PEST MANAGEMENT IN THE FUTURE

A Strategic Plan for the Wisconsin, Minnesota, Michigan, and North Dakota Potato Industry

April 5 & 6, 2005

Fargo, North Dakota

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WORKING GROUP PARTICIPANTS - 2005

A. J. Bussan	UW-Madison	ajbussan@wisc.edu
Abbas Lafta	NDSU	Abbas.lafta@ndsu.edu
Al Schneiter	NDSU	Albert.schneiter@ndsu.edu
Ann MacGuidwin	UW-Madison	aem@plantpath.wisc.edu
Annie Erickson	NDSU	Ann.erickson@ndsu.edu
Bryce Farnsworth	NDSU	Bryce.farnsworth@ndsu.edu
Carl Rosen	U of MN	crosen@umn.edu
Christian Thill	U of MN	thill005@umn.edu
Chuck Kostichka	UWisc.	cjkostic@wisc.edu
Collin Auwarter	NDSU	Collin.Auwarter@ndus.edu
David Ragsdale	U of MN	ragsd001@umn.edu
Dean Steele	NDSU	Dean.Steele@ndsu.edu
Deana Sexson	UW-Madison	dlsexson@wisc.edu
Denise Olson	NDSU	Denise.Olson@ndsu.edu
Doug Nelson	McCain Foods USA	doug.nelson@mccain.com
Duane Maatz	NPPGA	dmaatz@nppga.org
Duane Preston	U of MN, NDSU	dpreston@umn.edu
Ed Grafius	MSU	grafius@msu.edu
Ed Lulai	USDA ARS	lulaie@fargo.ars.usda.gov
Eric Auwarter	NDSU	Eric.Auwarter@ndsu.edu
Florian Lauer	U of MN emeritus	lauer002@umn.edu
Gary Secor	NDSU	gary.secor.ndsu.edu
Glenn Vogt	J.R.Simplot, Caldwell, ID	
Harlene Hatterman-Valenti	NDSU	h.hatterman.valenti@ndsu.edu
Jeff Suttle	USDA ARS	suttlej@fargo.ars.usda.gov
Jeff Wyman	UW-Madison	wyman@entomology.wisc.edu
Joe Sowokinos	U of MN	Sowok001@umn.edu
John Nordgaard	Black Gold Farms	johnn@blackgoldpotato.com
Ken Grafton	NDSU Ag Exp. Station	K.Grafton@ndsu.edu
Larry Olsen	Mich. State Univ.	Olsen1@msu.edu
Mike Carter	WPVGA	mcarter@wisconsinpotatoes.com
Neil Gudmestad	NDSU	Neil.Gudmestad@ndsu.edu
Randy VanHuren	Pest Pros, WI	pestpros@uniontel.net
Rick Gilbertson	Pro Ag Crop Consultants	rgilbertson@charter.net
Steve Marquardt	ND State Seed Department	smarquardt@state-seed.ndsu.nodak.edu
Susie Thompson	NDSU	asunta.thompson@ndsu.edu
Todd Phelps	NPPGA	vpgsales@nppga.org
Tom Michaels	U of MN	michaels@umn.edu
Walt Stevenson	UW-Madison	WRS@plantpath.wisc.edu
Zahi Atallah	UW-Madison	atila@plantpath.wisc.edu

Contact Persons:

Dr. Jeffrey Wyman
Department of Entomology
1630 Linden Drive
Madison, WI 53706
Phone: 608-262-3229
Email: wyman@entomology.wisc.edu

Dr. Walter Stevenson
Department of Plant Pathology
1630 Linden Drive
Madison, WI 53706
Phone: 608-262-6291
Email: wrs@plantpath.wisc.edu

Dr. Edward Grafius
Mchigan State University
Department of Entomology
East Lansing, MI 48824
Email: grafius@msu.edu

EXECUTIVE SUMMARY

The First Potato Pest Management Strategic Plan for Wisconsin, Minnesota, Michigan and North Dakota was developed from the input of a group of growers and technical experts that met in Madison, Wisconsin on April 1, 2003. The plan summarized the critical needs for the potato industry in these four states and discussed the issues pertaining to production and pest management. Critical research, education, and regulatory needs were identified for each pest type (insects, weeds, diseases) as well as general production issues. These issues were prioritized for future use and reference by EPA and USDA. In 2005 the strategic plan was updated to reflect additions and deletions of pest management tools. This was achieved as an objective of the North Central Potato IPM Working Group which met on April 5 and 6, 2005 in Fargo, ND. The 2005 update incorporated the suggestions and opinions of the Working Group membership which is attached. The plan reflects the opinions and suggestions of growers, processors, crop consultants, land-grant extension specialists, grower association, state departments of agriculture, IR-4, EPA and the North Central Pest Management Center at Michigan State University.

TOP CROP HEALTH PRIORITIES FOR WISCONSIN, MINNESOTA, MICHIGAN, AND NORTH DAKOTA POTATO PRODUCTION

Priorities were identified by the participants in each breakout session. These individual priorities were then grouped according to similarity by the groups to identify key issues related to potato production in the areas of research, regulation, and education. The growers, crop consultants, and processors in the group were then asked to rank each priority within the pest type and the results are as follows in decreasing order of importance as specified by the number of votes.

RESEARCH

General

1. Production practices and their affects on storability.
2. Host plant resistance for current and new varieties to insects and diseases.
3. Fumigation alternatives for effective management of early dying (*Verticillium* & nematodes.
4. Sprout inhibitors for use in potato storage **-** alternatives to CIPC.
5. Post Harvest disease management - Improve efficacy of chemistries which includes post harvest disease management and alternative strategies in storage.
6. Pesticide resistance management.
7. Development of environmentally friendly crop and pest management tools, i.e. BMPs and reduced risk tools.
8. Develop new varieties with improved fresh market and processing quality and better adapted for regional growing conditions including improved heat tolerance and nitrogen-use efficiency.
9. Bacteria and fungi for biocontrol of post harvest diseases.
10. Implementation of precision agriculture technologies into site specific management systems.
11. Use of MH30 and other growth regulators to improve processing qualities.

Insects

1. Chemical Control & Pesticide Resistance Management.
    - Alternative products – fipronil, abamectin and related products, growth regulators
    - Nicotinyl affect on wireworms
    - Resistance baselines
    - Evaluation of resistance management tactics
    - Cross resistance studies for CPB
2. Pest Impacts and Thresholds.
    - leaf hopper thresholds for existing varieties
    - susceptibility and thresholds of current varieties to aster yellows
    - understanding of varietal sensitivity
    - determine how potato flea beetles impact disease and stress
    - European corn borer impacts on potato
3. Host Plant Resistance.
    - resistant varieties traditional and GMO for CPB
    - resistant varieties for PLH
    - virus resistant varieties
4. Area-wide Management
    - aphid-trapping network
    - cultural controls for CPB
    - site specific management
    - research on plant sources of Aster Yellows and migration
    - aphid distribution within fields
    - ECB distribution maps
    - thresholds for cutworms on tuber damage
    - monitoring techniques for ECB
5. Beneficial Insect Management.

- Beneficial arthropod conservation through the use of selective insecticides
- Determine numbers and types of beneficial arthropods needed for aphid management
- Determine the impacts of new, narrow-spectrum fungicides on aphids and fungal diseases of aphids and leafhoppers.

Diseases

1. Improved tools for post harvest management of diseases.
   - Improved disinfectants
   - Influence of *Fusarium spp*. on process tuber quality
   - Post harvest management of *Fusarium spp*.
   - Need for post-harvest treatment for leak that's effective
   - Need for lower toxicity chemicals that supports eco-labeling efforts
   - Improved post harvest materials
   - Look at organic salts
2. Increase emphasis on breeding for disease resistance.
   - Development of commercially accepted varieties with partial scab resistance
   - Continue support of breeding efforts for early and late blight resistance
   - Encourage breeders to select for improved resistance to nematodes
   - Breeding for early dying disease resistance, black dot, leak, pink rot, Fusarium spp.
   - Develop new cultivars with greatly improved resistance to aphids and virus infection
3. Develop resistance management plans for mefenoxam and strobilurin chemistries and all new site-specific chemistries before introduction.
   - Resistance management on national scale for strobilurin chemistry
   - Relationship between timing of application and resistance for Group 11 products
   - Need for lower toxicity chemicals that supports eco-labeling efforts
   - Standardization and sampling analysis, interpretation and reporting
   - Determine whether the use of Ridomil is leading to resistance issues in pink rot
   - New product evaluation for pink rot control
4. Develop effective alternatives to fumigation.
   - Understanding the complexity of the soil biology, cover cropping, biological diversity, rotation crops.
   - Evaluate alternative fumigants and biocontrols
   - Potential rotation crops
   - Alternatives to fumigation such as cover crops, trap crops, biofumigation
   - Site specific fumigation and application technology for early dying management
   - Alternatives for black dot control
5. Improve pathogen diagnostics and application of diagnostic technology in production.
   - Ability to quickly differentiate deep-pitted scab, surface scab and powdery scab
   - Diagnostics to distinguish species of key pathogens in soil and from symptomatic and non-symptomatic plants and tubers
   - Standardization and sampling analysis, interpretation and reporting
   - Diagnostic efforts on tuber diseases such as bacterial ring rot
   - Better diagnostics of causal factors of early dying
6. Encourage collaboration between states in updating disease prediction tools to reflect current agricultural practices.
   - Continued tracking of pathogen genotypes – especially *P. infestans*
   - Temperature response and tolerance of the pathogen genotypes to temperature extremes
   - Potential for tracking disease outbreaks using GPS (site specific)
7. Improved tools for management for seed and soil borne diseases.
   - Improved disinfectants
   - Understanding the complexity of the soil biology, cover cropping, biological diversity, rotation crops
   - Improved understanding of calcium and pH on soilborne diseases
   - Differences in management tools between deep pitted scab and surface scab
   - Need for post-harvest treatment for management of storage diseases
   - Potential rotation crops

- Need for lower toxicity chemicals that supports eco-labeling efforts
- Need for a quantitative soil assay for pink rot and other pathogenic isolates
- Better understanding of the interactions between the organisms involved in the early dying disease complex
- Interaction of *Colletotrichum coccodes* with *Verticillium dahliae, Pratylenchus penetrans* and other nematode species

8. Issues related to virus and vector management
    - Planting of varieties that are symptomless carriers is a problem in virus control
    - Improved vector control using novel approaches
    - Need to characterize PVY strains and relationship to spread and tuber necrosis

Weeds

1. Herbicide issues
    - Develop alternatives to Sencor with equal efficacy and crop safety.
    - Herbicide resistant weed management
        i. Triazine-resistant lambsquarters and pigweed
    - Hairy nightshade management and other difficult to control weeds
    - Herbicide combinations to decrease reliance on metribuzin
    - Varietal sensitivity to Spartan and Sencor
2. Precision Agriculture
    - Spatial and temporal dynamics of weeds/pests
    - Distribution of resistant weed biotypes
    - Weed and pest monitoring techniques
3. System Scale Research
    - Pest interactions (alternative hosts)
        i. nightshade biotypes and management
    - Trophic level interactions
    - Interactions among pest types (i.e. early dying opens the canopy and get subsequent weed flush
4. Creation of Crop and Weed Development Models
    - Emergence, canopy development models for new varieties
    - Resource interactions

REGULATORY

1. Retain CIPC registration as a sprout inhibitor.
2. Retain metam-sodium registration.
3. Retain Monitor for aphid and virus control.
4. Retain OPs for wireworm and white grub control.
5. Section 3 label for Purogene.
6. Retain labels for chlorothalonil, EBDC, tin, and fumigants and pursue new, reduced-risk fungicides to expand the chemical tool box for resistance management for strobilurins.
7. Register fipronil, Diamond and mectins as nicotinyl alternative.
8. Retain dimethoate registration for leafhopper management.
9. Encourage expansion of labels to contain information on resistance management directions of use.
10. Retain registration of metribuzin.
11. Registration of Callisto in sweet corn to control volunteer potatoes.
12. Registration of Balance for use in sweet corn for control of wild proso millet.

EDUCATION

1. Area wide mapping of pest populations.
2. Pesticide resistance management education.
    - CPB Resistance management education.
    - Mapping of aster and potato leafhopper movement.
    - Real time website communication and leafhopper prediction.
    - Aphid mapping network in north central region.
    - Distribution maps for cutworms.
    - Mapping of European corn borer populations.

3. Herbicide resistance management.
4. Develop focused symposia on early dying, common scab, soil fumigation, pink eye and resistance management.
5. Biology and identification of soil insects.
   - White grub identification – soil insect bulletin
6. Educating growers on herbicide modes of action and their impact on production practices.
7. New species introductions, identification and control.

BACKGROUND

Potatoes are an important commodity in the upper Midwestern states of Wisconsin, Minnesota, Michigan and North Dakota. According to the National Potato Council 2002-2003 Potato Statistical Yearbook, a total of 308,500 acres of potatoes were planted in these four states in 2001. North Dakota had the most acreage with 118,000 planted acres, Wisconsin was second with 84,000 acres, Minnesota third at 59,000 acres and Michigan grew 47,500 acres of potatoes. Of the 308,500 planted acres, 294,000 acres were harvested in 2001 with a yield of 1265 cwt per acre for a total production of 90,810,000 cwt.

Wisconsin is 3rd leading producer of fall potatoes in the nation. North Dakota is 4th. Michigan is 6th and Minnesota 7th. The region is the national leader for the production of potatoes for chip processing.

The end potato products include fresh market, chips, french fries, dehydrated, frozen products and seed. Yields range from 200 to 600 cwt/acre and the costs of production range from $1,500 to $2,600 per acre with gross returns valued at $2 billion across the region. Cost of production is less on non-irrigated land; between $750 - $1,200 per acre. In the four states, over 40,000 acres are devoted to seed production with Wisconsin growing 10,000 acres of seed potatoes, Michigan growing 2,500 acres, and North Dakota and Minnesota growing 28,000 acres combined. Multiple seed varieties are grown.

Most production inputs are managed based on specific variety requirements with differences among varieties in nutrient requirements and susceptibility to pests

Production/Cultural Practices:

Potatoes are planted on a 1-4 year rotation, with a 3-4 year rotation generally recommended to manage diseases and insect pests. Fields should be geographically and temporally isolated from each other and from previous fields by a minimum distance of several hundred yards. Cover crops are planted following crop harvest in most years of rotation to minimize erosion, leaching, and to improve soil quality. Cover crop desiccation may or may not be done prior to planting or tillage (tillage, Roundup or both). Some fields may be fall fumigated prior to planting for disease management.

Potatoes are planted in fertile, well-drained soils including sands, sandy loams, or silt loams. Planting occurs from April through early June. Soil temperatures at planting are typically between 45-60°F at a planting depth of 4-6 inches. Rows are spaced 30-36 inches apart and seed pieces are planted 6-16 inches apart within the row, depending on the variety and projected end use. The average size of seed pieces is between 1.5-2.0 ounces.

The primary potato cultivars grown in Wisconsin include Red Norland, Dark Red Norland, Superior, Atlantic, Snowden, Russet Burbank, Russet Norkotah, Silverton Russet, Gold Rush, Little Yukon Gold, and Shepody. Several Frito Lay varieties are grown for chipping. The primary cultivar grown in the Red River Valley of North Dakota is Russet Burbank. The most popular chipping potato cultivars grown in Michigan are Snowden and Atlantic. Many growers also produce proprietary Frito Lay varieties. Fresh potato cultivars grown include Onaway, Superior, Russet Silvertons, Pikes and Russet Rangers and Russet Norkotah. Michigan has also cultivated a market for yellow potatoes.

Seed potatoes are warmed slowly in the spring to 50-55°F several days before handling and cutting. After cutting, seed may be planted immediately or stored for up to 21 days with good air circulation and high humidity of 95-99%. Storing potato prior to planting is a process known as suberization. Suberization allows wound healing allowing potato to develop a protective layer of suberin and periderm tissue on the cut surface of seed. Suberization of seed before planting will provide tolerance to seed piece decay. Whole or cut seed potatoes may be treated with a fungicide to reduce seed piece decay as well.

Soil pH is maintained at 5.0-6.0 where scab-susceptible potatoes are grown on organic and mineral soils, 5.6 for scab-resistant varieties on organic soils, and 6.0 for scab-resistant varieties on mineral soils. The majority of growers base their fertilizer applications on soil test results, potato variety, intended final use of the crop, and projected yield potential. Nitrogen is a critical nutrient for potatoes. Potatoes grown under nitrogen deficient conditions have drastically reduced yield and tuber quality while excess nitrogen can reduce tuber quality by lowering specific gravity. Total nitrogen is applied from 50 to 350 lb per acre depending on variety, soil type, and yield potential. Nitrogen application timing varies with soil type. On sandy soils, nitrogen applications are usually split with 35 to 50 pounds applied at planting and 2 to 3 subsequent applications at crop emergence, hilling, and 3 weeks after hilling. On sandy soils, 25-50% of the supplemental nitrogen is applied at emergence and the remainder is applied periodically after tuberization. Petiole nitrate samples are commonly taken throughout the season to determine subsequent nitrogen demand. Utilizing petiole nitrate data can prevent yield limitations due to nitrogen and allow for yield optimization based on variables such as precipitation or stress. On medium or heavy textured soils, there is no advantage to splitting nitrogen applications and all fertilizer is applied prior to or at planting.

Phosporous applications are based on soil type and soil test analysis. Some research on medium-textured, acid soils in northeastern Wisconsin shows responses to relatively high rates of P_2O_5 even on soils testing more than 100ppm soil test phosphorus. Sandy soils showed few responses when soil test phosphorus was higher than 75ppm. Phosporous is generally applied at planting in the starter fertilizer mix.

Potassium is broadcast in spring on highly leachable sandy and organic soils. Potato has a high potassium demand to optimize yield, but high rates of potassium fertilizers lower the specific gravity (percent of solids). Specific gravity is a key quality component in processing or chipping potato and has a direct effect on price. Some row-placed starter fertilizer (30-30-30) is recommended even when soil tests reveal excessively high levels of phosphorus.

Calcium is generally applied pre-plant as gypsum, or at hilling as part of a calcium fertilizer product. Many growers apply micronutrient formulations at planting with recommendations for specific micro-nutrients based on soil type and tissue analysis. Fertilizer rates are reduced to half for non-irrigated soils.

Weed management practices involve the use of herbicides and timely cultivation. During the 6-8 weeks after planting, cultivation and herbicide use are critical for keeping weed pressure down prior to canopy closure. Hilling is another effective weed management strategy and herbicide applications are timed in such a manner with the hilling operation to optimize weed control. Hilling is usually completed at emergence and soon thereafter. Most of the herbicide applications are made at emergence during the first hilling. Additional herbicides may be applied postemergence as needed for weed control.

Potato is irrigated across much of the North Central region to minimize yield and quality effects of heat and drought stress. Potato typical has an effective rooting depth of 18 to 24 inches and is grown on coars textured soils with minimal water holding capacity. As a result, water can become limiting to potato growth within 48 hours during summer months. Drought stress has the greatest impact on potato yield and quality during tuber formation and early bulking (until tubers reach 1 to 2 inches in size). Drought stress during late bulking has minimal yield impacts but can lead to quality defects such as hollow heart, sugar end, or tuber malformation. Irrigation management can be done with scheduling software, by calendar date, or by grower evaluation and estimation of soil moisture. Over irrigation can cause yield impacts as great as drought stress by leaching nutrients, especially nitrogen, from the potato root zone. Obviously nutrient leaching can directly influence environmental parameters as well as economic concerns such as yield and quality.

Some non-conventional additives of different types are being promoted in potato to improve growth and development:

To enhance the color of red skinned potatoes, 1-2 applications of Riverdale 2,4-D L.V.6 Ester may be made at least 45 days before harvest. If 2,4-D were not available, these Red Norland potatoes would not be acceptable to consumers. However, goals of current breeding efforts is to develop lines that will not require 2,4-D for color enhancement.

Maleic hydrazide is commonly applied to many different types of potato to improve the size and quality of potato. Sugar content which corresponds to fry color may also be affected by maleic hydrazide. However, the most important impact of maleic hydrazide is the improved shape and decreased roughness (knobbiness) of treated potato.

Potatoes are susceptible to many types of stress types including heat, drought, and cold. Optimal growth occurs when day time temperatures are between 50-85^{o}F and night time temperatures between 50-70^{o}F.

Depending upon the variety, the crop takes 70-120 days to mature. Two to three weeks prior to harvest, the vines are killed with a desiccant. Vine desiccation enables maturation of the periderm (skin set) and destruction of late blight spores within the crop. Periderm maturation is critical for preventing skinning during the harvest process and improving wound healing capability of the crop after harvest. Mature periderm and rapid wound healking are critical to prevent infection of potato tubers by pathogens in storage or during post harvest handling or shipping. Late blight is a serious threat to tuber quality after harvest and killing vines prior to harvest minimizes risk of tuber infection by innoculum that may have been present in the growing crop.

Where vine growth is dense, multiple applications of desiccant may be needed to ensure vine senescence. Diquat, paraquat, endothal, glufosinate, and sulfuric acid are registered as vine desiccants but have use restrictions based on soil type and intended crop use. Most potatoes are dug after vines are completely desiccated—usually 14-21 days after treatment. Harvest is completely mechanically by windrowing potato after vine desiccation and then picking them up with a digger. Vine killing early in the season diminishes the potential for virus transmission into potato by aphid. Seed growers often desiccate early to minimize risk of virus contamination within the crop.

Potatoes are only harvested when internal (pulp) temperatures are between 45 and 65^{o} F. Pulp temperatures below 45^{o} F promote the development of bruises or darkening of surface or internal tissue. Pulp temperatures greater than 65^{o} F promote high respiration rates and the development of storage diseases in stored potato. Most potato in the north central region are harvested at 60^{o} F or warmer temperatures.

Potato storages allow marketing of raw crop product and year round processing across northcentral production areas for close to 10 months out of the year. Year round marketing of raw and processed product has been crucial for the long-term success of the potato industry in the North Central Region. Potato storages are the intermediate destination for 75 to 85 % of the potato crop in the North Central Region. Lengthening the duration of potato storage, minimizing losses, and optimizing quality are key goals for potato storages.

Potatoes are stored in piles 15 to 18 foot tall on concrete or soil floor. Potato storages are designed to manage air temperature, relative humidity, and air quality (O_2 and CO_2 content). Each factor is varied to manage potato quality (sugar content), shrink (losses due to respiration or evaporation), disease management, and promotion of wound healing.

Temperatures are varied depending on the variety, time within the storage season, intended duration of potato storage, and to influence the respiration and other physiological processes (especially those governing sugar composition of tubers). Potatoes that first enter storages must be cooled to remove the "heat" of the pile. Most times freshly harvested potato have pulp temperatures in excess of 60 F. Above 60 F, potato have accelerated respiration rates and pathogens can quickly infest, spread, and rot potato.

Once potato are cooled to 57 to 58 F (may take several weeks to a month), the pile is maintained at this temperature for several weeks to cure the potato. Curing promotes final wound healing (happens relatively quickly) and allows growers to manage sugars of freshly harvested potato. Primary sugar within potato are sucrose (non-reducing) and glucose and fructose (reducing). When fried, potato tissue with high levels of reducing sugars will turn dark in color. Potato are stored with low sucrose and reducing sugar content to minimize potential for dark color upon frying. Potatoes are cured until sucrose and reducing sugars reach minimal levels. Sucrose and glucose are generally converted into starch. Curing at 57 to 58 F is selected because pathogen development is minimized, but tuber physiological processes are still high at these temperatures.

Once potatoes are cured the pile temperature is lowered to prepare for long-term storage. This involves slowly lowering the storage temperature by ½ to 1^{o} F every 1 to 2 days until reaching the long term storage temperature. The pile is cooled slowly to prevent reducing sugar accumulation by "shocking" potatoes with sudden changes in temperature. Often times cool outside air is brought into the storage during nights and evenings to cool potato. Some storages in the North Central region have refrigeration, but they are not always capable of providing the cooling power to lower pile temperature. The long term storage temperature is the lowest pile temperature which prevents "cold sweetening" of potato. Cold sweetening is conversion of starch to reducing sugars and is initiated at the minimum storage temperature. The minimum storage temperature is between 45 and 50 degrees for processing potatoes. Processing potatoes are generally stored until they start to accumulate reducing sugars (up to 10 months).

Fresh market potatoes do not require the intensive sugar management of processing potato so they are generally stored at cooler temperatures of 42 to 45 F. Seed potato are often stored at even cooler temperatures of 38 F. Seed potato are stored at cooler temperatures to prevent "physiological aging". Physiological aging can lead to adverse early growth on planted potatoes.

The relative humidity is generally maintained at 95% or higher within potato storages. Potato tubers near the bottom of the pile can withstand the tremendous weight of 15 to 18 foot of potatoes because of the turgor pressure within a tuber. If the potato dries out, the turgor pressure is reduced and tubers near the bottom of the pile can suffer from pressure bruise. Therefore, humidity is maintained at high levels to prevent water loss by potatoes which leads to weight loss (shrink) and loss and turgor which results in pressure bruise. Once tubers lose moisture in storage they can never recapture the same water content.

Balancing the oxygen and carbon dioxide ratio in potato storages is critical to preventing disease development, causing a change in sugar content, and promoting wound healing on damaged potato. Maintaining high oxygen content early in the storage season is especially critical. Many storage bacteria are anaerobic, so maintaining minimum oxygen levels within the potato pile can go along way toward suppressing storage diseases. High carbon dioxide levels can also stress potatoes which will trigger the conversion of starch to reducing sugars. Maintaining high oxygen is critical to managing sugars in storage.

Wound healing is a critical process in preparing potato for storage. Wound healing enables tubers to develop protective barriers on damaged surfaces or abrasions that may have occurred during growth, storage, or handling. Wound healing includes the process of suberization and formation of wound periderm. Suberization involves the deposition of water insoluble materials along the wounded surface of potatoes. The suberin is resistant to invasion by bacteria and fungi and generally takes 2-5 days to complete. Oxygen management is key during suberization as high carbon dioxide levels can surpress or prevent suberization. Wound periderm forms on cut surfaces to prevent further tuber injury in the affected region.

Multiple products are labeled for use in potato storages to prevent disease development. Purogene, Oxidate, Mertect and ozone are used to sanitize potato surfaces and minimize potential for disease.

Potatoes that will be stored long-term require a sprout inhibitor that can be applied either in the field or in storage after the tubers have been cured. Common sprout inhibitors include MH30 (in-field application), and CIPC, and napathalamine chemistry are used for in-storage applications.

INSECT PESTS

Colorado Potato Beetle (*Leptinotarsa decemlineata*)

Biology & Life Cycle:

- Colorado potato beetles overwinter as adults in the soil, often at field margins. Adults become active in the spring and females lay bright yellow eggs in clusters of 15-25 on the lower leaf surfaces. Eggs hatch in 4-9 days and larvae begin feeding immediately. After passing through four instars over the course of 2-3 weeks, larvae return to the soil to pupate. Within 10-14 days, summer adult beetles emerge, which feed and overwinter. In warmer regions, two full generations, and possibly a third may occur. In southern Michigan two generations are common.

Distribution:

- Occurs throughout the north central states but is often most destructive in growing areas where potatoes are intensively cropped.

Damage:

- Both adults and larvae are leaf defoliators, eating large irregular holes.
- Often whole leaves and petioles are consumed causing plant death and reduced tuber yield.
- Overwintered adults feed primarily on field edges in rotated fields.
- Most damage caused by 3rd and 4th instar larvae and summer adults.
- Defoliation can lead to weed escapes and plant nutrition complications.
- If uncontrolled, damage will result in 50-100% yield reduction.
- In treated fields, yields may be reduced by 0-10%.
- In cases of severe resistance losses can approach 20-50%.

Importance:

- Major pest with importance increased by its ability to develop resistance to a wide range of insecticides.
- Without adequate control the potato industry in the Midwest would cease to exist.
- Control is currently heavily dependent on nicotinyls and resistance to this chemistry is widespread in the eastern U.S. and first found in North Central Region (Michigan) in 2004.

Non-Chemical Control:

- Biological control from general predators such as ladybeetles or stink bugs that feed on eggs and small larvae rarely provide economic levels of control.
- Cultural controls are extremely effective in delaying infestation and reducing populations and should be employed whenever possible. Distance rotation of potato crops is most effective and rotating new plantings at least ¼ mile from the nearest previous crop can significantly reduce infestation. Fall trap crops formed by leaving a strip of potatoes unkilled prior to harvest will aggregate large numbers of adults, which may then be killed prior to overwintering. Spring trap crops or field edges, which are infested first, can be used to aggregate adults early in the season where spot or edge treatments can then be used effectively to reduce populations. Plastic-lined trenches (18 inches deep) placed between overwintering sites and the emerging crop can also reduce infestation. Propane flaming can also be effective.

Chemical Control:

- Insecticide resistance management is essential to maintain effective chemical control.

- Foliar sprays have repeatedly resulted in resistance with control failures noted following applications of carbamates (carbaryl, Furadan, Vydate), organophosphates (Phorate, Disulfoton, Imidan, Guthion), organochlorines (Thiodan), and pyrethroids (Ambush, Pounce, Asana, and Baythroid).
- Tank mixes sometimes improve efficacy when resistance to a single chemical has developed. PBO enhances efficacy in pyrethroids and organophosphates but loses effectiveness in 2-3 years.
- To manage resistance, selection pressure must be reduced by decreasing the number of applications by carefully timing applications to target first generation, 1st and 2nd instar larvae.
- Avoid treatment of overwintered adults infesting fields or confine treatment to field edges if severe defoliation is occurring.
- Strict insecticidal rotation by chemical class within and between seasons in combination with cultural controls should be followed to further avoid resistance build up.
- Thresholds: 20-30% defoliation prior to flowering, 10% defoliation during flowering, 30% post flowering, however to maintain manageable populations treatments must be initiated at lower levels. Treatment at 15-30% egg hatch or first instar larval stage is most effective.
- Currently nicotinyls are used on 80% of the potato acreage within the region, creating severe resistance management concerns.
- Treatments may be applied in a site specific manner, for example field borders and hot spots.

- **Organochlorine**
  - Endosulfan (Thiodan, Phaser, Endosulfan)
    - Rate = 0.5-1.0 lb ai/A
    - PHI = 1 day
    - REI = 24 hours
    - Efficacy = Poor to good (resistance)
- **Organophosphates**
  - Phosmet (Imidan 70W)
    - Rate = 1 lb ai/A
    - PHI = 7 days
    - REI = 24 hours
    - Efficacy = Poor to good (resistance)
  - Phorate (Phorate G)
    - Rate = 2 – 3 lb ai/A
    - PHI = 90 days
    - REI = 48 hours
    - Soil application at planting
    - Efficacy = Poor
  - Disulfoton (Disyston)
    - Rate = 3 lb ai/A
    - PHI = 75 days
    - REI = 48 hours
    - Soil-application - systemic
    - Efficacy = Not effective
- **Carbamates**
  - Carbofuran (Furadan F)
    - Rate = 0.5-1.0 lb ai/A
    - PHI = 14 days
    - REI = 48 hours
    - Efficacy = Poor (resistance)
  - Oxamyl (Vydate L, CLV)
    - Rate = 0.5-1.0 lb ai/A
    - PHI = 7 days
    - REI = 24 hours

        - Efficacy = Poor to good
    - Carbaryl (Sevin)
        - Rate = 0.5-2.0 lb ai/A
        - PHI = 0 days
        - REI = 12 hours
        - Efficacy = Poor (resistance)

- **Pyrethroids**
    - Widespread resistance to pyrethroids is present. Synergists (PBO) should be used to enhance activity.
    - Cyfluthrin (Baythroid 2E)
        - Rate = 0.025 – 0.044 lb ai/A
        - PHI = 0 days
        - REI = 24 hours
        - Efficacy = Poor to good (resistance)
    - Deltamethrin (Decis)
        - Rate = 0.018-0.028 lb ai/A (1.5-2.4 oz/A)
        - PHI = 3 days
        - Efficacy = Poor to good (resistance)
    - Esfenvalerate (Asana XL)
        - Rate = 0.025 – 0.05 lb ai/A
        - PHI = 7 days
        - REI = 12 hours
        - Efficacy = Poor to good (resistance)
    - Permethrin (Ambush, Pounce)
        - Rate = 0.05 – 0.2 lb ai/A
        - PHI = 14 days
        - REI = 12 hours
        - Efficacy = Poor

- **Nicotinyls**
    - Imidacloprid (Admire)
        - Rate = 0.2-0.3 lb ai/A
        - PHI = 21 days
        - REI = 12 hours
        - Systemic applied preplant, at planting, or at emergence
        - Efficacy = Good to excellent
    - Imidacloprid (Provado)
        - Rate = 0.047 lb ai/A
        - PHI = 7 days
        - REI = 12 hours
        - Foliar spray
        - Efficacy = Fair to good
    - Imidacloprid (Genesis 2F)
        - Rate = 0.4 – 0.8 fl oz/ 100 lb seed pieces
        - PHI = NA
        - REI = 12 hours
        - Seed piece treatment
        - Efficacy = Good to excellent
    - Imidacloprid + Thiophanate-methyl + zinc + manganese (Tops MZ-Gaucho)
        - Rate = 0.75 – 1.0 lb/100 lb seed pieces
        - PHI = NA
        - REI = 12 hours
        - Seed piece treatment
        - Efficacy = Good to excellent
    - Imidacloprid/cyfluthrin (Leverage 2.7E)
        - Rate = 0.0792 lb ai/A

    - PHI = 7 days
    - REI = 12 hours
    - Foliar spray
    - Efficacy = Good (resistance concerns)
  - Thiamethoxam (Platinum)
    - Rate = 0.079-0.125 lb ai/A (6-8 oz/A)
    - PHI = 30 days
    - REI = 12 hours
    - Systemic applies at preplant, at planting, or at emergence
    - May be premixed with mefenoxam
    - Efficacy = Good to Excellent
  - Thiamethoxam (Actara)
    - Rate = 0.0435 lb ai/A (3.0 oz/A)
    - PHI = 14 days
    - REI = 12 hours
    - Foliar spray
    - Efficacy = Good
  - Thiamethoxam (Cruiser)
    - Rate = 0.11-0.16 oz/cwt
    - PH I = Seed treatment
    - Systemic seed treatment
    - Efficacy = Good to excellent

- **Other Products**
  - Abamectin (Agrimek)
    - Rate = 0.009 -0.0187 lb ai/A (8-16 oz)
    - PHI = 14 days
    - REI = 12 hours
    - Expensive
    - Efficacy = Good, very short residual
  - *Bacillus thuringiensis* var. *tenebrionis* (Novodor)
    - Rate = 1-3 quarts/A
    - PHI = 0 days
    - REI = 4 hours
    - Target small larvae
    - Efficacy = Fair to good, short residual
    - Availability questionable
  - Indoxacarb (Avaunt)
    - Rate = 0.065-0.11 lb ai/A (3.5-6.0 oz)
    - PHI = 7 days
    - REI = 12 hours
    - Expensive at effective rate (4-5 oz/A)
    - Efficacy = Poor
  - Novaluron (Rimon)
    - Rate = 12 oz/A
    - PHI 14 days
    - Efficacy= Good (larva only)

  - Sodium aluminofluoride (Prokil Cryolite 96, Kryocide)
    - Rate = 9.6 – 11.5 lb ai/A
    - PHI = 0 days
    - REI = 12 hours
    - Corrosive to application equipment
    - Difficult to use with irrigation
    - Efficacy = Fair to good
  - Spinosad (SpinTor 2SC)

- Rate = 0.047- 0.094 lb ai/A
- PHI = 7 days
- REI = 4 hours
- Expensive at effective rates
- Target smaller larvae
- Efficacy = good

Pipeline Products:

- Fipronil
- Other nicotinyls, Assail, Venom, Poncho, Belay, Clutch
- Trigard

To Do List:

Research

- Resistance baselines
- Alternative products – fipronil, abamectin
- Cultural controls
- Resistance management tactics for nicotinyl resistance
- Cross resistance studies
- Site specific management, sampling, GPS
- Resistant varieties, traditional and genetically enhanced

Regulatory

- Register Fipronil as a nicotinyl alternative

Extension

- Resistance management education

Potato leafhopper (*Empoasca fabae*)

Biology & Life Cycle:

- Small, wedge-shaped, lime green adults insert eggs into stems and leaf veins. Eggs hatch in 7-10 days. Nymphal development takes 12-15 days for 5 successively larger instars. Two to three generations per year with development slowing in August.

Distribution:

- Leafhoppers do not overwinter in the north central states but migrate from southeast regions arriving in May-June. Their large host range includes forages, beans, and many other plant types allow populations to build to high levels and adults can move rapidly into potatoes in high numbers. Nymphal populations build more slowly.

Damage:

- Both nymphs and adults feed by inserting their piercing/sucking mouthparts into the vascular tissue of the plant and extracting sap. Damage is principally to the phloem cells, which become blocked by salivary products.
- General symptoms include stunted plants with chlorotic foliage that curls upward at the margins. Early symptoms include triangular, brownish spots at the leaflet tip or leaf margins. Browning progresses inward from the margins and leaf margins become dry and brittle. Often only a narrow strip of green tissue remains along midveins. The burned appearance of the foliage is where the term "hopperburn" is derived.
- Symptoms of feeding injury begin on older foliage and move upward. Premature death of untreated vines causes severe yield reduction.
- Damage may be more severe in hot, dry years and nymphs cause more damage than adults.

- Yield loss may occur before obvious hopperburn symptoms develop and the level of yield loss is not directly related to hopperburn. Some varieties are more tolerant.
- If uncontrolled, damage would result in 30-80% yield reduction.
- If controlled, damage is minimal with 0-5% yield reduction.

Importance:

- Potato leafhopper is a major pest throughout the region but is easily controlled.
- Timely identification of the problem is critical to avoid economic loss since damage is irreversible.

Non-Chemical Control:

- Biological and cultural controls do not provide effective management of potato leafhoppers and chemical control is usually required.

Chemical Control:

- A broad range of insecticides provide effective potato leafhopper control including organophosphates (Dimethoate, Penncap-M, Malathion), carbamates (Lannate, carbaryl), and pyrethroids (Ambush, Pounce, Asana, Baythroid).
- Since the potato leafhopper is a migratory insect with a broad host range, insecticide resistance is not a concern, however, insecticides should only be used which will not select for resistance to other key pests such as the Colorado potato beetle.
- For natural enemy preservation (e.g. for aphid control), low application rates, short persistence materials or early season applications should be used to keep disruption at a minimum.
- Low rates of most materials provide effective leafhopper control, providing coverage is adequate.
- Before applications are made plants should be scouted by sweep net (adults) and leaf counts (nymphs) and treatments applied only when thresholds are exceeded: when adults are below 0.5 adults/sweep do not treat until more than 1 nymph/10 leaves is present; if 0.5-1.0 adults/sweep are present, treat if populations persist for 10-14 days or if nymphs are found; if 1.0-1.5 adults/sweep are present, treat in 5-7 days or immediately if nymphs are found; if over 1.5 adults/sweep are present, treat immediately.
- Reduced rates of effective insecticides (quarter rates of Dimethoate, Asana, Baythroid and Decis) provide control without flaring aphid populations.

- **Organochlorine**
  - Endosulfan (Thiodan EC)
    - Rate = 0.5-1.0 lb ai/A
    - PHI = 1 day
    - REI = 24 hours
    - Efficacy = Fair
- **Organophosphates**
  - Phosmet (Imidan 70W)
    - Rate = 1 lb ai/A
    - PHI = 7 days
    - REI = 24 hours
    - Efficacy = Fair to good
  - Dimethoate (Dimethoate EC)
    - Rate = 0.25 – 0.5 lb ai/A
    - PHI = 0 days
    - REI = 48 hours
    - Inexpensive
    - Efficacy = Excellent
  - Malathion (several formulations)
    - Rate = 0.6 – 0.9 lb ai/A
    - PHI = 0 days

        - REI = 12 hours
        - Short persistence
        - Efficacy = Fair
    - Methamidophos (Monitor EC)
        - Rate = 0.75 lb ai/A
        - PHI = 14 days
        - REI = 24 hours
        - Efficacy = Excellent
    - Phorate (Phorate)
        - Rate = 2 – 3 lb ai/A
        - PHI = 90 days
        - REI = 48 hours
        - Soil application at planting
        - Efficacy = Excellent early to mid season control
    - Disyston
        - 15-23 oz/1000 ft row
        - PHI = 75 days
        - REI = 48 hours
        - Soil applied at planting
        - Efficacy = Excellent early to mid season control
- **Carbamates**
    - Carbofuran (Furadan F)
        - Rate = 0.5 lb ai/A
        - PHI = 14 days
        - REI = 48 hours
        - Efficacy =Good to excellent
    - Carbaryl (several formulations)
        - Rate = 0.5 – 2.0 lb ai/A
        - PHI = 0 days
        - REI = 12 hours
        - Efficacy = Good
    - Methomyl (Lannate LV, SP)
        - Rate = 0.45 – 0.9 lb ai/A
        - PHI = 6 days
        - REI = 48 hours
        - Efficacy = Good
- **Pyrethroids**
    - Esfenvalerate (Asana)
        - Rate = 0.025-0.05 lb ai/A
        - PHI = 7 days
        - REI = 12 hours
        - Efficacy = Excellent
    - Permethrin (Ambush, Pounce)
        - Rate = 0.05 – 0.1 lb ai/A
        - PHI = 14 days
        - REI = 12 hours
        - Efficacy = Good
    - Cyfluthrin (Baythroid 2E)
        - Rate = 0.025 – 0.044 lb ai/A
        - PHI = 0 days
        - REI = 24 hours
        - Efficacy = Excellent
    - Deltamethrin (Decis)
        - Rate = 0.018-0.028 lb ai/A (1.5-2.4 oz/A)
        - PHI = 3 days

        - Efficacy = Poor to good (resistance)

- **Nicotinyls**
    - Thiamethoxam (Platinum)
        - Rate = 0.078-0.125 lb ai/A
        - PHI = 30 days
        - REI = 12 hours
        - Planting application in furrow
        - Efficacy = Good
    - Thiamethoxam (Cruiser)
        - Rate = 0.11-0.16 oz/cwt
        - Seed treatment
        - Efficacy = Good
    - Thiamethoxam (Actara)
        - Rate = 0.023 lb ai/A - 0.046 lb ai/A (1.5-3.0 oz/A)
        - PHI = 14 days
        - REI = 12 hours
        - Efficacy = Good
    - Imidacloprid (Admire)
        - Rate = 0.2-0.3 lb ai/A
        - PHI = 21 days
        - REI = 12 hours
        - Systemic applied preplant, at planting, or at emergence
        - Efficacy = Fair to good
    - Imidacloprid (Provado)
        - Rate = 0.047 lb ai/A
        - PHI = 7 days
        - REI = 12 hours
        - Foliar spray
        - Efficacy = Fair to good
    - Imidacloprid (Genesis 2F)
        - Rate = 0.4 – 0.8 fl oz/ 100 lb seed pieces
        - PHI = NA
        - REI = 12 hours
        - Seed piece treatment
        - Efficacy = Fair to good
    - Imidacloprid + Thiophanate-methyl + zinc + manganese (Tops MZ-Gaucho)
        - Rate = 0.75 – 1.0 lb/100 lb seed pieces
        - PHI =
        - REI = NA
        - Seed piece treatment
        - Efficacy = Fair to good
    - Imidacloprid/cyfluthrin (Leverage 2.7E)
        - Rate = 0.0792 lb ai/A
        - PHI = 7 days
        - REI = 12 hours
        - Foliar spray
        - Use low rate
        - Efficacy = Excellent

Pipeline Products:

- Other nicotinyls

To Do List:

Research

- o Prediction
- o Resistant varieties
- o Thresholds for existing varieties

Regulatory

- o Retain dimethoate registration

Extension

- o Mapping of distribution
- o Real time website communication, prediction

Aster leafhopper (*Macrosteles fascifrons*)

Biology & Life Cycle:

- The first aster leafhopper adults that appear in May to June are migrants from overwintering sites in grain fields from Louisiana to Kansas. Large influxes of adults may occur in May and June on southerly winds, when temperatures are above 60^{o}F. Aster leafhoppers do not reproduce on potatoes and nymphal populations are not a problem. Adults are usually only a problem early in the season on young potatoes.

Distribution:

- Annual migration pathway is usually centered west of the Mississippi with most severe infestation in Minnesota and more variable populations in North Dakota, Wisconsin, and Michigan which depend on weather patterns in March/April.

Damage:

- Occasional pest of early potatoes because of its ability to transmit the phytoplasma that causes aster yellows. On potatoes, this disease is called purple top.
- Newly sprouted potatoes are most susceptible while mature plants are almost totally resistant to aster yellows.
- Symptoms typically are not expressed for 30 days or more and include yellowing and reddening of mature foliage, and aerial tuber formation. Infected plants are generally stunted and have small tubers. When processed, infected tubers produce a dark-colored product.
- If uncontrolled, damage is dependent on the location of the crop and its age in relation to the migrating leafhopper population. Losses can be 5-10%. More severe loss (100%) can occur on processing potatoes.
- If controlled, losses are generally minimal (0-2%).

Importance:

- Aster leafhopper is a sporadic pest on early season potatoes.

Non-Chemical Control:

- The aster leafhopper has no effective biological controls and cultural controls cannot reduce infestation.

Chemical Control:

- Aster leafhopper must feed for extended periods (8-24 hours) to transmit the yellows organism and thus the disease is best managed by controlling the vector.
- Chemical control is necessary if the Aster Yellows Index (AYI) exceeds 50. AYI is derived from the number of adults/100 sweeps times the percent infectivity in the population. Adult numbers

are obtained by sweep sampling and a percent infectivity for the migrating population is determined by UW Extension.

- Since leafhoppers annually migrate to potatoes from untreated grain, resistance is not an issue.
- Systemic organophosphate insecticides (Thimet, DiSyston) provide effective control while nicotinyls are less effective. Foliar insecticides should only be used if populations exceed the AYI.

- **Organochlorine**
  - Endosulfan (Thiodan EC)
    - Rate = 0.5-1.0 lb ai/A
    - PHI = 1 day
    - REI = 24 hours
    - Efficacy = Poor
- **Organophosphates**
  - Dimethoate (Dimethoate EC)
    - Rate = 0.25 – 0.5 lb ai/A
    - PHI = 0 days
    - REI = 48 hours
    - Efficacy = Good
  - Disulfoton (Disyston)
    - Rate = 3 lb ai/A
    - PHI = 75 days
    - REI = 48 hours
    - Soil-application - systemic
    - Efficacy = Good
  - Malathion (several formulations)
    - Rate = 0.6 – 0.9 lb ai/A
    - PHI = 0 days
    - REI = 12 hours
    - Short persistence
    - Efficacy = Poor
  - Methamidophos (Monitor 4S)
    - Rate = 0.75 – 1.0 lb ai/A
    - PHI = 14 days
    - REI = 24 hours
    - Efficacy = Good
  - Phorate (Phorate G)
    - Rate = 2 – 3 lb ai/A
    - PHI = 90 days
    - REI = 48 hours
    - Soil application at planting
    - Efficacy = Good
  - Phosmet (Imidan 70W)
    - Rate = 1 lb ai/A
    - PHI = 7 days
    - REI = 24 hours
    - Efficacy = Good
- **Carbamates**
  - Carbofuran (Furadan F)
    - Rate = 0.5-1.0 lb ai/A
    - PHI = 14 days
    - REI = 48 hours
    - Efficacy = Good
  - Carbaryl (several formulations)
    - Rate = 0.5 – 2.0 lb ai/A
    - PHI = 0 days

- REI = 12 hours
- Efficacy = Poor to good

- Methomyl (Lannate LV, SP)
  - Rate = 0.45 – 0.9 lb ai/A
  - PHI = 6 days
  - REI = 48 hours
  - Efficacy = Good

- **Pyrethroids**
  - Cyfluthrin (Baythroid 2E)
    - Rate = 0.025 – 0.044 lb ai/A
    - PHI = 0 days
    - REI = 24 hours
    - Efficacy = Excellent
  - Deltamethrin (Decis)
    - Rate = 0.018-0.028 lb ai/A (1.5-2.4 oz/A)
    - PHI = 3 days
    - Efficacy = Excellent
  - Esfenvalerate (Asana XL)
    - Rate = 0.025 – 0.05 lb ai/A
    - PHI = 7 days
    - REI = 12 hours
    - Efficacy = Excellent
  - Permethrin (Ambush, Pounce)
    - Rate = 0.05 – 0.2 lb ai/A
    - PHI = 14 days
    - REI = 12 hours
    - Efficacy = Good
- **Nicotinyls**
  - Imidacloprid (Admire)
    - Rate = 0.2-0.3 lb ai/A
    - PHI = 21 days
    - REI = 12 hours
    - Systemic applied preplant, at planting, or at emergence
    - Efficacy = Fair to good
  - Imidacloprid (Provado)
    - Rate = 0.047 lb ai/A
    - PHI = 7 days
    - REI = 12 hours
    - Foliar spray
    - Efficacy =Fair
  - Imidacloprid (Genesis 2F)
    - Rate = 0.4 – 0.8 fl oz/ 100 lb seed pieces
    - PHI = NA
    - REI = 12 hours
    - Seed piece treatment
    - Efficacy = Fair to good
  - Imidacloprid + Thiophanate-methyl + zinc + manganese (Tops MZ-Gaucho)
    - Rate = 0.75 – 1.0 lb/100 lb seed pieces
    - PHI = NA
    - REI = 12 hours
    - Seed piece treatment
    - Efficacy = Fair to good
  - Thiamethoxam (Platinum)
    - Rate = 0.078-0.125 lb ai/A
    - PHI = 30 days

        - REI = 12 hours
        - Efficacy = Fair to good
    - Thiamethoxam (Cruiser)
        - Rate = 0.11-0.16 oz/cwt
        - PHI = 14 days
        - REI = 12 hours
        - Efficacy = Fair to good
    - Thiamethoxam (Actara)
        - Rate = 0.023 lb ai/A
        - PHI = 14 days
        - REI = 12 hours
        - Efficacy = Fair to good
    - Imidacloprid/cyfluthrin (Leverage 2.7E)
        - 0.0792 lb ai/A
        - PHI = 7 days
        - REI = 12 hours
        - Foliar spray
        - Efficacy = Good

Pipeline Products:

- None

To Do List:

Research

- Research on sources of aster yellows phytoplasma in migration
- Susceptibility of current varieties to leafhoppers and to aster yellows phytoplasma

Regulatory

- Retain pyrethroid registrations

Extension

- Map migration

Aphids:

Aphids are a concern primarily as vectors of several viruses, which affect potato although direct damage can also occur. Since potato seed is certified annually for virus content, aphids are more serious pests on seed potatoes. There are two economically important aphid species, which reproduce on potatoes, the green peach aphid and potato aphid. Buckthorn aphids, foxglove aphids, and melon aphids may occur periodically on potatoes but are rarely of economic importance. In addition to resident aphids there are numerous species of winged aphids which are not associated with potatoes but which can serve as vectors of non-persistent aphid viruses. Aphids from corn and small grains predominate.

Green peach aphid (*Myzus persicae*)

Biology & Life Cycle

- The green peach aphid does not overwinter successfully in the north central states and winged aphids migrate into northern areas from crops in southern states. When winged aphids infest potatoes, usually in mid season, they begin producing wingless nymphs asexually. Infestations often begin in the field margins and many generations of wingless forms can be produced during the summer. A single female can produce 50-100 live young and with a complete generation requiring less than 10 days under ideal conditions. In response to adverse conditions, such as crowding, winged, asexual forms are produced and further dispersal occurs.

Distribution:

- Green peach aphids are distributed throughout the north central region with earliest infestations (June) occurring in southern production areas. Seed production areas are in the northern range of the region with infestation typically occurring in mid July. Initial infestations are found on the lower leaves of potato plants.

Damage:

- Aphids feed by extracting plant sap and small to moderate infestations cause little direct injury. As populations increase rapidly (thousands/leaf) wilting and eventual plant death can occasionally occur. This is usually seen as small circular patches of dead vines (aphid holes). When present in large numbers, a black sooty mold fungus frequently grows on the excess sap secreted by the aphids (honeydew). This fungus is not pathogenic.
- Primary damage caused by aphids' results from transmission of plant viruses with potato leafroll virus and potato virus Y being most important. Green peach aphids are the most effective vectors of these diseases. Other aphids are more commonly associated with PVY.
- Virus symptoms of PVY are rarely severe from current season infection although some yield reduction can occur if infestation levels are high. Symptoms are primarily a mild mosaic pattern on leaves. When tubers are produced for seed, second season PVY infections cause severe mottling, stunting, and yield loss from small tubers. For this reason PVY must be kept at extremely low levels in seed stock and infected lots may be rejected causing severe economic loss.
- Virus symptoms for PLRV in current season consist of chlorosis and curled leaves. On fresh market stock PLRV is rarely an economic problem. On processing potatoes PLRV can cause net necrosis (internal discoloration) of the tubers in some varieties (e.g. Russet Burbank) which may reduce tuber quality for processing. This problem is more severe in western production areas. For seed stock, PLRV infection is a major economic concern due to seed lot rejections.
- If uncontrolled losses to aphid transmitted virus would be 2-5% for fresh, 5-10% for processing and 80-100% on seed.
- If controlled losses to aphid transmitted virus are minimal (0-5%) for fresh and processing and 5-30% for seed.

Importance:

- Green peach aphid is a major economic pest for seed potato production and a sporadic pest on processing and fresh potatoes.

Non-Chemical Control:

- **Biological:** Biological control by predators (e.g. Lady beetles, syrphids, lacewings) and parasitic wasps can effectively regulate aphid populations in potatoes and these natural enemies should be preserved by avoiding broad spectrum sprays where possible. This approach can only be used in table stock where virus transmission is not a primary concern and should not be used in seed production where extremely low thresholds must be maintained.
- In wet conditions, particularly where aphids are crowded, entomopathogenic fungi can cause epidemics which can rapidly decimate aphid populations. Fungicides used for late blight control can delay or prevent this natural control.
- **Cultural:** Winged green peach aphids land preferentially on crop edges adjoining bare soil. Planting edges with cover crops not susceptible to virus can reduce virus spread.

Chemical Control:

- Chemical control can be achieved by systemic insecticides or foliar sprays. Systemics are most effective in early and mid season with nicotinyls being used most frequently.
- Foliar sprays should be employed when aphid populations exceed thresholds (normally in mid-late season) and thresholds (aphids/25 leaves) vary by end use:
    - For Fresh Market or Processing
        - Early season: 50 wingless (all species)
        - After bloom: 100 wingless (all species)
    - For Fresh or Processing in Seed Production Areas
        - 7.5 wingless green peach aphids
        - 50 aphids (all other species)
    - For Seed Potatoes (PLRV Management)
        - 2.5 green peach aphids (susceptible varieties)
        - 7.5 green peach aphids (resistant varieties)
        - 25 potato aphids
- Repeated foliar applications of similar mode of action should be avoided since the green peach aphid can rapidly develop resistance.

- **Organochlorine**
    - Endosulfan (Thiodan EC)
        - Rate = 0.5-1.0 lb ai/A
        - PHI = 1 day
        - REI = 24 hours
        - Efficacy = Poor
- **Organophosphates**
    - Dimethoate (Dimethoate EC)
        - Rate = 0.25 – 0.5 lb ai/A
        - PHI = 0 days
        - REI = 48 hours
        - Efficacy = Fair
    - Disulfoton (Disyston)
        - Rate = 0.4 – 1.0 lb ai/A
        - Foliar spray
        - PHI = 30 days
        - REI = 48 hours
        - Systemic
        - Efficacy = Good early to mid season
    - Malathion (several formulations)
        - Rate = 0.6 – 0.9 lb ai/A
        - PHI = 0 days
        - REI = 12 hours
        - Efficacy = Poor
    - Methamidophos (Monitor 4S)
        - Rate = 0.75 – 1.0 lb ai/A
        - PHI = 14 days
        - REI = 24 hours
        - Efficacy = Excellent
    - Phorate (Phorate G)
        - Rate = 2-3 lb ai/A
        - PHI = 90 days
        - REI = 24 hours
        - Soil application at planting
        - Efficacy = Poor to Fair, early to mid season control

- **Carbamates**
  - Methomyl (Lannate LV, SP)
    - Rate = 0.45 – 0.9 lb ai/A
    - PHI = 6 days
    - REI = 48 hours
    - Efficacy = Poor
  - Oxamyl (Vydate L)
    - Rate = 0.5 – 1.0 lb ai/A
    - PHI = 7 days
    - REI = 24 hours
    - Efficacy = Fair to good
- **Pyrethroids; not recommended**
  - Cyfluthrin (Baythroid 2E)
    - Rate = 0.025 – 0.044 lb ai/A
    - PHI = 0 days
    - REI = 24 hours
    - Efficacy = Fair to poor
  - Esfenvalerate (Asana XL)
    - Rate = 0.025 – 0.05 lb ai/A
    - PHI = 7 days
    - REI = 12 hours
    - Efficacy = Fair to poor
- **Nicotinyls**
  - Higher rates of systemics are needed to control pests full-season
  - Imidacloprid (Admire)
    - Rate = 0.2-0.3 lb ai/A
    - PHI = 21 days
    - REI = 12 hours
    - Systemic applied preplant, at planting, or at emergence
    - Efficacy = Excellent
  - Imidacloprid (Provado)
    - Rate = 0.047 lb ai/A
    - PHI = 7 days
    - REI = 12 hours
    - Foliar spray
    - Efficacy = Fair to good
  - Imidacloprid (Genesis 2F)
    - Rate = 0.4 – 0.8 fl oz/ 100 lb seed pieces
    - PHI = NA
    - REI = 12 hours
    - Seed piece treatment
    - Efficacy = Good to excellent
  - Imidacloprid + Thiophanate-methyl + zinc + manganese (Tops MZ-Gaucho)
    - Rate = 0.75 – 1.0 lb/100 lb seed pieces
    - PHI = NA
    - REI =
    - Seed piece treatment
    - Efficacy = Good to excellent
  - Thiamethoxam (Platinum)
    - Rate = 0.079-0.125 lb ai/A
    - PHI = 30 days
    - REI = 12 hours
    - Systemic applies at preplant, at planting, or at emergence
    - May be premixed with mefenoxam
    - Efficacy = Excellent

- Thiamethoxam (Actara)
  - Rate = 0.0235-0.046 lb ai/A (1.5-3.0 oz/A)
  - PHI = 14 days
  - REI = 12 hours
  - Foliar spray
  - Efficacy = Good
- Thiamethoxam (Cruiser)
  - Rate = 0.11-0.16 oz/cwt
  - PHI = 14 days
  - REI = 12 hours
  - Efficacy = Good to excellent
- Imidacloprid/cyfluthrin (Leverage 2.7E)
  - Rate = 0.0792 lb ai/A
  - PHI = 7 days
  - REI = 12 hours
  - Foliar spray
  - Efficacy = Good

- **Others**
  - Pymetrozine (Fulfill 50WDG)
    - Rate = 2.75 oz product/A
    - PHI = 14 days
    - REI = 12 hours
    - Feeding arrestant – takes 4-7 days to reduce populations
    - Spray at lower thresholds
    - Efficacy = Good to excellent
    - Better when applied early in infestation

Pipeline Products:

- Other nicotinyls

To Do List:

Research

- Distribution, trapping network
- Resistant varieties
- Understanding of varietal virus sensitivity
- Beneficial arthropod conservation through the use of selective insecticides
- Determine effective numbers and types of beneficial arthropods
- Impacts of new narrow spectrum fungicides on aphids and fungal diseases of aphids and leafhoppers

Regulatory

- Increase rate of Actara
- Retain Monitor for seed treatment

Extension

- Aphid mapping network in north central region

Potato Aphid (*Macrosiphum euphorbiae*)

Biology & Life Cycle:

- Potato aphids overwinter as eggs on wild and cultivated roses. Eggs hatch in the spring and several generations are produced asexually on the succulent, developing tissue of the rose before winged forms of the aphid are produced. Winged aphids migrate to susceptible host plants in early summer. On potatoes, aphids give birth to nymphs asexually. Aphid nymphs become mature in two weeks. The short generation time, along with the high numbers of offspring, result in rapidly exploding populations. As conditions become adverse or crowding occurs, the aphids disperse to new hosts. In late fall, winged forms return to roses, undergo sexual reproduction, and lay overwintering eggs prior to frost.

Distribution:

- Potato aphids are distributed throughout the north central region. Infestation from locally-occurring overwintered populations occurs in June and is earlier in southern areas. Infestations are often found on terminals and new foliage.

Damage:

- Potato aphids rarely cause direct plant damage.
- Primary damage is caused by vectoring viruses of potato but the potato aphid is not as efficient a vector as green peach aphids (particularly for PLRV) and is primarily of concern in PVY transmission. See green peach aphid section above for virus symptoms.
- If uncontrolled, losses attributed to potato aphids would be 2-5% for fresh and processing and 10-30% for seed.
- If controlled effectively, losses are minimal on fresh potatoes and 5-10% on seed.

Importance:

- Potato aphid is a sporadic, mid-season pest with major impact on seed potatoes.

Non-Chemical Control:

- The potato aphid normally infests potatoes in mid-season (June/July) and is susceptible to the same non-chemical controls as the green peach aphid described earlier.

Chemical Control:

- Chemical control can be achieved with a broader range of insecticides (including pyrethroids) and since potato aphids are not as efficient as vectors, thresholds are higher.
- **Organochlorine**
    - Endosulfan (Thiodan EC)
        - Rate = 0.5-1.0 lb ai/A
        - PHI = 1 day
        - REI = 24 hours
        - Efficacy = Good
- **Organophosphates**
    - Dimethoate (Dimethoate EC)
        - Rate = 0.25 – 0.5 lb ai/A
        - PHI = 0 days
        - REI = 48 hours
        - Efficacy = Good
    - Disulfoton (Disyston)
        - Rate = 0.4 – 1.0 lb ai/A
        - PHI = 30 days
        - REI = 48 hours
        - Efficacy = Good to excellent
    - Malathion (several formulations)
        - Rate = 0.6 – 0.9 lb ai/A
        - PHI = 0 days
        - REI = 12 hours
        - Efficacy = Fair
    - Methamidophos (Monitor 4S)

        - Rate = 0.75 – 1.0 lb ai/A
        - PHI = 14 days
        - REI = 24 hours
        - Efficacy = Excellent
    - Phorate (Phorate G)
        - Rate = 2-3 lb ai/A
        - PHI = 90 days
        - REI = 24 hours
        - Soil application at planting
        - Efficacy = Excellent
- **Carbamates**
    - Methomyl (Lannate LV, SP)
        - Rate = 0.45 – 0.9 lb ai/A
        - PHI = 6 days
        - REI = 48 hours
        - Efficacy = Good
    - Oxamyl (Vydate L)
        - Rate = 0.5 – 1.0 lb ai/A
        - PHI = 7 days
        - REI = 24 hours
        - Efficacy = Good
- **Pyrethroids**
    - Cyfluthrin (Baythroid 2E)
        - Rate = 0.025 – 0.044 lb ai/A
        - PHI = 0 days
        - REI = 24 hours
        - Efficacy = Excellent
    - Esfenvalerate (Asana XL)
        - Rate = 0.025 – 0.05 lb ai/A
        - PHI = 7 days
        - REI = 12 hours
        - Efficacy = Excellent
    - Permethrin (Ambush, Pounce)
        - Rate = 0.05 – 0.2 lb ai/A
        - PHI = 14 days
        - REI = 12 hours
        - Efficacy = Good
- **Nicotinyls:**
    - Higher rates of systemics are needed to control pests mid-season
    - Imidacloprid (Admire)
        - Rate = 0.2-0.3 lb ai/A
        - PHI = 21 days
        - REI = 12 hours
        - Systemic applied preplant, at planting, or at emergence
        - Efficacy = Excellent
    - Imidacloprid (Provado)
        - Rate = 0.047 lb ai/A
        - PHI = 7 days
        - REI = 12 hours
        - Foliar spray
        - Efficacy = Good to excellent
    - Imidacloprid (Genesis 2F)
        - Rate = 0.4 – 0.8 fl oz/ 100 lb seed pieces
        - PHI = NA
        - REI = 12 hours

    - Seed piece treatment
    - Efficacy = Excellent
  - Imidacloprid + Thiophanate-methyl + zinc + manganese (Tops MZ-Gaucho)
    - Rate = 0.75 – 1.0 lb/100 lb seed pieces
    - PHI = NA
    - REI = 12 hours
    - Seed piece treatment
    - Efficacy = Fair to good
  - Thiamethoxam (Platinum)
    - Rate = 0.078-0.125 lb ai/A
    - PHI = 30 days
    - REI = 12 hours
    - Efficacy = Excellent
  - Thiamethoxam (Cruiser)
    - Rate = 0.11-0.16 oz/cwt
    - PHI = 14 days
    - REI = 12 hours
    - Efficacy = Good to excellent
  - Thiamethoxam (Actara)
    - Rate = 0.023 lb ai/A
    - PHI = 14 days
    - REI = 12 hours
    - Efficacy = Excellent
  - Imidacloprid/cyfluthrin (Leverage 2.7E)
    - Rate = 0.0792 lb ai/A
    - PHI = 7 days
    - REI = 12 hours
    - Foliar spray
    - Efficacy = Good to excellent
- **Others**
  - Pymetrozine (Fulfill 50WDG)
    - Rate = 2.75 oz product/A
    - PHI = 14 days
    - REI = 12 hours
    - Feeding inhibitor, takes 4-7 days to reduce population
    - Efficacy = Good to excellent

Pipeline Products:

- Same as green peach aphid

To Do List:

Research

- Same as green peach aphid

Regulatory

- Same as green peach aphid

Extension

- Aphid mapping

Potato fleabeetle (*Epitrix cucumeris*)

Biology & Life Cycle:

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

Distribution:

- Fleabeetles are present throughout the region and populations can fluctuate annually.

Damage:

- Adult fleabeetles feed on both leaf surfaces but usually on the underside where they chew small, circular holes less than ⅛ inch, through the tissue to the upper cuticle. The circular holes give the plant a shotgun blast appearance which is characteristic of fleabeetle injury. Heavy feeding on young plants may reduce yields or even kill plants in severe cases. Larvae feed on the roots and tubers but do not cause economic injury.
- If uncontrolled, high populations can reduce yields by 5-10%.
- If controlled, yield losses are minimal.

Importance:

- Rarely a serious pest.

Non-Chemical Control:

- **Biological:** Fleabeetles are not regulated effectively by natural control.
- **Cultural:** Controls such as crop rotation may reduce populations but in severe infestations, chemical control may occasionally be necessary.

Chemical Control:

- Systemic insecticides normally provide excellent control. Foliar sprays of many classes also provide excellent control but should not be employed unless high populations are present at bloom.
- **Organochlorine**
    - Endosulfan (Thiodan EC)
        - Rate = 0.5-1.0 lb ai/A
        - PHI = 1 day
        - REI = 24 hours
        - Efficacy = Good
- **Organophosphates**
    - Methomidophos (Monitor 4S)
        - Rate = 0.75 – 1.0 lb ai/A
        - PHI = 14 days
        - REI = 24 hours
        - Efficacy = Excellent
- **Carbamates**
    - Carbofuran (Furadan F)
        - Rate = 0.5-1.0 lb ai/A
        - PHI = 14 days
        - REI = 48 hours
        - Efficacy = Excellent
    - Carbaryl (several formulations)
        - Rate = 0.5 – 2.0 lb ai/A
        - PHI = 0 days

        - REI = 12 hours
        - Efficacy = Good
    - Methomyl (Lannate LV, SP)
        - Rate = 0.45 – 0.9 lb ai/A
        - PHI = 6 days
        - REI = 48 hours
        - Efficacy = Good
- **Pyrethroids**
    - Cyfluthrin (Baythroid 2)
        - Rate = 0.025 – 0.044 lb ai/A
        - PHI = 0
        - REI = 24 hours
        - Efficacy = Excellent
    - Esfenvalerate (Asana XL)
        - Rate = 0.025 – 0.5 lb ai/A
        - PHI = 7 days
        - REI = 12 hours
        - Efficacy = Excellent
    - Permethrin (Ambush, Pounce)
        - Rate = 0.05 – 0.2 lb ai/A
        - PHI = 14 days
        - REI = 12 hours
        - Efficacy= Excellent
- **Nicotinyls**
    - Imidacloprid (Admire)
        - Rate = 0.2-0.3 lb ai/A
        - PHI = 21 days
        - REI = 12 hours
        - Systemic applied preplant, at planting, or at emergence
        - Efficacy = Excellent
    - Imidacloprid (Provado)
        - Rate = 0.047 lb ai/A
        - PHI = 7 days
        - REI = 12 hours
        - Foliar spray
        - Efficacy = Excellent
    - Imidacloprid (Genesis 2F)
        - Rate = 0.4 – 0.8 fl oz/ 100 lb seed pieces
        - PHI = NA
        - REI = 12 hours
        - Seed piece treatment
        - Efficacy = Excellent
    - Imidacloprid + Thiophanate-methyl + zinc + manganese (Tops MZ-Gaucho)
        - 0.75 – 1.0 lb/100 lb seed pieces
        - PHI = NA
        - REI = 12 hours
        - Seed piece treatment
        - Efficacy = Excellent
    - Thiamethoxam (Platinum)
        - Rate = 0.078-0.125 lb ai/A
        - PHI = 30 days
        - REI = 12 hours
        - Efficacy = Excellent
    - Thiamethoxam (Cruiser)
        - Rate = 0.11-0.16 oz/cwt

        - PH I=Seed treatment
        - Systemic seed treatment
        - Efficacy = Good to excellent
    - Thiamethoxam (Actara)
        - Rate = 0.023 lb ai/A
        - PHI = 14 days
        - REI = 12 hours
        - Efficacy = Excellent
    - Imidacloprid/cyfluthrin (Leverage 2.7E)
        - Rate = 0.0792 lb ai/A
        - PHI = 7 days
        - REI = 12 hours
        - Foliar spray
        - Efficacy = Excellent

Pipeline Products:

- None

To Do List:

Research

- Do they impact disease levels
- Do they contribute to multiple stress factors

Regulatory

- None

Extension

- None

Cutworms (*Agrotis ipsilon, Peridroma saucia*)

Biology & Life Cycle:

- There are at least two species of cutworms that are problematic in potatoes: black cutworm and the variegated cutworm. Larvae of both insects feed at night and hide in the soil during the day.
- Black cutworm moths migrate from southern states each spring. Mated females lay eggs on low-growing vegetation or plant residue from the previous crop. Larvae go through several instars before pupation. There are 2-3 generations per year but it is the first generation that is most damaging as it occurs when crops are small. Larvae are foliage feeders in early instars and later instars may "cut" plant stems.
- Black cutworms in Michigan: mid to late season situations where mid-sized to large larvae burrow into the soil and cause tuber damage.
- Variegated cutworms overwinter in the soil as partially matured larvae or pupae. Adults emerge in spring and eggs are laid in clusters on grass, weeds and vegetables. Larvae are primarily foliage-feeders. There are two generations per year.

Distribution:

- Cutworms are found throughout the region with earliest and most severe infestations occurring in southern areas.
- Damage is often confined to isolated areas of fields where eggs were laid in spring.

Damage:

- Larvae of both black and variegated cutworm cause defoliation ranging from "window-paning" to larger holes. Damage is most severe from late instar larvae and may be confined to isolated field areas.

- If uncontrolled, infested areas may suffer 5-20% yield losses with whole field losses less than 5%.
- If controlled, losses are minimal. In situations involving tuber damage control is problematic.

Importance:

- Cutworms are a sporadic pest of limited economic importance. In isolated situations damage can be severe. Systemic nicotinyl insecticides do not control cutworms and minor damage may be more evident in these fields.

Non-Chemical Control:

- **Biological:** Although cutworms are susceptible to attack by general predators and some parasitoids, these do not provide adequate regulation.
- **Cultural:** Tillage to remove crop residue and weeds may reduce early season black cutworm problems.

Chemical Control:

- Chemical control is effective, but since cutworm defoliation rarely causes yield loss, sprays should only be applied when populations exceed thresholds (4/row foot in early season and 8/row foot late in the season). Systemic insecticides do not provide cutworm control.
- Thresholds for black cutworms, where tuber damage may be involved, are much lower.
- **Carbamates**
  - Carbaryl (several formulations)
    - Rate = 0.5 – 2.0 lb ai/A
    - PHI = 0 days
    - REI = 12 hours
    - Efficacy = Poor
- **Pyrethroids**
  - Cyfluthrin (Baythroid 2)
    - Rate = 0.025 – 0.044 lb ai/A
    - PHI = 0
    - REI = 24 hours
    - Efficacy = Good
  - Esfenvalerate (Asana XL)
    - Rate = 0.025 – 0.5 lb ai/A
    - PHI = 7 days
    - REI = 12 hours
    - Efficacy = Good
  - Permethrin (Ambush, Pounce)
    - Rate = 0.05 – 0.2 lb ai/A
    - PHI = 14 days
    - REI = 12 hours
    - Efficacy = Good
- **Others**
  - *Bacillus thuringiensis* subsp. *kurstaki* (several formulations)
    - Rate = 1 -2 lb Bt/A
    - PHI = 0 days
    - REI = 4 hours
    - Efficacy = Poor
  - Spinosad (SpinTor 2SC)
    - Rate = 4.5 – 6.0 fl oz product/A
    - PHI = 7 days
    - REI = 4 hours
    - Efficacy = Good
  - Indoxacarb (Avaunt)

- Rate = 0.065-0.11 lb ai/A (3.5-6.0 oz)
- PHI = 7 days
- REI = 12 hours
- Expensive at effective rate (4-5 oz/A)
- Efficacy = Good

Pipeline Products:

- Reduced risk lepidopteran materials

To Do List:

Research

- Tuber damage thresholds

Regulatory

- None

Extension

- Distribution maps
- Pheromone monitoring

European corn borer (*Ostrinia nubilalis*)

Biology & Life Cycle:

- European corn borers overwinter as mature 5th instar larvae in corn stalks and stems of weedy hosts. Pupation occurs in the spring with the first moths flying shortly thereafter. Eggs are laid in masses on the underside of leaves and the early instar larvae feed on leaves and in the midrib of the leaf. Third instar larvae begin to bore into the stems. There are normally two generations per year but only the first generation is damaging to potatoes. In some locations a single generation is present.

Distribution:

- European corn borer is found throughout the region with a wide host range including field corn and sweet corn (preferred hosts), beans, and a wide range of herbaceous plants. Infestations are most severe in southern growing areas with large acreages of corn. Certain potato varieties are highly susceptible (Norgold, Red Dale and Norkotah).

Damage:

- Early instars feed on leaves and cause no damage. Later instars tunnel in stems and these plants may be chlorotic and wilted. Secondary infection with bacterial pathogens can increase the scope of damage and reduced tuber quality.
- Damage is often related to the availability of alternate hosts for oviposition in spring (June) with potatoes suffering more damage if corn development is delayed.
- If uncontrolled, susceptible varieties in years of high infestation may suffer yield reductions of 5-20%.
- If controlled, damage rarely exceeds 2-5%.

Importance:

- A sporadic pest of potatoes with economic damage increasing when alternative hosts such as corn are not available.

Non-Chemical Control:

- **Biological:** Regulation of overwintering larvae by parasites and predation of eggs by predators (e.g. lady beetles, stink bugs) can reduce populations.
- **Cultural:** Cultural controls are not effective in the potato crop although mowing edge grassy areas where moths congregate, may reduce oviposition.

Chemical Control:

- In years when first generation adult flights are high, insecticidal controls may be necessary if egg masses are found on more than 10% of the leaves.
- **Carbamates**
    - Carbaryl (several formulations)
        - Rate = 0.5 – 2.0 lb ai/A
        - PHI = 0 days
        - REI = 12 hours
        - Efficacy = Fair
    - Carbofuran (Furadan F)
        - Rate = 0.5 – 1.0 lb ai/A
        - PHI = 14 days
        - REI = 48 hours
        - Efficacy = Good
- **Pyrethroids**
    - Cyfluthrin (Baythroid 2)
        - Rate = 0.025 – 0.044 lb ai/A
        - PHI = 0 days
        - REI = 24 hours
        - Efficacy = Good
    - Esfenvalerate (Asana XL)
        - Rate = 0.025 – 0.5 lb ai/A
        - PHI = 7 days
        - REI = 12 hours
        - Efficacy = Fair
    - Permethrin (Ambush, Pounce)
        - Rate = 0.05 – 0.2 lb ai/A
        - PHI = 14 days
        - REI = 12 hours
        - Efficacy = Fair
- **Others**
    - *Bacillus thuringiensis* subsp. *kurstaki* (several formulations)
        - Rate = 1 -2 lb Bt/A
        - PHI = 0 days
        - REI = 4 hours
        - Efficacy = Poor
    - Indoxacarb (Avaunt)
        - Rate = 0.065 – 0.11 lb ai/A
        - PHI = 7 days
        - REI = 3 hours
        - Efficacy = Fair to good
    - Spinosad (SpinTor 2SC)
        - Rate = 4.5 – 6.0 fl oz product/A
        - PHI = 7 days
        - REI = 4 hours
        - Efficacy = Fair to good
    - Novaluron (Rimon)
        - Rate = 12 oz/A

        - PHI = 14 days
        - Efficacy = good (eggs and larvae only)

Pipeline Products:

- None.

To Do List:

Research

- Sampling regime for egg laying
- Indicator crops

Regulatory

- None

Extension

- Pest mapping

Wireworms

Biology & Life Cycle

- Wireworms have an extended life cycle, taking from 1-6 years to complete a single generation. Larvae live in the upper six inches of the soil and feed on seeds and roots. Adults become active in spring as they fly searching for a site on which to oviposit. Eggs are laid in grassy areas such as pastures, alfalfa, sod, and grassy row crop fields.
- Wireworms feed primarily on grasses including corn and small grains as well as nearly all wild and cultivated grasses.

Distribution:

- Widely distributed in the north central region. Most severe damage will be where previous cropping history includes several years of sod or grassy weeds.

Damage:

- Larvae tunnel into tubers causing deep ⅛ inch cylindrical holes which cause quality downgrades and may result in crop rejection in severe infestations.
- If uncontrolled, losses due to quality rejection could be 50-100% in severe cases.
- If controlled, losses may be 5-10%.

Importance:

- A sporadic pest which can cause economic loss in rotations following sod, grassy weeds or forage with pasture.

Non-Chemical Control:

- **Biological:** No biological controls are known.
- **Cultural:** Crop rotations which avoid grassy crops or sod will reduce damage.

Chemical Control:

- **Organophosphates**
    - Diazinon (several formulations)
        - Rate = 2 – 4 lb ai/A

        - PHI =
        - REI = 24 hours
        - Efficacy = Poor
    - Ethoprop (Mocap EC)
        - Rate = 4 – 6 lb ai/A
        - PHI = NA
        - REI = 48 hours
        - Applied at planting
        - Efficacy = Fair to good
    - Phorate (Phorate 20G, Thimet 20G)
        - Rate = 0.14 – 0.22 lb ai/1000 ft row
        - PHI = 90 days
        - REI = 48 hours
        - Efficacy = Fair to good
- **Nicotinyls**
    - Nicotinyl insecticides including imidacloprid and thiamethoxam have shown some wireworm on seed pieces.

Pipeline Products:

- Fipronil

To Do List:

Research
- Nicotinyl efficacy

Regulatory
- Need organophosphate alternatives (e.g. Mocap)

Extension
- None

White Grubs

Biology & Life Cycle

- White grubs have an extended life cycle, taking from 1-3 years to complete a single generation. Larvae live in the upper six inches of the soil and feed on seeds and roots. Adults become active in spring as they fly searching for a site on which to oviposit. Eggs are laid in grassy areas such as pastures, alfalfa, sod, and grassy row crop fields.

Distribution:

- Widely distributed in the north central region. Most severe damage will be where previous cropping history includes several years of sod or grassy weeds.

Damage:

- Larvae tunnel into tubers causing deep cylindrical holes which cause quality downgrades and may result in crop rejection in severe infestations.
- If uncontrolled, losses due to quality rejection could be 50-100% in severe cases.
- If controlled, losses may be 5-10%.

Importance:

- A sporadic pest which can cause economic loss in rotations following sod, grassy weeds or forage with pasture.

Non-Chemical Control:

- **Biological:** No biological controls are known.
- **Cultural:** Crop rotations which avoid grassy crops or sod will reduce damage.

Chemical Control:

- **Organophosphates**
  - Ethoprop (Mocap EC)
    - Rate = 4 – 6 lb ai/A
    - PHI = NA
    - REI = 48 hours
    - Applied at planting
    - Efficacy = Poor to fair
  - Phorate (Phorate 20G, Thimet 20G)
    - Rate = 0.14 – 0.22 lb ai/1000 ft row
    - PHI = 90 days
    - REI = 48 hours
    - Efficacy = Poor to fair
- **Nicotinyls**
  - Nicotinyl insecticides including imidacloprid and thiamethoxam have shown some white grub efficacy but are unproven.

Pipeline Products:

- Fipronil

To Do List:

Research

- None

Regulatory

- Need organophospate alternatives.

Extension

- White grub identification-soil insect bulletin.

Potato Diseases

Bacterial Ring Rot (*Clavibacter michiganensis var. michiganensis*)

Symptoms & Life Cycle:

- Highly infectious disease spread by potato cutters, planters, harvesters, and containers.
- The bacterium overwinters in tubers or as bacterial exudates on baskets, bags, and equipment.
- Healthy plants are infected through wounds or lesions or through the use of contaminated knives during seed cutting. Once inside the plant, the bacteria invades the xylem tissues.
- Symptoms don't appear until late in the growing season. Some infected plants may be asymptomatic.
- Symptoms include interveinal chlorosis, upward-rolling leaves and ultimately plant death. When an infected stem is cut, the vascular tissues appear brown and a milky-white bacterial exudate can be squeezed from the base of the infected stem.
- Infected tubers may have reddish areas near the eyes or the skin may be swollen. When the tuber is cut across the stem end, a creamy yellow to light brown rot is visible in the vascular ring. The rot is crumbly to cheesy and odorless.

Distribution & Importance:

- Losses can be high if infected plants rot in the field or in storage.

Non-Chemical Control:

- Effective seed certification with zero tolerance on a national scale.

Chemical Control:

- Use of disinfectants in storage, handling equipment, conveyors, seed cutters and trucks.

Pipeline Products:

- None

To Do List:

Research

- Better detection and diagnostic tools.
- Evaluation of disinfectants for treatment of storages and equipment

Regulatory

- Accreditation of diagnostic labs
- Symptomless varieties should not be approved for use

Extension

- New bulletin focusing on disinfectants

Bacterial Soft Rot (*Erwinia carotovora var. carotovora*)

Symptoms & Life Cycle:

- The bacterium overwinters on crop debris, may be present on seed tubers, and is spread by splashing rain and irrigation.
- In wet soil, tuber lenticels are enlarged, providing an entrance for the bacteria. On wet stems and leaves, infection often occurs through wounds.
- Infected tissues collapse and dry, leading to wilting of the foliage or affected vines.

- Affected tubers are typically white to cream-colored, soft, somewhat watery and slightly granular demarcated by a black margin. Later, the infected tissue becomes grey-brown.
- 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.

Distribution & Importance:

- Highly infectious disease spread by potato cutters, planters, harvesters, containers and trucks.
- Ubiquitous

Non-Chemical Control:

- Sanitation, destruction of volunteer potatoes, crop rotation, careful irrigation to avoid continuously wet vines, calcium nutrition, avoiding skinning and harvesting a mature crop.

Chemical Control (bacterial soft rot of stems only):

- Copper hydroxide (Kocide, Champ)
  - Rate = 1-2 lb ai/A
  - PHI = 0 Days
  - REI = 24 hours
  - Efficacy = Poor, not used much

Pipeline Products:

- None

To Do List:

Research

- Need effective post-harvest treatment
- Efficacy data on Oxidate
- Indirect control of stem rot by control of white mold
- Interaction between anti-transpirants and soft rot

Regulatory

- None

Extension

- Irrigation scheduling in field

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

Symptoms & Life Cycle:

- The bacteria overwinters in the soil or in tubers associated with infected plant debris but does not appear to survive in the absence of host tissue. It is spread by the movement of soil water and insects.
- Early symptoms appear as chlorosis of the leaves but progress to a dark, inky black, slimy lesions on the stems ultimately resulting in a girdling of the lower stems.
- Vascular tissue is darkly colored.
- Infected tubers decay beginning at the stolon end and there is a circular black opening on the tuber surface. Internal symptoms show varying degrees of soft rot.
- Primarily a seed-borne issue.

Distribution & Importance:

- Highly infectious disease spread by potato cutters, planters, harvesters, and containers.

Non-Chemical Control:

- None

Chemical Control:

Sanitizers

- Calcium or Sodium Hypochlorite (Hilex, Chlorox)
    - 0.5% in 10 gallons water
    - Disinfects machinery, warehouse, planters, and seed cutters
- Quaternary ammonium

Pipeline Products:

- None

To Do List:

Research

- Improved disinfectants

Regulatory

- None

Extension

- Bulleting focusing on disinfectants

Common Scab (*Streptomyces scabies*)

Symptoms & Life Cycle:

- Overwinters in soil indefinitely.
- Soils with pH above 5.8 that have been continuously planted to potatoes are most likely to suffer loses from scab.
- Symptoms begin as small brownish spots that enlarge to form raised, corky areas on the tuber surface.

Distribution & Importance:

- Reduces the commercial grade and market price of infected tubers.
- Scabbed tubers tend to shrink excessively during storage and are sometimes invaded by secondary soft-rotting organisms.
- Increasing problem in the Midwest.
- Ubiquitous.

Non-Chemical Control:

- Control is best achieved by maintaining a soil pH between 5.2-5.8.
- Grow scab-tolerant varieties.
- Plant scab-free seed pieces on land that is free from scab.
- Plow down cover crops.
- Maintain adequate soil moisture during tuber initiation and early growth.
- Rotate out of potatoes for 3-5 years. Avoid root crops (e.g. carrots, beets) in rotation with potatoes.
- Avoid planting potatoes in soils recently amended with animal manure.

Chemical Control:

- Mancozeb
  - Rate = 1 lb/cwt of 6% dust
  - PHI = NA
  - REI = 12 hours
  - Dust on seed piece
  - Efficacy = Poor
- PCNB (Blocker 10G)
  - Rate = 1.65 lb/ 1,000 ft row
  - PHI = 45 days
  - REI = 12 hours
  - In-furrow
  - Efficacy = poor at labeled rates, some efficacy with previous label of Terrachlor used at twice the label rates of Blocker
  - Likely less effective on high organic soils

Pipeline Products:

- Possible biological control with scab-suppressive inoculants
- Elexa (Chitinase inhibitor) – evaluation has shown poor efficacy
- Headsup (saponin) - evaluation has shown poor efficacy

To Do List:

Research

- Useful alternative to PCNB
- Development of commercially accepted varieties with partial scab resistance.
- Understanding the complexity of the soil biology, cover cropping, biological diversity, rotation crops.
- Calcium applied to increase pH.
- Difference between deep pitted scab and surface scab.
- Understand relationships between fumigation and incidence/severity of common scab.

Regulatory

- Consider raising rates of Blocker to a level that will be efficacious

Extension

- Symposium to extend research findings

Early Blight (*Alternaria solani*)

Symptoms & Life Cycle

- Overwinters as spores and mycelium in plant refuse in the soil.
- The fungus penetrates the leaves directly or through natural openings.
- Secondary infection occurs when foliar lesions begin to sporulate and spores are carried to nearby, non-infected plants.
- Moderate temperatures, high humidity, and prolonged leaf wetness from dews, rain, or irrigation, favor the development of early blight. Rain is not necessary for the development of the disease. Alternating periods of wet and dry weather tend to increase progression of the disease.
- Dark, necrotic round, oval, or angular leafspots appear first on the lower foliage but progress upward in the plant. As the lesions enlarge, they are often delimited by leaf veins.
- Tuber infections are characterized by small, sunken, round or irregular in shape with slightly raised margins. The skin around the margin is slightly puckered. Affected tissue also

develops a corky, brown, dry rot. Tissue near the margin of the tuber lesion is yellow to light brown in color initially and may be water-soaked. Wounds are generally necessary for tuber infection to occur.

Distribution & Importance:

- In years when environmental conditions favor disease development, disease management costs on susceptible varieties will exceed $100/acre.
- Bigger problem in Wisconsin, Minnesota and North Dakota than Michigan (not as big a problem in chipping varieties).

Non-Chemical Control:

- Crops that are nitrogen deficient are more susceptible to early blight.
- Early blight is more prevalent on manganese-deficient muck soils.
- Predictive models for timing of fungicides are being used.

Chemical Control:

- Azoxystrobin (Quadris)
  - Rate = 6.2 – 15.4 fl oz /A
  - PHI = 14 day
  - REI = 4 hours
  - Efficacy = Fair to good, but resistance management issues
  - Group 11 fungicide
- Pyraclostrobin (Headline)
  - Rate = 6-9 oz /A
  - PHI = 3 days
  - REI = 12 hours
  - Efficacy= Fair to good, but resistance management issues
  - Group 11 fungicide
- Trifloxystrobin (Gem)
  - Rate = 6-8 oz /A
  - PHI = 7 days
  - REI = 12 hours
  - Efficacy = Fair to good, but resistance management issues
  - Group 11 fungicide

  * efficacy depends on if there is resistance
- Chlorothalonil (Bravo, Echo, Equus)
  - Rate = 1.0-1.5 pt /A for flowables, 0.9-1.4 lb/A for Bravo Ultrex
  - PHI = 7 days
  - REI = 12 hours
  - Efficacy = Fair to good
  - Needed for resistance management of strobolurins
- Copper Hydroxide (Champ, Kocide)
  - Rate = 1-4 lb/A
  - PHI = 0 days
  - REI = 24 hours
  - Efficacy = Poor to Fair
  - Can be used by organic growers at present
- Maneb (Maneb plus ZN, Maneb, Manex)
  - Rate = 1.2 – 2.0 lb 80 WP, 1.2-1.6 pt Manex F4
  - PHI = 3 days
  - REI = 24 hours
  - Efficacy = Fair to good
  - Needed for resistance management of strobilurins
- Mancozeb (Dithane, Manzate, Penncozeb)

- Rate = 1.5-2 lbs 75DF
  - PHI = 3 days
  - REI = 24 hours
  - Efficacy = Fair to good
  - Needed for resistance management of strobilurins.
- Metiram (Polyram)
  - Rate = 1.5-2 lbs 80 DF
  - PHI = 3 days
  - REI = 24 hours
  - Efficacy = Fair to good
  - Needed for resistance management of strobilurins .
- Triphenyltin Hydroxide (Super-Tin, Agri-Tin)
  - Rate = 2.5-3.75 oz
  - PHI = 7-21 days
  - REI = 48 hours
  - Tank mix with EBDC or chlorothalonil
  - Efficacy = Good to excellent
  - Potential problem – can't be mixed with MH30 or EC insecticides such as Asana XL
  - Some varieties are sensitive to phytotoxicity
  - Should not be applied by air when temperature exceeds 80 degrees and /or relative humidity exceeds 90%.
- Eymoxanil + famoxadone (Tanos)
  - Rate = 6.0 oz/A
  - PHI = 14 days
  - Efficacy = Fair to good
- Boscalid (Endura)
  - Rate = 2.5 - 4.5 oz/A
  - PHI = 30 days
  - Efficacy = Excellent
- Fenamidone (Reason)
  - Rate = 5.5 - 8.2 oz/A
  - PHI = 14 days
  - Efficacy = Fair
  - Note plantback restrictions
- Pyrimethanil (Scala)
  - Rate = 7 oz/ A
  - PHI = 7 days
  - Efficacy = unknown

Pipeline Products:

- None

To Do List:

Research

- Resistance management on national scale for strobilurin chemistry.
- Rate study for Quadris, Headline and Gem.
- Relationship between timing of application and resistance for Group 11 products.

Regulatory

- Group 11 labeling on all strobilurin materials.

Extension

- Intensive work with growers on improving knowledge of resistance management.

Fusarium Dry & Tuber Rots (F. solani var. *coeruleum, F. sambucinum, F. graminearum and other Fusarium spp.*)

Symptoms& Life Cycle:

- Infection occurs via wounds on the tuber during the handling of tubers.
- More prevalent in warm soils but can be present in cooler soils.
- High storage temperatures and humidity favor disease development.
- Infected tubers develop a dry rot but may develop a moist rot under the right conditions.
- Internal discoloration of the stem end of the tuber.
- Brownish skin discoloration that may become sunken or wrinkled. There may be a white fungal growth on the wrinkled and rotted areas.
- Vascular discoloration is common.

Distribution & Importance:

- Widespread and can cause losses to potatoes in storage and markets. These diseases reduce market quality.
- Symptoms confused or go hand in hand with potato rot nematode.

Non-Chemical Control:

- Fir bark and alder bark
- Careful harvest to avoid bruising and careful storage management with care on temperature and humidity.

Chemical Control:

Post Harvest

- Thiabendazole (Mertect)
    - Rate = 0.42 fl oz Mertect/2000 lb tubers
    - PHI = NA (post-harvest application)
    - REI = 12 hours
    - Widespread resistance. Use has been reduced in recent years.
    - Efficacy = Poor to good depending on sensitivity of isolate.
    - Application of liquid suspended materials in the Midwest can lead to increased breakdown of potatoes in storage.

Pre Plant

- Mancozeb (Tops MZ, Moncot MZ, Evolve, Maxim MZ,)
    - Rate = 0.5 lb product/100 lb seed
    - PHI = NA
    - REI = 24 hours
    - Efficacy = Good
- Fludioxonil (Maxim MZ)
    - Rate = 0.5 lb product/100 lb seed
    - PHI = NA
    - REI = 24 hours
    - Efficacy = Good

Pipeline Products:

- Potential biocontrols need to be evaluated for efficacy and registered for use.

To Do List:

Research

- Timing of cutting and application of seed treatments.
- Influence of fusarium species on process tuber quality
- Post harvest management of fusarium
- TBZ sensitivity for *F. graminearum*

Regulatory

- None

Extension

- Bulletin on management of post harvest diseases

Gray Mold (*Botrytis cinerea*)

Symptoms & Life Cycle:

- Symptoms appear late in the season and are often mistaken for late blight.
- Gray-green, wedge-shaped spreading lesions with concentric rings on leaves.
- Leaves may appear blighted and a soft-gray, fuzzy rot attacks stems.
- Infected tissues are usually covered with a layer of brown spores and fungal mycelium.
- Less frequently, there is a watery and odorless rot of tubers.

Distribution & Importance:

- Typically not economically important on potatoes except under high irrigation and high fertility regimes.

Non-Chemical Control:

- Careful use of irrigation and nitrogen.

Chemical Control:

- Chlorothalonil
    - Rate = 1.0-1.5 pt ai/A for flowables, 0.9-1.4 for Bravo Ultrex
    - PHI= 7 days
    - REI = 12 hours
    - Efficacy = Good
    - Not used specifically for control of gray mold
- Boscalid (Endura)
    - Rate = 2.5 - 4.5 oz/A
    - PHI = 30 days
    - Efficacy = Fair to Good
- Pyrimethanil (Scala)
    - Rate = 7 oz/A
    - PHI = 7 days
    - Efficacy = Unknown

Pipeline Products:

- None

To Do List:

Research

- Relative importance of gray mold in foliar disease complex

Regulatory
- None

Extension
- None

Late Blight (*Phytophthora infestans*)

Symptoms & Life Cycle:

- Two major mating types of late blight fungus, A1 and A2.
- The pathogen overwinters on potato tubers in the field and cull piles and seed.
- The late blight fungus grows in and on plants which develop from infected tubers.
- Symptoms appear on leaves, stems, and tubers.
  - Leaf symptoms appear as pale green, water-soaked spots that often begin at the edges of leaves or leaf tips where water from rain or dew accumulates. The lesions are often surrounded by a pale yellow to yellow green border that blends into healthy green tissue and enlarge rapidly.
  - Killed tissues turn brown to black.
  - Wind, rain, machinery, workers, and wildlife can dislodge the sporangia and carry them to other plant parts and neighboring plants.
  - Stems and petioles may also be infected by late blight fungus causing them to turn brown to black and entire vines may be killed.
  - Tuber infection occurs when sporangia or zoospores, washed into the soil via cracks or crevices in the hill, come in contact with tubers.
  - Varieties with shallow-set tubers and plantings where there is a significant hill erosion or cracking experience the greatest risk of tuber infection.
  - Tuber infection results in a coppery brown dry rot that spreads irregularly from the tuber surface through the outer ⅛ to ½ inch of the tuber tissues.
  - In storage, lesions become sunken as water is lost from infected areas.
  - Tubers infected with the late blight fungus are often infected with soft rotting bacteria and fungi, often leading to a slimy and smelly breakdown of stored tubers.
  - Predictive models for timing of fungicides are being used.

Distribution & Importance:

- Very serious disease on potatoes particularly where the weather is consistently cool and rainy in late summer and fall. Late blight is responsible for millions of dollars of losses in the U.S. due to recent epidemics confronting North American growers and throughout the world.

Non-Chemical Control:

- Increased emphasis in breeding programs throughout the world developing multiple sources of resistance to late blight.

Chemical Control:

- Azoxystrobin (Quadris)
  - Rate = 12.4 – 15.4 fl oz Quadris/A
  - PHI = 14 day
  - REI = 4 hours
  - Needs to be mixed with chlorothalonil or mancozeb for improved control of late blight.
  - Efficacy = Fair
  - Not recommended when late blight is the primary disease because of resistance issues in early blight.
- Pyraclostrobin (Headline)
  - Rate = 6-12 oz Headline/A

- PHI = 3 days
- REI = 12 hours
- Needs to be mixed with chlorothalonil or mancozeb for improved control of late blight.
- Efficacy = Fair
- Not recommended when late blight is the primary disease because of resistance issues in early blight.

- Trifloxystrobin (Gem)
  - Rate = 8 oz Gem/A
  - PHI = 7 days
  - REI = 12 hours
  - Needs to be mixed with chlorothalonil or mancozeb for improved control of late blight.
  - Efficacy = Fair
  - Not recommended when late blight is the primary disease because of resistance issues in early blight.
- Chlorothalonil (Bravo, Echo, Equus)
  - Rate = 1.0-1.5 pt /A for flowables, 0.9-1.4 for Bravo Ultrex
  - PHI= 7 days
  - REI = 12 hours
  - Efficacy = Good
  - Seasonal limit of 11.5 lbs a.i./A/season in all states except WI which is 16 lbs.
  - In years of high late and early blight pressure, the need may exceed label limits.
  - Affordable
- Copper Hydroxide (Champ, Kocide)
  - Rate = 1-4 lb/A
  - PHI = 0 days
  - REI = 24 hours
  - Efficacy = Poor
  - Used by organic growers
- Cymoxanil (Curzate)
  - Rate = 3.3 oz Curzate/A
  - PHI = 14 days
  - REI = 12 hours
  - Needs to be mixed with chlorothalonil or mancozeb for improved control of late blight.
  - Efficacy = Good
- Cymoxonil + famoxadone (Tanos)
  - Rate = 8.0 oz/A
  - PHI = 14 days
  - Efficacy = Good
- Dimethomorph (Acrobat)
  - Rate = 4.0 – 6.4 oz Acrobat
  - PHI = 4 days
  - REI = 12 hours
  - Needs to be mixed with chlorothalonil or mancozeb for improved control of late blight.
  - Efficacy = Good
- Fenamidone (Reason)
  - Rate = 5.5 - 8.2 oz/A
  - PHI = 14 days
  - Efficacy = Fair to good
  - Note plantback restrictions
- Fluazinam (Omega)
  - Rate = 5.5 fl oz
  - PHI = 14 days
  - REI = 48 hours
  - Efficacy = Good
  - Expensive

- Maneb (Maneb plus ZN, Maneb, Manex)
    - Rate = 1.5 – 2.0 lb for 75DF
    - PHI = 3 days
    - REI = 24 hours
    - Efficacy = Fair to good
    - High value for resistance management
- Mancozeb (Dithane, Manzate, Penncozeb)
    - Rate = 1-2 lbs
    - PHI = 3 days
    - REI = 24 hours
    - Efficacy = Fair to good
    - High value for resistance management
- Metiram (Polyram)
    - Rate = 1-2 lbs
    - PHI = 3 days
    - REI = 24 hours
    - Efficacy = Fair to good
    - High value for resistance management
- Propamocarb hydrochloride (Previcur Flex)
    - Rate = 0.7 – 1.2 pt Previcur
    - PHI = 14 days
    - REI = 12 hours
    - Needs to be mixed with chlorothalonil or mancozeb for improved control of late blight.
    - Efficacy = Good
- Triphenyltin Hydroxide (Super-Tin, Agri-Tin)
    - Rate = 2.5-3.75 oz
    - PHI = 7-21 days
    - REI = 48 hours
    - Mix with mancozeb to reduce crop injury
    - Efficacy = Fair to good
- Zoxamide (Gavel)
    - Rate = 1.5-2.0 lb
    - PHI = 3 days
    - REI = 48 hours
    - Efficacy = Good
    - Less expensive

Pipeline Products:

- Cyazofamid (Ranman)
    - Efficacy = Good to excellent
    - Expected registration in 2005
- Ethaboxam (Guardian)
- Public acceptance of GMO potatoes with resistance to late blight could reduce fungicide use.
- Conventionally bred resistance can be effective in limiting sprays

To Do List:

Research

- Continued tracking of genotypes.
- Temperature response and tolerance of the genotypes.
- Continued support of breeding efforts.

Regulatory

- Seasonal limit of 11.5 lbs ai/A/season of chlorothalonil in all states except Wisconsin in which the limit is 16 lbs.

- In years of high late and early blight pressure, the need for chlorothalonil may exceed label limits.
- Continued registration for chlorothalonil is essential for resistance management.

Extension

- Need effective post-harvest treatment.
- Maintain and improve forecasting programs.

Leak (*Pythium ultimum* & *P. debaryanum*)

Symptoms & Life Cycle:

- Soil-borne disease.
- Infects plants through wounds.
- Light-skinned potatoes have light to dark brown lesions on the surface. Internally, tissues are creamy initially but become tan or slightly reddish, then brown and finally black as the disease progresses. Flesh is granular, soft, and very watery.

Distribution & Importance:

- Losses can be high if infected plants rot in the field or in storage.
- Sporadic problem across the Midwest .
- Varietal susceptibility is important.

Non-Chemical Control:

- Potatoes should not be planted on heavy, poorly drained soils. Can also occur on sandy, well-drained soils.
- Avoid harvesting hot potatoes over 65 degrees pulp temperature.
- Harvest only fully mature tubers and care should be taken to avoid bruising and injuring the skin.
- Harvested tubers should be moved to storage as quickly as possible and kept dry and cool.

Chemical Control:

- Mefenoxam (Ridomil, Ultra Flourish)
  - Rate = 0.42 oz Ridomil Gold per 1,000 feet
  - PHI = NA
  - REI = 48 hours
  - Efficacy = Poor to good depending on location, expectations of product performance are easily exceeded
  - Performance in Midwest is variable
- Mefanoxam/chorlothalonil (Ridomil Gold Bravo, Fluorinil)
  - Rate = 2.0 lb Ridomil Gold Bravo
  - PHI = 14 days
  - REI = 48 hours
  - Applied to foliage when tubers reach nickel-size diameter. 1-2 sprays at 14 day intervals.
  - Efficacy = Good
  - Performance in Midwest is variable
- Mefanoxam/copper hydroxide (Ridomil Gold Copper)
  - Rate = 2.0 lb Ridomil Gold Copper
  - PHI = 14 days
  - REI = 48 hours
  - Applied to foliage when tubers reach nickel-size diameter. 1-2 sprays at 14 day intervals.
  - Efficacy = Good
  - Performance in Midwest is variable

- Mefanoxam/mancozeb (Ridomil Gold MZ)
  - 2.5 lb Ridomil Gold MZ
  - PHI = 3 days
  - REI = 48 hours
  - Applied to foliage when tubers reach nickel-size diameter. 1-2 sprays at 14 day intervals.
  - Efficacy = Good
  - Performance in Midwest is variable

Pipeline Products:

- None.

To Do List:

Research

- Need for post-harvest treatment that's effective

Regulatory

- None

Extension

- None

Lesion Nematode (*Pratylenchus spp.*)

Symptoms & Life Cycle:

- Infect both potato roots and tubers.
- Eggs are laid in the soil or within the root. Nematodes undergo the first of their molts while still in the egg.
- Upon emerging from the egg, second instar larvae and subsequent stages penetrate unsuberized areas of the root.
- Typically, the larvae feed and develop into adults within 40-45 days depending on temperatures and other environmental conditions.
- Above-ground symptoms of severely affected potato plants are manifested as poor growth. In the field, affected plants often appear in patches with stunted growth and chlorosis.
- Underground symptoms include root girdling at the infection site, root necrosis, destruction of small feeder roots.
- Internally, nematodes tunnel through root tissue as they feed, damaging root cells. This damage causes plants to grow poorly with reduced yields. Where nematodes feed on tubers, bumps appear that later change to black depressions.
- Ubiquitous.
- Wide host range.
- Interacts with *Verticillium dahliae* to cause potato early dying.

Distribution & Importance:

- Nematode infestations can reduce plant growth by almost 60% and can cause losses in tuber yields of 20-50%.
- Nematode feeding damage may predispose potatoes to other diseases, or they may act with other pathogens in the development of potato disease complexes.

Non-Chemical Control:

- Biofumigation has potential but needs more work.

Chemical Control:

- Metam-sodium (Vapam, Metam, Nemasol, Sectagon)
    - Rate = 37-60 gallons
    - PHI = NA
    - REI = NA
    - Efficacy = Good
    - Applied 3 weeks before planting or usually the previous fall
    - Injected and by pivot
- Oxamyl (Vydate)
    - Rate = 2 qts CLV in-furrow followed by 1-2 pts foliar.
    - PHI = 7 days
    - REI = 24 hours
    - In-furrow plus foliar application
    - Efficacy = Fair to good
- Ethoprop (Mocap)
    - PHI = NA
    - REI = 48 hours
    - In-furrow and broadcast
    - Efficacy = Fair to good

Pipeline Products:

- None

To Do List:

Research

- Evaluate alternative fumigants and biocontrols such as Telone C.
- Diagnostics to distinguish species.
- Potential rotation crops.
- Potential for variably applying using GPS (site specific).
- Need for lower toxicity chemicals that support eco-labeling efforts.
- Standardization and sampling analysis, interpretation and reporting.
- Encourage breeders to select for improved resistance to nematodes.
- Use of new molecular approaches such as real-time PCR to quickly quantify pathogen propagule numbers in the soil to increase accuracy and decrease response time.

Regulatory

- Must maintain registration of Vapam.

Extension

- Distribute information on interpreting thresholds via bulletins, etc.

Pink Rot (*Phytophthora erythroseptica*)

Symptoms & Life Cycle:

- Tubers become infected through diseased stolons have brown, round or irregular, spots that develop on the tuber surface. On wet tubers, the spots are silvery and glassy and easily observed.
- Infected tissues are spongy but intact and are salmon pink when exposed to the air.

Distribution & Importance:

- Increasing problem worldwide.
- Sporadic problem, decreasing problem in MN over the last 10 years.

Non-Chemical Control:

- Plant in well drained soils and manage irrigation to limit the amount of soil moisture present.

Chemical Control:

- Mefenoxam (Ridomil, Ultra Flourish)
  - Rate = 0.42 oz Ridomil Gold per 1,000 feet
  - PHI = NA
  - REI = 48 hours
  - Efficacy = Good
  - Isolates are now being detected with resistance to mefenoxam
- Mefenoxam/chorlothalonil (Ridomil Gold Bravo, Flourinil)
  - Rate = 2.0 lb Ridomil Gold Bravo
  - PHI = 14 days
  - REI = 48 hours
  - Efficacy = Good
  - Isolates are now being detected with resistance to mefenoxam
- Mefenoxam/copper hydroxide (Ridomil Gold Copper)
  - Rate = 2.0 lb Ridomil Gold Copper
  - PHI = 14 days
  - REI = 48 hours
  - Efficacy = Good
  - Isolates are now being detected with resistance to mefenoxam
- Mefenoxam/mancozeb (Ridomil Gold MZ)
  - Rate = 2.5 lb Ridomil Gold MZ
  - PHI = 3 days
  - REI = 48 hours
  - Efficacy = Good
  - Isolates are now being detected with resistance to mefenoxam
- mono- and dibasic sodium, potassium and ammonium salts of phosphorous acid (Phostrol)
  - Efficacy = fair to good but variable

Pipeline Products:

- Ranman (Cyazofamid) in furrow replacement for mefenoxam

To Do List:

Research

- Determine whether the use of Ridomil has led to resistance issues.
- Need for a quantitative soil assay for this organism and other pathogenic isolates.

Regulatory

- None

Extension

- None

Silver Scurf

Symptoms & Life Cycle:

- Overwinters in infected tubers and other debris in storage.
- Infection occurs through wounds and lenticels.
- Silvery blemishes on periderm.

Distribution & Importance:

- Widespread, especially severe on stored red and russet potatoes for fresh market.
- Problem in Wisconsin, Minnesota, and North Dakota in red potato varieties, not an issue in Michigan in chip stock but in table stock it is a problem.

Non-Chemical Control:

- Plant disease-free seed pieces.
- Crop rotation.
- Chlorinated water through humidification.
- Current storage practices have encouraged silver scurf.
- Hot water treatment?
- Resistant variety selection.

Chemical Control:

- Azoxystrobin (Quadris)
    - Rate = 0.4 - 0.8 oz/ 1000'
    - Furrow application
- Fludioxonil (Maxim MZ)
    - Rate = 0.5 lb product/100 lb seed
    - PHI = NA
    - REI = 24 hours
    - Efficacy = Poor to fair depending on inoculum load.
    - Seed piece treatment
    - Maxim alone may have resistance problems
- Mancozeb (Tops MZ, Moncoat MZ, Maxim MZ, Evolve, others)
    - Rate = 0.5 lb product/100 lb seed
    - PHI = NA
    - REI = 24 hours
    - Seed piece treatment
    - Efficacy = Poor to fair depending on inoculum load

Pipeline Products:

- Post harvest treatments including organic salts as reported by Cornell University.

To Do List:

Research

- Improved post harvest materials
- Look at organic salts
- Chorine dioxide in storage
- Diagnostic efforts on tuber diseases
- Differentiate silver scurf and black dot

Regulatory

- None

Extension

- None

Early Dying Including:

Verticillium Wilt (*Verticillium albo-atrum, Verticillium dahliae*)

Symptoms & Life Cycle:

- Leaves wilt from the bottom of the plant upward with the wilted foliage turning pale yellow and then brown. Sometimes only one stem is affected or possibly all but one stem may escape infection.
- Plants may either die very quickly or may succumb gradually. Often, on hot, sunny days, plants may wilt but regain turgor after sundown.
- Some curling and rolling of the leaflets and a tipburn may occur.
- Tubers may exhibit a brown or black discoloration of the veins at the stem end.

Distribution & Importance:

- Verticillium can cause serious losses in potatoes across the Midwest. In conjunction with nematodes more serious on light sandy soils.
- Wilt severity and yield losses depend on the level of inoculum in the soil, prevailing weather conditions, and cultivar susceptibility.

Non-Chemical Control:

- Assay soil for the presence of verticillium and nematodes prior to planting.
- Breeding for reduced susceptibility is helping.
- Rotation is critical to reduce the survival.

Chemical Control:

- Metam-sodium (Vapam, Metam, Sectagon)
  - 40-60 gallons
  - PHI = NA
  - REI = 48 hours
  - Efficacy = Good, careful application is essential

Pipeline Products:

- No chemicals but cultivars with improved resistance to verticillium need to be evaluated.

To Do List:

Research

- Breeding for disease resistance.
- Biofumigation
- Alternatives to fumigation.
- Better diagnostics of causal factors of early dying.
- Better understanding of the interactions between the organisms involved in the disease complex.
- Site specific fumigation and application technology.

Regulatory

- Retain metam sodium label.

Extension

- Recommendations related to site specific fumigation.

Black Dot (*Colletotrichum coccodes*)

Symptoms & Life Cycle:

- Leaves wilt from the bottom of the plant upward with the wilted foliage turning pale yellow and then brown. Sometimes only one stem is affected or possibly all are infected except one stem.
- Plants may either die very quickly or may succumb gradually. Often, on hot, sunny days, plants may wilt but regain turgor after sundown.
- Some curling and rolling of the leaflets and a tipburn may occur.
- Tubers may exhibit a brown or black discoloration of the veins at the stem end.
- Tubers from black dot infected plants may exhibit microsclerotia on stolon remnants.
- Often misdiagnosed.
- Stress related disease.

Distribution & Importance:

- Black dot impact on yield not well documented.
- Wilt severity and yield losses depend on the level of inoculum in the soil, prevailing weather conditions, and cultivar susceptibility.

Non-Chemical Control:

- Assay soil for the presence of *Colletotrichum* prior to planting.
- Plant black dot-free seed.

Chemical Control:

- Metam-sodium (Vapam, Metam, Sectagon)
  - 40-60 gallons
  - PHI = NA
  - REI = 48 hours
  - Efficacy = Poor in the Midwest
- Azoxystrobin (Quadris)
  - Rate = 6.2 – 15.4 fl oz product/acre
  - PHI = 14 days
  - REI = 4 hours
  - In-furrow application
- Chlorothalonil (Bravo, Echo, Equus)
  - Rate = 1.0-1.5 pt /A for flowables, 0.9-1.4 for Bravo Ultrex
  - PHI= 7 days
  - REI = 12 hours
  - Efficacy = Good
  - Seasonal limit of 11.5 lbs a.i./A/season in all states except WI which is 16 lbs.
  - In years of high late and early blight pressure, the need may exceed label limits.
  - Affordable
- Mancozeb (Dithane, Manzate, Penncozeb)
  - Rate = 1-2 lbs
  - PHI = 3 days
  - REI = 24 hours
  - Efficacy = Good
  - High value for resistance management
- Pyraclostrobin (Headline)
  - Rate = 6 -9 oz/A
  - PHI = 3 days
  - Early foliar spray
  - Efficacy = Good

Pipeline Products:

- o None.

To Do List:

Research

- Breeding for disease resistance.
- Biofumigation.
- Alternatives to fumigation.
- Efficacy of strobulirins and other chemistries.
- Interaction with Verticillium.
- Documentation of effect with black dot on yield and tuber quality.

Regulatory

- None

Extension

- None

Viruses

Symptoms & Life Cycle:

Potato Virus X - "potato latent virus".

- Infected plants typically show mild stunting or deformation of the foliage and doesn't affect the eating quality.
- Tuber size and number can be reduced by 15% or more.
- The virus moves up through the plant killing the tip and the plant dies from the top, downward preventing tuber development.
- May produce mottled foliage on some varieties and some plants may or be stunted.

Potato Virus Y - Multiple strains including O, N, NTN, N:O

- Can cause complete crop failure.
- It is most serious when potato virus X is present concurrently.
- Transmitted by aphids, primarily the green peach aphid.
- Symptom severity varies with virus strain and potato cultivar and ranges from a wild mosaic to severe foliage necrosis and plant death. The severe symptoms of rugose mosaic make it easy to identify from other mosaics on potato. In the first year of infection, black streaks develop in the veins, leaf stalks, and stems which cause the leaves to shrivel. The leaves are left hanging on the plant by the withered petiole. Some leaves become so brittle they drop from the plant.
- Plants emerging from tubers infected with potato virus Y are dwarfed. The leaves on these plants are severely mottled, wrinkled, distorted, and reduced in size. Tubers are smaller than those produced on healthy plants.

Mild mosaic virus (Potato virus X, M, S and A)

- Most common of all potato virus diseases but does not affect the eating or marketing quality of the potatoes.
- Tubers produced from virus-infected plants are smaller and the reduction in yield is comparable to the reduction in size and vigor of the infected plants.
- Transmitted by green peach, potato, and buckthorn aphids.
- The plants may have slightly rugose leaves with an upward roll. Plants may or may not be stunted.

Potato leafroll virus

- Becoming more important.

Distribution & Importance:

- Widespread and increasing especially PVY and leafroll due to increase of aphids.

Non-Chemical Control:

- Some seed certification programs are effective in limiting some viruses (leafroll) in certified seed.
- Not working as well as needed for stylet-borne viruses.
- Trap crops for aphids.

Chemical Control:

- Insecticides for vector control are effective only for leafroll virus

Pipeline Products:

- See aphid section under insect pests.

To Do List:

Research

- New cultivars with greatly improved resistance to aphids and virus infection
- Improved vector control using novel approaches
- Planting of varieties that are symptomless carriers is a problem in virus control
- Distribution of PVY strains in region

Regulatory

- Stringent certification standards

Extension

- Improved guidelines for vector and virus control.

WEEDS

A number of weeds infest potato production regions of the NorthCentral states. A composite list of the major species influencing the region will be described at length. However, the total spectrum of current and potential weeds can not be covered. Future adjustments in potato production systems will likely lead to alternative resource utilization patterns by the potato crop. Changes in resource use within the system will likely lead to development of new niches which will enable new weeds to invade or current minor weeds to colonize new areas and create management problems. Wild proso millet, woolly cupgrass, and tall waterhemp are three weed species which are recent examples of the ability of invasive plants to colonize agroecosystems and cause huge economic losses on an annual basis in the NorthCentral US.

- Potato crop emergence typically occurs 15-30 days after the seed pieces are planted, depending on soil temperatures and the date of planting.
- Growers utilize cultural and mechanical weed management techniques.
    - Narrower row spacing to shade the soil and reduce weed seed germination - seldom used due to the fixed nature of the equipment.
    - Long rotations out of potatoes for 3-8 years depending on the severity of the problem to reduce weed problems.
- Shallow cultivation over the top of the planted crop is possible because of deep planting of seed pieces.
    - Drag-off
- Control weeds after germination and through the cotyledon stage of growth.
- Hill potatoes to bury weeds.
- Healthy, competitive vines are most effective in providing competition to weed infestations.
    - Season-long weed management related to canopy health as influenced by disease, insect, fertility, and irrigation management
- Many herbicide application options exist, including preplant, drag-off, pre-emergence, post-emergence, and hill-spray applications.
    - Hill-spray refers to applying the herbicide immediately after hilling when potatoes are beginning to emerge.
    - Pre-emergent applications are delayed as long as possible to maximize length of residual activity thus delaying emergence of weeds.
- Perennial weeds are difficult to control because of their large underground root system and there are very few effective options for perennial weed management in potatoes.
    - Perenniel weed control requires management in rotational crops.
    - Fall applications of glyphosate are often made to control perennial weeds the year prior to planting
- Commercially no one is using smother crops as a method of weed management.
- Pre-plant control of perennial weeds such as smartweed is achieved with tillage and, to a lesser extent, burn-down herbicides.
- Tillage is another pest management tool.

Annual Broadleaf Weeds

Annual broadleaf weeds that pose a problem in potato production include lambsquarters, redroot pigweed, common ragweed, buckwheat, and Eastern black, black, and hairy nightshades.

Eastern Black and Black Nightshade (*Solanum ptycanthum, Solanum nigrum)*

- Potential alternate host for insects and diseases as it is in the same plant family as potato.
- Management in rotational crops is an issue due to alternative host to insect and disease pests.
- There are limited effective herbicide options for control within the potato crop.
- Matrix applied post-emergence will suppress eastern black nightshade but is poor on black nightshade.
- Metolachlor applied pre-emergence provides poor to fair control.

- Spartan is effective on all nightshade spp.
- Crop rotation with row crops that incorporate between row cultivation or herbicide resistant crops such as Roundup Ready soybean will aid in reducing nightshade problems.

Hairy Nightshade *(Solanum sarrachoides)*

- Potential alternate host for insects and diseases as it is in the same plant family as potato.
- Management in rotational crops is essential.
- Spartan is the only consistent herbicide option for management within the potato crop.
- Germinates late in the season after residual activity of early season herbicides have dissipated.
- Crop competition and rapid canopy establishment is an important management strategy for hairy nightshade.

Common Lambsquarters (*Chenopodium album*)

- Very adaptable broadleaf weed.
- Sets thousands of seeds that can remain in the soil for many years.
- Thrives on all soil types and over a wide range of disturbed habitats.
- Vigorous competitor for nutrients.
- Germinates throughout the growing season.
- There are enough escaped weeds to replenish seed source.
- Management window is early to minimize competition during early crop growth.
- Inhibits effective harvest.
- Sencor (metribuzin) applied pre-emergence and post-emergence provides good control.
    - Triazine resistant lambsquarters have been identified in WI and may be a developing issue.
    - Spartan will provide control of triazine resistant lambsquarters
- Heavy infestations limit the choice of desiccants due to differences in activity.
- Lambsquarters growing above the potato canopy can decrease the efficacy of fungicide or insecticide programs (acts as an umbrella and prevents pesticides from reaching the crop) and change the micro-environment within the crop.
- No effective cultural management strategies.

Pigweed spp (*Amaranthus retroflexus, blitoides, hybridus, palmeri, powelli*) Redroot, Prostrate, Smooth, Palmer Amaranth, Powell Amaranth

- Prolific seed producers–large seed bank.
- Germinates throughout the growing season.
- There are enough escaped weeds to replenish seed source.
- No resistance shown to potato herbicides at this time
    - Triazine-resistant pigweed have been identified in WI and could be a developing issue.
    - ALS inhibiting herbicide (Matrix) resistant pigweed has been identified and could also become and issue.
    - Spartan has activity if triazine or ALS herbicides become resistant
- Treat during early season–when germinating.
- Vigorous competitor for nutrients
- Creates harvest problems.
- Heavy infestations limit the choice of desiccants due to differences in activity.
- Pigweed growing above the potato canopy can decrease the efficacy of fungicide or insecticide programs (acts as an umbrella and prevents pesticides from reaching the crop) and change the micro-environment within the crop.
- Sencor (metribuzin) is the primary product used to control pigweed. Sencor is commonly tank-mixed with Dual (metolachlor), Prowl (pendimethalin), or Matrix (rimulfuran) which improves activity on pigweed.

Waterhemp *(Amaranthus tuberculatis)*

- More difficult to manage than other *Amaranthus* species.
    - Waterhemp has quickly developed resistance to mode of actions of herbicides commonly used in potato.
        - Resistance to triazines and ALS herbicides

        - Spartan has activity on ALS or triazine resistant waterhemp
    - Waterhemp has delayed germination relative to many common crops and weeds of WI and can avoid control by herbicides by emerging after the residual activity of spring applied herbicides has dissipated.
- Prolific seed producers–large seed bank.
- Enough escapes to replenish seed source.
- Vigorous competitor.
- Creates harvest problems.
- Heavy infestations limit the choice of desiccants due to differences in activity.
- Waterhemp growing above the potato canopy can decrease the efficacy of fungicide or insecticide programs (acts as an umbrella and prevents pesticides from reaching the crop) and change the micro-environment within the crop.
- Sencor (metribuzin) is the primary product used to control waterhemp. Sencor is commonly tank-mixed with Dual metolachlor), Prowl (pendimethalin), or Matrix (rimulfuran).

Wild Buckwheat (*Polygonum convolvulus*)

- Twining, vine-like weed that climbs over neighboring plants.
- Irrigated potatoes more likely to be infested – less of a management issue in dryland potato production regions in North Dakotah.
- Capable of reducing crop yield and quality.
- Herbicide use has increased the difficulty of wild buckwheat management as more susceptible weeds (lambsquarters and pigweed) are controlled more resources are available to promote buckwheat growth.
- Not currently a serious problem within the region.
- No currently registered herbicides provide adequate control.
- Managed through crop rotation.
- Suspected alternative host for Black Dot.

Common Ragweed (*Ambrosia artemisiifolia*)

- Prolific seed producer and seed remains viable in the seed bank for many years (10 to 20).
- Stiff stem can inhibit harvest and subsequent tillage operations.
- Limited effective herbicide options.
    - Difficult to manage in rotational crops such as peas, snapbeans, soybeans, and other vegetable crops
- Pollen is a major allergen source.
- Major competitor with potato and rotational crops and cause large yield and quality reductions.
- Heavy infestations limit the choice of desiccants due to differences in activity.
- Common ragweed growing above the potato canopy can decrease the efficacy of fungicide or insecticide programs (acts as an umbrella and prevents pesticides from reaching the crop) and change the micro-environment within the crop.
- Matrix (rimsulfuran), Lorox (linuron), Spartan (sulfentrazone) and Sencor (metribuzin) used in combination pre-emergence or post-emergence applications provide good to excellent control.

Velvetleaf (*Abutilon theophrasti*)

- Becoming more of a problem in the region in recent years.
- Seed remains viable in the soil for more than 20 years.
- Prolific seed producer.
- Will grow over potato canopy.
- Capable of emerging from deep within the soil profile limiting the influence of tillage.
- Very competitive with potato and rotational crops
- Alternative host for *Verticillium dahlia.*
- New weed to the system that growers are unaware of and how to manage.
- Sencor (metribuzin) will provide good control applied pre-emergence.

Cocklebur (*Xanthium strumarium*)

- Extremely competitive.
- Problem in North Dakota.

- Double seed nature causes a problem – one germinates and is controlled but there's a second seed still there that germinates after the first one.

Annual grasses

Annual grasses also pose a problem in the production of potatoes because of their vigorous growth, competitive nature, and ability to produce copious amounts of seed. Grasses cause more significant interference with potato harvest than broadleaf weeds as the fibrous root system prevent tubers from dropping out of the soil while traveling over digger chains. Desiccant selection is governed by the grass weed pressure in the field. Grass weeds tolerate of moisture and temperature extremes once established. All annual grasses should be controlled before seed set. The most problematic grasses in potato are foxtail spp., barnyardgrass, crabgrass, and wild proso millet.

Green Foxtail *(Setaria viridis)*

- Most prevalent of the foxtail spp in North Dakota, but less significant in Wisconsin.
- Prolific seed production, 3-5 year supply of seed in one reproduction event.
- Can go from seed to seed in 60 days.
- Tolerates low light and can grow beneath the canopy under shady conditions.
- Germinate throughout the growing season.
- Currently labeled herbicides provide good control.
- ACC-ase resistance has developed within 3-5 years of continuous selection pressure.
    - Herbicides with alternative modes of action are available in rotational crops
- Becomes a problem if you don't want to use corn in the rotation.

Yellow Foxtail *(Setaria glauca)*

- Prolific seed production, 3-5 year supply of seed in one reproduction event.
- Can go from seed to seed in 60 days.
- Germinate throughout the growing season.
- Currently labeled herbicides provide good control.
- Becomes a problem if you don't want to use corn in the rotation.
- Rely is ineffective in desiccating yellow foxtail.
- More difficult than green foxtail to manage with pre-emergence herbicides (Dual, Prowl, Outlook).

Giant Foxtail (*Setaria faberi*)

- Prolific seed production, 3-5 year supply of seed in one reproduction event.
- Can go from seed to seed in 60 days.
- Germinate throughout the growing season.
- Currently labeled herbicides provide good control.
- Becomes a problem if you don't want to use corn in the rotation (I disagree with this statement for all the foxtails and think it should be deleted, but it is likely a grower suggestion).
- ACCase resistance in vegetable growing regions in Wisconsin.

Barnyard grass *(Echinochloa crusgalli)*

- Potential to emerge after residual activity of pre-emergent herbicides has dissipated.
    - good crop canopy essential for management of late emerging weeds
- Currently labeled herbicides are fairly effective.
- Prolific seed production, 3-5 year supply of seed in one reproduction event.

Wild Proso Millet (*Panicum milleaceum*)

- Introduced into NorthCentral region via contamination of corn seed.
- Widespread dispersal through vegetable and custom harvesting equipment.
    - Then intensity of vegetable production within the potato producing areas of the North Central states has resulted in wide distribution of wild proso millet in MN, WI, ND, and MI.
- Difficult to manage in rotational crops such as in particular.

Large Crabgrass (*Digitaria sanguinalis*)

- Later emergence pattern enables avoidance of residual activity or pre-emergence residual herbicides.

- ACCase resistance in potato and vegetable production areas.
- Prolific seed producer because of tillering habit.
- More difficult to manage in rotational crops than the foxtails so it can build a large seedbank.
- Germinates throughout the growing season.

Perennial weeds

Yellow nutsedge (*Cyperus esculentus*)

- Perennial monocot with grass-like foliage.
- Serious weed pest on both muck and mineral soils but right now it's geographically confined.
- Dual will suppress yellow nutsedge but no other labeled products provide any control in potato.
- Growers typically avoid planting in fields with nutsedge.
- Harvest issue because the harvester won't dig through the stand of nutsedge.
- Prevention is the best management strategy.
- Fall management programs are important.

Quackgrass (*Elytrigia repens*)

- Readily propagated by cultivation that fragments the rhizomes leading to the production of daughter plants from each fragment.
- Becoming less of a problem.
- Glyphosate is the management tool of choice prior to planting.
    - Fall management programs are important.
    - Rotation with glyphosate resistant crops such as corn or soybean
- Makes harvest very difficult because of the rhizomes can clog digger blades.

Swamp smartweed *(Polygonum coccineum)*

- Makes harvest very difficult because of the rhizomes on the digger blades.
- Infinite number of buds.
- Extensive and deep root system.
- Fall management programs are important.

Emerging weed problems

- Nightshade species – ALS resistance in rotational crops may lead to heavier populations.
- Giant foxtail – ALS resistance in rotational crops may lead to heavier populations.
- ALS resistance for velvetleaf, cocklebur, woolly cupgrass, and waterhemp.
- ACC-ase resistance in giant foxtail, green foxtail, large crabgrass and other grass weeds

Management of volunteer potatoes

- "Alternative" host for CPB, late blight, viruses and other insects and diseases.
- Volunteer potato is an issue when the soil doesn't freeze for extended periods (less than 25 degrees will kill volunteers).
- 2,4-D, Starane (fluroxypyr) currently have labels and will control volunteer potatoes.
    - Callisto (labeled in field corn but not sweet corn) has excellent activity on volunteer potato
    - Rotation restrictions to vegetables commonly occurring in rotation with potato
- Repeated cultivation will aide management of volunteer potato.
- Destruction of cull piles before May 15.

Chemical Control

Pre-emergence:

Dimethenamid (Outlook)

- Only one application per year
- Excellent control of annual grasses
- Good control of small selected broadleaves
- 40 day PHI

EPTC (Eptam)

- Applied as a pre-plant incorporated application for broadleaf and grass control.

- Incorporate immediately to prevent volatilization
- PHI = 45 days
- REI = 12 hrs

Flumioxazin (Valor)
- Good control of hairy nightshade and other broadleaves
- Registered only west of Mississippi River due to injury concerns

Linuron (Lorox DF)
- Broadleaf control with some annual grass control.
- Apply preemergence to the crop before broadleaf weeds are 6 inches tall and grasses 2 inches tall.
- Alternative product to Sencor.
- Will manage triazine-resistant weeds.
- PHI = NA
- REI = 24 hrs

Metolachlor (Dual Magnum)
- Excellent control of annual grasses.
- Good control of small-seeded annual broadleaf weeds.
- PHI varies with type of application.
- REI = 24 hrs

Metribuzin (Sencor, Lexone)
- The backbone of any potato weed management program.
- Applied after drag-off or hilling.
- May be applied post-emergence on some potato varieties.
- Provides excellent control of annual smartweeds, common lambsquarters, pigweed, ragweed, and velvetleaf.
- High potential for use restrictions on metribuzin because of environmental concerns.
    - Common use in a vulnerable region.
- Current use practices of tank mixes and reduced rates will diminish environmental risks.
- PHI = 60 days
- REI = 12 hrs

Pendimethalin (Prowl, Pendimax)
- Applied after planting but before weeds or crop emerges.
- May also be applied early post-emergence if crop is not under stress.
- Provides excellent control of crabgrass and green foxtail
- Provides good control of lambsquarters and redroot pigweed.
- PHI = NA
- REI = 24 hrs

Rimsulfuran (Matrix)
- Applied post-emergence after hilling or drag-off to young, actively-growing weeds
- PHI = 60 days
- REI = 4 hrs

Sulfentrazone (Spartan)
- Activity and spectrum that compliments Sencor
- At hilling but before emergence
- Excellent control of pigweed, lambsquarters, nightshade and smartweed
- Poor to fair on ragweed, buckwheat and grasses
- Can be injurious, variety specific (Shepody, Yukon Gold)
- Soil pH influences activity

Trifluralin (Treflan)
- Not often used in potatoes.
- Applied as a pre-plant incorporated application for broadleaf and grass control.
- Provides excellent control of purslane, barnyardgrass, large crabgrass, green foxtail, and witchgrass.

- Provides good control of pigweeds and lambsquarters.
- PHI = NA
- REI = 12 hrs

Post-emergence:

Clethodim (Select 2EC)
- Excellent control of many annual grass weeds, but no activity on broadleaf weeds
- No residual activity so repeat applications may be necessary on subsequent flushes
- Applied to actively growing grasses
- PHI = 30 days
- REI = 24 hrs

Glyphosate (several)
- Applied post-emergence to the weed prior to crop emergence.
    - Often applied in the fall to manage perennial weeds
- REI = 4-12 hrs

Rimsulfuran (Matrix)
- Applied post-emergence after hilling or drag-off to young, actively-growing weeds
- Good to excellent activity on many broadleaf and grass weeds
- PHI = 60 days
- REI = 4 hrs

Sethoxydim (Poast)
- Grass herbicide only
- residual activity so repeat applications may be necessary on subsequent flushes
- Excellent control of barnyardgrass, large crabgrass, green foxtail, sandbur, witchgrass
- PHI = 30 days
- REI = 12 hrs

Desiccants

Variety of desiccants is imperative to address resprouting of vine-killed vegetation for prevention of tuber infection by late blight.. The only alternative to desiccation would be to green-dig (harvest with growing vines), mechanically remove vines (time inefficient with large fuel requirements), or burning .

Glufosinate (Rely)
- Slower acting
    - Takes 7- 10 days longer than diquat to kill vines
    - Does not desiccate weeds

Endothall (Desiccate 2 (endothal)
- Slower acting than other products

Diquat (Reglone)
- Most accepted industry standard
- Most effective.
- Fastest acting.
- Only one that desiccates escaped weeds.

Paraquat (Gramoxone Max, Boa)
- Restricted use
- Can't use on seed potatoes.

Sulfuric acid and nitrogen (Enquick)
- Restricted use
- Not used in Wisconsin because of the nitrogen

Carfentrazone-ethyl (Aim)

Other Weed Management Aids

- Tillage
- Hilling plus cultivation.
- Seedbank management.
- Maintaining a healthy canopy.
- Smother crops.
- Other crops planted in rotation as green manure to break up the row crop rotation.

Pipeline Pest Management Tools

- Halosulfuron-methyl (Sandea)
  - IR4 field trials completed in 2004

To-Do List

Research

- Modification of weed emergence models in vegetable production systems.
- Evaluate the growth habits and management effectiveness of biotypes of the nightshades.
- Effective nightshade management.
- Investigate the distribution of triazine-resistant lambsquarters.
- Long-term (10 year) research on limited till vs. moldboard plowed fields and weed response/shift.
- The effect and method of fumigation on the weed seedbank distribution in the soil profile.
- Quantify interference between potato and key weed species.
- Monitor the species shift as production practices move away from moldboard plowing into limited tillage.
- Determine the impact of herbicide combinations on use rates of each product.
- Find an alternative for Sencor.
- Build emergence and canopy development models for new varieties.
- Develop Callisto recommendations for use in sweet corn for management of volunteer potato

Regulatory

- Registration of Spartan
- Registration of Balance for sweet corn for control of wild proso millet.
- Registration of Callisto in sweet corn to control volunteer potatoes.

Education

- Education on the environmental impact of triazine herbicides.
- New species identification and control.
- Educating growers on generic modes of action of herbicide products and how these impact on production practices.
- Herbicide resistance management.

Table 1: Efficacy Ratings of Potato Insecticides

	CPB	PLH	ALH	GPA	PA	PFB	CW	ECB	TPB	WW	WG
Abamectin	G	-	-	-	-	-	-	-	-	-	-
Bt	F-G	-	-	-	-	-	G	P	-	-	-
Carbaryl	-	G	P-G	-	-	G	F	F	F	-	-
Carbofuran	P	G-E	G	-	-	E	-	G	-	-	-
Cyfluthrin	P-G	E	E	F-G	E	E	G	G	G	-	-
Deltamethrin	P-G	E	E	F-G	E	E	G	G	G	-	-
Dimethoate	-	E	G	F	G	-	-	-	-	-	-
Disulfoton	P	-	N	G	G-E	-	-	-	-	-	-
Endosulfan	P-G	F	P	P	G	G	-	-	-	-	-
Esfenvalerate	P-G	E	E	F-G	E	E	G	F	G	-	-
Ethoprop	-	-	-	-	-	-	-	-	-	F-G	F-G
Imidacloprid	G-E	F-G	F-G	G-E	G-E	G-E	-	-	-	F-G	F-G
Imidacloprid/ Thiophante-methyl	G-E	F	F-G	F-G	F-G	E	-	-	-	-	-
Imidacloprid/cyfluthrin	G	E	F-G	G	G-E	E	-	-	-	-	-
Indoxacarb	P	-	-	-	-	-	G	F-G	-	-	-
Malathion	-	F	P	P	F	-	-	-	-	-	-
Methamidophos	-	E	G	E	E	E	-	-	G	-	-
Methomyl	-	G	G	P	G	G	-	-	-	-	-
Novaluron	G	-	-	-	-	-	-	F-G	-	-	-
Oxamyl	P-G	-	-	F-G	G	-	-	-	-	-	-
Permethrin	P	G	G	P	G	E	G	F	F	-	-
Phorate	P	E	P	P-F	E	-	-	-	-	F-G	F-G
Phosmet	P-F	F-G	F-G	-	-	-	-	-	-	-	-
Pymetrozine	-	-	-	E	G-E	-	-	-	-	-	-
Sodium aluminofluoride	G	-	-	-	-	-	-	-	-	-	-
Spinosad	G	-	-	-	-	-	G	F-G	-	-	-
Thiamethoxam	G-E	G	F-G	G-E	G-E	G-E	-	-	-	F-G	F-G

CPB = Colorado Potato Beetle; PLH = Potato Leafhopper; ALH = Aster Leafhopper; GPA = Green peach aphid; PA = Potato aphid; PFB = Potato flea beetle; CW = Cutworms; ECB = European Corn Borer; TPB = Tarnish plant bug; WW = Wireworm; WG = White grub. P = Poor, F = Fair, G = Good, E = Excellent, N = Not Effective, - = Not Labeled.

Table 2: Efficacy Ratings of Potato Fungicides

	BD	BS	CS	EB	F	GM	LB	L	N	PR	R	SS	VT
Azoxystrobin	F	-	-	E	-	-	F	-	-	-	G	G	-
Boscalid	-	-	-	E	-	G-E	-	-	-	-	-	-	-
Chlorothalonil	-	-	-	F-G	-	G	G	-	-	-	-	-	-
Copper hydroxide	-	-	-	F	-	-	P	-	-	-	-	-	-
Cyazofamid	-	-	-	-	-	-	G-E	-	-	?	-	-	-
Cymoxanil	-	-	-	-	-	-	G	-	-	-	-	-	-
Cymoxanil + famoxadone	-	-	-	-	-	-	E	-	-	-	-	-	-
Dimethomorph	-	-	-	-	-	-	G	-	-	-	-	-	-
Ethoprop (insecticide)	-	-	P	-	-	-	-	-	F-G	-	-	-	-
Fenamidone	-	-	-	-	G	-	-	-	-	-	G	-	-
Fluazinam	-	-	-	-	-	-	G	-	-	-	-	-	-
Fludioxonil	-	-	-	-	G	-	-	-	-	-	-	P-F	-
Fludioxonil + mancozeb	-	G	-	-	G-E	-	-	-	-	-	G	-	-
Flutolanil + mancozeb	-	G	-	-	-	-	-	-	-	-	G	-	-
Iprodione	-	-	-	P	-	-	-	-	-	-	-	-	-
Maneb	-	-	-	F-G	-	-	F-G	-	-	-	-	-	-
Mancozeb	-	-	P	F-G	F	-	F-G	-	-	-	-	P-F	-
Mefenoxam	-	-	-	-	-	-	-	F	-	G	-	-	-
Metam-sodium	P	-	-	-	-	-	-	-	G	-	-	-	G
Metiram	-	-	-	F-G	-	-	F-G	-	-	-	-	-	-
Oxamyl (insecticide)	-	-	-	-	-	-	-	-	F-G	-	-	-	-
PCNB	-	-	P	-	-	-	-	-	-	-	-	-	-
Propamocarb hydrochloride	-	-	-	-	-	-	G	-	-	-	-	-	-
Pyraclostrobin	-	-	-	E	-	F	-	-	-	-	-	-	-
Pyrimethanil	-	-	-	?	-	E	-	-	-	-	-	-	-
Thiabendazole	-	-	-	-	P-F	-	-	-	-	-	-	P-F	-
Thiabendazole + mancozeb	-	G	-	-	G-E	-	-	-	-	-	G	-	-
Thiophanate methyl	-	-	-	-	G	-	-	-	-	-	G	-	-
Trifloxystrobin	-	-	-	F	-	F	-	-	-	-	-	-	-
TPTH	-	-	-	G	-	-	F	-	-	-	-	-	-
TPTH + mancozeb	-	-	-	G	-	-	F-G	-	-	-	-	-	-
TPTH + metiram	-	-	-	G	-	-	F-G	-	-	-	-	-	-
zoxamide	-	-	-	-	-	-	G	-	-	-	-	-	-

BD = Black Dot; BS = Black Scurf; CS = Common Scab; EB = Early Blight; F = Fusarium Dry & Tuber Rots; GM = Gray Mold; LB = Late Bight; L = Leak; N = Nematodes; PR = Pink Rot; R = Rhizoctonia Canker; SS = Silver Scurf; VT = Verticillium
P = Poor; F = Fair, G = Good, E = Excellent

Table 3: Efficacy Ratings of Potato Herbicides

	Dual	Eptam	Lorox	Matrix	Poast	Prowl	Sencor	Treflan	Spartan	Outlook	Valor[1)]
Annual Broadleaf											
Black Nightshade	E	F	G	P	N	P	P	P	E	E	E
Carpetweed	-	-	-	-	N	-	E	-	E	E	E
Ladysthumb Smartweed	P	F	E	F	N	-	E	P	E	P	G
Lambsquarter	F	G	E	F	N	G	E	G	G	F	G
Redroot Pigweed	G	G	E	E	N	G	E	G	E	G	E
Prostrate Pigweed	-	G	-	E	N	-	-	G	E	G	E
Common Purslane	G	-	E	F	N	-	G	E	E	G	E
Common Ragweed	F	F	E	F	N	P	E	P	F	P	F
Shepherd's Purse	-	-	-	E	N	-	-	-	G	P	G
Pennsylvania Smartweed	F	F	E	F	N	P	E	P	E	P	G
Velvetleaf	P	G	G	F	N	P	E	P	P	P	F
Wild Buckwheat	P	F	F	F	N	-	-	P	E	P	G
Annual Grasses											
Barnyard Grass	E	F	G	E	E	G	P	E	G	E	G
Large Crabgrass	E	E	G	F	E	E	G	E	G	E	G
Green Foxtail	E	E	G	E	E	E	G	E	G	E	F
Sandbur	F	-	-	-	E	-	P	-	P	P	P
Witchgrass	-	E	F	-	E	-	P	E	P	G	P
Perennial Grass											
Quackgrass	P	F	P	G	G	P	P	P	P	P	P

1) Has full registration but labels are on a state-by-state case.

Table 4: Field Activity Timeline for Potatoes.

<table>
<tr><th colspan="3">April</th><th colspan="3">May</th><th colspan="3">June</th><th colspan="3">July</th><th colspan="3">August</th><th colspan="3">September</th><th colspan="3">October</th></tr>
<tr><td>early</td><td>mid</td><td>late</td><td>early</td><td>mid</td><td>late</td><td>early</td><td>mid</td><td>late</td><td>early</td><td>mid</td><td>late</td><td>early</td><td>mid</td><td>late</td><td>early</td><td>mid</td><td>late</td><td>early</td><td>mid</td><td>late</td></tr>
<tr><td colspan="21">In-Field Activities</td></tr>
<tr><td colspan="5">Planting</td><td colspan="5">Some planting</td><td colspan="11"></td></tr>
<tr><td colspan="2"></td><td colspan="9">Cultivation</td><td colspan="10"></td></tr>
<tr><td colspan="3"></td><td colspan="9">Hilling</td><td colspan="9"></td></tr>
<tr><td></td><td colspan="20">Scouting</td></tr>
<tr><td colspan="10"></td><td colspan="6">Harvest Early Varieties</td><td colspan="5">Harvest Fall Potatoes</td></tr>
<tr><td colspan="9"></td><td colspan="7">Vine Dessication</td><td></td><td colspan="4">Vine Dessication</td></tr>
<tr><td colspan="21">Insect Control</td></tr>
<tr><td colspan="3"></td><td colspan="6">Colorado Potato Beetle, 1st generation</td><td colspan="3">CPB, both generations</td><td colspan="3">CPB 2nd generation</td><td colspan="2"></td><td colspan="4">CPB 3rd generation (MI)</td></tr>
<tr><td colspan="7"></td><td colspan="9">Potato Leafhopper</td><td colspan="5"></td></tr>
<tr><td colspan="10"></td><td colspan="5">Potato Aphid</td><td colspan="6"></td></tr>
<tr><td colspan="11"></td><td colspan="4">Tarnished Plant bug</td><td colspan="6"></td></tr>
<tr><td colspan="3"></td><td colspan="4">Aster Leafhopper</td><td colspan="14"></td></tr>
<tr><td colspan="9">Green Peach Aphid</td><td colspan="8">Green Peach Aphid</td><td colspan="4"></td></tr>
<tr><td colspan="7"></td><td colspan="2">PFB</td><td></td><td colspan="3">PFB</td><td colspan="8"></td></tr>
<tr><td colspan="7"></td><td colspan="2">ECB 1st Generat.</td><td colspan="5"></td><td colspan="2">ECB 2nd Generation</td><td colspan="5"></td></tr>
<tr><td colspan="21">Wireworms: Always Present</td></tr>
<tr><td colspan="21">White Grub: Always Present</td></tr>
<tr><td colspan="9"></td><td colspan="7">Cutworms</td><td colspan="5"></td></tr>
<tr><td colspan="21">Diseases and Control</td></tr>
<tr><td colspan="21">Black Dot: Always Present</td></tr>
<tr><td colspan="7"></td><td colspan="9">Early Blight</td><td colspan="5"></td></tr>
<tr><td colspan="12"></td><td colspan="9">Early Dying Complex: Fumigation Previous Fall</td></tr>
<tr><td></td><td colspan="4">Fusarium Tuber Rot Seed Treatment</td><td colspan="10"></td><td colspan="6">Storage Treatment</td></tr>
<tr><td></td><td colspan="2">Late Blight Seed Tx</td><td colspan="4"></td><td colspan="9">Late Blight</td><td colspan="5"></td></tr>
<tr><td colspan="7"></td><td colspan="9">White Mold</td><td colspan="5"></td></tr>
<tr><td colspan="11"></td><td colspan="4">Gray Mold</td><td colspan="6"></td></tr>
<tr><td colspan="11"></td><td colspan="4">Bacterial Vine Rot</td><td colspan="6"></td></tr>
<tr><td colspan="21">Annual Broadleaf & Grass Weed Control</td></tr>
<tr><td colspan="5"></td><td colspan="9">Clethodim</td><td colspan="7"></td></tr>
<tr><td colspan="9">EPTC</td><td colspan="12"></td></tr>
<tr><td colspan="10">Glyphosate</td><td colspan="5"></td><td colspan="6">Glyphosate</td></tr>
<tr><td colspan="10">Linuron</td><td colspan="11"></td></tr>
<tr><td colspan="10">Metolachlor</td><td colspan="11"></td></tr>
<tr><td colspan="10">Pendimethalin</td><td colspan="11"></td></tr>
<tr><td colspan="5"></td><td colspan="10">Rimsulfuran</td><td colspan="6"></td></tr>
<tr><td colspan="5"></td><td colspan="10">Sethoxadim</td><td colspan="6"></td></tr>
<tr><td colspan="10">Trifluralin</td><td colspan="11"></td></tr>
</table>

*****For Perennial Weeds:
-Spot treat if necessary
-Treat in rotation
-Treat before planting/after harvest for problem perennials
**Roundup (Glyphosate) used as a wick application

Black leg – Seed-borne disease – not treated with pesticides.
Nematodes -Treated at planting the fall before or after emergence applications.
Rhizoctonia stem canker – Seed-borne or soil-borne – seed and furrow treatments.
Scab – Not treated with pesticides.
Silver Scurf – Seed- and soil-borne – seed treatment.
Pythium tuber rot – Always present - treatment in furrow or foliarly.
Pink rot – Soil-borne – In-furrow treatment.
Tuber soft rot – storage concern: treated in storage.

Table 5: Worker Exposure Times for Field Activities.

In-Field Activity	Per 10 acres				
	People	Hours/Person	Total hours	Potential Exposure hrs[1]	% of Total Acres
Seed cutting	8	.5	4	4	
Planting (seed grower)	1-2	4	4-8	4-8	100
Planting (commercial)	1-2	2	2-4	2	100
Irrigation	1	2 min. X 100 days	3.3 hours	3.3 hours	35-90
Scouting[2]	1	0.15 X 12 visits	1.8 hours	1.8 hours	90
Cultivation	1	0.5 X 1-3	0.5-1.5 hour	0-1.5 hours	100
Harvest	2-5	1-10 hours	5-20 hours	2.5 –10 hours	100
Storage handling	5-10	1-10 hours	10-50 hours	10-50 Hours[3]	10-20%
Packaging handling	5-30	2-10 hours	20-50 hours	20-50 hours[4]	15%
Chemical Application: Weeds	0-2	0.5 –2 hours X 1-3	0.5-6 hours	0.25-3 hours	90
Chemical Application: Diseases[5]	1-2	0.5-2 hours X 5-20	2.5-40 hours	1.25-20 hours	99
Chemical Application: Insects[6]	1-2	0.5-2 hours X 2-5	[7]	[8]	99
Chemical Application Post Harvest - Storage	1-3	1-10 hours	3-10 hours	1.5-5 hours	10-20
Post Harvest Chemical Application - Packaging	5-30	2-10 hours	20-50 hours	20-50 hours	15%
Sprout inhibitor – Storage Tx	2	.5-2 hours x 2 apps	2-8 hours	.5-2 hours	50%

[1] Due to enclosed cab tractor rigs for planting and chemical application and mechanical harvest.
[2] Actual "scouted" acreage is a representative fraction of the total planted acreage.
[3] Low risk of contact.
[4] Low risk of contact.
[5] Insecticides and fungicides are often applied simultaneously.
[6] Insecticides and fungicides are often applied simultaneously.
[7] Included with fungicide application above.
[8] Included with fungicide application above.