PEST MANAGEMENT IN THE FUTURE

A Strategic Plan for the Michigan Onion Industry

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TABLE OF CONTENTS

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TOP PRIORITIES OF THE MICHIGAN ONION INDUSTRY

RESEARCH:

- Develop management strategies for thrips based on the biology of the insect, dispersal patterns and interaction with foliar diseases.
- Develop management strategies to control black mold.
- Identify onion varieties suitable for Michigan that are resistant to black mold and thrips.
- Identify the source of infection and appropriate crop management techniques for bacterial soft rot.
- Identify effective reduced-risk fungicides and/or biocontrol agents, develop disease predictors and determine rotational strategies to manage foliar blights on onions.
- Identify effective reduced-risk herbicides and develop alternative weed control methods for yellow nutsedge.
- Evaluate cover crops and bio-fumigants for nematode, insect, disease, and weed management.
- Develop improved facilities and disease management strategies for harvesting and storing onions.
- Develop a rapid diagnostic tool to determine aster leafhopper infectivity rates for use in combination with economic thresholds to trigger control measures.

REGULATORY:

- In order for Michigan onion growers to remain competitive and produce a quality product, it is imperative that the following pesticides be retained until effective and cost efficient pesticides are identified and registered:
  - Fungicides: chlorothalonil (Bravo, Echo, Equus), mancozeb (Dithane, Manzate, Manex II, Penncozeb), maneb (Manex), iprodione (Iprodione, Rovral).
  - Insecticides: chlorpyrifos (Lorsban), methomyl (Lannate), pyrethroids (Ambush, Ammo, Pounce).
  - Herbicides: oxyfluorfen (Goal), pendimethalin (Prowl), s-metolachlor (Dual Magnum), bromoxynil (Buctril) , sethoxydim (Poast), fluazifop-p (Fusilade), clethodim (Select).
- For the reasons stated previously, it is important that full registration of the following products be expedited:
  - Insecticide: fipronil (Regent)
  - Herbicide: dimethenamid (Outlook)

EDUCATION:

- Demonstration and education regarding cull pile management, specifically disposal, placement and composting of piles along with the associated advantages/disadvantages in disease and insect control.
- Continue Integrated Pest management (IPM) education and on-farm demonstration plots.
- As new products and methods become available, alert the industry of any effects they may have on the crop with regard to interactions in the field and in tank mixes.
- Demonstration and education regarding the impact of storage conditions and post-harvest handling (temperature, relative humidity, airflow, and sanitation) on disease problems.

BACKGROUND

Michigan ranks 5th nationally and 1st in the Midwest in dry bulb onion production (Anonymous, 2004). In 2003, Michigan planted 3,700 acres, and harvested 3,600, for a value of $13.4 million (Anonymous, 2004). In 2002, onions accounted for 3.3% of all the acres harvested for vegetable production in Michigan (Kleweno and Matthews, 2003). Virtually all of the onions grown in Michigan are dry bulb for the fresh market. The majority of onion production in Michigan occurs in the southwest and southcentral regions of the state (Allegan, Ottawa, Calhoun, Eaton and Ionia counties), but there is also some scattered production elsewhere in the state.

Onions are a cool season biennial that grows best between 55-75ºF (13-24ºC) but tolerates temperatures ranging from 45-85ºF (7-29ºC). Early leaf growth is important for bulb size later in the season; however, even after leaves collapse the bulb will grow 10-20%. Time from seedling emergence to maturity averages about 100-105 days. Onions are usually planted from seed using a precise mechanical seeder. The industry standard for seed germination is 70%. Some growers will plant sets; however, this is more costly and time consuming than planting seed. Planting begins in early April and continues into May. It takes about 13 days from seeding to emergence when soil temperatures are 50ºF (10ºC).

Traditionally, onions have been grown on muck soils in Michigan, but can they can also be grown on mineral soils. Soil type and quality is a critical factor in onion production. Onions need a highly fertile soil that will allow bulbs to expand. Onions that are grown in compacted soil produce small or misshapen bulbs which are not readily marketable. Once the bulbs have reached a marketable size or when approximately 10-20% of the tops have fallen over, the bulbs are undercut 1-2 inches and mechanically harvested or left in the field to dry. In storage, it is important to maintain relative humidity between 65-70% with adequate air circulation at 32ºF (0ºC) to prevent splitting, sprouting and disease. The bulbs are packed at an on-farm site or sent in bulk containers to the packing facility.

Profitable onion production is dependent on growing bulbs of good size and quality. Onions grown in Michigan are pungent long-day types; bulb initiation occurs when the day length is >14 hours. Most Michigan onions are grown from seed that germinates and grows slowly during the first 6 weeks. Thus, early planting and growth increases the opportunity for producing a quality crop. Studies by Davis et al. (1951) and Warncke (1997) showed that placing nitrogen and phosphorus 2" directly under the seed improves early growth and yields. Sowing of multiple lines per row makes fertilizer placement more challenging. The effectiveness of below-seed placement of nitrogen and phosphorus decreases once it is >2" to the side of the seed (Warncke, 2000, 2001). Placement studies for other nutrients is needed for onions sown in multiple lines. Early foliar application of manganese on onion helps to maintain stands and increases yields. In acid organic soils, addition of molybdenum is beneficial, and studies show foliar molybdenum improved plant stand and yields when pH >6.0. Sodium silicate treatment has helped improve overall growth and disease tolerance of some crops.

Onion flavor is important to consumers. Pungency is increased by accumulation of sulfur, and adjusting the nutrition to reduce sulfur uptake should reduce the pungency (Randle and Bussard, 1993). However, organic soils in Michigan (where most onions are grown) have an abundance of available sulfur. In the soil, phosphorus competes with sulfur for uptake, and increasing phosphorus in the rooting zone may decrease sulfur uptake and the pungency of onion bulbs. Studies indicate that low soil potassium levels significantly increased the sodium content of radishes and carrots (Warncke, 1997), and that reduced pungency is associated with increased sodium uptake. Thus, growing onions on low organic matter mineral soils may be an alternative for producing low pungency onions.

Successful pest management should incorporate many different methods of pest control. Pesticides, treated seed, resistant cultivars, crop rotation and pest scouting are all aspects of a good management program. Pesticides should be applied in a program designed to avoid development of resistance in the pest. Resistance management depends upon two key points: the ability to rotate applications of products with different modes of action; and the ability to rotate between broad-spectrum and target-specific products. Newer products on the market tend to fall under the category of single site action, while older products, especially many that are under evaluation for safety reasons, generally tend to be broad-spectrum products. Loss of the pesticides listed under the top priorities is a major concern for Michigan onion growers who want to remain competitive and produce a quality product.

Cultural practices such as crop rotation are useful in limiting foliar disease occurrence, but are not helpful in managing seed-borne pathogens. Some fungicides, effective against foliar diseases, include B2 carcinogens. Newly available reduced-risk fungicides may provide disease control, but may be too costly to use in a calendar-based spray program. A disease forecaster can reduce grower costs, fungicide residues on the crop, risk of development of fungicides resistance in the pathogens, and numbers of sprays needed for a healthy crop. MSU researchers have begun testing the Tom-Cast disease forecaster (Pitblado, 1992), originally used for tomatoes, for managing foliar diseases of onion. Commercial asparagus growers routinely rely on Tom-Cast to time fungicide sprays (Meyer et al., 2000), and a similar program is under development for carrots (Bounds, 2003; Dorman, 2003). Tom-Cast schedules sprays by using leaf wetness duration and average air temperature during the wetness period for each 24-hour period (11 AM to 11 AM) to determine a disease severity value (DSV) of 0 to 4, corresponding to conditions unfavorable to highly favorable for disease development. Preliminary data suggests that Tom-Cast could reduce the number of sprays without compromising onion yield and quality.

Damping off is a fungal disease of onion seedlings, caused by *Pythium* spp. and *Rhizoctonia solani*. Seedlings infected with *Pythium* damping off become grayish and water-soaked, then collapse and die. Mature plants infected with damping off rarely die, but can become severely stunted. Leaves become yellowed from the tip to the base, and may wilt. Roots appear water-soaked, then become collapsed with a white strand visible within. The *Pythium* spp. that infect onions are ubiquitous in agricultural soils, and infect onions when the environmental conditions favor disease development. *Rhizoctonia* causes roots to discolor and decay, and seedlings wilt and collapse. *Rhizoctonia* survives in soil, plant debris and on roots of weeds. The fungus can be disseminated on tillage equipment and in irrigation water (Schwartz and Mohan, 1995).

The major diseases of onion in Michigan are purple blotch (*Alternaria porri*), Stemphylium leaf blight (*Stemphylium vesicarium*), Botrytis leaf blight (*Botrytis aclada = B. allii*, *B. cinerea*, *Botrytis squamosa*), downy mildew (*Peronospora destructor*), and black mold (*Aspergillus niger*) (Howard, et al., 1994). All can defoliate the crop prematurely, and usually at least one of these diseases occurs yearly. Foliar pathogens (*Alternaria, Botrytis, Peronospora*) compromise bulb quality, resulting in storage rot caused by secondary bacterial pathogens.

A severe purple blotch infection (30%) can reduce yield by 33% and numbers of marketable onions by 14% (Hausbeck et al, 2000). Purple blotch is a yearly problem for Michigan's onion growers. Purple blotch first appears as small water-soaked lesions that quickly develop white centers. As they age, lesions turn brown to purple, surrounded by a zone of yellow. Lesions can coalesce, girdle the leaf, and cause tip dieback. Occasionally bulbs are infected through the neck or wounds on the scales. Bulb decay is first semiwatery and yellow to red in color, turning to dark brown to black as the dark-colored mycelium develops in the diseased tissue. Under moist conditions, brown to gray conidia form in the lesions. Conidia of *Alternaria porri* can form repeatedly on lesions with cycles of low and high relative humidity (Schwartz and Mohan, 1995). When free water is available, conidia can germinate in 45-60 minutes at 82-97ºF (28-36°C) (Howard et al., 1994). Spores can form after 15 hours of relative humidity ≥90%, and can be spread by wind, rainfall, irrigation, and spraying. Fungal growth is favored by temperatures of 43-93ºF (6-34°C), with an optimum temperature of 77ºF (25°C). Older leaves and young leaves injured by onion thrips are more susceptible to infection. Symptoms can appear 1-4 days after infection, and spores can appear by the 5th day. The pathogen can overwinter as mycelium in onion debris (Schwartz and Mohan, 1995).

Botrytis leaf blight is an occasional problem in Michigan and occurs during cool, wet growing seasons. Botrytis leaf blight first occurs as a white lesion with a necrotic center, surrounded by a light green halo. Lesions may expand with age, become elliptical and brownish-white in color, and the halo may disappear (Schwartz and Mohan, 1995). Lesions that extend through the leaf tissue may split open, exposing the interior of the leaf (Howard, et al., 1994). Under prolonged moist conditions at 54-75ºF (12-24°C), blighting, drying out, and death of leaves may occur, which results in smaller bulb sizes. Older leaves are more susceptible to blighting. Conidia of *B. aclada* can form after 60-72 hours of 37-81ºF (3-27°C) temperatures (optimum 48ºF [9°C]), and are released and carried by air (Schwartz and Mohan, 1995). Germination of the spores occurs with temperatures >43ºF (6°C) and leaf wetness for at least 6 hours. Optimum conditions for infection are 12 hours of leaf wetness at 59-64ºF (15-18°C) (Howard, et al., 1994). *Botrytis* spp. can overwinter in onion cull piles, onion leaf debris or in the soil (Schwartz and Mohan, 1995).

Stemphylium leaf blight (*S. vesicarium*) occurs as small, light yellow to brown, water-soaked lesions that develop into elongated spots that turn dark olive brown to black with spore development. Coalescing spots can blight leaves, but rarely affects the bulb. The pathogen normally invades dead and dying onion tissue, thus it generally occurs on the side of the leaf facing the prevailing winds. Disease development is favored by long warm periods with leaf wetness (Schwartz and Mohan, 1995).

Downy mildew occurs every 3 to 4 years in Michigan. It is an especially devastating disease because it spreads rapidly and is not readily controlled. Downy mildew first infects older leaves, occurring as pale, elongated patches that may have a grayish-violet fuzzy growth appear early in the morning during moist periods. Lesions can be violet-purple in color; affected leaves become pale green, then yellow and can fold over and collapse. Infection can occur systemically, with stored bulbs becoming soft, wrinkled, watery and amber in color. Asymptomatic bulbs can sprout prematurely and form light green foliage. *Peronospora destructor* initiates infection during cool temperatures (<72ºF [22°C]) and wet conditions. Multiple infections cycles can occur in a season, and consist of 9-16 days of latency, 1-2 days of sporulation, dispersal and infection. Spores are produced at night and dispersed during the day, where they can survive on host leaves for 1-3 days. Four infection cycles can almost completely destroy the foliage of an onion field (Schwartz and Mohan, 1995). High daytime temperature and short or interrupted periods of humidity at night can prevent sporulation of the fungus (Howard et al., 1994). The fungus overwinters in volunteer onions, other host plants, onion cull piles, and in stored infected bulbs (Schwartz and Mohan, 1995).

Black mold occurs on onions in the field, during transit, or during storage. Black mold is a bulb disease, occurring as black discoloration and shallow lesions at the neck of the bulb, with black mycelium and spores of *A. niger* under the outer scales. Severe infection results in infection of all scales, and shriveling and blackening of the entire bulb. Asymptomatic bulbs may have gray to black discoloration of the neck into the central portion of the bulb. The black mold fungus can grow on dead plant and animal tissues, and is a common soil inhabitant, and spores are common in the air and soil. Infection usually occurs through wounds. The fungus may be disseminated in infected seed or transplants. Fungal germination is optimal at 63ºF (17ºC), growth is favored by 82-93ºF (28-34ºC) (Schwartz and Mohan, 1995). Keeping the storage atmosphere dry is essential for reducing black mold incidence in onions. Free moisture must be present on the onion for 6-12 hours for spores to germinate and infect the onion (Maude, 1990).

Pink root is a common disease of onions in Michigan, and results in significant yield loss. Roots of onions infected with *P. terrestris* first appear light pink to yellow-brown in color, darkening to deep pink-purple. As pink root progresses, roots become water-soaked, then later dry and disintegrate. New roots become infected as they form and die. Infected seedlings may be killed, or survive to produce stunted plants with shriveled, undersized bulbs. Plants in the field appear to be nutrient deficient or drought-stressed and stunted (Schwartz and Mohan, 1995). Leaves die back from the tip, turning yellow-white or yellow-red (Howard, et al., 1994). Leaf number and size are reduced, plants begin to form bulbs early. *Phoma terrestris* can survive in soil as deep as 45 cm. Optimum temperature for pathogen growth and disease development is 75-82ºF (24-28°C). Infection is reduced at 68ºF (20°C), and rare at <61ºF (16°C) (Schwartz and Mohan, 1995). The fungus can be spread by onion sets and soil through machinery, dust storms and surface run-off. *Phoma territstris* also infects cereals, grasses, parsnip, radish and spinach (Howard et al., 1994).

Smut, caused by the fungi *Urocystis magica* and *U. colchici*, is a sporadic but increasingly common bulb disease in Michigan. Smut first appears as dark, thickened lesions on cotyledons, and as raised, blister-like lesions near the base of scales on older plants. Large lesions can cause leaves to curve downward. Mature lesions contain masses of black, powdery spores. Infection progresses inward into the leaf cluster, and can cause stunting and death within 3-4 weeks from emergence. Susceptibility to smut decreases with leaf and plant age 50-54ºF (10-12°C) (Schwartz and Mohan, 1995). Bulbs can have elongated dark lesions (Howard et al., 1994). The disease is also spread by infected onion sets and transplants, and spores carried by wind, equipment and water. Spore germination and growth is favored by temperatures 55-72ºF (13-22°C), but can occur at temperatures as low as 50-54ºF (10-12°C). *Urocystis* spores can overwinter in the soil and persist for many years (Schwartz and Mohan, 1995).

Basal rot, caused by *Fusarium oxysporum* f.sp. *cepae*, is a bulb disease that is an occasional problem that may affect as much as 30% of Michigan onion fields depending on the season and location. Basal rot first appears as curving, yellowing and/or necrosis of leaves progressing from the tip down. Plants may wilt and bulbs may appear discolored, with brown watery tissues. The rot progresses from the stem plate up through the leaves, with the roots rotting and white mycelium may appear on the stem plate (Schwartz and Mohan, 1995). The basal rot pathogen is commonly found in soil and can survive long periods of time through formation of chlamydospores, which can be spread in water, soil or air. The fungus can penetrate the roots directly or infect roots and bulbs through wounds (Howard et al., 1994). Disease rarely occurs when soil temperatures are <59ºF (15°C), but becomes more prevalent at 77-82ºF (25-28°C). Disease appears to increase if plants are injured (Schwartz and Mohan, 1995). Harvested bulbs become diseased quickly if temperatures are 68-86ºF (20-30°C) in storage or transit (Howard et al., 1994). Asymptomatic bulbs may rot in storage (Schwartz and Mohan, 1995). Disease is considerably slowed when onions are stored at temperatures <59ºF (15°C), but premature sprouting will likely occur. High relative humidity in storage also favors this disease (Howard et al., 1994). Cultivars resistant to basal rot are available, and include Armada, Canada Maple, Copra, Daytona, Duration, Granite, Long White Summer Bunching, Northern Oak, Prince, Sentinel, Stokes Exporter II, Valiant, and Wolverine (Stevenson and Heimann, 1994).

In addition to leaf blight described previously, *Botrytis* spp. also cause neck rot (*B. aclada, B. squamosa*) and stalk rot (*B. aclada*), sporadic diseases of onion in Michigan. Neck rot is a serious storage problem, occurring as a semiwatery decay beginning in the neck area, which gradually moves down through the entire bulb. Bulb scales soften and become water-soaked. Sclerotia and a gray mold may form on bulbs. Succulent necks at harvest may favor neck rot, if they come into contact with this fungus. The fungus overwinters as sclerotia in the soil or on bulb debris (Schwartz and Mohan, 1995).

Smudge (causal organism, the fungus *Colletotrichum circinans*) is a disease that occurs occasionally in Michigan. Symptoms occur primarily on the dried outer scales and lower portions of white onion, first appearing as small, dark green spots, often in circular, concentric rings about 1 cm in diameter. The spots turn black with age. *Colletotrichum* is a soil-borne pathogen, surviving on onion or plant debris or as a saprophyte for many years. Warm, wet weather favors disease development. Germination of the spores occurs at 55-77ºF (13-25°C) (optimum 68ºF [20°C]) and disease develops at 50-90ºF (10-32°C) (optimum 79ºF [26°C]). The pathogen can complete a life cycle in a few days when conditions are favorable. The fungus is spread by infested plant material and soil (Schwartz and Mohan, 1995).

White rot is a minor fungal disease, caused by *Sclerotium cepivorum*. It rarely causes seedling death. Field infestations may appear as dead plants in small (2-40 plants) to large areas depending on the soil infestation; plants in the center of the areas will die first. Symptoms on plants occur as premature yellowing and dying of older leaves, stunting, and death of all foliage. White, fluffy mycelium is visible on the stem plate, then progresses up and into the bulb. Small black sclerotia (the size of poppy seeds) form in diseased tissue, and can become abundant. Sclerotia can lie dormant in soil for many years. Germination of sclerotia is optimum at 57-64ºF (14-18°C), and mycelium can grow 1-2 cm laterally through soil and up to 30 cm vertically to infect plants (Schwartz and Mohan, 1995). Disease development is favored by 50-68ºF (10-20°C) and moderate moisture (Howard et al., 1994). Widespread plant loss can occur if successive crops of *Allium* spp. are planted in infested fields. The fungus can be transported by infested soil on equipment, harvest containers, shoes, and plant materials, including allium sets/transplants (Schwartz and Mohan, 1995).

Bacterial diseases occur each year and can be minor or major problems. Bacterial soft rot symptoms include water-soaking and discoloration of scale tissues to a pale yellow to light brown. As the disease progresses, tissues become soft, and break down into a watery, foul-smelling viscous liquid. Leaves wilt and whiten. The bacteria can occur in soil and crop debris, and are spread by rain, irrigation water and insects (Schwartz and Mohan, 1995). *Erwinia* enters the bulb through the neck tissue of maturing plants and through wounds. The bacteria can survive on infested crop residues in the soil, and be spread by rain and irrigation or by direct contact with infested soil (Howard et al., 1994). The onion maggot can harbor the bacteria in the guts of larvae and adult flies and spread the pathogen. Optimum temperature for infection is 68-

86ºF (20-30°C) and high humidity. Infection can continue in storage or transit if the temperature is >37ºF (3°C) (Schwartz and Mohan, 1995).

Center rot is caused by the bacterium, *Pantoea ananatis*. Symptoms of center rot include the rapid death of the two center leaves followed by a soft rot of the heart of the bulb. Little is known about the epidemiology and control of this disease.

Slippery skin is caused by the bacterium, *Burkholderia gladioli* pv. *alliicola*. The disease first occurs as softening of the neck tissue, with 1-2 inner bulb scales that are water-soaked. The rot progress down along the scales, and does not affect adjacent scales; however, the bacteria can invade other scales. Plants may have 1-2 wilted leaves in the middle of the leaf cluster, which turn pale yellow to off-white and die back (Howard et al., 1994). Eventually, all internal tissue may rot, then dry out and shrivel the bulb. The center core of the infected bulb may slip out the top if the base is pressed. The bacterium, *B. gladioli* pv. *alliicola*, enters leaves and maturing bulbs through wounds, probably just before or at harvest. Young leaves are only slightly susceptible. The disease is usually more severe if onion tops are damaged by hail or high winds, or subjected to wet or rainy conditions prior to harvest. Mature bulbs are very susceptible and can rot completely within 10 days at room temperature (Schwartz and Mohan, 1995).

Sour skin, another bacterial disease (bacterium, *Burkholderia cepacia*) first appears on onion bulbs as a slimy, pale yellow to light brown decay and breakdown of one to several inner bulb scales. The bulb may appear normal, but the neck region may soften after leaves have collapsed (Schwartz and Mohan, 1995). One to two leaves may turn light brown, and young leaves may die back. Affected leaves can easily be pulled out of the bulb. Healthy scales may slip off during handling of bulbs with advanced disease. The bacterium, *B. cepacia*, has been found in organic soils and irrigation water (Howard et al., 1994). Infection generally occurs through a wound in the presence of water from rain, irrigation or flooding, or can occur when water with bacteria strike young leaves and flow down them into the neck area. Young leaves are much more susceptible than older leaves, and infection can remain latent until the plant begins to form a bulb. Infection into the bulb occurs along the infected leaf, and does not move between scales. Temperatures >86ºF (30°C) favor rapid disease progression (Schwartz and Mohan, 1995).

Aster yellows is a disease caused by a phytoplasma. Symptoms include yellow streaks or general yellowing of basal portions of young leaves, spreading until the entire leaves turn yellow. Infrequently leaves can wilt and the plant can die. The aster yellows phytoplasma has a wide host range, including vegetable crops such as carrot and celery. It can overwinter in host plants such as grains, perennial weeds and ornamentals. Several leafhopper species, especially the aster leafhopper, can acquire and vector the phytoplasma during feeding. Leafhoppers can remain infective for ≥100 days (Schwartz and Mohan, 1995).

Onion thrips are the most important insect pest of onions in Michigan. Insecticides may cost >$100/A and adequate control may not be obtained due to the thrips' cryptic habits and their ability to become resistant to insecticides (Eckenrode et al., 1999; Grafius et al., 1990; Shelton et al., 2004). Currently in Michigan, organophosphate and pyrethroid insecticides are ineffective or marginally effective and only methomyl (Lannate, a carbamate) provides high levels of control (Grafius et al., 2004). Continuous use of methomyl or any other single insecticide is likely to result in resistance problems and control failures in future. Spinosad (SpinTor) is a new type of insecticide with moderate to very good effectiveness on onion thrips; registration of spinosad on onions is pending.

Onion thrips feed by rasping the surface of the leaf tissue, destroying the surface cells and disrupting photosynthetic capability of the leaf. High thrips populations can cause yield losses or even plant death. Thrips damage also creates potential sites for disease entry. Spanish type onions are more sensitive to thrips damage than other varieties.

Thrips overwinter as adults in or adjacent to onion fields, but also may migrate long distances on weather fronts. Many crops and weeds are hosts, in addition to onions. Thrips take 15 to 30 days to complete a generation, depending on temperature. Eggs are laid beneath the surface of the leaf tissue and hatch in 3 to 7 days. Larvae complete development in 5 to 10 days under favorable conditions, and drop to the soil surface and pupate in the soil for 4 to 7 days before emerging as adults. Adults begin laying eggs in 3 to 6 days after emergence. Onion thrips are usually all females and reproduce without mating.

About half of the onion thrips' life cycle is spent protected from insecticides in the plant tissue (eggs) or in the soil (pupae). Even thrips larvae and adults are most often found down inside the onion plant on the new growth, protected from weather, predators and pesticides by the onion foliage.

Because thrips reproduce without mating, there is no genetic mixing between generations. One female that is resistant to insecticides can rapidly reproduce identical copies of herself and create a control problem. Research has shown farm-to-farm differences in thrips' resistance to insecticides and even major increases in resistance within a growing season on individual farms (Grafius et al., 1990; Shelton et al., 2004). This suggests that thrips populations may be local around individual onion fields, and that thrips migrating into fields may be rapidly killed by insecticides early in the season, leaving the local, insecticide-resistant thrips. These survivors would be more difficult to control and resistance problems would be more serious late in the season.

Onion maggot, *Delia antiqua*, has historically been the most severe pest of onions in Michigan. Onion maggots overwinter as pupae in the soil and adults emerge in late May and June and lay eggs on onion seedlings. Larvae attack the seedlings, usually through the basal root zone, and a single larva can kill multiple seedlings. Crop losses have been >50% in some situations. Second generation onion maggots tend to attack previously damaged onions and the third generation usually occurs on cull onions left after harvest. The first generation is the most damaging and the target of most control efforts.

Catastrophic losses have occurred as far back as the 1950s, when onion maggots in Michigan became resistant to DDT and its relatives (Guyer and Wells, 1959). In response to resistance to chlorpyrifos (Lorsban) and serious losses from onion maggot in Michigan onions in the 1980s and early 1990s, research began on the insect growth regulator cyromazine (Trigard) in Michigan (Grafius and Hayden, 1987; Hayden and Grafius, 1990). Scientists in New York studied cyromazine as a seed treatment. Cyromazine received Section 18 emergency registration as a seed treatment application for control of onion maggot in Michigan in 1996. Full federal registration followed in 1999. Cyromazine affects only newly hatched onion maggot larvae (Hayden and Grafius, 1990). It is highly effective as a preplant seed treatment at a rate of approximately 50 g active ingredient per acre. Because it is a new category of insecticide for onion maggot and is used only on the first generation of onion maggot, insecticide resistance development is not currently a major concern. Commercial fields where onion seed was treated with cyromazine have significantly more natural enemies than fields treated with the organophosphate insecticide chlorpyrifos, although the impact of these natural enemies on onion maggot damage has not been documented (McCornack et al., 2001).

Onion maggot is not currently considered a severe pest of onions in Michigan. However, growers rely on a single insecticide applied as a seed treatment, with no other options in case of adverse environmental conditions, exceptionally high onion maggot populations, or other factors; this is a potentially unstable situation.

Aster leafhoppers, *Macrosteles quadrilineatus*, can also be a significant pest of onions because they transmit aster yellows phytoplasma. Aster yellows causes abnormal growth or death of onions in the field and sprouting of onions in storage. The only control available for aster yellows is use of insecticides to control the aster leafhopper. This is a difficult proposition because the aster leafhopper is highly mobile and may move into and out of onion fields within hours or 1-2 days of arrival, before scouting can detect the problem and before insecticides can be applied. Treatment is almost never applied directed at the aster leafhopper, although insecticides applied for control of onion thrips will usually also control aster leafhoppers.

The most important plant parasitic nematodes affecting onions in Michigan are the northern root-knot nematode (*Meloidogyne hapla*), common needle nematode (*Longidorus elongatus*), root-lesion nematode (*Pratylenchus penetrans*), stem and bulb nematode (*Ditylenchus dipsaci*), and stubby-root nematode (*Paratrichodorus* spp.). The stem and bulb nematode feeds on modified leaf tissue (the onion bulb), while the others are root tissue pathogens. Because of the significance of nematodes as models for biological systems, a significant amount of new information has been learned about nematode host-parasite relationships during the past 10 years (Wyss, 2002).

Second-stage juveniles of the northern root-knot nematode enter root tissue in the zone of elongation (von Mende, 1997). They migrate intercellularly between cortical cells moving toward the root tip. They do not cause damage during this process. The juveniles reverse their direction and migrate intercellularly between cortical cells until they reach the newly formed vascular cylinder. They migrate between the cambial cells until movement ceases and multinucleate giant cell initiation begins. The nematode continues its development and root galls are produced mitotically. The most conspicuous above ground symptoms of root-knot nematode on onions is stunted shoot system growth and slightly off-color or yellow foliage. Root galls may or may not be readily visible since onion roots are shed in response to this host-parasite relationship. Most of the infected roots are shed through formation of an abscission layer at the crown (Bird and Graney, personal communication). In some cases, however, the abscission layer may form immediately above or below the root gall. Onion bulb yields in infested areas are low. Because of the root-shedding, however, population densities of the northern root-knot nematode do not increase significantly on onion root tissue. Nematode damage is more severe in sandy-textures and muck soils than in clay soils. Maintaining adequate soil moisture in a crop may lessen the effect of the root-knot nematode on onion (Schwartz and Mohan, 1995).

The common needle nematode (*L. elongatus*) feeds exclusively on root tissue immediately adjacent to the subapical meristem, resulting in terminal root galls. The initial hypertrophy of individual uninucleate cells is followed by hyperplasia with synchronized cell divisions followed by secondary hypertrophy (Griffiths and Robertson, 1984). When present, this nematode results in severely stunted off-color onion plants and significantly reduced bulb yield. Plants in small circular areas may fail to develop and die within six weeks after seeding.

All stages of the root-lesion nematode can be found in root cortical tissue of the onion plant. *Pratylenchus penetrans* stunts plants and prevents development of fine roots. Small necrotic lesions are often present on root epidermal tissue. This nematode has a very wide host range and crop rotation is frequently of little value unless combined with other nematode management tactics. The life cycle can be completed in as little as 20 days depending on temperature (68-86ºF [20-30°C] is optimum), moisture tension (moderate is optimum), and host. Lesions are associated with densities of >100 nematodes per g of root (Schwartz and Mohan, 1995).

Symptoms of the stem and bulb nematode (*D. dipsaci*) include erratic stands, stunting, looping and bending of leaves below the soil surface, swelling, and extensive longitudinal splitting of cotyledons and leaves. Leaves appear short, thickened, often with brown to yellow spots and bloat (stem swelling). Infected seedlings twist, enlarge, deform and can die. Leaves eventually collapse, and the bulbs soften from the neck down. Scales become light gray and soft. Bulbs usually become infected with secondary pathogens. The stem and bulb nematode usually penetrates the germinating seed before the cotyledons emerge. Young plants can be invaded at any point. A mature plant is usually entered through the basal plate. *Ditylenchus dipsaci* completes its life cycle on onion seedlings in 19-23 days at 59ºF (15°C). Nematodes become active during heavy rains and move up the plant in a film of water, and can enter the plant through stomates. Population densities of stem and bulb nematode in soil can fluctuate, depending on soil type and host plants, but an infected plant can harbor as many as 50,000 nematodes. Damage can occur at infestation levels as low as 10 nematodes per 500 g of soil. Low soil moisture and soil temperatures near or below freezing are optimum for nematode survival. A soil temperature of 70ºF (21°C) favors penetration of onion seedlings, movement, reproduction and symptom severity by stem and bulb nematode (Schwartz and Mohan, 1995).

Damage due to the stubby-root nematode occurs as stunting of plants and abnormal, stunted growth of lateral roots with browning and stubbiness of root tips. Affected roots usually branch, resulting in stubby, coarse, curly root tips, which can become discolored and necrotic. *Patrichodorus* adults are strictly external feeders. The life cycle of these nematodes can be completed in 16-17 days at 86ºF (30°C). Stubby-root nematodes are mostly found in sandy or sandy loam soils, but also occur in organic soils (Schwartz and Mohan, 1995).

Yellow nutsedge and annual weeds can reduce plant stand, compete for water, light and nutrients, delay maturity, complicate harvest, and serve as hosts or homes for onion insect pests (Zandstra and Wallace, 1989). Growers spend a large percentage of their pest management dollars on weed control. Adequate management of weeds in onions is particularly important early in crop growth when weeds compete with the crop for moisture, nutrients, light and space. Onions have a shallow, non-aggressive, fibrous root system and weed competition early in the growing season can significantly reduce yield. Weeds can also interfere with chemical sprays, harvest operations and exacerbate the environmental conditions favorable for foliar disease development by decreasing air movement within the canopy.

Several new herbicides will soon be registered for onions, which will help maintain good weed control, but the added cost may not be justified by the increased yields (Boydston and Seymour, 2002; Zandstra et al., 2002). Determining the most cost effective and efficient methods of weed control for onion production will help growers operate more efficiently and produce greater yields of a better quality product.

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OUTLINE OF PLAN

Following is a pest by pest analysis of the current role of pesticides registered for use in onion production with emphasis on those classified as organophosphates, carbamates and B2 carcinogens. Other pest management tools (chemical, cultural and otherwise) that offer some control or are important in pest resistance management, but are not "stand alone" tools, are also discussed. In some instances, products that have been identified as effective through preliminary research, but are currently unavailable for use on onion, are discussed under the heading "pipeline pest management tools." Immediately following each pest analysis is a "to do" list for research, regulatory, and educational needs. Pests are presented in alphabetical order.

DISEASES

BACTERIAL PATHOGENS

1. BACTERIAL SOFT ROT (*Erwinia carotovora* subsp. *carotovora*)

A major concern that is always present, but not always epidemic. Warm wet conditions promote disease development. Commonly found where overhead irrigation is used. Affected scales become spongy, water-soaked and pale yellow to light gray. As rot progresses, the whole interior can break down to a sticky mass inside the dry outer scales. If infection occurs through an injury, the rot can progress from the site through several bulb scales, exacerbating bulb decay.

2. CENTER ROT (*Pantoea ananatis*)

Symptoms of center rot include the rapid death of the two center leaves followed by a soft rot of the heart of the bulb. Little is known about the epidemiology and control of this disease. It was verified in Michigan for the first time in the mid-1990s.

3. SLIPPERY SKIN (*Burkholderia gladioli* pv. *alliicola*)

Onions in the field may have 1-2 wilted leaves in the middle of the leaf cluster. Other early symptoms include neck softening and, if the onion is cut longitudinally, water-soaked lesions are evident. The rot progresses from the top of the infected scales downward without spreading across adjacent scales. In advanced stages of disease, the bulb will appear to be dried out and shriveled.

4. SOUR SKIN (*Burkholderia cepacia*)

Young leaves may die back beginning at the tips. Onion may appear healthy on the outside except for minor neck softening. Decay occurs on inner bulb scales, which turn slimy and yellow to light brown.

B2 carcinogenic bactericides currently registered:

- None identified.

Other bactericides currently registered:

- Copper-based products (Champ, Cuprofix Disperss [soft rot only], Kocide, Nu-Cop): Efficacy – fair, but overall has not been thoroughly tested. Often used in small amounts due to concerns regarding phytotoxicity. Relatively inexpensive.

Other pest management aids for bacterial pathogens:
- Use furrow or drip irrigation.
- Remove old plant material.
- Avoid damaging bulbs during harvest.
- Store onions only when completely dry at 32ºF (0ºC) and <70% RH with adequate ventilation.

Pipeline pest management tools for bacterial pathogens:
- None identified.

"To do" list for bacterial pathogens:

Research needs:
- Screen varieties for resistance to bacterial pathogens.
- Determine the effect of cultural practices, including plowing, on bacterial disease.
- Test new products, including those that promote induced resistance of the onion to pathogens.
- Develop recommendations regarding the timing and frequency necessary for copper bactericides to be most effective.
- Monitor the potential for development of resistance of the bacteria to the copper.

Regulatory needs:
- Expand labels of currently registered coppers to encompass all bacterial problems.

Educational needs:
- Educate growers on disease symptoms and identification.

FUNGAL PATHOGENS

1. BASAL ROT (*Fusarium oxysporum* f. sp. *cepae*)

Long-lived, soil-borne pathogen causing above-ground symptoms such as bending, yellowing, and/or necrosis of leaves beginning at the tips and progressively developing downward. Infected bulbs may appear discolored, and when cut, affected tissues appear brown and watery. Bulbs may display no decay/symptoms at harvest but subsequently rot in storage. A severe infestation can result in highly infested soil that is unsuitable for growing onions in the future. Disease incidence varies by locality, variety and cultural management.

B2 carcinogenic fungicides currently registered for basal rot:
- None identified.

Other fungicides currently registered for basal rot:
- None identified.

Other pest management aids for basal rot:
- Plant resistant varieties.
- Long term rotation with non-host crops for 4 or more years.

Pipeline pest management tools for basal rot:
- None identified.

"To do" list for basal rot:

Research needs:
- Screen varieties for resistance to basal rot.

- Explore the potential of cover crops, green manure and brassica crops and biofumigants as rotational crops in reducing *Fusarium* inoculum.
- Test new products for potential activity against *F. oxysporum* f. sp. *cepae*.

Regulatory needs:

- None identified.

Educational needs:

- None identified.

2. BLACK MOLD (*Aspergillus niger*)

A major storage problem; a significant infection can reduce the value of the crop by 30% or more. Economically important due to disease development during transit and storage. Infected bulbs have a black discoloration at the neck, shallow lesions on the outer scales and streaks of black mycelium and conidia beneath the outer scales. Severe infections appear to predispose the bulb to bacterial saprophytes and pathogens. Cull piles and/or seeds could be a source of initial inoculum. Disease symptoms are not typically observed in the field. Storage conditions (temperature and humidity) appear to be an important aspect of disease control.

B2 carcinogenic fungicides currently registered for black mold:

- None identified.

Other fungicides currently registered for black mold:

- None identified.

Other pest management aids for black mold:

- Plant disease-free seed when available.
- Manipulation of storage environment to enhance quick drying.
- Avoid damaging bulbs during harvest and storage to minimize infection.

Pipeline pest management tools for black mold:

- None identified.

"To do" list for black mold:

Research needs:

- Investigate fungicide chemistries for efficacy when applied to seeds, seedlings, and/or bulbs.
- Determine field management practices and storage conditions that can limit disease development.
- Quantify economic impact of black mold.
- Determine sources of inoculum (cull piles, storage facilities, field soil, seed, air).

Regulatory needs:

- Speed registration of fungicides proven to be effective against black mold.

Educational needs:

- Explain the role of the storage environment in disease development.

3. BOTRYTIS LEAF BLIGHT (*B. aclada = B. allii, B. cinerea, B. squamosa*)

Symptoms start as small white spots on the leaves surrounded by a green halo. Leaf death can occur, and results in smaller bulb size. The inoculum is soil-borne as sclerotia in the field. This disease can spread rapidly when environmental conditions are favorable for development, i.e. warm, humid evenings.

B2 carcinogenic fungicides currently registered for Botrytis leaf blight:

- Chlorothalonil (Bravo, Echo, Equus): Efficacy – excellent/good. Broad-spectrum. Important as a rotational product in resistance management. It is cost effective.
- Copper hydroxide/mancozeb (ManKocide): Efficacy – good. Currently undergoing the re-registration process. Cost effective. Important as a rotational product in a resistance management program.
- Fosetyl-aluminum/maneb (Aliette/Maneb): Efficacy – fair. Cannot tank mix with copper fungicides. Cannot apply to exposed bulbs. Not recommended since only maneb is active against this pathogen and it is available separately.
- Iprodione (Iprodione, Rovral): Efficacy – good. Somewhat broad-spectrum systemic product. Development of resistance is a concern and has been documented. To delay resistance, this product should be used in a program with fungicides that have a different mode of action.
- Mancozeb (Dithane, Manzate, Manex II, Penncozeb): Efficacy – good. Currently undergoing the re-registration process. Cost effective. Important as a rotational product with other fungicides for resistance management. Broad-spectrum.
- Mancozeb/copper sulfate (Cuprofix MZ Disperss): Efficacy – good. Currently undergoing the re-registration process. Cost effective. Important as a rotational product with other fungicides for resistance management. Broad-spectrum.
- Maneb (Maneb, Manex): Efficacy – good. Currently undergoing the re-registration process. Cost effective. Important as a rotational product in a resistance management program.
- Mefenoxam/chlorothalonil (Ridomil Gold Bravo): Efficacy – good. Not recommended since only chlorothalonil is active against this pathogen and it is available separately.

Other fungicides currently registered for Botrytis leaf blight:

- Boscalid (Endura): Efficacy – good. Classified as a reduced-risk fungicide. Development of pathogen resistance is a concern. To delay the development of resistance, this fungicide needs to be used in alternation with a fungicide with a different mode of action.
- Cyprodinil/fludioxonil (Switch): Efficacy – good. Classified as a reduced-risk fungicide. Expensive. The preharvest interval is 7 days. Twelve month crop rotation limited to crops listed on the label.
- DCNA (Botran): Efficacy – fair. Limited use, old product.
- Harpin protein (Messenger): Efficacy – ineffective in controlled research plots. Classified as a biopesticide. Not used by growers.
- Neem oil (Trilogy): Efficacy – ineffective in controlled research plots. Classified as a biopesticide. Not used by growers. Not readily available to growers.
- Pyraclostrobin/boscalid (Pristine): Efficacy – good. Classified as a reduced-risk fungicide. Development of pathogen resistance is a concern. To delay the development of resistance, this fungicide needs to be used in alternation with a fungicide with a different mode of action.
- Pyrimethanil (Scala): Efficacy – fair/poor. Classified as a reduced-risk fungicide.

Other pest management aids for Botrytis leaf blight:

- Scouting helps alert growers to disease onset and prompts fungicide applications.
- Crop rotation help reduce overwintering inoculum.

Pipeline pest management tools for Botrytis leaf blight:

- Onion leaf blightcast, a forecasting tool that is not widely used by Michigan growers.

"To do" list for Botrytis leaf blight:

Research needs:

- Evaluate the onion leaf blight predictor when using the newly-registered fungicides. Determine the adjustments needed for implementation.
- As new products become available, test for efficacy.

Regulatory needs:

- Maintain current fungicide labels. Once new, cost effective products are available, current broad-spectrum fungicides may be needed to use in alternation to delay the development of pathogen resistance.

Educational needs:

- Illustrate the potential benefit of forecasting systems for managing Botrytis leaf blight. As new fungicides become available, explain the resistance management required.

4. DAMPING OFF (*Pythium* spp., *Rhizoctonia solani*)

Diseases caused by soil-borne fungi. Damping off occurs during cool, wet conditions. Infected seedlings wilt, or leaves develop a water-soaked, discolored lesion on the stem at the ground level and topple over, resulting in plant death.

B2 carcinogenic fungicides currently registered for damping off:

- None identified.

Other fungicides currently registered for damping off:

- Mefenoxam (Apron XL, Ridomil Gold, Ultra Flourish): Efficacy – has known activity against *Pythium*. Classified as a reduced-risk fungicide. Used as an in-furrow treatment. Expensive.
- Thiram (Thiram): Efficacy – good activity against *Rhizoctonia*. Apply as a seed treatment.

Other pest management aids for damping off:

- Avoid excessive irrigation between the flag leaf and first true leaf stage to lessen disease development.
- Plant in raised beds (currently used by many farmers) – may cause difficulty in harvesting.
- Long season crop can promote early disease problems.

Pipeline pest management tools for damping off:

- Captan (Captan): Efficacy – good. Classified as a B2 carcinogen. Would be a low cost treatment that could be helpful against commonly occurring soil-borne pathogens.

"To do" list for damping off:

Research needs:

- Determine which damping off pathogen is most prevalent in Michigan onion fields.
- Test currently unregistered fungicides for their ability to control these pathogens.
- Test Apron XL seed treatment vs. Ridomil as in-furrow applications.
- Determine the minimum amount of Ridomil needed for disease control

Regulatory needs:

- None identified.

Educational needs:

- Primary pathogen responsible for damping off needs to be identified so growers can develop an appropriate and effective management plan.

5. DOWNY MILDEW (*Peronospora destructor*)

This disease occurs every 3 to 4 years in Michigan, and is very destructive when left untreated. Under favorable weather conditions the pathogen spreads quickly. First symptoms include purple sporulation of the pathogen on the leaves. Lesions can enlarge and girdle the leaves causing the tissue to collapse. Bulb infection can also occur resulting in storage rot. Field infections usually begin in small patches and progress rapidly throughout the field. In dry weather with relative humidity less than 80% and temperatures greater than 75ºF (24ºC), the fungal growth disappears, but the fungus may reappear and cause new lesions on neighboring tissues when the weather becomes wet and cool and again.

B2 carcinogenic fungicides currently registered for downy mildew:

- Chlorothalonil (Bravo, Echo, Equus): Efficacy – fair. Long re-entry time (48 hours). Broad-spectrum.
- Fosetyl-aluminum/maneb (Aliette/Maneb): Efficacy – fair.
- Mancozeb (Dithane, Manzate, Manex II, Penncozeb): Efficacy – excellent/good. Good rotational product; important in resistance management. Cost effective. Currently undergoing the re-registration process. Broad-spectrum.
- Mancozeb/copper sulfate (Cuprofix MZ Disperss): Efficacy – good. Good rotational product; important in resistance management. Cost effective. Currently undergoing the re-registration process. Broad-spectrum.
- Maneb (Maneb, Manex): Efficacy – excellent/good. Good rotational product; important in resistance management. Cost effective. Currently undergoing the re-registration process.
- Mefenoxam/chlorothalonil (Ridomil Gold/Bravo): Efficacy – good/fair. Expensive. Potential for the downy mildew pathogen to develop resistance.
- Mefenoxam/mancozeb (Ridomil Gold MZ): Efficacy – excellent/good. Expensive. Potential for the downy mildew pathogen to develop resistance.

Other fungicides currently registered for downy mildew:

- Azoxystrobin (Amistar, Quadris): Efficacy – poor. Classified as a reduced-risk fungicide. Development of pathogen resistance is a concern. To delay the development of resistance, this fungicide needs to be used in alternation with a fungicide with a different mode of action.
- Copper-based products (Champ, Champion, Copper-Count N, Kocide, Nu-Cop, Tenn-Cop): Efficacy – fair/poor. Broad-spectrum.
- Dimethomorph (Acrobat): Efficacy – good/fair. Specific to this group of pathogens. Not thoroughly tested on onions in Michigan.
- Fosetyl-aluminum (Aliette): Efficacy – fair. Specific to this group of pathogens.
- Harpin protein (Messenger): Efficacy – ineffective in controlled research plots. Classified as a biopesticide. Not used by growers.
- Mefenoxam/copper hydroxide (Ridomil Gold Copper): Efficacy – good/fair. Potential for the downy mildew pathogen to develop resistance.
- Neem oil (Trilogy): Efficacy – poor, ineffective in controlled research plots.

Classified as a biopesticide. Not used by growers. Not readily available to growers.

- Pyraclostrobin (Cabrio): Efficacy – fair. Classified as a reduced-risk fungicide. Development of pathogen resistance is a concern. To delay the development of resistance, this fungicide needs to be used in alternation with a fungicide with a different mode of action.
- Pyraclostrobin/boscalid (Pristine): Efficacy – fair. Classified as a reduced-risk fungicide. Development of pathogen resistance is a concern. To delay the development of resistance, this fungicide needs to be used in alternation with a fungicide with a different mode of action.

Other pest management aids for downy mildew:

- Eliminate cull piles and plant debris.
- Use a 3-4 year crop rotation.
- Scouting as an alert to initiate fungicide sprays.

Pipeline pest management tools for downy mildew:

- Downy mildew forecaster may be a tool that indicates when the weather conditions are favorable for disease development prompting preventive sprays.

"To do" list for downy mildew:

Research needs:

- Determine efficacy of new unregistered fungicides that are specific to oomycetes.
- Validate disease forecasting programs using currently registered and soon to be registered fungicides (Downcast).

Regulatory needs:

- Maintain current fungicide labels, specifically mancozeb. Mancozeb is highly effective when used preventively and would be good used with new fungicides as part of a resistance management program.

Educational needs:

- Demonstrate to growers which fungicides are most effective.
- Train growers to use the forecasting system.

6. NECK ROT (*Botrytis* spp.), STALK ROT (*B. aclada*)

A serious disease of stored onions. The fungus enters directly through wounded tissue and causes the neck region to become soft and spongy. Infected areas of the onion are water-soaked and brown. In severe cases sclerotia form and are observed in the bulb tissue. Disease may be held in check when fungicides are applied to control other foliar diseases and if bulbs are not rolled prior to harvest. If broad-spectrum products are not available then neck rot may become a greater problem.

B2 carcinogenic fungicides currently registered for neck and stalk rot:

- Iprodione (Iprodione, Rovral): Efficacy – good/fair. Development of pathogen resistance is a potential problem.
- Mancozeb (Dithane, Manzate, Manex II, Penncozeb): Efficacy – fair/poor.
- Maneb (Maneb, Manex): Efficacy – fair/poor.

Other fungicides currently registered for neck and stalk rot:

- *Bacillus subtilis* (Serenade): Efficacy – unknown. Classified as a biopesticide. Needs to be applied before disease development. Based on information from other crops control will likely be poor under moderate or severe disease pressure. Classified as a biopesticide or biological control product.

- Copper resinate (Tenn-Cop): Efficacy – poor.
- Neem oil (Trilogy): Efficacy – ineffective in controlled research plots. Classified as a biopesticide. Not used by growers. Not readily available to growers.
- Pyrimethanil (Scala): Efficacy – fair/poor. Classified as a reduced-risk product.

Other pest management aids for neck and stalk rot:

- Destroy onion cull and debris piles which may serve as sources of inoculum.
- Manage timing of irrigation so foliage can dry rapidly.
- Avoid rolling tops and other handling practices that cause wounding, providing an entry point for the pathogen.

Pipeline pest management tools for neck and stalk rot:

- None identified.

"To do" list for neck and stalk rot:

Research needs:

- Test currently unregistered products for disease control.
- Determine whether this pathogen can be seed-borne.

Regulatory needs:

- Maintain availability of iprodione (Iprodione, Rovral) until an effective product is identified and registered.

Educational needs:

- Educate growers of early disease symptoms and management strategies.

7. PINK ROOT (*Phoma terrestris*)

Pink root is a common problem in Michigan, and is most serious during especially hot summers. Disease symptoms include discolored roots that turn light pink then purple. Roots become very weak and plants may lodge prematurely. The fungus overwinters in soil and is most prevalent in growing regions with warmer climates. Economic losses result from small bulb size and poor marketability.

B2 carcinogenic fungicides currently registered for pink root:

- Dichloropropene/chloropicrin (Telone C-17, C-35): Efficacy – good. Very expensive and can be difficult to apply.

Other fungicides currently registered for pink root:

- None identified.

Other pest management aids for pink root:

- Tolerant commercial varieties should be planted when possible.
- Long-term (4-6 years) crop rotation with non-host crops.
- Soil fumigation.

Pipeline pest management tools for pink root:

- None identified.

"To do" list for pink root:

Research needs:

- Screen varieties for resistance.
- Determine the epidemiology of the pathogen under Michigan's growing conditions.
- Determine whether new unregistered fungicides have activity against the pathogen.

Regulatory needs:

- Maintain dichloropropene/chloropicrin (Telone C-17, C-35) as a control option until a suitable replacement is identified and registered.

Educational needs:

- Resistant varieties need to be promoted as a disease management tool.

8. PURPLE BLOTCH (*Alternaria porri*)

A yearly problem in Michigan. Older leaves are more susceptible than younger leaves. Symptoms begin as water-soaked spots with a white center that eventually become surrounded by brown and red lesions. When the lesions expand and coalesce, the leaf becomes girdled and dies. The disease can progress rapidly throughout the entire field if left untreated.

B2 carcinogenic fungicides currently registered for purple blotch:

- Chlorothalonil (Bravo, Echo, Equus): Efficacy – excellent/good.
- Copper hydroxide/mancozeb (ManKocide): Efficacy – fair.
- Fosetyl-aluminum/maneb (Aliette/Maneb): Efficacy: – fair/poor.
- Iprodione (Iprodione, Rovral): Efficacy – excellent/good.
- Mancozeb (Dithane, Mancozeb, Manex II, Penncozeb): Efficacy – good.
- Mancozeb/copper sulfate (Cuprofix MZ Disperss): Efficacy – good.
- Maneb (Maneb, Manex): Efficacy – good.
- Mefenoxam/chlorothalonil (Ridomil Gold Bravo): Efficacy – good. Only the chlorothalonil component is active against this pathogen.

Other fungicides currently registered for purple blotch:

- Azoxystrobin (Amistar, Quadris): Efficacy – excellent. Classified as a reduced-risk fungicide. Development of pathogen resistance is a concern. To delay the development of resistance, this fungicide needs to be used in alternation with a fungicide with a different mode of action.
- Boscalid (Endura): Efficacy – excellent/good. Classified as a reduced-risk fungicide. Development of pathogen resistance is a concern. To delay the development of resistance, this fungicide needs to be used in alternation with a fungicide with a different mode of action.
- Copper-based fungicides (Champ, Champion, Copper Count N, Cuprofix Disperss, Kocide, Nu-cop): Efficacy – fair/poor.
- Cyprodinil/fludioxonil (Switch): Efficacy – good. Very expensive compared to the older protectant fungicides, mancozeb and chlorothalonil. Classified as a reduced-risk fungicide.
- Fosetyl-aluminum (Aliette): Efficacy – fair.
- Harpin protein (Messenger): Efficacy – ineffective in controlled research plots. Classified as a biopesticide. Not used by growers. Not readily available to growers.
- Neem oil (Trilogy): Efficacy – ineffective in controlled research plots. Classified as a biopesticide. Not used by growers. Not readily available to growers.
- Pyraclostrobin (Cabrio): Efficacy – excellent. Classified as a reduced-risk fungicide. Development of pathogen resistance is a concern. To delay the development of resistance, this fungicide needs to be used in alternation with a fungicide with a different mode of action.
- Pyraclostrobin/boscalid (Pristine): Efficacy – excellent. Classified as a reduced-

risk fungicide. Development of pathogen resistance is a concern. To delay the development of resistance, this fungicide needs to be used in alternation with a fungicide with a different mode of action.

- Pyrimethanil (Scala): Efficacy – good. Classified as a reduced-risk fungicide.

Other pest management aids for purple blotch:

- Rotate away from *Allium* spp. for two or more years.
- Manage irrigation to minimize the duration of leaf wetness.

Pipeline pest management tools for purple blotch:

- None identified.

"To do" list for purple blotch:

Research needs:

- Determine whether disease forecasting programs effectively prompt fungicide sprays.
- Test the disease forecasting programs using newly registered fungicides.

Regulatory needs:

- Maintain chlorothalonil, mancozeb, and iprodione registrations until safe, effective, and cost efficient alternatives are identified and registered. Chlorothalonil and mancozeb are especially important because they have broad-spectrum activity and it is unlikely that pathogen resistance will develop. Also these products will be key for use with the newer fungicides in a resistance management program.

Educational needs:

- Demonstrate the potential for disease forecasting as a tool to better time fungicide sprays.

9. SMUDGE (*Colletotrichum circinans*)

Disease occurs late in season and continues to occur during storage. Disease appears as dark green to black rings around the neck and on the surface of the outer scales. In extreme cases the bulb may shrivel and prematurely sprout. White onions appear to be most susceptible. Disease may be held in check through fungicides applied for the control of other foliar diseases.

B2 carcinogenic fungicides currently registered for smudge:

- None identified.

Other fungicides currently registered for smudge:

- None identified.

Other pest management aids for smudge:

- Rotate away from *Allium* spp. for two or more years.
- Manage irrigation to minimize the duration of leaf wetness.

Pipeline pest management tools for smudge:

- None identified.

"To do" list for smudge:

Research needs:

- Test currently unregistered products for disease control.
- Determine the environmental conditions that prompt disease development.

Regulatory needs:

- None identified.

Educational needs:

- Accurate disease identification for growers and scouts.

10. SMUT (*Urocystis colchici*, *U. magica = U. cepulae*)

Seedlings that are infected often die within six weeks of emerging. Older plants exhibit disease symptoms on leaves, neck and bulb. Dark streaks are the most visible symptom on any part of the plant. Mature lesions contain dark patches of mycelium with dark dusty spores. A consistent problem nearly every year in the state. There is a short time frame in onion development during which effective treatments may be made.

B2 carcinogenic fungicides currently registered for smut:

- Mancozeb (Dithane, Manzate, Manex II, Penncozeb): Efficacy – excellent. In furrow treatment used in combination with seed treatment PRO-GRO.
- Maneb (Maneb, Manex): Efficacy – fair.

Other fungicides currently registered for smut:

- Carboxin/thiram (PRO-GRO): Efficacy – fair. Most effective when used in combination with an in-furrow treatment of mancozeb.

Other pest management aids for smut:

- Crop rotation (3-4 years).

Pipeline pest management tools for smut:

- None identified.

"To do" list for smut:

Research needs:

- Test currently unregistered products for efficacy.
- Screen varieties for disease resistance.

Regulatory needs:

- Maintain registration of mancozeb until safe, effective, and cost efficient alternatives are identified and registered.

Educational needs:

- Promote the current management strategy of seed treatment and in-furrow fungicide application.

11. STEMPHYLIUM LEAF BLIGHT (*Stemphylium vesicarium*)

Infection by *S. vesicarium* causes yellow or brown water-soaked lesions on leaf tissue. As the fungus spreads, the lesions turn black as sporulation occurs. The fungus can be seed-borne. This pathogen may enter the bulb through mechanical wounding and insect damage. Senescing leaves as a result of pink root are susceptible to Stemphylium leaf blight. Disease may be held in check through fungicides applied for the control of other foliar diseases, especially purple blotch.

B2 carcinogenic fungicides currently registered for Stemphylium leaf blight:

- None identified.

Other fungicides currently registered for Stemphylium leaf blight:

- Pyraclostrobin/boscalid (Pristine): Efficacy – excellent. Classified as a reduced-risk fungicide. Development of pathogen resistance is a concern. To delay the development of resistance, this fungicide needs to be used in alternation with a fungicide with a different mode of action.

Other pest management aids for Stemphylium leaf blight:

- Rotate away from *Allium* spp. for three or more years.
- Use clean, treated seed.
- Destroy cull piles.

Pipeline pest management tools for Stemphylium leaf blight:

- None identified.

“To do” list for Stemphylium leaf blight:

Research needs:

- Currently unregistered fungicides need to be screened for efficacy.
- Seed treatment using currently unregistered products needs to be tested.
- Identify cultural strategies that reduce disease.

Regulatory needs:

- Speed registration of new fungicides as effective, safe products are identified.

Educational needs:

- Leaf blight caused by *Stemphylium vesicarium* is difficult to distinguish from purple blotch caused by *Alternaria porri*. Growers need to accurately identify each blight in order to apply the appropriate controls.

12. WHITE ROT (*Sclerotium cepivorum*)

One of the most serious diseases of onions on the west coast of the US and Canada. Initial disease symptoms include yellowing and wilting of older leaves. The infection eventually moves to the onion bulb and root system. A soft rot will develop in the bulb and die-back of the foliage occurs. Although this is a rare problem in Michigan, the predominance of this pathogen in other onion growing regions indicates that it is a potential threat to all regions.

B2 carcinogenic fungicides currently registered for white rot:

- Thiophanate-methyl (Topsin M): Efficacy – currently not known.

Other fungicides currently registered for white rot:

- Azoxystrobin (Amistar, Quadris): Efficacy – currently not known. Classified as a reduced-risk fungicide. Development of pathogen resistance is a concern. To delay the development of resistance, this fungicide needs to be used in alternation with a fungicide with a different mode of action.
- DCNA (Botran): Efficacy – currently not known.

Other pest management aids for white rot:

- Prevent introduction of the pathogen into non-infested areas.

Pipeline pest management tools for white rot:

- None identified.

“To do” list for white rot:

Research needs:

- Determine how the pathogen spreads to prevent its introduction into Michigan.
- Survey Michigan onion fields to look for symptoms of this disease.

Regulatory needs:

- If transplants or sets are used, insure that they are pathogen-free.

Educational needs:

- Distribute the description and pictures of the disease so growers may be on the look-out for this new threat.

PHYTOPLASMAS

1. ASTER YELLOWS – See aster leafhopper.

A widespread disease that affects a large number of cultivated and wild plants, including carrot, celery and lettuce. When infected, the youngest leaves yellow beginning at the base, flatten and become streaked with green and yellow.

INSECT PESTS

1. ASTER LEAFHOPPERS (*Macrosteles quadrilineatus*)

Nymphs and adults vector a phytoplasm causing aster yellows disease. Most migrate into Michigan in the spring on wind currents from the south; however, small populations are known to overwinter on plant material. The phytoplasm has a wide host range including many crop and weed species that may act as reservoirs of pathogen inoculum. Frequent aster leafhopper flight in and out of onions and the relatively short residence time in the crop makes management difficult. Populations may be held in check through insecticides applied for the control of thrips. Populations of aster leafhoppers are rarely high enough in Michigan to require treatment.

Organophosphate insecticides currently registered for aster leafhoppers:

- None identified.

Carbamate insecticides currently registered for aster leafhoppers:

- None identified.

Other insecticides currently registered for aster leafhoppers:

- None identified.
- Pyrethroids are most effective (Ambush, Pounce). NOTE: Onions are on the label, but aster leafhoppers are not.

Other pest management aids for aster leafhoppers:

- Weed control of alternate hosts in and around fields.
- Scout adjacent fields for leafhoppers and aster yellows disease.

Pipeline pest management tools for aster leafhoppers:

- None identified.

"To do" list for aster leaf hoppers:

Research needs:

- Refine aster yellows detection and infectivity levels in leaf hopper populations (PCR method).
- Identify movement of aster leafhoppers in an onion field.
- Develop an economic threshold of aster yellows infection.

Regulatory needs:

- None identified.

Educational needs:

- Report aster yellows infection rates in leafhoppers to extension agents and growers.
- As new management tools become available, provide training on use.

2. ONION MAGGOTS (*Delia antiqua*)

The most serious insect pest of onion in temperate growing regions. Onion maggots are highly specific to plants in the onion family. First generation larvae cause the greatest damage by feeding on the underground bulb tissue of seedlings in the spring, resulting in death. A single larva can destroy 20 to 30 seedlings and readily move between adjacent plants. The feeding from the third generation in mid-August can lead to storage rot as onion maggots can introduce bacteria into feeding wounds. The insects overwinter as pupae in the soil associated with onion culls in the field. If the insects have not caused any problems by June, then problems later in the season do not occur.

Organophosphate insecticides currently registered for onion maggots:

- Chlorpyrifos (Lorsban): Efficacy – good. Use cyromazine (Trigard) as a seed treatment at planting. Resistance management is a concern. Only available option for the transplant industry or as a rescue treatment in post-crop emergence. The preharvest interval is 60 days. Not effective against adults.
- Diazinon (Diazinon): Efficacy – poor.
- Malathion (Atrapa, Malathion): Efficacy – poor. Not used by growers due to the development of insect resistance.

Carbamate insecticides currently registered for onion maggots:

- None identified.

Other insecticides currently registered for onion maggots:

- Cypermethrin (Ammo, Mustang, Fury): Efficacy – poor. Not used by growers due to the development of insect resistance.
- Cyromazine (Trigard): Efficacy – excellent. Used as a seed treatment.
- Lambda-cyhalothrin (Warrior): Efficacy – poor. Not used by growers due to the development of insect resistance. Classified as an OP alternative.
- Permethrin (Ambush, Pounce): Efficacy – poor. Not used by growers due to the development of insect resistance. Classified as an OP alternative.

Other pest management aids for onion maggots:

- Crop rotation.
- Cull pile management. Tillage to reduce culls.

Pipeline pest management tools for onion maggots:

- Fipronil (Regent, Icon): Efficacy – excellent/good. Broad-spectrum. Systemic activity, with long residual. Pending registration for a seed treatment. Rotational with Trigard.
- Spinosad (SpinTor, Success): Efficacy – currently unknown. Low environmental impact. Good residual activity. Safe to many beneficial insects. Expensive. Classified as a reduced-risk product and OP alternative.

"To do" list for onion maggots:

Research needs:

- Post harvest practices to control third generation.

Regulatory needs:

- Expedite fipronil registration.

Educational needs:

- As new management tools become available, provide training on use.

3. THRIPS (*Thrips tabaci*)

Onion thrips feed on onions leaves by piercing the plant tissue with their mouthparts and sucking up the plant juices. Populations of thrips thrive in hot, dry conditions. In most cases of severe infestation, onions can ripen prematurely, be reduced in bulb size, or die. Onion thrips overwinter as an adult in plant debris, onion bulbs, or in standing winter crops. Airborne dispersal is an important method of spread for onion thrips. Thrips can be possible vectors for disease pathogens. A severe thrips infestation has the potential to promote storage diseases. No one product provides excellent control, therefore all products are needed unless new, effective chemistries become available.

Organophosphate insecticides currently registered for thrips:

- Diazinon (Diazinon): Efficacy – poor.
- Malathion (Atrapa, Malathion): Efficacy – poor.
- Methyl parathion (Penncap M): Efficacy – fair.

Carbamate insecticides currently registered for thrips:

- Methomyl (Lannate): Efficacy – excellent/good. Used in rotation with other products. Expensive.
- Oxamyl (Vydate): Efficacy – fair. Occasionally used. Expensive.

Other insecticides currently registered for thrips:

- Azadirachtin (Aza-Direct): Efficacy – poor. Classified as a biopesticide.
- Cypermethrin (Ammo, Mustang, Fury): Efficacy – good/fair. Cost effective. Insect resistance may develop.
- Lambda-cyhalothrin (Warrior): Efficacy – good/fair. Rotational product. Cost effective. Classified as an OP alternative.
- Permethrin (Ambush, Pounce): Efficacy – fair. Rotational product. Cost effective. Classified as an OP alternative.

Other pest management aids for thrips:

- None identified.

Pipeline pest management tools for thrips:

- Fipronil (Regent, Icon): Efficacy – excellent/good. Broad-spectrum. Systemic activity, with long residual. Pending registration as a seed treatment or as an in-furrow treatment. Can be rotated with Trigard.
- Imidacloprid (Admire, Provado): Efficacy – poor. Classified as an OP alternative.
- Spinosad (SpinTor): Efficacy – excellent. Has low environmental impact, good residual activity and is safe to many beneficial insects making it ideal for use in IPM programs. Classified as a reduced-risk product and an OP alternative.
- Thiamethoxam (Actara, Platinum): Efficacy – poor. Broad-spectrum. Classified as an OP alternative.

"To do" list for thrips:

Research needs:

- Develop of economic thresholds at which insecticides are needed.
- Identify varieties resistant/tolerant to thrips.
- As new products become available, test for their efficacy.
- Determine the extent to which thrips act as vectors for disease.
- Monitor for development of thrips resistance to current insecticides.

Regulatory needs:

- None identified.

Educational needs:

- As new management tools become available, provide training on use.

NEMATODES

IPM scouting that includes detailed field histories, field maps, soil-tissue sample records and symptomatology-yield records form the foundation of a sound onion production system designed to minimize risks to plant parasitic nematodes. Crop rotation is the primary management tactic used for control of the bulb and stem, northern root-knot and needle nematodes. Because of its broad host range, there is a need for alternatives to control root-lesion nematode.

1. **NORTHERN ROOT-KNOT NEMATODE *(Meloidogyne hapla*)**
   Shoot system symptoms include wilting, stunting, yellowing and low bulb yield. Roots branch prolifically and galls may be observed on root tissue. However, onions form an abscission layer in response to this infestation and shed the gall.

2. **NEEDLE NEMATODE *(Longidorus elongatus*)**
   Shoot symptoms include yellowing, stunting and low bulb yield. Root symptoms include excessive branching and swelling of root tips.

3. **ROOT LESION NEMATODE *(Pratylenchus penetrans*)**
   Symptoms occur in patches in heavy infestations. Shoot symptoms include stunting, wilting, yellowing and low bulb yields. Root systems can be stunted with necrotic lesions.

4. **STEM AND BULB NEMATODE *(Ditylenchus dipsaci*)**
   Shoot system symptoms include swollen seeding bases, and twisted, wilted, stunted, and yellowed leaves. Bulbs soften and have mealy-bloated scales. Young roots and bulbs may rot. A significant offensive characteristic odor is associated with this infectious disease.

5. **STUBBY-ROOT NEMATODE *(Paratrichodorus* spp.)**
   Plants are stunted, with yellow leaves, or may be wilting with low bulb yields. Roots are short and stubby with excessive secondary proliferation.

Organophosphate nematicides currently registered:
- None identified.

Carbamate nematicides currently registered:
- Oxamyl (Vydate): Efficacy – variable depending on the timing of application. Commonly used. Expensive. Can be used during growing season.
- Metam sodium (Busan 1020, Vapam): Efficacy – excellent/good. Cost prohibitive. Bare ground required. Applied either as a soil-injected fumigant or as chemigation through irrigation systems.

B2 carcinogenic nematicides currently registered:
- 1,3-dichloropropene (Telone II) (fumigant): Efficacy – excellent.

Other pest management aids for nematodes:
- Green manure crops (i.e., oil seed radish, sudan grass) need to be plowed down, avoid legumes (clovers, alfalfa and vetch) unless established for two or more years.

- Crop rotation.
- Biofumigants (*Brassicae* spp.)

Pipeline pest management tools for nematodes:
- None identified.

"To do" list for nematodes:

Research needs:
- Identify the most effective crops to be included in a rotation.
- Role of biofumigants, such as *Brassicae* spp., in managing nematode populations.
- Soil amendments.
- Develop nematode population thresholds before control action is necessary.
- Determine the soil characteristics that minimize nematode problems.

Regulatory needs:
- None identified.

Educational needs:
- Proper sampling, identification of pest, and time of sampling.
- Use of crop rotation.

WEEDS

Yellow nutsedge is a serious weed in many onion fields in Michigan. There are no registered herbicides that will control it in onions postemergence, after it has germinated. The only current timing of control is preemergence, and registered products are only partially effective. Management of annual and perennial grasses and broadleaf weeds is especially important in onions grown on high organic soils that tie up herbicides. Onion plants do not form a canopy, and thus competition from weeds is more severe than with other crops. Most onions in Michigan are grown on organic soils which are subject to wind erosion in the spring after seeding. Therefore, most fields are interplanted with a small grain cover, or nurse crop (usually barley or oats), which germinates and emerges quickly and helps to hold the soil in place during windy conditions. The nurse crops are killed with a grass herbicide (graminicide) when they are 4-5 inches high, and before they compete with onions for water and light.

Pre-plant herbicides (used in preparation prior to planting):
- Glyphosate (Round-Up): Efficacy – good for many weeds, but not for long-term control of yellow nutsedge. Can be used in a crop rotation (Round-Up ready soybeans) program for perennial weed control. Also used to kill cover crops.

Pre-emergence herbicides:
- Pendimethalin (Pendimax, Prowl): Efficacy – good on annual grasses and fair to good on annual broadleaves. Widely used by all onion growers 2-3 times per year (alternate with Dual). Cost effective. Necessary to grow an onion crop. Sporadic, extreme wet weather conditions may cause plant thinning.
- s-metolachlor (Dual Magnum): Efficacy – good suppression but does not eradicate annual grasses and yellow nutsedge. Cost effective. Used only after 2nd leaf stage. Classified as a reduced-risk product. Available to Michigan growers through a special label (24c). Use is critical to compliment other herbicides (alternate with Outlook).

Pre and post-emergence herbicides:

- Bromoxynil (Buctril): Efficacy – excellent/good. May be applied after seeding but before crop emergence to kill emerged broadleaves.

Post-emergence herbicides:

- Bromoxynil (Buctril): Efficacy – excellent/good on annual broadleaf weeds (including mustards). Used as a stand-alone product and has a narrow application window (must be used at 3-5 true leaves). Cost effective. May cause serious crop injury if applied incorrectly. Commonly used. Critical use.
- Clethodim (Select): Efficacy – excellent on annual grasses and annual bluegrass. Can be used in a tank mix with broadleaf herbicides. Cost effective. Commonly used.
- Glyphosate (Round-Up): Efficacy – good on perennials after onion crop has been harvested.
- Fluazifop-p (Fusilade): Efficacy – excellent on annual and perennial grasses. Used to kill small grain nurse crops. Can be used in a tank mix with broadleaf herbicides. Cost effective.
- Oxyfluorfen (Goal): Efficacy – excellent/good (depending on weed species) on annual broadleaves, such as redroot pigweed and common purslane. Widely used and cost effective. Cannot apply more than 2 pints per acre per year. The preharvest interval is 45 days. Can be used at low rates (2-4 fl oz/A). Used frequently with multiple applications.
- Paraquat (Gramoxone Max): Efficacy – good burn down of annual weeds before and after onion crop. An important and effective cleanup tool. Normally not used in year of onion production because of potential crop injury. Good on chickweed in the spring.
- Sethoxydim (Poast): Efficacy – good on annual grasses. Cost effective.

Other weed management aids:

- Crop rotation with Roundup Ready crops, nurse crops and cover crops.
- Cultivation.
- Plow to prepare land instead of using herbicides.
- Hand weeding.
- Cover crops.

Pipeline weed management tools:

- Dimethenamid-P (Outlook): Efficacy – good on yellow nutsedge, annual grasses and some broadleaf weeds. Available to Michigan growers through a special label (Section 18) for one application per year. Widely used, however growers are still learning its capabilities. Excellent crop tolerance. Reasonably cost effective. May be applied after 2nd leaf stage. Classified as a reduced-risk product.
- Flufenacet (Define): Soil applied for annual grasses and some broadleaf weeds.
- Flumioxazin (Valor): Post-emergence broadleaf herbicide with contact activity and some residual soil activity. A low rate is sufficient for efficacy.
- Fluroxypyr (Starane): Post-emergence application to control annual and perennial broadleaf weeds. Classified as a reduced-risk product.
- Sulfentrazone (Spartan): Controls annual broadleaf and grass species and yellow nutsedge. Moderately safe on onions.

"To do" list for weeds:

Research needs:

- Investigate the weed-suppressive effect of cover crops (especially mustard biofumigants) and evaluate their potential for use in integrated weed management systems.
- Investigate potential phytotoxicity problems using Basagran on previous crop to control yellow nutsedge.
- Reduce the preharvest interval of registered herbicides.
- Investigate the sporadic crop injury observed when using Dual Magnum in relation to specific weather conditions.

Regulatory needs:

- Registration of new products proven to be effective as they become available.
- A short preharvest interval is needed for all herbicides, because weeds could invade when onion tops die at the end of the season.
- Register the herbicide Outlook on onion.

Educational needs:

- Provide extension programs regarding the proper use of all herbicides, demonstration plots.
- Document the yield loss due to ineffective weed control.

NUTRIENT MANAGEMENT

Nutrient management aids:

- Fall plowing: Used occasionally.
- Spring plowing: Broadcasting nurse crop one week prior to final fitting.
- Nurse crop: Planted at time of planting to conserve moisture.
- Fertilize mainly with potash before plowing.
- Begin fertilization program at time of planting.

Nitrogen management:

- First application is as a pre-plant broadcast, as a starter fertilizer or with split applications as top dress.
- Dependent on crop stage.
- Too much late in the growing season can affect crop maturity and storage quality.

Other nutrient management:

- Foliar applications, may help delay foliar senescence making the tissue less susceptible to some foliar pathogens.
- TechMangan (manganese sulfate) alone or with some form of nitrogen (28%, urea).
- Other micronutrients (copper, zinc, molybdenum) may be used by some growers.

Irrigation:

- Every operation is different, and is dependent on soil quality.
- Equipment includes primarily sprinkler, solid set, pivots, hard hose, and some trickle.
- Chemigation is possible, however fertigation is primarily through trickle irrigation.

TABLE 1. CLASSIFICATION OF PESTICIDES

Chemical group	Human risk assessment
Carbamate	Acetylcholinesterase inhibitor; disrupts the nervous system.
Organophosphate	Acetylcholinesterase inhibitor; disrupts the nervous system.
B2 carcinogen	Likely human carcinogen.
C carcinogen	Possible human carcinogen for which there is limited animal evidence.
D carcinogen	There is inadequate evidence to determine carcinogenicity in humans.
E chemical	Evidence of non-carcinogenicity in humans.

TABLE 2. Registered Pesticides for Onion in Michigan

Active ingredient	Trade name	Company
FUNGICIDES		
azoxystrobin	Amistar, Quadris	Syngenta Crop Protection, Inc.
Bacillus subtilis	Serenade	AgraQuest, Inc.
boscalid	Endura 70WG	BASF Ag Products
carboxin/thiram	PRO-GRO	Gustafson, LLC
chlorothalonil	Bravo Ultrex/Weather Stik Bravo Weather Stik ZN Equus DF Echo	Syngenta Crop Protection, Inc. Syngenta Crop Protection, Inc. E.I. duPont de Nemours and Co. Sipcam Agro USA, Inc.
copper ammonium carbonate	Copper Count N 8L	Mineral Research & Development Corp.
copper hydroxide	Champ Kocide Nu-Cop	NuFarm Americas Inc. E.I. duPont de Nemours and Co. Micro Flo Co.
copper hydroxide/mancozeb	ManKocide	E.I. duPont de Nemours and Co.
copper resinate	Tenn-Cop 5E	E.I. duPont de Nemours and Co.
copper sulfate	Cuprofix Disperss	Cerexagri, Inc.
cyprodinil/fludioxonil	Switch 62.5WG	Syngenta Crop Protection, Inc.
DCNA	Botran 75W	Gowan Co.
dichloropropene/chloropicrin	Telone C-17	Dow AgroSciences
dimethomorph	Acrobat 50WP	BASF Ag Products
fosetyl-aluminum	Aliette WDG	Bayer CropScience
fosetyl-aluminum/maneb	Aliette/Maneb 2+2 75DF/WSP	Bayer CropScience
harpin protein	Messenger 3WDG	Eden Bioscience Corp.
iprodione	Iprodione Rovral	Micro Flo Co. Bayer CropScience
mancozeb	Dithane Manzate, Manex II Penncozeb 80WP	Dow AgroSciences E.I. duPont de Nemours and Co. Cerexagri, Inc.
mancozeb/copper sulfate	Cuprofix MZ Disperss	Cerexagri, Inc.
maneb	Maneb 75DF Manex	Cerexagri, Inc. E.I. duPont de Nemours and Co.
mefenoxam	Apron XL, Ridomil Gold Ultra Flourish	Syngenta Crop Protection, Inc. NuFarm Americas Inc.
mefenoxam/chlorothalonil	Ridomil Gold Bravo	Syngenta Crop Protection, Inc.
mefenoxam/copper hydroxide	Ridomil Gold Copper	Syngenta Crop Protection, Inc.
mefenoxam/mancozeb	Ridomil Gold MZ	Syngenta Crop Protection, Inc.
neem oil	Trilogy	Certis USA L.L.C.
pyraclostrobin	Cabrio EG	BASF Ag Products
pyraclostrobin/boscalid	Pristine 38WG	BASF Ag Products
pyrimethanil	Scala 4SC	Bayer CropScience
thiophanate-methyl	Topsin M 70W/WSB	Cerexagri, Inc.
thiram	42-S Thiram	UCB Chemicals Corp.

Active ingredient	Trade name	Company
INSECTICIDES		
azadirachtin	Aza-Direct	Gowan Co.
chlorpyrifos	Lorsban 15G/4E	Dow AgroSciences
cypermethrin	Ammo 2.5 EC, Fury, Mustang	FMC Corp.
cyromazine	Trigard	Syngenta Crop Protection, Inc.
diazinon	Diazinon 4E	Gowan Co.
lambda-cyhalothrin	Warrior	Syngenta Crop Protection, Inc.
malathion	Atrapa 5E Malathion 57EC	E.I. duPont de Nemours and Co. United Agri Products
methomyl	Lannate LV/SP	E.I. duPont de Nemours and Co.
methyl parathion	Declare Penncap-M 2F	E.I. duPont de Nemours and Co. Cerexagri, Inc.
oxamyl	Vydate 2L	E.I. duPont de Nemours and Co.
permethrin	Ambush 2EC Pounce 3.2EC	Syngenta Crop Protection, Inc. FMC Corp.
NEMATICIDES		
1,3-dichloropropene	Telone II	Dow AgroSciences
metam sodium	Busan 1020 Vapam	Buckman Syngenta Crop Protection, Inc.
oxamyl	Vydate 2L	E.I. duPont de Nemours and Co.
HERBICIDES		
bromoxynil	Buctril 4EC	Bayer CropScience
clethodim	Select 2EC	Valent USA Corporation
dimethenamid-p *(section 18 only)*	Outlook	BASF Ag Products
fluazifop-p	Fusilade DX	Syngenta Crop Protection, Inc.
glyphosate	Roundup	Monsanto Company
s-metolachlor	Dual Magnum	Syngenta Crop Protection, Inc.
oxyfluorfen	Goal 2XL	Dow AgriSciences LLC
paraquat	Gramoxone Max	Syngenta Crop Protection, Inc.
pendimethalin	Pendimax 3.3 Prowl 3.3EC	Dow AgriSciences LLC BASF Ag Products
sethoxydim	Poast	BASF Ag Products Micro Flo Company

TABLE 3. UNREGISTERED PESTICIDES TESTED ON ONION IN MICHIGAN

Fungicides	**Pathogens tested**	
	Downy mildew	**Purple blotch**
cyazofamid (Ranman 3.3SC)	F	P
famoxadone/cymoxanil (Tanos 50WG)	G	G
fenamidone (Reason 4.16SC)	F	P
fenhexamid (Elevate 50WDG)	P	P
fenhexamid + captan (Captevate 68WDG)	?	P
fluazinam (Omega 500F)	G/F	F
fludioxonil (Scholar 50WP)	–	?
polyoxin D zinc salt (Endorse 2.5WP)	P	F

Insecticides	**Insects tested**	
	Onion maggot	**Thrips**
fipronil (Regent, Icon)	G/E	F/G
spinosad (SpinTor, Success)	?	F/G
imidacloprid (Admire, Provado)	F	F/G
thiamethoxam (Actara, Platinum)	F	F/G

Herbicides	**Weeds tested**				
	Annual		**Perennial**		
	Broadleaf	**Grass**	**Broadleaf**	**Grass**	**Yellow nutsedge**
flufenacet (Define)	F-P	–	–	–	–
flumioxazin (Valor)	E-G	G-F	–	–	–
fluroxypyr (Starane)	G-F	–	F	–	–
sulfentrazone (Spartan)	G-F	G-F	–	–	E-G

[1] Efficacy rating symbols: E = excellent (90-100% control), G = good (80-90%) control), F = fair (70-80%), P = poor (<70% control), ? = no data, but successful on related organisms, – = not applicable and /or used.

TABLE 4. DESCRIPTION OF PESTS AND PATHOGENS OF ONION

Pest/pathogen	Symptoms
BACTERIAL PATHOGENS	
Bacterial soft rot (*Erwinia carotovora* subsp. *carotovora*)	Affected areas appear water-soaked, develop a soft decay and have a distinctive foul odor. Infection occurs through wounds or other injured areas. Warm wet conditions promote disease development.
Center rot (*Pantoea ananatis*)	Symptoms include blighted leaves, bleached and rotted seed stalks, and bulb rot. Little is known about the epidemiology and control of this disease. Crop rotation strategies are uncertain.
Slippery skin (*Burkholderia gladioli* pv. *alliicola*)	First symptoms include neck softening and, if the onion is cut longitudinally, water-soaked lesions. The rot progress from the top of the infected scales downward without spreading across adjacent scales. Advanced stages will cause the bulb to dry out and shrivel.
Sour skin (*Burkholderia cepacia*)	Onion may appear healthy on the outside except for minor neck softening. Decay occurs on inner bulb scales, which turn slimy and yellow to light brown. Young leaves sometimes die back starting at the tips.
FUNGAL PATHOGENS	
Basal rot (*Fusarium oxysporum* f. sp. *cepae*)	Above-ground symptoms include yellowing, curling necrosis at the leaf tips. Infected roots turn dark brown, flatten, and often completely die. White mycelium may colonize basal plate in advanced stages of infection.
Black mold (*Aspergillus niger*)	An economically important disease due to the ability to infect during transit and storage. Infected bulbs have a black discoloration at the neck, shallow lesions on the outer scales and streaks of black mycelium and conidia beneath the outer scales.
Botrytis leaf blight (*Botrytis* spp.)	Symptoms start as small white spots on the leaves surrounded by a greenish halo. Leaf death occurs eventually, resulting in small bulb size.
Damping off (*Pythium* spp., *Rhizoctonia solani*)	Several fungi cause this disease. Damping off occurs during cool, moist conditions. Infected seedlings wilt, or leaves develop a water-soaked, discolored stem at the ground level and topple over, resulting in poor stands.
Downy mildew (*Peronospora destructor*)	First symptoms show as purplish-brown sporulation of the pathogen on leaves. Lesions will then enlarge and girdle the leaves and cause tissue collapse. Bulb infection can occur resulting in storage rot.
Neck and stalk rot (*Botrytis aclada, B. squamosa*)	A serious disease of stored onions. The fungus enters directly through wounded tissue. The neck region becomes soft and spongy. Infected areas of the onion are water-soaked and brown. Patches of mycelium will become visible and eventually in severe cases sclerotia formation will occur.

Pest/pathogen	Symptoms
Pink root (*Phoma terrestris*)	Disease symptoms reflect common name. Roots turn light pink then purple and water-soaked. Roots become very weak and plants are easily uprooted. The fungus overwinters in soil and is most prevalent in warm temperatures. Economic losses result from reduced bulb size.
Purple blotch (*Alternaria porri*)	Fungus attacks older leaves more often then younger ones. Symptoms begin as water-soaked lesions with white center, which eventually become surrounded in brown and red. The leaf will become girdled by the lesion and die.
Smudge (*Colletotrichum circinans*)	Disease occurs late in season and continues to progress during storage. Dark green to black rings appear around the neck and on the surface of the outer scales. In extreme cases the bulb may shrivel and prematurely sprout.
Smut (*Urocystis colchici*, *U. magica*)	Infection causes thickening and darkening of the cotyledon and first true leaf. Long, dark blisters with powdery black spores form within the leaves. Leaves may bloat, distort and split open releasing spores as they grow. The fungus invades the leaf bases and bulb scales of successive leaves.
Stemphylium leaf blight (*Stemphylium vesicarium*)	Small, light yellow-brown water-soaked lesions elongate turn light brown-tan then dark olive brown-black as spores form. Lesions can coalesce into extended patches which blight leaves. Lesions generally occur on the windward side of the leaves, as the pathogen normally invades dead and injured tissue.
White rot (*Sclerotium cepivorum*)	Leaf tips yellow and die back until leaves collapse. The fungus can cause death of seedlings prior to emergence. White, fluffy mycelium and soft rot occur around the base of bulbs, destroying the bulb and roots. Masses of tiny black sclerotia form on the mycelium and in infected bulb tissues.
PHYTOPLASMAS	
Aster yellows	Yellowing occurs at the base of the youngest leaves that spreads toward the top. Leaves flatten but do not twist, and become marked with yellow and green streaking.
INSECT PESTS	
Aster leafhopper (*Macrosteles quadrilineatus*)	Typically is not a problem for onions in Michigan. Vectors of the phytoplasma disease aster yellows.
Onion Maggots (*Delia antiqua*)	Feed on and make tunnels in onion bulbs potentially allowing disease organisms to enter. Larval feeding may kill seedlings. Host specific to plants in the onion family. Stand losses may be >50%.
Thrips (*Thrips tabaci*, *Frankliniella occidentialis*)	Both the adult and nymph feed on the foliage, mainly near the growing tip making them difficult to detect unless the inner leaves are parted. Large populations can result in reduced onion yields, increased incidence of bacterial rot, and outright death of seedlings. More of a problem in hot dry weather.

Pest/pathogen	Symptoms
NEMATODE PESTS	
Common needle nematode (*Longidorus elongatus*)	The common needle nematode is a very large plant parasitic nematode that occurs in muck soils in Michigan. It is a significant pathogen of onion, celery and mint.
Northern root-knot nematode (*Meloidogyne hapla*)	The northern root-knot nematode is widely distributed throughout both muck and mineral soils in Michigan. It is a pathogen of most vegetable crops except corn. Root galling may not be observed because the onion plant sheds infected roots at the crown or immediately above the infected tissue.
Root-lesion nematode (*Pratylenchus penetrans*)	The penetrans root-lesion nematode is the most common plant parasitic nematode in Michigan. It has an extremely broad host range which makes it difficult to manage using crop rotation or cover crops.
Stem and bulb nematode (*Ditylenchus dipsaci*)	The bulb and stem nematode is a pathogen of shoot tissue that causes soft, bloated and mealy bulbs that are unsuitable for market.
Stubby-root nematode (*Paratrichodorus* spp.)	The stubby-root nematode is much less of a problem in Michigan onion production that it was 25 years ago. The reason for this is unknown. Most species reproduce well on corn.

TABLE 5. ADVANTAGES AND DISADVANTAGES OF PESTICIDES FOR ONION

Active ingredient	Disease/Pest	Advantages/disadvantages
FUNGICIDES		
azoxystrobin	Damping Off Downy mildew Purple blotch White rot	• broad-spectrum, locally systemic • must be used in resistance management programs • highly toxic to fish and aquatic invertebrates • non-toxic to bees, mammals and birds • expensive • reduced-risk fungicide
Bacillus subtilis	Neck rot	• needs to be applied before disease development • control limited • not currently used
boscalid	Botrytis leaf blight Purple blotch	• newly registered • research regarding efficacy is limited
carboxin/thiram	Smut	• seed treatment
chlorothalonil	Botrytis leaf blight Downy mildew Purple blotch	• B2 carcinogen • broad-spectrum foliar protectant • inexpensive • most important tool in resistance management programs • very effective
Copper products: copper ammonium carbonate copper hydroxide copper resinate copper sulfate	Bacterial diseases Downy mildew Neck rot Purple blotch	• inexpensive • toxic to fish • broad-spectrum bactericide/fungicide • not effective alone, must be used in rotation or combination • pre-harvest interval=0 • used against bacterial blight • may cause phytotoxicity to leaves when used heavily or under certain environmental conditions • do not apply to exposed bulbs • pre-harvest interval = 0
copper hydroxide/ mancozeb	Botrytis leaf blight Purple blotch	• mancozeb: B2 carcinogen • do not apply to exposed bulbs
cyprodinil/ fludioxonil	Botrytis leaf blight Purple blotch	• reduced-risk product • pre-harvest interval = 7 • cannot rotate with other crops (except strawberries or onions) for 12 months following last application • expensive

Active ingredient	Disease/Pest	Advantages/disadvantages
DCNA	Botrytis leaf blight White rot	• effective, but expensive • specific to sclerotia-forming fungi; may also be effective on other soil-borne pathogens • pre-harvest interval = 14 days
dichloropropene/ chloropicrin	Pink root	• B2 carcinogen • soil fungicide and nematicide • only product available for use against this pathogen
dimethomorph	Downy mildew	• specific to this group of pathogens • not thoroughly tested on onions in Michigan • good to fair efficacy
fosetyl-aluminum	Downy mildew Purple blotch	• specific to oomycete (downy mildew) pathogens
fosetyl-aluminum/ maneb	Botrytis leaf blight Downy mildew Purple blotch	• particularly helpful for oomycete (downy mildew) pathogens
harpin protein		• not proven consistently effective compared with commercial fungicide standards • not readily available to growers and not currently used
iprodione	Botrytis leaf blight Neck rot Purple blotch	• on EPA Phase 1 list; B2 carcinogen • some systemic activity • expensive • potential for *Botrytis* to develop resistance
mancozeb	Botrytis leaf blight Downy mildew Neck rot Purple blotch Smut	• B2 carcinogen • do not apply to exposed bulbs • for damping off caused by smut, apply in furrow • inexpensive • broad-spectrum • important tool in resistance management
maneb	Botrytis leaf blight Downy mildew Neck rot Purple blotch Smut	• B2 carcinogen • do not apply to exposed bulbs • broad-spectrum • inexpensive • for damping off caused by smut, apply in furrow • important tool in resistance management
mefenoxam	Damping off	• resistance concerns • long residual • corrosive • site specific • effective against oomycete pathogens only • expensive • reduced-risk fungicide

Active ingredient	Disease/Pest	Advantages/disadvantages
mefenoxam/ chlorothalonil	Botrytis leaf blight Downy mildew Purple blotch	• mefenoxam: resistance concerns, corrosive, long residual • chlorothalonil: broad-spectrum foliage protectant fungicide, Group B2 carcinogen • expensive
mefenoxam/ copper hydroxide	Downy mildew	• mefenoxam: resistance concerns, corrosive, long residual • copper hydroxide: toxic to fish • expensive
mefenoxam/ mancozeb	Downy mildew	• mefenoxam: resistance concerns, corrosive, long residual • mancozeb: B2 carcinogen, non to moderately persistent (up to 18 months) in the environment, broad-spectrum, long residual • do not apply to exposed bulbs • no more than 4 applications per season • expensive
neem oil	Botrytis leaf blight Downy mildew Neck rot Purple blotch	• efficacy data and use pattern lacking for onions • very limited efficacy demonstrated for the same pathogens on other crops
pyraclostrobin	Downy mildew	• used in resistance management programs • reduced-risk fungicide
pyraclostrobin/ boscalid	Botrytis leaf blight Purple blotch Stemphylium leaf blight Downy mildew (suppression)	• newly registered • research regarding efficacy is limited, but has shown excellent efficacy on purple blotch and Stemphylium leaf blight • resistance concerns • must be used in resistance programs
thiophanate-methyl	Smut White rot	• carbamate • in furrow pre-plant treatment • B2 carcinogen • not widely used
thiram	Damping off	• seed treatment • broad-spectrum, less expensive than alternatives • considered an industry standard
INSECTICIDES		
azadirachtin	Thrips	• Michigan research shows it to be ineffective
chlorpyrifos	Maggots	• organophosphate • only option for use at transplant or as a rescue treatment • long pre-harvest interval = 60 days • resistance concerns • at planting in-furrow treatment

Active ingredient	Disease/Pest	Advantages/disadvantages
cypermethrin	Maggots Thrips	• inexpensive • not effective on maggots, fairly effective on thrips • used in rotation
cyromazine	Maggots	• safe for beneficial insects • used in resistance management programs • effective, but highly toxic to aquatic organisms • expensive • used as a seed treatment
diazinon	Maggots Thrips	• organophosphate • toxic to bees and birds • long residual time • not used, not effective
lambda-cyhalothrin	Maggots Thrips	• used in rotation • not effective on maggots, fairly effective on thrips • inexpensive
malathion	Maggots Thrips	• organophosphate • not effective due to insect resistance, not used
methomyl	Thrips	• carbamate • expensive, but very effective • used in resistance management programs • broad-spectrum; short residual • toxic to bees, fish and birds • short pre-harvest interval = 7 days
methyl parathion	Thrips	• organophosphate
oxamyl	Thrips	• carbamate • expensive • also used against nematodes • only used on dry bulb onions
permethrin	Maggots Thrips	• used in resistance management programs • not effective on maggots, fairly effective on thrips • broad-spectrum • inexpensive • pre-harvest interval = 1 day • group C carcinogen

Active ingredient	Disease/Pest	Advantages/disadvantages
NEMATICIDES		
1, 3-dichloropropene	Nematodes	• group B1 or B2 carcinogen • soil fumigant nematicide • requires specialized equipment • expensive • specific soil temperature requirements limit its use in Michigan • phytotoxic
metam sodium	Nematodes	• group B1 or B2 carcinogen • chemigant--nematicide, herbicide, fungicide • toxic to fish
oxamyl	Nematodes	• carbamate • commonly used • moderately expensive • controls stubby root, stem and bulb, root-lesion and root-knot nematodes, but not known to control needle nematode
HERBICIDES		
bromoxynil	Broadleaf weeds	• seldom used • cost effective • small application window preemergence or 3-5 true leaves • stand alone tool • may injure onion crop if not used properly
clethodim	Grasses	• important grass herbicide • effective against annual grasses • only product to control annual bluegrass • used for nurse crop control • expensive
dimethenamid-p	Annual grasses Some annual broadleaf weeds Yellow nutsedge	• Section 18 label only • moderately effective control of yellow nutsedge and annual grasses • expensive • only one application per season, by label
fluazifop-p	Grasses	• widely used for nurse crop control • effective on many annual and perennial grasses
glyphospate	Grasses Broadleaf weeds	• no pre-harvest interval • broad-spectrum, excellent on perennials, no residual activity • no effective window for use on onions • mildly toxic to birds • Group E chemical

Active ingredient	Disease/Pest	Advantages/disadvantages
s-metolachlor	Grasses Sedges	• 24C label in Michigan • one of the few products effective against yellow nutsedge • 3-4 week residual activity • high rates needed on muck soils • two applications allowed per season • some sporadic crop injury, related to weather conditions • group C carcinogen
oxyfluorfen	Broadleaf weeds	• good efficacy, excellent on redroot pigweed and purslane, many other broadleaves • inexpensive • can be tank mixed • low use rate, 2-4 fl oz per acre • group C carcinogen
paraquat	All weeds	• restricted use herbicide, Group E chemical • kills all emerged green foliage; cheap, effective rapid knockdown • no control of perennials, no residual control, no soil action • no effective window for use on onions
pendimethalin	Annual grasses Broadleaf weeds	• very important herbicide, widely used • inexpensive • 2-3 applications allowed per season • good control of annual grasses
sethoxydim	Grasses	• important postemergence grass herbicide • not effective at temperatures less than 60ºF (15.5ºC) • long pre-harvest interval = 30 days • weak on quackgrass • no broadleaf or yellow nutsedge control • inexpensive • resistance concerns

TABLE 6. EFFICACY OF PEST MANAGEMENT TOOLS FOR CONTROL OF DISEASES ON ONION

Management tool	Bacterial[1]				Fungal diseases[2,3]								
	SS	BS	SoS	CR	Bot	DO	DM	NR	PR	PB	Smt	SLB	WR
B2 CARCINOGENIC FUNGICIDES REGISTERED IN MICHIGAN													
chlorothalonil (Bravo, Echo, Equus)	–	–	–	–	E/G	–	F	–	–	E/G	–	–	–
copper hydroxide/mancozeb (ManKocide)	–	–	–	–	F	–	–	–	–	F	–	F/P	–
dichloropropene/chloropicrin (Telone C-17)	–	–	–	–	–	–	–	–	G	–	–	–	–
fosetyl-aluminum/maneb (Aliette/Maneb 2+2)	–	–	–	–	F	–	F	–	–	F	–	–	–
iprodione (Iprodione, Rovral)	–	–	–	–	G	–	–	G/F	–	E/G	–	E/G	–
mancozeb (Dithane, Manex II, Manzate, Penncozeb)	–	–	–	–	G	–	E/G	F	–	G	E	E/G	–
mancozeb/copper sulfate (Cuprofix MZ Disperss)	–	–	–	–	G	–	G	–	–	G	–	–	–
maneb (Maneb, Manex)	–	–	–	–	G	–	E/G	F/P	–	G	F	–	–
mefenoxam/chlorothalonil (Ridomil Gold Bravo)	–	–	–	–	G	–	G/F	–	–	G	–	–	–
mefenoxam/mancozeb (Ridomil Gold MZ)	–	–	–	–	–	–	E/G	–	–	–	–	–	–
thiophanate-methyl (Topsin-M)	–	–	–	–	–	–	–	–	–	–	–	–	G/F
OTHER FUNGICIDES REGISTERED IN MICHIGAN													
azoxystrobin (Amistar Quadris)	–	–	–	–	–	–	P	–	–	E	–	–	F
Bacillus subtilis (Serenade)	–	–	–	–	–	–	–	P	–	–	–	–	–
boscalid (Endura)	–	–	–	–	G	–	–	–	–	E/G	–	–	–
carboxin/thiram (PRO-GRO)	–	–	–	–	–	–	–	–	–	–	F	–	–
copper ammonium carbonate (Copper Count N)	–	–	–	–	–	–	F/P	–	–	F/P	–	–	–
copper hydroxide (Champ, Champion, Kocide, Nu-Cop)	F	F	F	F	–	–	F/P	–	–	F/P	–	–	–
copper resinate (Tenn-Cop)	–	–	–	–	–	–	F/P	P	–	–	–	–	–
copper sulfate (Cuprofix Disperss)	–	F	–	–	–	–	F/P	–	–	F/P	–	–	–
cyprodinil/fludioxonil (Switch)	–	–	–	–	G	–	–	–	–	G	–	–	–
DCNA (Botran)	–	–	–	–	F	–	–	–	–	–	–	–	?
dimethomorph (Acrobat)	–	–	–	–	–	–	G/F	–	–	–	–	–	–
fosetyl-aluminum (Aliette)	–	–	–	–	–	–	F	–	–	F	–	–	–
harpin protein (Messenger)	–	–	–	–	P	–	P	–	–	P	–	–	–
mefenoxam (Apron, Ridomil Gold, Ultra Flourish)	–	–	–	–	–	G	–	–	–	–	–	–	–

Management tool	Bacterial[1]				Fungal diseases[2,3]								
	SS	BS	SoS	CR	Bot	DO	DM	NR	PR	PB	Smt	SLB	WR
mefenoxam/copper hydroxide (Ridomil Gold Copper)	–	–	–	–	–	–	G/F	–	–	–	–	–	–
neem oil (Trilogy)	–	–	–	–	P	–	P	P	–	P	–	–	–
pyraclostrobin (Cabrio)	–	–	–	–	–	–	F	–	–	E	–	–	–
pyraclostrobin/boscalid (Pristine)	–	–	–	–	G	–	F	–	–	E	–	E	–
pyrimethanil (Scala)	–	–	–	–	F/P	–	–	F/P	–	G	–	–	–
thiram (Thiram)	–	–	–	–	–	G	–	–	–	–	–	–	–
PIPELINE PEST MANAGEMENT TOOLS													
onion leaf blightcast	–	–	–	–	G	–	–	–	–	–	–	–	–
downy mildew predictor	–	–	–	–	–	–		–	–	–	–	–	–

1 Key for bacterial diseases: SS = slippery skin, BSR = bacterial soft rot, SoS = sour skin, CR = center rot.

2 Key for fungal diseases: Bot = Botrytis leaf blight, DO = damping off, DM = downy mildew, NR = neck rot, PR = pink root, PB = purple blotch, SLB = Stemphylium leaf blight, Smt = smut, WR = white rot.

3 Excluded from the table are fungal diseases with no fungicides registered for them: basal rot, black mold, and smudge.

4 Efficacy rating symbols: E = excellent (90-100% control), G = good (80-90% control), F = fair (70-80%), P = poor (<70% control), ? = no data, but successful on related organisms, – = not applicable and/or used.

TABLE 7. Efficacy of Pest Management Tools for Control of Insects on Onion

Management tool	Insect pests of onion[1]	
	Onion maggot	Thrips
CARBAMATE INSECTICIDES REGISTERED IN MICHIGAN		
methomyl (Lannate)	–	G[2]
oxamyl (Vydate)	–	P
ORGANOPHOSPHATE INSECTICIDES REGISTERED IN MICHIGAN		
chlorpyrifos (Lorsban)	G	P
diazinon (Diazinon)	F	F/P
malathion (Atrapa, Malathion)	P	P
methyl parathion (Declare)	–	F/P
OTHER INSECTICIDES REGISTERED IN MICHIGAN		
azadirachtin (Aza-Direct)	–	P
cypermethrin (Ammo, Mustang, Fury)	P	G/F
cyromazine (Trigard) – seed treatment	E	–
lambda-cyhalothrin (Warrior)	P	G/F
permethrin (Ambush, Pounce)	P	F/P
PIPELINE PEST MANAGEMENT TOOLS		
fipronil (Regent, Icon)	E/G	G/F
imidacloprid (Admire, Provado)	–	F
spinosad (SpinTor, Success)	F	G/F
thiamethoxam (Actara, Platinum)	F	F

[1] Aster leafhoppers are not included on table because there are no insecticides registered for their control.

[2] Efficacy rating symbols: E = excellent (90-100% control), G = good (80-90% control), F = fair (70-80%), P = poor (<70% control), ? = no data, but successful on related organisms, – = not applicable and/or used.

TABLE 8. EFFICACY OF PEST MANAGEMENT TOOLS FOR CONTROL OF NEMATODE PESTS ON ONION

Management tool	Nematode pests of onion				
	needle	northern root-knot	root lesion	stem and bulb	stubby root
B2 CARCINOGENIC NEMATICIDES REGISTERED IN MICHIGAN					
1,3-dichloropropene (Telone II)	E[1]	E	E	E	E
CARBAMATE NEMATICIDES REGISTERED IN MICHIGAN					
oxamyl (Vydate)					
pre-plant	P	F	F	?	?
at-plant	P	F	G	?	?
post-plant	F/P	G	V	?	?
at-plant and post planting	F	V/G	E	?	?
metam sodium (Busan 1020, Vapam)	?	G	E	?	?
CULTURAL CONTROLS					
crop rotation	E	G	P	?	?
PIPELINE PEST MANAGEMENT TOOLS					
conditioner, trap and nematicidal crops	?	G	G	?	?

[1] Efficacy rating symbols: E = excellent (98-100% control), V = very good (90-98% control), G = good (85-90% control), F = fair (80-85%), P = poor (<80% control), ? = no data, but successful on related organisms, – = not applicable and/or used.

TABLE 9. EFFICACY OF PEST MANAGEMENT TOOLS FOR CONTROL OF WEEDS ON ONION

Management tool	Annual weeds		Perennial weeds	
	Broadleaf	Grass	Broadleaf	Grass
PRE-PLANT				
glyphosate (Round-up)	E	E	E	E
PRE-EMERGENCE				
s-metolachlor (Dual Magnum)	–	G*	–	G*
pendimethalin (Pendimax, Prowl)	E/G	–	–	–
dimethenamid-p (Outlook)	G	G	–	–
POST-EMERGENCE				
bromoxynil (Buctril)	E/G	–	–	–
clethodim (Select)	–	E	–	F
fluazifop-p (Fusilade)	–	E	–	E
glyphosate (Round-Up)		E	E	E
oxyfluorfen (Goal)	E/G	–	–	–
sethoxydim (Poast)	–	E	–	–
paraquat (Gramoxone Max)	E	E	P	P
OTHER PEST MANAGEMENT PRACTICES				
cover crops	P	P	–	–
wind breaks	P	P	–	–
crop rotation	F	F	–	–
fall tillage (in conjunction with herbicide treatment)	F	F	–	–
herbicide rotation to reduce resistance	F	F	–	–
PIPELINE PEST MANAGEMENT TOOLS				
flufenacet (Define)	F	G	–	–
flumioxazin (Valor)	G	G	–	–
fluroxypyr (Starane)	–	–	–	–

[1] Efficacy rating symbols: E = excellent (90-100% control), G = good (80-90% control), F = fair (70-80%), P = poor (<70% control), ? = no data, but successful on related organisms, – = not applicable and/or used or data not available, * = no control over composites, wild carrot and nutsedge, ** = effective on only some grasses, *** = weak on quack grass and no nutsedge control.

TABLE 10. GENERAL TIMELINE FOR CROP STAGES, WORKER ACTIVITIES AND KEY PESTS ON ONIONS IN MICHIGAN

Crop Stages	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
Planting								
Seed cotyledon loop								
Flag & 1st true leaf								
2-leaf								
3-5 leaf								
4-7 leaf								
8-11 leaf								
Bulb initiation								
Bulb enlargement								
Mature leaves collapse								
Harvest								
Worker Activities	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
Planting								
Scouting (*1-2x*)								
Disease control								
Insect control								
Cultivation-mechanical								
Hand weeding[1]								
Fertilization (*4x*)								
Irrigation (variable)								
Harvest								
Diseases	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
Bacterial soft rot								
Slippery skin								
Sour skin								
Basal rot								
Black mold[2]								
Botrytis leaf blight								
Center rot								
Damping off								
Downy mildew[3]								
Neck rot[2]								
Pink root								
Purple blotch								
Smudge[4]								
Smut								
Stemphylium leaf blight[4]								
Insect Pests	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
Aster leafhoppers								
Onion maggots								
Thrips (*1x/week*)								

Insect Pests	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
Nematodes	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
Non-fumigation app.								
Soil fumigation								
Chemigation[5]								
Scouting								
Soil sampling[5]								
Weeds	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
Typical herbicide app.[6]								

[1] Each field weeded once for 4 weeks (28 days).

[2] Storage disease problem.

[3] Sporadic problem.

[4] Incidentally controlled in the same time frame as the other pathogens (i.e., purple blotch).

[5] Until November 15th.

[6] 4-5 sprays per season.