the virus to healthy plants for the remainder of its life.

At the time of symptom expression, necrosis of phloem tissue begins. Symptoms caused by PVY infection can vary depending upon the strain and potato variety grown. A rugose mosaic is characteristic for some strains, but is most commonly ascribed to a mixture of PVY and PVX.

The virus affects both the foliage and the tubers. PVX is tuberborne and is readily mechanically transmitted by human activities. Besides infecting potato, PVY affects other solanaceous crops (tomato, pepper) and weeds (nightshade, groundcherry).

Scouting

Look for symptoms of virus infection during field visits. Primary infection results when an initially healthy plant is inoculated by aphids during the current season. Symptoms first appear where aphids were feeding. The upper leaves become pale, upright, and rolled, with some reddening of the tissue around the leaf edges. The lower leaves may or may not have symptoms. If late season infection occurs, plants may show no symptoms. Thus infected tubers or tubers

Rhizoctonia

Rhizoctonia solani

present in soil, most activity during cool, wet weather

April

May

June

July

August

September

October

Rhizoctonia canker, also called black scurf or stem canker is a common and serious disease of potato. An expression often applied to this disease is “the dirt that won’t wash off”, referring to the dark resting structures (sclerotia) of the fungus on the mature tubers. Yield losses are mainly due to uneven stands that produce small, irregular potatoes. The presence of sclerotia on the tuber surface may reduce the tuber grade.

Rhizoctonia solani is a common soil fungus that lives indefinitely in the soil on plant debris. It is also a root pathogen on a wide range of plants, including potato, beet, cabbage, carrot, celery, cucumber, eggplant, lettuce, melon, onion, pepper, rhubarb, soybean, snap bean, spinach, squash, and tomato. The conditions that favor disease are high moisture, cool soil temperatures, high soil fertility, and soil with a neutral or acidic pH.

Rhizoctonia causes root rot most severely on younger plants. Seedlings infected by *Rhizoctonia* are weakened, or may wilt and collapse from a water-soaked rot of the stem near the soil line. Losses of 5-10% are common. If the infection is mild, plants only show a lack of vigor. Unlike *Pythium*, soil water conditions have little effect on disease severity. Older plants are less susceptible to Rhizoctonia.

Rhizoctonia survives between crops as sclerotia or mycelia in the soil. Sclerotia are dense, compacted aggregates of dormant hyphae, resistant to unfavorable environmental conditions. Sclerotia in infested soil or plant debris can be moved throughout the field by wind, rain, irrigation water, and farm implements. Once soil becomes infested, it remains infested. In the spring, sclerotia germinate into fungal strands that can directly infect the plant.



Rhizoctonia solani is a common soil fungus that cause root and stem rot on young plants.

Scouting

Monitor fields weekly after emergence for symptoms of Rhizoctonia. The fungus causes dark-brown lesions on roots, stolons, and sprouts. Infection may be so severe that it may kill the infected plant part or the tips of sprouts before or after they emerge. The leaves of infected plants become thick and sparse, roll upward, and turn pinkish to purple in color. The stalks may also thicken and bear green or reddish aerial tubers.

During harvest and grading, inspect tubers for discoloration. Affected tubers develop in a tight cluster with small, numerous, and irregularly shaped tubers, which may be cracked or pitted. The most common symptom of Rhizoctonia canker is the presence of numerous, hard, dark-brown resting bodies called sclerotia on the surface of mature tubers. These sclerotia may vary from the size of the head of a pin to 1/4 inch in diameter. Sclerotia are often mistaken for adhering soil until it is found that they do not wash off.

Management

Cultural Control

- ▶ Rhizoctonia canker is very difficult to control. Always plant disease-free, certified seed.
- ▶ Plant during conditions that promote quick emergence and vigorous growth. Avoid planting in cold, wet soil. Plant shallowly.
- ▶ Rotate potatoes with cereals, grasses, or some other type of green cover crop that is plowed under before potatoes are planted.
- ▶ Harvest tubers as soon as they are mature to reduce the number of sclerotia that develop on the tubers.

Biological Control

- ▶ *Rhizoctonia solani* is known to be susceptible to microbial antagonism and competition in soil. Commercial products containing specific beneficial soil microbial products have recently become available.

Chemical Control

- ▶ None

Silver Scurf

Helminthosporium solani

high soil moisture and humidity favor disease development

April

May

June

July

August

September

October

Silver scurf is a common and wide-spread potato disease caused by a soil fungus. All potato varieties are susceptible to some degree. The symptoms of silver scurf are mainly cosmetic, but their presence can affect fresh market quality and marketability.

Silver scurf has previously been considered of little economic importance. However, the increasing demand for “clean” potatoes has recently made it a major problem. This is particularly true where potatoes are washed before being offered for sale in plastic bags. When potatoes are grown on muck soil, the blemishes produced by this fungus may cause reduction in grade or prevent seed certification.

The fungus overwinters on infected tubers in storage and those left in the soil after harvest. Tubers become susceptible at the time of maturity while they are still in the soil and remain susceptible throughout storage. Healthy tubers are infected through wounds or lenticels. High soil moisture and humidity favor disease development.



Symptoms of silver scurf are recognized 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.

Scouting

The symptoms of silver scurf are mainly cosmetic and confined to the tubers. Light to dark brown round or irregular spots 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 may form in the diseased spots, which makes them look sooty or smudgy. The affected areas become black and may develop small black lumps. The affected skin sloughs off and tubers shrivel and shrink. The color of red-skinned potatoes may be completely destroyed by the disease.

Management

Cultural Control

- ▶ Plant certified disease-free seed pieces
- ▶ Practice crop rotation
- ▶ Harvest tubers as soon as they are mature.
- ▶ Cull out noticeably infected tubers at digging and grading.
- ▶ Store healthy tubers in a cool, dry place.

Chemical Control

- ▶ Fungicides are not generally recommended for this disease.

Aphids: Green Peach & Potato

Myzus persicae and *Macrosiphum euphorbiae*

peak activity							
April	May	June	July	August	September	October	

Aphids are important pests of seed potatoes because of their role in spreading potato viruses. The green peach aphid and potato aphid are most common in Wisconsin. Both aphids spread the potato leafroll virus, one of the most yield-limiting potato viruses, but the green peach aphid is by far the more effective vector. Green peach aphids feed in groups, called colonies, primarily on older, mature leaves in the lower canopy. Potato aphids are more common on new growth.

The green peach aphid has a wide host range which includes potato, beet, celery, cole crops, cucurbits, lettuce, peppers, spinach, and tomato. The potato aphid is primarily found on roses in the spring but migrate to a wide variety of vegetables, flowers and weeds during the season.

Aphids damage potatoes primarily by spreading plant viruses. Occasionally, aphid populations are high enough that their feeding weakens the plants. Early season leafroll virus infection may cause plant stunting, but current season virus infections usually have little effect of tuber yield. However, plants grown from infected seed potatoes will not produce marketable potatoes.

In Wisconsin, some green peach aphids may overwinter as eggs on the bark of *Prunus* species. More green peach aphids migrate to the north in the spring

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The green peach aphid has an egg-shaped body, creamy white-green to light peach.

The potato aphid (on right) is larger with longer cornicles ("tailpipes") and legs.

Scouting

Check plants weekly for green peach aphids. Remove leaves from the mid to lower half of 25 potato plants per sample site. Count the total number of adults and nymphs. Sample at least five sites per 30 acres and add one sample site for each additional 20 acres.

If potato aphids are found in the sweep net while sweeping for potato leafhoppers, then a leaf sample should be taken to get an accurate estimate of the potato aphid population present in the field. Remove the leaves from the terminal parts of 25 plants per sample site and count the total number of adults and nymphs. Sample at least five sites per 30 acres and add one sample site for each additional 20 acres.

Aphid sampling should always include an evaluation of the presence and activity of natural enemies. Parasitic wasps are common, leaving characteristic swollen hard shelled "aphid mummies" adhering to plant leaves.

Threshold

If insecticides will be used, treat when green peach aphids exceed one per leaf for seed production, or three aphids per 10 leaves for table stock.

Since aphid species vary in vector efficiency and may not be easily identifiable in the field, the following thresholds may be followed for all aphid species.

Control measures are recommended when counts are as follows:

Fresh Market or Processing:

- ▶ Early season — more than 50 wingless aphids per 25 leaves (all species)
- ▶ After bloom — 100 wingless aphids per 25 leaves (all species)

Seed Potatoes

- ▶ 2.5 green peach aphids per 25 leaves on virus susceptible varieties
- ▶ 5.0 potato aphids per 25 leaves on virus-susceptible varieties
- ▶ 7.5 green peach aphids per 25 leaves on virus resistant varieties



Aphid mummies are an indicator of natural predators.

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Management

Cultural control

- ▶ Plant certified, virus-free seed potato.
- ▶ Plant virus-resistant varieties.
- ▶ Control weeds along ditches, roads, farmyards, and other non-cultivated areas, which provide reservoirs and volunteer hosts for both aphids and virus diseases. Plants in the nightshade family and volunteer potatoes are especially good reservoirs for potato leafroll virus. Pokeweed, burdock, and other perennial broadleaf weeds, milkweed, jimsonweed, pigweed, plantain, and field bindweed harbor aphids.
- ▶ Rogue infected potato plants to reduce the spread of the disease within a field. For maximum effectiveness remove the diseased plant, the three plants on each side of the diseased plant in the same row, and the three closest plants in adjacent rows. Rogueing is most important in seed fields.

Biological control

- ▶ The green peach aphid has many natural enemies, including ladybeetles, syrphid flies, and parasitic braconid wasps. Natural enemies are often numerous enough to keep aphid populations in check, depending on environmental conditions. Sometimes wasp parasites are the most effective, sometimes generalist predators. There can be a lag period between when aphid populations first arrive and when their natural enemies build up.
- ▶ Be sure to evaluate predator and parasite populations when making treatment decisions. An increase in aphid populations can sometimes be caused by applications of insecticides that have killed natural enemies.
- ▶ Natural enemies will not kill aphids in time to prevent the spread of viruses.
- ▶ Encourage the activity of beneficial insects by maintaining habitat for them around the field.
- ▶ Heavy rain can rapidly decrease aphid populations as well as produce ideal conditions for the development of fungal diseases which can rapidly reduce or wipe out entire aphid colonies.

Chemical control

- ▶ If infestations are localized, spot spraying can be an effective way of reducing aphid numbers while maintaining predator populations. Treat 100 feet beyond the edges of the infestation. Refer to A3422 *Commercial Vegetable Production in Wisconsin* for labeled products.
- ▶ Choose products to manage aphids with Colorado potato beetle resistance in mind. Rates used to control aphids will likely be sub-lethal for Colorado potato beetle, increasing the development of resistance.
- ▶ Use selective insecticides to conserve natural enemies. Most materials available for aphid control are highly disruptive of natural enemy populations.
- ▶ Good coverage is critical for control of aphid infestations with insecticides.
- ▶ Initial virus infections cannot be controlled by spraying for aphids.
- ▶ The green peach aphid can develop resistance rapidly to chemicals that are used repeatedly. Apply insecticides only when thresholds are reached in order to minimize selection pressure. Do not use products with the same mode of action in consecutive applications. Rotate with pesticides with different Resistance Group numbers.
- ▶ It's important to obtain thorough plant coverage when treating for green peach aphid because it is mainly located on the lower parts of the plant.

from southern states. The development of aphid populations on summer hosts can be very rapid because of their short generation time. Adult females are capable of producing offspring without mating or laying eggs, and can give birth to as many as 12 female wingless nymphs (immature aphids) per day in warm weather. A generation may be completed in a week. Winged offspring are produced when colonies become overcrowded or when the day length begins to shorten. The winged offspring will fly short or longer distances to new fields. Late in the season, the females mate and produce the eggs that will overwinter on *Prunus* trees and shrubs.

The potato aphid overwinters on wild and cultivated roses. Eggs hatch in the spring and several generations are produced on roses before winged forms of the aphid are produced. Winged aphids migrate to potatoes in late June and July. Potato aphids have a short generation time and high numbers of offspring, so populations can develop quickly. In late fall, winged forms return to roses, and lay overwintering eggs prior to frost.



Potato aphid colonies are made up of adults with offspring closely clustered together.

Cabbage Looper

Trichoplusia ni

peak activity

April

May

June

July

August

September

October

The cabbage looper is an occasional late-season pest of potatoes. Looper caterpillars can be distinguished from other caterpillars by their distinctive looping movement when they crawl. The cabbage looper feeds on potato as well as all cruciferous crops, beet, celery, lettuce, spinach, peas, and tomatoes.

Larvae feed high on the plant and are usually easily seen. They chew large holes in the foliage, but are rarely present in damaging numbers in potatoes. Most damage is caused by the second generation of larvae in August.

Cabbage loopers do not overwinter in large numbers in the upper Midwest. Most adult moths migrate into the area from southern states in mid-July to September. Adults are brown, night-flying moths with a distinctive silvery figure-8 on the front wings. The female moths lay white eggs singly on the lower leaf surfaces in July. Four to five weeks after hatching, the mature larvae spin silken cocoons and pupate, usually attached to leaves. Moths emerge 10 to 14 days later, mate, and lay eggs which give rise to a second generation. This generation causes the most damage to crops in Wisconsin.



The cabbage looper gets its name from the way it arches its body when it moves.

Cabbage loopers are pale green caterpillars up to 1½ inches long with a light stripe down each side.

Scouting

Cabbage loopers are easy to recognize as 1½ inch-long green caterpillars which arch their backs into a loop as they crawl. Look for the presence of round, white eggs that are laid singly or in small numbers on the undersides of leaves, and for greenish-brown fecal pellets.

Shake the foliage of five foot sections of two adjacent rows into the furrow and count the larvae on the soil surface. Divide the number of larvae counted by five. The resulting number is the number of worms per row foot. Sample at least five sites per 30 acres and add one additional sample site for each additional 20 acres.

Threshold

Prior to July 25: Control measures are recommended if the looper counts exceed four per row foot as a field average.

After July 25: Control measures are recommended if the looper counts exceed eight per row foot as a field average.

Management

Cultural control

- ▶ Locate fields away from previous host crops, especially cole crops. The further away the field, the longer it will take for the caterpillar pests to find and infest the current crop.
- ▶ Remove alternate hosts, including mustards and related weeds, around field borders. Cruciferous weeds can support populations during the crop season.
- ▶ Handpick larvae in small plantings.
- ▶ Bury crop debris to destroy potential overwintering pupae

Biological control

- ▶ Natural enemies can be an effective and cost-effective way to keep caterpil-

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lar pests below threshold level. Several general predators feed on looper egg and larval stages.

- ▶ *Trichogramma*, a non-stinging parasitic wasp, is a major parasite of looper eggs. Natural parasitism can be increased by timed introduction of commercially available, inexpensive *Trichogramma* spp. The most suitable species commercially available is *Trichogramma pretiosum*.
- ▶ A naturally-occurring virus disease is also important under certain conditions; the bodies of diseased caterpillars turn into shapeless sacks of dark liquid and can often be spotted hanging from leaves.

Chemical control

- ▶ Use spot treatments if infestations are patchy. Refer to A3422 *Commercial Vegetable Production in Wisconsin* for currently-labeled products.
- ▶ Avoid using broad-spectrum insecticides early in the season when caterpillars are present in low numbers and crops can tolerate some feeding. This preserves parasitoids and predators so they can help suppress caterpillar numbers later in the season.
- ▶ The microbial insecticide Bt is very effective in controlling caterpillar pests. The use of Bt rather than a chemical insecticide early in the season allows parasites to survive and exert greater control of the pest population later in the season.
- ▶ Bt sprays can be effective through harvest, but only if smaller ($\frac{1}{2}$ -inch) caterpillars are present. Good coverage of the lower leaf surfaces is important, and the use of a sticker can improve the effectiveness of Bt.
- ▶ Resistance is a key concern. Avoid consecutive use of products with a similar mode of action.

Colorado Potato Beetle

Leptinotarsa decemlineata

	1st generation peak		both generations		2nd generation peak		
April	May	June	July	August	September	October	

The Colorado potato beetle is the most common and most destructive pest of potato in most potato growing areas of the U.S., including Wisconsin. The beetle can completely defoliate plants, resulting in reduced yield or plant death. Once a planting has been infested, the crop will suffer progressively worse damage in subsequent years. Potato is the preferred host but beetles also feed on eggplant and weeds such as nightshade, groundcherry, jimsonweed, horsenettle, and mullein.

Both adults and large larvae are voracious leaf feeders, chewing holes larger than 1/8 inch in diameter. Often entire leaves on the tips of plants are consumed. Larvae typically feed in groups and may completely defoliate plants. Older larvae do the most feeding damage. Heavy defoliation will severely reduce plant yields, especially if it occurs when potatoes are in the flower stage.

Colorado potato beetles overwinter as adults 2-8 inches below the surface of 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 lay clusters of bright yellow-orange eggs on lower leaf surfaces. Larvae hatch 4-9 days later and begin feeding. They frequently congregate on new growth on the ends of stems. Larvae soon turn the characteristic brown-red. Although the feeding of young larvae is evident on new growth, damage is generally not severe enough to require treatment. It is the older larvae that causes more serious crop damage. Second-generation adults normally appear in mid-July and can also cause severe defoliation. There are usually one to two generations per year in most of Wisconsin.



Adult Colorado potato beetles are easily recognized, with bright yellow bodies with black stripes running the length of their backs and black spots behind the head. They are 3/8 inches long.

Scouting

Begin scouting for egg masses at plant emergence by turning over all leaves and examining the undersides of for bright yellow eggs. Sample 25 consecutive plants per sample site. Egg-laying is a useful sign for timing insecticide treatments. Begin calculating degree days (see below) when the first eggs are found. Selection of sample sites should cover the field, but since infestations are frequently clumped near field edges, sampling may be concentrated in these areas.

To sample adults and larvae, take 25 sweeps with a sweep net per sample site or count them by inspecting 25 consecutive plants. Infestations often will be detected in the field edges before the center of the field. It is important to distinguish between larval stages (instars) because small larvae are more sensitive to insecticides and the older, 4th instars feed more voraciously than other stages, and need to be controlled before they enter the soil for pupation. Head width is the most reliable means of determining when larval stage because the head is a hard structure that stays at a constant size between molts, while the overall body size can increase greatly as the insect feeds. When the insect molts, the head expands, giving the larva more room to grow.

Head width for Colorado potato beetle are approximately ½ mm for 1st instars, 1 mm for 2nd instars, 1.5 mm for 3rd instars and 2 mm for 4th instars. New summer adults just emerged from pupation also should be identified in scouting, because they can cause severe foliar injury and are more difficult to control than overwintered adults. The new adults will have clear hind wings for the first 5-7 days after emerging. Older adults (either overwintered adults or old summer adults) have smokey orange wings with bright orange veins.

Degree Days

Degree day accumulation can be used to accurately predict the occurrence of third instar larvae. A base temperature of 52°F is used and accumulation is begun when the first egg mass is found in the field, usually in May.

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Degree day accumulations for Colorado potato beetles are as follows:

Life Stage	DD ₅₀	Cumulative DD ₅₀
Egg	120	120
First Instar	65	185
Second Instar	55	240
Third Instar	60	300
Fourth Instar	100	400
Pupae	275	675

Thresholds

Insecticide applications must be properly timed so that sprays are targeted against the most vulnerable life stages. This keeps the number of sprays at a minimum. Delaying the main larval spray until 240-250 DD₅₀ will allow as many eggs as possible to hatch into susceptible larvae, and, at the same time, avoid the most damaging 4th larval stage, where 70% of the feeding occurs.

The need for control is also based on percent defoliation at different plant growth stages. Treat adults in mid-July if needed based on percent defoliation and plant growth stage.

Varying levels of plant defoliation by Colorado potato beetle can be tolerated without yield loss, depending on the plant growth stage

Plant stage	Allowable defoliation	Pest stage
Pre-flowering (6-8 inches)	20-30% defoliation	Overwintering adults and larvae
Flowering	5-10% defoliation	Larvae and summer adults
Tuber formation	30% defoliation	Summer adults and larvae

Management

Cultural Control

- ▶ Crop rotation is important. This pest has a limited host range, so rotating out of eggplant and potatoes will reduce and delay beetle populations.
- ▶ Plant strips of early-planted potatoes as trap crops on field edges next to overwintering sites to attract and concentrate adults moving into fields in the spring. When adults gather in these trap crops, use propane flamers or vacuum suction to remove the beetles.
- ▶ Propane flamers can be effective for early season beetle control on plants up to 8 inches tall. Best control is achieved on warm, sunny days when beetles are actively feeding on top of the plants. In trials, flaming resulted in 90% control of overwintering adults.
- ▶ In small plantings, physical barriers, such as floating row covers can be used to prevent adult beetles from finding plants and laying eggs. Cover plants with row covers immediately after transplanting and keep covers in place until mid-June.
- ▶ Another exclusion strategy is the use of plastic-lined trenches as a barrier to

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the beetles entering a potato field. Place the plastic-lined trenches between fields and overwintering sites before transplanting.

- ▶ In small plantings, the large larvae and adults may be hand-picked or removed with a net. Colorado potato beetles contain a chemical that can burn and blister sensitive skin, so be sure to wash your hands after handling the beetles.

Biological Control

- ▶ Colorado potato beetle has several natural enemies, including ground beetles, ladybird beetles, lacewings, predatory stink bugs, and spiders, as well as parasitic wasps and flies. Natural enemies seem to be rare in commercial potato fields because of heavy pesticide use and lack of habitat to support them.
- ▶ Increase habitat for natural enemies by providing pollen and nectar sources along field borders or by planting insectary strips in the field to increase the effectiveness of natural enemies. Mulched plots may support greater numbers of predators than non-mulched plots.
- ▶ When weather is cool and wet (night temperatures below 45°F), egg mortality from predation and disease can be quite high.
- ▶ Adult beetle mortality will be high during winters in which snow cover is sparse and soil temperatures where the beetles are overwintering fall below 23°F.

Chemical Control

- ▶ Systemic insecticides applied to the soil at planting as well as foliar sprays are commonly used to control this pest. Refer to A3422 *Commercial Vegetable Production in Wisconsin* for currently available products.
- ▶ Pesticide resistance is a serious threat to continued effective chemical control of Colorado potato beetles. A high proportion of populations are resistant to pyrethroids insecticides, and certain races of this pest are resistant to every class of insecticide currently registered for control. Yearly rotation of insecticides of different classes and modes of action must be practiced.
- ▶ Whenever possible, use edge sprays or spot treatments.
- ▶ Reduced risk foliar insecticides are available that are specific to the beetles, preserve natural enemies, and provide good control. Note that specific timing and adequate coverage is essential.
- ▶ *Bacillus thuringiensis* (Bt), are effective against young larvae only; eggs, older larvae, and adults will be unharmed. Only *Bacillus thuringiensis-tenebreonis* (Btt) is effective against Colorado potato beetles. The more commonly available *Bt-kurstaki* (Btk), which is effective against caterpillar larvae, will have no effect on beetles.



Eggs are bright orange and found on the underside of leaves.



Young larvae are small and blackish-brown.



Older larvae are reddish-brown with black heads, legs, and spots along each side of their bodies.

European Corn Borer

Ostrinia nubilalis

1st generation

2nd generation peak activity

April

May

June

July

August

September

October

The European corn borer is a sporadic pest of potatoes. Heavy infestations can occur in years when the first generation of the borer adults occurs early, and the preferred egg-laying sites in corn are not yet available. European corn borers feed on over 200 different kinds of plants including corn, vegetables, field crops, flowers and common weeds. Favored hosts are sweet corn, peppers, snap beans and potatoes.

Most of the damage is caused by the larvae that develop from eggs laid by moths flying in early summer. Larvae feed on foliage as well as inside stems. Secondary bacterial infection may invade the stems and cause stalk death.

European corn borers overwinter as mature larvae in old corn stalks and stems of weed hosts. They pupate in the spring when temperatures are over 50°F. Peak moth emergence for the overwintering generation is usually in June in southern Wisconsin. The adult moths spend most of their time in moist grassy areas, where they rest during the day. On warm, calm evenings, female adults fly about in corn fields and deposit eggs.

The first moths of the year are attracted to the tallest corn for egg laying. If corn is not available, potatoes are an alternate host for egg-laying. Young larvae hatch from eggs and feed on leaves and in the midrib of the leaves for 5-7 days (125 DD₅₀) before boring into stems. Boring usually begins with the second and third larval stages. The larvae pass through five instars (larval stages) and complete their feeding and development while boring inside stems. Second generation moths peak in mid-summer when approximately 1700 DD₅₀ have been reached and may lay eggs in potatoes or other crops.



The adult European corn borer is a night-flying, straw-colored moths with a 1-inch wing span. Males are slightly smaller and distinctly darker than females.

Scouting

Monitor adult moth activity and peak flights using weekly reports provided by the Wisconsin Department of Agriculture Trade and Consumer Protection (DATCP) during the growing season. This information will help you know when to start looking for moths near your fields. Or you can monitor them with black light traps. Traps should be operated in dense weedy areas on field edges or corners of the field where the adult moths congregate. They should be far enough from buildings to avoid interference. Refer to University of Wisconsin Extension publications A1220 *European Corn Borer* and A3855 *Moth Identification for Black Light Trap in Wisconsin* for more detailed information.

By referring to light traps in several fields or areas, and by following statewide black light trap catches, you can follow the general population and predict local areas more effectively. Trap catches will vary with location, but when an increase in catch occurs on 3 consecutive nights, or if moth flights are greater than 25 moths/trap/night anytime during the early summer flight, egg-laying may be high enough to cause economically important levels of crop damage. Scout for egg masses from the mid to lower portion of the plant by examining the lower leaf surface of 25 leaves per sample site.

Degree day accumulation may also be used to predict moth flights. Using a base temperature of 50°F, peak flights will occur at 600 DD₅₀ and 1700 DD₅₀. Action sites along field edges can be walked regularly to gauge the level of European corn borer populations close to an individual field. For the first generation, scouting should begin at 500 DD₅₀ and continue through 700 DD₅₀ or until egg counts drop off.

Degree Days = (daily high + daily low temperature/2) – 50

European Corn Borer Development (Degree days with base temperature of 50°F)

First Generation	Accumulated Degree Days
First moth	375
First eggs	450
Peak moth flight	600
Larvae present	800-1000

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Threshold

If greater than 4% of the leaves (one out of 25 leaves) are infested with eggs as a field average, control is recommended. Because Norgold, Norkota and Norchip varieties are particularly susceptible to damage, control is recommended if greater than 2% of the leaves are infested with egg masses.

Management

Cultural control

- ▶ Plowing under crop stubble in the fall, thereby destroying overwintering larvae, has long been an effective method of reducing borer populations. This is especially important in nearby corn fields, where the majority of corn borers are produced. Removing corn by harvesting it for silage will kill a high percentage of the borers, perhaps as much as 80%.
- ▶ European corn borer moths rest in weedy, grassy areas at field edges during the day and then fly into nearby crops to lay eggs at night. Cleaning up such areas around fields can reduce borer pressure.
- ▶ Norgold and Norkota are especially susceptible to damage. Where borers are a problem, consider planting less susceptible varieties.

Biological control

- ▶ Biological control plays a key role in moderating European corn borer populations, sometimes up to 80-90%. Weather conditions, predators, parasitoids, and diseases take their toll on borer eggs and larvae. Given ideal conditions, natural controls can kill off approximately 80–90% of the eggs and larvae. We typically have 5 to 7 years of relatively low borer populations separating outbreak years, and this is primarily a result of natural control.
- ▶ Excessive heat and drought in spring may cause increased mortality of all stages. The number of eggs laid is affected by the availability of drinking water of which, dew is considered an important source. Heavy rainfall will decrease moth activity and drown newly-hatched larvae in whorls and leaf axils, or even wash them from the plant.
- ▶ Conservation of natural enemies is an important part of pest management programs. Using insecticides only when absolutely necessary is an important step in conserving natural enemies.
- ▶ *Bacillus thuringiensis* var. *kurstaki* (Btk) formulations can be effective if timed to target young larvae.

Chemical control

- ▶ Refer to UW Extension publication A3422 *Commercial Vegetable Production in Wisconsin* for a list of currently labeled insecticides.
- ▶ *Bacillus thuringiensis* (Bt) can be effective in controlling young larvae.



European corn borer eggs are white and overlap like fish scales. As they develop, the eggs change to a creamy color. Just before hatching, the black heads of the larvae become visible inside each egg. This is referred to as the black-head stage and each egg reaching this stage usually hatches within 24 hours.



Full grown larvae are ¾ to 1 inch long, grey to cream-colored, with a small, dark brown head and dark spots covering the body.

Root Lesion Nematode

Pratylenchus penetrans

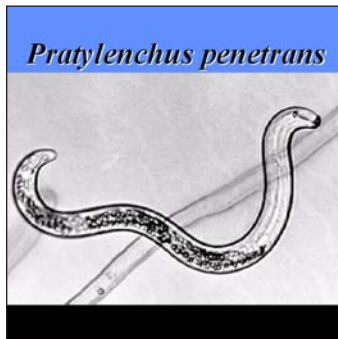
present in soil			symptoms visible in field				
April	May	June	July	August	September	October	

The lesion nematode is a microscopic, unsegmented roundworm that occurs in soils throughout Wisconsin. Root lesion nematodes damage roots by feeding and moving through cortical tissues. They tend to be more common and damaging in sandy soils, but they may also be abundant in heavier soils.

The host range of the lesion nematode is very wide. For nematodes, a host is defined as a plant on which the nematode can reproduce. Over 500 species of plants including ornamentals, field and vegetable crops, and weeds are hosts of the lesion nematode. Crops commonly infected include apple, beet, cabbage, carrot, corn, forages, grape, grasses, mint, onion, pea, potato, soybean, strawberry, and tomato.

Lesion nematodes damage 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%. Plants infested with nematodes may be stunted, unthrifty and likely to wilt under hot, dry conditions. In other cases, infections can occur without above-ground symptoms, but yield will be reduced and tubers may be blemished. Nematode feeding increases the susceptibility of potato plants to Verticillium wilt (early dying) disease.

The lesion nematodes are parasites that move freely into and out of roots. Eggs are laid in the soil or in the root. Nematodes undergo the first of their molts while still in the egg. Upon emerging from the egg, second stage larvae penetrate the root. Lesion nematodes require moderate soil moisture for migration from plant to plant. Some species however, are relatively resistant to drought. The larvae pass through several developmental stages and develop into adults in 40-45 days, depending on environmental conditions. Alternate freezing and thawing of the soil in winter can cause high nematode mortality.



Nematode feeding blemishes tubers and increases the susceptibility of potato plants to Verticillium wilt.

Scouting

During the season, look for symptoms of nematode feeding during field visits. Affected plants often appear in patches with poor, stunted growth and yellow leaves. Sometimes, affected plants show no obvious above-ground symptoms, but underground symptoms can be seen. Roots may be girdled where nematodes feed, so that the outer tissue layers will readily slip off from the central cylinder. Small feeder roots are often completely destroyed, resulting in a reduced root system. Where nematodes feed on tubers, pimples appear that later change to black depressions. When infection is severe and pimples and depressions are numerous, tubers are marred and become unmarketable.

Soil analyses are available to determine the number and type of nematodes in soil. Take soil samples in fall from within the root zone of the previous crop after harvest or, preferably, just before harvest. Divide the field into sampling blocks of not more than five acres, similar to the procedure for soil fertility sampling. Keep samples cool (do not freeze), and transport them as soon as possible to a diagnostic laboratory. Contact your farm advisor to help you find a nematode laboratory in your area.

Management

Cultural Control

- ▶ Plant only certified nematode-free seed pieces.
- ▶ Plant as early as possible.
- ▶ Practice crop rotation. Non-host crops grown for 1-2 years will generally reduce the nematode population so that potatoes may be grown for at least one year.
- ▶ Good weed control is necessary as the nematodes can reproduce on many weeds.
- ▶ Clean soil from equipment before moving between fields to avoid moving nematodes.

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- ▶ Plowing, disking, harrowing, and cultivation after harvest helps to reduce nematode populations by exposing them to sun, wind, and mechanical injury as well as depriving them of a living host.
- ▶ Check nematode history of land before renting or buying. The Wisconsin Department of Agriculture, Trade and Consumer Protection (DATCP) and the University of Wisconsin Seed Certificate Office maintain complete records and an updated map of fields known to be infested.

Chemical Control

- ▶ Soil fumigation can reduce nematode populations in infested fields, except on heavier soils. A minimum of three weeks is necessary between fumigation and planting to prevent phytotoxicity. Refer to A3422 *Commercial Vegetable Production in Wisconsin* for currently labeled products.
- ▶ Note that soil fumigants will eliminate populations of non-target beneficial soil microorganisms and their activities of microbial antagonism and competition, which can lead to increased pathogen populations and soil-borne diseases in subsequent crops.

Potato Fleabeetle

Epitrix cucumeris

peak activity

April

May

June

July

August

September

October

The potato fleabeetle is common in Wisconsin potato fields, but it is rarely a serious pest. Fleabeetles are small, shiny, black beetles with enlarged hind legs which allow them to jump from foliage when disturbed. The beetle feeds on leaves and roots of a wide range of plants, including cabbage, carrots, eggplant, beans, tomatoes, and peppers, as well as flowering plants, trees, and weeds. The tuber fleabeetle, western potato fleabeetle and the tobacco fleabeetle are other species found in Wisconsin, but in smaller numbers.

Adult fleabeetles feed on both leaf surfaces but usually on the underside where they chew small, circular holes less than 1/8 inch, through the tissue to the upper cuticle. The circular holes give the plant a shotgun blast appearance which is characteristic of flea-beetle 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.

Potato fleabeetles overwinter as adults in the soil in fields in which they have matured. Beetles become active when temperatures reach 50°F, and emerge from the soil in late May and June. 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 July - August.



Adult fleabeetles are small, shiny, black beetles which jump quickly when disturbed. Fleabeetles are generally not a serious pest in Wisconsin.

Scouting

Scout for adult fleabeetles by taking 25 sweeps per sample site with an insect sweep net. Sample at least five sites per 30 acres and add one sample site for each additional 20 acres.

Threshold

This insect typically does not cause yield loss. Consider treatment only if adult counts are greater than two beetles per sweep.

Management

Cultural Control

- ▶ Practice clean cultivation and eliminate early-season hosts to reduce populations.
- ▶ Practice crop rotation.

Chemical Control

- ▶ Threshold levels are rarely exceeded in Wisconsin. Foliar sprays should be coordinated with the need to control more damaging pests. Refer to A3422 *Commercial Vegetable Production in Wisconsin* for currently labeled products.

Leafhoppers: Potato & Aster

Empoasca fabae and *Macrostelus fascifrons*

	Aster LH peak activity			Potato LH peak activity			
	April	May	June	July	August	September	October

The potato leafhopper is a serious annual pest of potatoes in Wisconsin. Heavy feeding by adult and nymph potato leafhoppers injures the conductive tissues of the plant, sometimes causing leaf symptoms called hopperburn. Significant yield loss can occur even before obvious symptoms appear. Potato leafhoppers feed on a wide range of host plants including alfalfa, apples, all types of beans, clover, dahlia, eggplant, rhubarb, soybeans, strawberries, and other bedding plants and many weed species.

The aster leafhopper is an occasional pest of potatoes because of its ability to transmit the aster yellows phytoplasma pathogen, causing a disease called "purple top" in potatoes. There is no evidence that aster leafhoppers directly damage potatoes. Unlike the potato leafhopper, the aster leafhopper will not reproduce on potatoes. Only the adult stage is found on potatoes. Leafhopper nymphs found on potato are not aster leafhoppers.

Damage from adult and nymph potato leafhoppers is principally to the phloem cells which become blocked by salivary products during feeding, preventing the movement of sugars from the leaves to the rest of the plant. General symptoms include stunted plants, with yellowing foliage that curls upward at the margins. Eventually the whole leaf browns and dies. Yield loss can occur at even small populations of nymph feeding, when symptoms have not yet developed. Leafhopper injury develops most rapidly during hot, dry weather.

Feeding by the aster leafhopper does little direct damage. However, it is the transmission of the aster yellows pathogen that causes problems. Newly sprouted potatoes are the most susceptible stage; mature plants are almost totally resistant to aster yellows. Infected plants are generally stunted and have small tubers. Processing infected tubers results in a dark-colored product.

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Potato leafhoppers are vivid green, wedge-shaped, highly mobile insects, about 1/8 inch long. In contrast, aster leafhoppers are a more drab olive green, with two rows of 3 black spots on the top of the head.

Scouting

Scouting for potato leafhoppers is important because yield loss can occur at even small populations of nymph feeding. Sample adults by taking 25 sweeps at 5 sample sites per 30 acres and add one sample site for each additional 20 acres.

Nymphs are less mobile and are best scouted by leaf samples. Carefully turn over 25 leaves per sample site. from the middle part of the canopy and check for the presence of nymphs.

Threshold

Thresholds are listed in the table below. Thresholds may need to be adjusted based on the cultivar's relative susceptibility to damage.

Threshold	Treatment
Fewer than 0.5 adult/sweep	Do not treat unless nymph populations exceed 2.5/25 leaves
.5 to 1.0 adults /sweep	Treat if adults persist at this level for 10-14 days or nymphs are present
1.0-1.5 adults/sweep	Treat within 5-7 days or immediately if nymphs are present

Large numbers of aster leafhoppers does not necessarily predict more purple top disease because the most important factor is the number of leafhoppers in the population that are carrying the pathogen (infectivity rate). To find out how much of the current leafhopper population is infective, contact your county Extension office or call the UW-Madison Entomology department at 608-262-6510. If you are not able to do this, assume 2.5%. The need for aster leafhopper treatment is determined by an index which is based on the number of leafhoppers per 100 sweeps multiplied by the percent of the leafhopper population that is carrying the virus. Treat potatoes at an index of 200. For example: if the percent of infectivity is 1%, treatment would be necessary at 200 leafhoppers per 100 sweeps.

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Management

Cultural Control

- ▶ Healthy, vigorously growing vines will withstand damage more effectively than stressed plants.
- ▶ Infestations are likely to be more severe in crops planted adjacent to alfalfa, particularly after alfalfa is cut in mid-summer.
- ▶ Plant early and harvest early to reduce leafhopper feeding.
- ▶ Varieties differ in their susceptibility to leafhopper injury. Choose varieties with more resistance.
- ▶ Plants are also most susceptible to injury from emergence to completion of flowering.
- ▶ There will be fewer migrants in the absence of southerly winds in May.

Biological Control

- ▶ Parasitic wasps are common when leafhopper populations are high. In humid conditions, insect-infecting fungi may reduce populations and a rapid natural decline in population normally occurs in late summer.

Chemical Control

- ▶ Foliar insecticides are available to control leafhoppers. Refer to A3422 *Commercial Vegetable Production in Wisconsin* for currently labeled products.
- ▶ When selecting a product, be sure that Colorado potato beetle and green aphid resistance is not promoted by the leafhopper control program. Note that some products marketed for leafhopper control are mixture of more than one active ingredient.
- ▶ Apply insecticides only when thresholds are reached in order to minimize selection pressure. Do not use products with the same mode of action in consecutive applications. Rotate with pesticides with different Resistance Group numbers.

Potato leafhoppers 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 mid-western states in early summer. Large influxes of migrants in June and early July can cause populations to increase rapidly. White eggs are laid on susceptible crops by insertion into stems or large leaf veins. Nymphs develop in 12-15 days. The first generation offspring mature in late July and the second generation matures in early September. There are normally only two generations per year in the north.

Aster leafhoppers also migrate from the south and are first detected in May and June in the north. Large influxes may occur in June and early July as the preferred hosts, small grains, begin to mature. The aster leafhopper prefers lettuce and small grains for feeding and breeding, while other crops such as potatoes, tomatoes, and onions provide a temporary source of food and refuge. These temporary sites are used only by the adults as the nymphs fail to develop on these plants. The purple top pathogen, a phytoplasma, overwinters in infected perennial plants, or is brought to the north with leafhopper migration from southern states in the spring. Leafhoppers spread the phytoplasma from plant to plant when they feed.

Tarnished Plant Bug

Lygus lineolaris

peak activity

April

May

June

July

August

September

October

Tarnished plant bugs have a wide host range and are an occasional pest of potato. They feed on alfalfa, beans, cucumber, celery, beet, chard, cabbage, cauliflower, turnip, potatoes, strawberries and other small fruit, tree fruit, and many flowering plants. The tarnished plant bug causes injury to potatoes during feeding with their piercing-sucking mouthparts.

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 cause blossoms to fall off (bud blasting), unhealthy plants and reduced yields.

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 April to early May. After feeding for a few weeks, they migrate to weeds, vegetables, and flowers where eggs are inserted into the stems, petioles, or mid-ribs of leaves. Eggs hatch in about 10 days. Nymphs pass through 5 growth stages over 20-30 days before becoming adults. Second generation adults begin to emerge in late June-July. There may be 2 or 3 generations per year until adults enter hibernation in October or November.



Tarnished plant bug adults are 1/4 inch long, generally brown with splotches of white, yellow, reddish-brown and black. There is a clear yellow triangle tipped with a smaller black triangle on the rear end of the abdomen

Scouting

Appreciable numbers of plant bugs are not seen on potatoes until mid-July. Monitor populations with an insect sweep net. Take 25 sweeps per sample site, with at least 10 sites per 100 acres scattered throughout the field.

Threshold

Although no economic thresholds have been determined for this pest on potatoes one/sweep is a good indication that population levels are high.

Management

Cultural control

- Remove weeds, especially those that stand semi-erect during winter, to reduce overwintering sites.

Biological control

- A few insect predators feed on the tarnished plant bug, including a predaceous stink bug, assassin bugs, the big-eyed bug and damsel bugs. The amount of control provided by natural predators is not well known.

Chemical control

- Insecticide programs to control European corn borer will also control tarnished plant bug. Refer to A3422 *Commercial Vegetable Production in Wisconsin* for currently labeled products.