PEST MANAGEMENT IN THE FUTURE

A Strategic Plan for the Michigan Celery Industry

Workshop Summary
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TOP PRIORITIES OF CELERY PRODUCTION

Research:

- Develop a rapid diagnostic tool to determine aster leaf hopper infectivity rates for use in combination with economic thresholds to trigger control measures.
- Breed for resistance to *Fusarium* and other diseases.
- Develop disease predictor models for foliar blights.
- Evaluate the fungicides Quadris and Tilt for possible growth regulator effects.
- Evaluate biopesticides, induced-resistance products, and other currently unregistered products for efficacy against *Fusarium* and other diseases.
- Evaluate trap crops and other alternatives for nematode management.
- Evaluate broad-spectrum, systemic insecticides for use in resistance management programs.
- Evaluate control measures in the greenhouse, including the use of fungicides, insecticides and cultural methods, with regard to their impact on disease and pest suppression in the field.
- Conduct herbicide resistance studies on groundsel and other weeds to find alternatives for their control.

Regulatory:

- Celery growers have a limited selection of products, which makes it difficult to manage resistance as their choices for rotation narrow. In order for Michigan celery growers to remain competitive and produce a quality product, it is imperative that the following pesticides be retained:
  - ! Fungicide: Bravo (chlorothalonil - broad spectrum, cost effective: nothing currently available compares with its efficacy).
  - ! Insecticides: Lannate (methomyl - broad spectrum, cost effective), Vydate (oxamyl - only product registered for carrot weevil, important for nematode control), Orthene (acephate - systemic, broad spectrum), Ambush/Pounce (permethrin - broad spectrum, fast acting, short PHI).
  - ! Herbicides: Dual Magnum (metolachlor - suppresses nutsedge and annual grasses), Lorox (linuron) and Caparol (prometryn) (both are broad-spectrum and are versatile with pre- and post-emergence use).
- For the reasons stated previously, it is important that registration of the following products be expedited:
  - ! Fungicide: Topsin-M (thiophanate-methyl) to fill the gap left by the cancellation of Benlate (benomyl), which was an important tool in halting disease once it had started.
  - ! Insecticide: Provado (imidacloprid) has the same active ingredient as Admire but is less expensive.
- Clarification is needed on pesticide labels for greenhouse use.

Education:

- 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.

- Emphasize scouting and IPM.
- Emphasize farm and greenhouse ecology regarding whole system interactions, as described in *Michigan Field Crop Ecology: Managing Biological Processes for Productivity and Environmental Quality* (MSU Extension Bulletin E2646).
- Demonstration and education regarding optimum spray patterns, drying times, environmental conditions and use of equipment in pesticide application.
- Demonstrate spray technology as a means to reduce application rates and increase spray coverage efficiency.
- More about the biology and potential significance of nematodes as pests in Michigan.

BACKGROUND

Michigan ranks second nationally (6.3% of total national production) after California in celery (*Apium graveolens* L.) production. Approximately 2,000 acres are planted of which 1,900 acres are harvested for a value of about $12.4 million annually. About 60% of Michigan celery is packed for fresh market as full sized stalks, of which 15% are packed as hearts grown for specialty markets. The remaining 40% is processed in frozen foods, soups, juice blends and other products. Average yields of celery grown for the fresh market range from around 25 tons per acre, and up to 40 to 45 tons per acre for celery grown for processing. The majority of celery production in Michigan occurs on the south west side along Lake Michigan (Newaygo, Oceana, Muskegon, Ottawa, Kent, Allegan, and Van Buren counties), but there is also some scattered production elsewhere in the state.

Celery seed is small and difficult to germinate, thus all commercial celery is planted from greenhouse-grown transplants that are produced in plug trays using peat-based media. Seeds are sown in early February in greenhouses and are ready for transplanting to the field in about eight weeks. Transplanting begins in April and ends in late July. Once celery reaches marketable size, there is a narrow window of opportunity for harvesting (about 6 to 8 days) before a significant reduction in quality occurs. Therefore, planting is scheduled so that a uniform quantity of celery is ready to harvest every week. Using transplants as opposed to direct seeding ensures uniform stands and faster maturing crops.

Celery is a cool season biennial that grows best between 60° to 65°F (16° to 18°C), but tolerates temperatures from 45° to 75°F (7° to 24°C). However, celery is sensitive to both high and low temperature extremes. Although young transplants can tolerate minor freezes, if temperatures drop below 50°F for 10 to 14 days when plants are young, bolting may occur, which slows growth while flower stalks form, rendering the crop unmarketable. Damage on mature celery characteristic of freezing includes split petioles, again, making the stalks unmarketable. On the other hand, under high temperatures and moist conditions, the crop is more susceptible to disease and insect damage, as well as physiological problems.

Traditionally, celery has been grown on muck soils in Michigan, but can be grown on course textured mineral soils. Regardless of soil type, high fertility and moisture are necessary for tender succulent stalks. Overhead sprinkler or drip irrigation is used to apply

frequent water and fertilizer applications to the shallow-rooted crop. If the soil is allowed to get too dry, physiological disorders such as blackheart, a calcium deficiency, will develop. Crop rotation with such commodities as onions or corn is practiced whenever possible to avoid a buildup of pests in the soil. At the end of the season, a winter cover crop of barley or rye is often planted to reduce erosion and add active organic matter to the soil.

Fresh market and processing celery grown in Michigan is harvested mechanically. Fresh market celery is trimmed, sized, washed and packed into 50-pound cartons at on-farm packing sheds. Growers transport the packed celery to shippers where it is cooled and placed into cold storage for shipment.

The most important insect and related pests of celery in Michigan are aster leafhoppers (*Macrosteles quadrilineatus*), cutworms (Noctuidae), and the tarnished plant bug (*Lygus lineolaris*). Aphids, carrot weevil larvae (*Listronotus oregonensis*), loopers (*Anagrapha falcifera* and *Trichoplusia ni*) and spider mites are minor or occasional pests. Vegetable leafminers (Agromyzidae), wireworms (Elateridae) and slugs may occasionally be seen but currently are not economically damaging.

Plant parasitic nematodes are microscopic roundworms found in soils, which primarily attack plant roots. General symptoms of nematode damage include stunting, premature wilting, leaf yellowing and related symptoms characteristic of nutrient deficiencies. Stunting and poor stand development tend to occur in patches throughout the field as a result of the irregular distribution of nematodes in the soil. The northern root-knot (*Meloidogyne hapla*) and pin (*Pratylenchus neglectus*) nematodes are the main nematode pests of celery in Michigan. Occasionally root-lesion (*Pratylenchus penetrans*) and needle (*Longidorus elongatus*) nematodes are also seen.

The most important diseases affecting celery in Michigan are bacterial blight (*Pseudomonas syringae* pv. *apii*), foliar leaf blights (*Cercospera apii* and *Septoria apiicola*), *Fusarium* yellows (*F. oxysporum* f. sp. *apii*), and aster yellows (MLO). Soft rot (*Erwinia carotovora*), crater rot (*Rhizoctonia solani*) and damping off (*Pythium* spp. and *Rhizoctonia solani*) are occasionally a problem depending on season and location. White or pink mold (*Sclerotinia sclerotium*) and heart mosaic virus are minor diseases on celery in the state. For a detailed description of these and the other pests listed above, please refer to Table 4.

Weeds compete with the crop plant for moisture, nutrients, light and space and can interfere with harvest operations. Additionally, many weed species serve as alternate hosts for common celery pests such as aster leafhoppers as well as plant pathogens and nematodes. Since weeds can also provide shelter and food for natural enemies of celery pests, weed management strategies should adequately address the positive and negative roles of weeds in and around the celery field. Adequate management of weeds in celery is particularly important early in crop growth. Weed competition during the first four weeks after transplanting will cause significant reductions in harvest quality.

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 target-specific action, while older products, especially many that are under evaluation for safety reasons, generally tend to be broad-spectrum products. Celery growers already have a limited choice of products, which means that their ability to manage resistance becomes increasingly difficult as their choices for rotation narrow. Some products stand alone in their ability to combat certain pests. Loss of the pesticides listed under the top priorities is a major concern for Michigan celery growers who want to remain competitive and produce a quality product.

OUTLINE OF PLAN

Following is a pest by pest analysis of the current role of pesticides registered for use in celery 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 through preliminary research have been identified as effective, but are currently unavailable for use on celery, are discussed under the heading "pipeline pest management tools." Immediately following each pest analysis is a "to do" list for research, regulatory, and education needs. Pests are presented in alphabetical order.

INSECT PESTS

1. **Aphids (green peach aphid *Myzus persicae*, sunflower aphid) –** Aphids are not often a significant problem because of resident insect predators and entomophagous (insect-eating) fungi. However, they can become a major problem late in the season during the heat of summer when broad-spectrum insecticides for control of other pests have been used. Also, some concerns have been raised regarding the effects of fungicides on the entomophagous fungi. Earlier in the year, aphids may appear as pests in the greenhouse. Scouting is used to determine if and when control measures are needed. In the field, control measures are taken when 3% of plants are infested before leaf curling is noted or if there are more than 6 aphids/100 sweeps. Aphid control is especially important close to harvest because aphids found in a load will result in rejection of the celery. For this reason, insecticides with a short PHI are desired. Another issue with aphids is their potential ability to vector viral diseases. Weeds can act as alternate hosts for aphids and viruses, while aphids overwinter on trees. Both species of aphids easily develop resistance to insecticides especially pyrethroids and organophosphates.

   Organophosphate insecticides currently registered:

   - acephate (Orthene, Address)
     - Efficacy: good. Probably the best product available, most commonly used. Limiting factors: its PHI of 21days prohibits its use at harvest; can only be used when celery is young; and only two applications per year are allowed.

- malathion (Malathion)
  - Efficacy: poor. Seldom used.

Carbamate insecticides currently registered:

- methomyl (Lannate)
  - Efficacy: fair-good. Can be used closer to harvest. PHI=7 days

Other insecticides currently registered:

- endosulfan (Phaser, Thiodan)
  - Efficacy: fair. One application allowed per year. Used when an outbreak occurs close to harvest. PHI=4 days.
- pyrethrin and piperonyl butoxide (Pyrenone)
  - Not used for aphids, may increase aphid problems when used in the control of other pests.
- pyrethrin and rotenone (Pyrellin)
  - Not used for aphids, may increase aphid problems.
- imidacloprid (Admire)
  - Efficacy: good-excellent? (tested one year on celery, works well on other crops). Newly registered for use at planting. Very expensive.

Other pest management aids:

- Use scouting to initiate management program at 2-5% infestation before leaf curl.

Pipeline pest management tools:

- pymetrozone (Fulfill) – Efficacy: good, but not useful close to harvest because it works slowly by paralyzing the aphid mouth parts and they starve to death and any aphids found in a load of celery will result in rejection. (Feeding inhibitor specific to aphids.)
- thiamethoxam (Platinum, Actara) – Efficacy: good.

"To do" list for aphids:

Research needs:

- More insecticide options to combat insecticide resistance issues.
- Scouting in the greenhouse to set thresholds for initiation of control measures.

Regulatory needs:

- Registration of Provado (imidacloprid), (same chemical as Admire, but less expensive) for foliar applications.
- Expedited registration of pymetrozone and thiamethoxam.
- Expansion in the greenhouse of products labeled for field use.

Education needs:

- Aphid biology and mode of action of insecticides.

2. **Aster leafhopper (*Macrosteles quadrilineatus*) –** Most important insect pest on celery because it vectors aster yellows disease. Control measures are implemented if numbers exceed 14/100 sweeps when 2% of leafhopper are infected. Threshold depends on infection rate. Most leafhoppers migrate in the spring on wind currents from the south, however, small populations are known to overwinter. Wide host range, including many weeds which may act as reservoirs of disease inoculum.

   Organophosphate insecticides currently registered:

   - acephate (Orthene, Address)
     - Efficacy: good. Probably the best product available, frequently used in rotation with methomyl. Limiting factors: PHI=21 days and only two applications per year allowed.
   - azinphosmethyl (Guthion Solupak, Armor 2L)
     - Efficacy: fair-good. Long residual. Insect resistance to the product may be a problem. Because of its broad spectrum nature, it is hard on beneficial insects and also may lead to increased aphid problems. Registration may be revoked due to worker hazards. This product is under evaluation by EPA and may not be available in the future.

   Carbamate insecticides currently registered:

   - carbaryl (Sevin)
     - Efficacy: fair. Not used very often.
   - methomyl (Lannate)
     - Efficacy: good. although it is expensive, it is used frequently because of its efficacy against multiple pests. Useful as a rotation product for resistance management. Product has a short residual.

   Other insecticides currently registered:

- permethrin (Ambush, Pounce)
  - Efficacy: excellent. Used in rotation for resistance management, however, it can increase aphid populations. It is inexpensive and a relatively safe product.
- imidacloprid (Admire)
  - Efficacy: good. Newly registered for use in celery at transplant. Works well in other crops, although it is considered weak on Lepidoptera. Very expensive.

Other pest management aids:

- Weed control in and around fields.
- Planting near small grains or alfalfa should be avoided, because leafhopper activity in neighboring crops may increase dramatically during grain or alfalfa harvests.

Pipeline pest management tools:

- thiamethoxam (Actara, Platinum)
  - Efficacy: good.

"To do" list for aster leafhopper:

Research needs:

- Determine how long an application of Admire made to seedlings in the greenhouse will last after transplanting in the field.
- Determine the efficacy of Provado (imidacloprid).
- More research to refine pathogen detection and infectivity levels in leafhopper populations.
- Identify celery varieties resistant to aster yellows.

Regulatory needs:

- Registration of Provado (imidacloprid) for foliar applications, because it has the same active ingredient as Admire, but is less expensive.

Education needs:

- Report pathogen infection rates in leafhoppers.

3. **Carrot weevil (*Listronotus oregonensis*)** – Minor pest, not usually targeted for control because insecticides used to control other pests usually covers any problem. When it is a problem, it is usually in non-rotated fields, early in the season. Locality differences in severity are usually observed. Carrots and related weeds can act as alternate hosts to the insect. Insect overwinters as adults in ditches.

Organophosphate insecticides currently registered:

- None

Carbamate insecticides currently registered:

- oxamyl (Vydate)
  - Efficacy: good. Product is expensive but translocates into the roots and affects the larvae. Also used for control of nematodes.

Other insecticides currently registered:

- permethrin (Ambush, Pounce)
  - Used on adults

Other pest management aids:

- Crop rotation.
- Scouting: trapping.

Pipeline pest management tools:

- None

"To do" list for carrot weevil larvae:

Research needs:

- Study of population dynamics, interaction with diseases.

Regulatory needs:

- Labeling for insecticides registered for use in the field for use in the greenhouse.

Education needs:

- None

4. **Lepidoptera:**

Cutworms (Noctuidae) – Can be an annual problem. Preventive treatments needed within 4 weeks of harvest.

Loopers (celery looper (*Anagrapha falcifera*), cabbage looper (*Trichoplusia ni*)) – Controlled as needed. Main problem occurs with cocoons found in harvested celery, resulting in rejection of load.

Organophosphate insecticides currently registered:

- acephate (Orthene, Address)
  - Efficacy: good. PHI = 21 days.

Carbamate insecticides currently registered:

- methomyl (Lannate)
  - Efficacy: good. Commonly used. Shorter PHI than acephate (Orthene, Address).

Other insecticides currently registered:

- *Bacillus thuringiensis* (Agree, Biobit, Condor, Cutlass, Dipel, Javelin, Ketch, Lepinox, MVP II, Mattch, Vault, Xentari)
  - Efficacy: fair-good, depends on timing of application and quite a bit of damage can occur before it starts to be effective. Residual activity sometimes low. Not widely used.
- endosulfan (Phaser, Thiodan)
  - Efficacy: fair-good. Not widely used.
- permethrin (Ambush, Pounce)
  - Efficacy: good. Most frequently used, however, rotation is necessary because of resistance issues in aphids.
- pyrethrin and piperonyl butoxide (Pyrenone)
  - Efficacy: good, however, may increase aphid problems, and it is not widely available.
- pyrethrin and rotenone (Pyrellin)
  - Efficacy: good, however may increase aphid problems, and it is not widely available.
- spinosad (SpinTor)
  - New product, good results in research, expensive.
- tebufenozide (Confirm)
  - Efficacy: fair-good, may not be effective on larger caterpillars, expensive.

Other pest management aids:

- Pheromone traps for monitoring populations.

Pipeline pest management tools:

- methoxyfenozide (Intrepid)
  - Insect growth regulator, second generation product (Confirm) in registration process.

"To do" list for Lepidoptera:

Research needs:

- Determine efficacy and develop use patterns of reduced risk insecticides and growth regulators such as spinosad (SpinTor) and Intrepid.

Regulatory needs:

- Expedite Intrepid registration.

Education needs:

- None

5. **Tarnished plant bug (*Lygus lineolaris*) –** This insect is found on numerous crops and is a major pest of celery that causes cosmetic damage important in fresh market. This insect can also reduce yields when young plants are attacked. Control measures are taken if insect numbers exceed 2-4 per 20 plants. Insect populations usually increase after hay cutting. Long lasting product needed with a short PHI.

   Organophosphate insecticides currently registered:

   - azinphosmethyl (Guthion Solupak, Armor 2L)
     - Efficacy: fair-good. Long lasting. PHI=14 days. This product is under review by the EPA and registration is likely to be revoked.

   Carbamate insecticides currently registered:

   - carbaryl (Sevin)
     - Efficacy: good, not used very often.
   - methomyl (Lannate)
     - Efficacy: good

   Other insecticides currently registered:

   - acephate (Orthene, Address)
     - Efficacy: good, PHI = 21 days
   - permethrin (Ambush)
     - Efficacy: good
   - imidacloprid (Admire)
     - Efficacy: good. Used at planting only.

   Other pest management aids:

   - Weed control around the field.
   - Awareness of nearby activities, especially hay harvesting.
   - Scouting: sweepnet.

Pipeline pest management tools:

- thiamethoxam (Actara, Platinum)
  - Efficacy: good.

"To do" list for tarnished plant bug:

Research needs:

- Application of the trapping techniques used in apple production to celery production.
- Development of usable economic thresholds.
- Better scouting techniques.

Regulatory needs:

- None

Education needs:

- As new tools become available, educate growers on their use.

6. **Vegetable leaf miner (Agromyzidae) –** This insect is a sporadic pest, appearing only when environmental conditions are favorable. Often resides in weeds. Resistance to insecticides is a problem.

Organophosphate insecticides currently registered:

- None

Carbamate insecticides currently registered:

- None

Other insecticides currently registered:

- abamectin (Agrimek)
- cyromazine (Trigard)
  - Efficacy: fair-good. Most commonly used although it is expensive. It is slow acting and multiple applications are necessary.
- spinosad (SpinTor)
  - Efficacy: effective on leaf miners in other crops, but there are no data on celery.

Other pest management aids:

- Scouting.

Pipeline pest management tools:

- None

"To do" list for vegetable leaf miner:

Research needs:

- Effects of crop rotation on insect incidence.
- Efficacy trials using spinosad.

Regulatory needs:

- None

Education needs:

- None

7. **Wireworms (Elateridae) –** Minor problem depending on field location. They are most damaging to young plants. No products are registered and no control measures are used.

"To do" list for wireworms:

Research needs:

- Monitoring populations for potential problems in the future.

Regulatory needs:

- None

Education needs:

- None

NEMATODES

The following are listed in order of importance to the celery industry of Michigan.

1. **Northern root-knot nematode (*Meloidogyne hapla*)** – Most important nematode problem in Michigan celery production. Distribution spotty, both between farms and fields and within fields. Limited host range compared with other nematode problems with celery. Symptoms consist of stunted plants, uneven growth, yellowing, and small but numerous root galls.
2. **Pin nematode (*Pratylenchus neglectus*)** – Serious problem in a small number of locations. Symptoms include severely stunted plants of uneven growth and no lateral root growth (witches broom symptoms).
3. **Needle nematode (*Longidorus elongatus*) –** Problem rare, but known to exist in Michigan celery production. Symptoms consist of stunted plants with swollen root tips.
4. **Root-lesion nematode (*Pratylenchus penetrans*)** – Very wide host range and the most common plant parasitic nematode in Michigan. Can result in celery yield losses;

however, relatively little is known about this in Michigan celery production. Causes root stunting and discoloration.

Organophosphate nematicides currently registered:

- None

Carbamate nematicides currently registered:

- oxamyl (Vydate)
  - Efficacy: good. Most effective when used in multiple applications at a low rate. Also used to control carrot weevil larvae and aphids. May not be effective in some locations in Michigan. Interest among celery growers in applying oxamyl through trickle irrigation.

B2 carcinogenic nematicides currently registered:

- 1, 3-Dichloropropene (Telone II) (fumigant)
  - Efficacy: good-excellent. Not used because of cost and the specialized application equipment required. Soil temperature requirements needed for application also limit its use in celery production in Michigan.
- metham (various commercial products marketed)
  - Efficacy: good. Most commonly used soil fumigant in Michigan agriculture. Use has not been adopted by celery growers. Applied either as a soil injected fumigant or as chemigation through irrigation systems.

Other pest management aids:

- 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.

Pipeline pest management tools:

- None

"To do" list for nematodes:

Research needs:

- Investigate trap crop options.
- Investigate role of soil quality in relation to nematode problems.
- Evaluate efficacy of metham in celery production.
- Other application methods for nematicides.
- Map nematode populations throughout Michigan celery production.

Regulatory needs:

- None

Education needs:

- Demonstrate use of different nematicides.
- Educate growers, field and extension personnel to recognize symptoms on plants.
- Teach field personnel how to sample fields for nematodes.

OTHER INVERTEBRATE PESTS

1. **Spider mites-** An occasional problem during hot, dry conditions especially around the edges of fields. Symptoms include stunted growth, yellowing. Unsightly webbing can result in rejected celery loads. May be a problem in the greenhouse.

   Miticides currently registered:

   - abamectin (Agrimek)
     - Efficacy: good. Potential for pest to develop resistance.

   Other pest management aids:

   - Naturally occurring predatory mites.

   Pipeline pest management tools:

   - None

   "To do" list for spider mites:

   Research needs:

   - Identify and test alternative products.

   Regulatory needs:

   - Expedite registration of newer products.

   Education needs:

   - Recognition of symptoms and awareness of the potential for economic loss.
   - Scouting.

2. **Slugs –** An uncommon pest, when a problem occurs it is generally in the greenhouse.

   Pesticides currently registered:

   - abamectin (Agrimek)

   Other pest management aids:

   - Scouting

PATHOGENS

Bacterial pathogens

1. **Bacterial Blight (*Pseudomonas syringae* pv. *apii*)** – Major problem in the field and greenhouse. Can be seedborne so hot water treatments are usually used by the seed companies.

   B2 carcinogenic pesticides currently registered:

   - None

   Other pesticides currently registered:

   - copper hydroxide (Kocide, Champ Formula, Champion, Nu-Cop)
     - Efficacy: fair-good, must be applied prior to disease incidence, better for use in greenhouse when bacterial populations are lower and environmental conditions are favorable. Most commonly used copper formulation.
   - copper ammonium carbonate (Copper Count N)
     - not typically used.
   - copper oxychloride (C-O-C-S)
     - not typically used.

   Other pest management aids:

   - Plant treated seed.
   - Crop rotation may be helpful, but the disease can be seedborne.
   - Greenhouse cultural management to reduce bacterial populations including sanitation.
   - Post-harvest tilling to speed breakdown of infected plant debris to reduce pathogen carry over in the field.

   Pipeline pest management tools:

   - Plant resistance inducers such as Actigard, Messenger.

   "To do" list for bacterial blight:

   Research needs:

   - Test pipeline pest management tools for efficacy against bacteria and plant phytotoxicity.
   - Tracking bacterial populations in the greenhouse, using PCR fingerprinting as a tool.
   - Alternative seed treatments.
   - Variety resistance screening.

- Determine the ability of the bacterium to survive in the greenhouse between crops.

Regulatory needs:

- None

Education needs:

- Emphasize sanitation techniques for the greenhouse. Understand the potential source of inoculum and the importance of implementing management strategies in the greenhouse.

2. **Soft Rot (*Erwinia carotovora*) –** Affected areas appear water-soaked, develop a soft decay, and have a distinctive foul odor. This bacterium, generally thought to be a secondary pathogen, usually infects plants through wounds or other injured areas. May be observed more during hot and humid summers in low lying areas of fields, and during post-harvest. Because of its sporadic nature, and because stalks that are affected are generally unmarketable anyway, there are no treatments recommended except for prevention through the usual sanitation practices.

Fungal pathogens

3. **Crater Rot (*Rhizoctonia solani*)** – Periodic problem, is usually controlled using current products. Characterized by brick-red lesions on the stalks and at the base of plants. Usually appears during hot weather.

B2 carcinogenic pesticides currently registered:

- chlorothalonil (Bravo Ultrex, Bravo Weather Stik, Equus 720, Echo 75, Echo 90)
  - Efficacy: good-excellent. Most commonly used for crater rot and other fungal pathogens. Reasonably priced, very cost effective.

Other pesticides currently registered:

- DCNA (Botran)
  - Efficacy: good, but expensive.

Other pest management aids:

- None

Pipeline pest management tools:

- None

"To do" list for crater rot:

Research needs:

- Determine the optimum planting depth to reduce disease.
- Determine the efficacy of unregistered products to control *Rhizoctonia*.
- Devise rotational strategies to reduce pathogen inoculum.

Regulatory needs:

- None

Education needs:

- None

4. **Damping off (*Pythium* sp., *Rhizoctonia solani*) –** A sporadic problem that can cause serious losses in the seedbeds of greenhouses and in the field.

   B2 carcinogenic pesticides currently registered:

   - iprodione (Rovral)
     - Efficacy: poor-fair for *Rhizoctonia*, not effective on *Pythium.*
   - mefenoxam (Ridomil Gold, Ultra Flourish) – seed or, in-furrow treatment
     - Efficacy: good-excellent on *Pythium* in the field, however it is expensive and is not registered for use in greenhouse, due to resistance issues.

   Other pesticides currently registered:

   - fludioxonil (Maxim) – seed treatment
     - Efficacy: good. Used against *Rhizoctonia*.
   - oxadixyl (Anchor) – seed treatment
     - Efficacy: good. Used against *Pythium*.
   - thiram (Thiram) – seed treatment
     - Efficacy: good. Most commonly used chemical.

   Other pest management aids:

   - Crop rotation to reduce pathogen inoculum.
   - Good soil drainage.
   - Focus on disease management in the greenhouse.

   Pipeline pest management tools:

   - None

   "To do" list for damping off:

   Research needs:

   - *Pythium* control strategies, especially in the greenhouse.

Regulatory needs:

- Label expansion to include products for use in the greenhouse.

Education needs:

- None

5. **Foliar Leaf Blights; Early Blight (*Cercospora appii*) and Late Blight (*Septoria apiicola*) –** Both blights cause major problems and occur every season. Yield losses occur as a result of defoliation and stunting of the plants and petiole blighting. Varietal resistance and disease-free seed are important. Both pathogens can be seedborne. Symptoms of *Cercospora* early blight include yellow to tan spots, circular-shaped lesions on the upper and lower surface of leaves and elongate lesions on petioles. *Septoria* late blight is the most common disease of celery in Michigan, and spreads quickly. Symptoms of *Septoria* late blight include yellow to brown, irregularly shaped lesions on the leaves and petioles. Embedded in these lesions are small, black pycnidia, which are the reproductive structures of the fungus.

   B2 carcinogenic pesticides currently registered:

   - chlorothalonil (Bravo Ultrex, Bravo Weather Stik, Equus 720, Echo 75, Echo 90)
     - Efficacy: good – excellent. Most important tool against blights. Cost effective.

   Carbamates currently registered:

   - None

   Other pesticides currently registered:

   - azoxystrobin (Quadris)
     - Efficacy: good – excellent. Expensive and must be used in rotation with fungicides of a different mode of action for resistant management. Reduced-risk product, however, growers question its efficacy and effects on yield (potential to act as a growth regulator especially when used in combination with other fungicides).
   - copper hydroxide (Kocide, Champ Formula, Champion, Nu-Cop)
     - Efficacy: poor – fair. Not used as a stand-alone product. Inexpensive.
   - copper ammonium carbonate (Copper Count N)
     - Efficacy: poor – fair. Not used as a stand-alone product. Inexpensive.
   - copper oxychloride (C-O-C-S)

  - Efficacy: poor – fair. Not used as a stand-alone product. Inexpensive.
- copper sulfate (Basicop)
  - Efficacy: poor – fair. Not used as a stand-alone product. Inexpensive.
- Propiconazole (Tilt)
  - efficacy: fair – good. Commonly used in rotation with Bravo. May have growth regulator affects.

Other pest management aids:

- Plant certified, tested and treated seed.
- Post-harvest tilling to speed breakdown of infected plant debris in the field.
- Scouting to ensure early disease detection.

Pipeline pest management tools:

- fenbuconazole (Indar)
  - Efficacy: poor – fair
- kresoxim-methyl (Sovran)
  - Efficacy: good
- pyraclostrobin (BAS 500)
  - Efficacy: good
- tebuconazol (Folicur)
  - Efficacy: poor – fair
- thiophanate-methyl (Topsin-M)
  - Needed to transition away from Benlate
- trifloxystrobin (Flint)
  - Efficacy: good

"To do" list for foliar blights:

Research needs:

- Overwintering of inoculum.
- Develop disease tolerant cultivars suitable for Michigan and targeted markets.
- Develop and implement disease forcasting, Tom-Cast.
- Coppers and biocontrol agents.
- Determine whether rates of Quadris and other systemic fungicides can be reduced to limit potential growth regulatory effects.

Regulatory needs:

- Continued registration of Bravo.
- Expedited registration of pipeline products.

Education needs:

- None

6. **Fusarium Yellows (*Fusarium oxysporum* f. sp. *apii*) –** A major problem with no known effective chemical control. The introduction of the resistant cultivar, Tall Utah 52-70 in the 1950s, halted *Fusarium* disease problems until recently where significant yield and quality losses have been sighted in California and Florida on previously resistant cultivars. The fungus causes yellowing and stunting, and vascular discoloration inside the crown and petiole. Wide spread. Disease incidence and severity varies by locality and stress level of plants.

   B2 carcinogenic pesticides currently registered:

   - None

   Other pesticides currently registered:

   - None

   Other pest management aids:

   - Planting resistant cultivars.
   - Crop rotation (minimum 2-3 years with onion or lettuce) may helpful, but not as a stand alone tool.
   - Water and nutrient management to reduce plant stress may help increase plant resistance, but is not a stand alone tool.

   Pipeline pest management tools:

   - Biological controls have been studied in the past but were not effective.

   "To do" list for Fusarium yellows:

   Research needs:

   - Plant breeding for disease resistant varieties and identification of alternative resistance pathways.

   Regulatory needs:

   - None

   Education needs:

- None

7. **White or Pink Mold (*Sclerotinia sclerotiorum*) –** Generally of minor economic significance. Occasionally causes damage in the field and in storage. Because of the use of chlorothalonil (Bravo) to control other diseases, white or pink mold is rarely a problem.

   B2 carcinogenic pesticides currently registered:

   - chlorothalonil (Bravo Ultrex, Bravo Weather Stik, Equus 720, Echo 75, Echo 90)
     - Efficacy: excellent, very important and widely used. A broad-spectrum fungicide used mainly on foliar blights.

   Other pesticides currently registered:

   - DCNA (Botran)
     - Efficacy: good, specific to white mold.

   Other pest management aids:

   - None

   Pipeline pest management tools:

   - vinclozolin (Ronilan)
     - ! registered on other crops for *Sclerotinia* problems.

   "To do" list for white mold:

   Research needs:

   - Test currently unregistered and newly registered products for efficacy.

   Regulatory needs:

   - None

   Education needs:

   - None

MLO/Viral pathogens

8. **Aster Yellows –** See Aster Leafhopper
9. **Heart Mosaic (Cucumber mosaic virus) –** See aphids. Causes a mottling of celery leaflets and sunken, buff-colored streaks and spots on petioles. Wide host range and can overwinter in many cultivated and wild plants.

WEEDS

Annual and perennial grasses and broadleaf weeds. It is a common practice to rotate herbicides that have different modes of action in order to guard against resistance, but Michigan celery growers are limited in their ability to do so, because compared to other agricultural crops, there are fewer herbicides registered for use on celery.

Pre-plant (Herbicides used in preparation or prior to planting)**:**

- glyphosate (Roundup)
  - Efficacy: excellent on perennials. Good for clearing fields of cover crops prior to planting. Cannot be used during production or with a wiper (wick) applicator. No residual activity.

Pre-emergence herbicides (Used prior to weed emergence and prior to or following celery transplanting)**:**

- metolachlor (Dual Magnum)
  - Efficacy: good on grasses and nutsedge and has a short residual. Special label (24c third party) needed because of concerns about breakdown products and is undergoing EPA cumulative assessment.
- trifluralin (Treflan, Trilin) [C carcinogen]
  - Efficacy: poor especially on muck soils. Generally not used in Michigan.

Pre-and post-emergence herbicides (Used prior to or after weeds emerge)**:**

- linuron (Lorox, Linex) [C carcinogen]
  - Efficacy: good-excellent on broadleaf weeds and some grasses. Widely used as a necessary tool for early season weed management. Effective on most soil types. Fast acting and cost effective. One application of 2 pounds active ingredient per acre per year allowed. Some weeds have developed resistance to linuron. Minimal pre-emergence grass control and poor control of composites, wild carrot, and nutsedge.
- prometryn (Caparol)
  - Efficacy: good-excellent on broadleaf weeds and some grasses. Widely used because of its residual and contact activity. One application or 2 pounds per acre allowed per year. Other main use is on cotton. Potential leaching and run-off concern. Although it is considered safer than linuron on celery, it has the same mode of action and may enhance development of weed resistance.

Post-emergence herbicides (used to control weeds after they emerge)**:**

- clethodim (Select)
  - Efficacy: good-excellent for control of annual grasses and cost effective. Very effective against small grain cover crops. Better than sethoxydim (Poast) on annual bluegrass, but weak on quackgrass and no broadleaf or yellow nutsedge control. There is potential for weeds to develop resistance.
- sethoxydim (Poast)
  - Efficacy: good control of annual grasses and cover crops and cost effective. Weak on quackgrass, no broadleaf activity or yellow nutsedge control. There is potential for weeds to develop resistance.

Other pest management aids:

- Cultivation of cover crops or wind breaks.
- Crop rotation with Roundup Ready™ soybeans.
- Fall tillage.
- Cultivation.

Pipeline pest management tools:

- flumioxazin (Valor) - Low rates are effective, broad spectrum with some grass activity, but marginal crop safety.

"To do" list for weeds:

Research needs:

- More cost effective, safe herbicides needed for use in crop rotation to delay or prevent weed resistance.
- Control of common groundsel and other difficult weeds.

Regulatory needs:

- Registration of new products expedited as they become available.

Education needs:

- Best rotation of available products for resistance management.

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 Celery in Michigan

Active ingredient	Trade name	Company
INSECTICIDES/NEMATICIDES		
abamectin	Agrimek 0.15EC	Syngenta Crop Protection, Inc.
azinphosmethyl	Guthion Solupak 50 WP	Bayer Crop Protection
	Armor 2L	Syngenta Crop Protection, Inc.
acephate	Orthene 75S	Valent
	Address 75S	Dow AgroSciences
Baccillus subtilus	Agree, Biobit, Condor…ect.	Multiple manufacturers
carbaryl	Sevin 80S	Multiple manufacturers
cyromazine	Trigard 75WP	Syngenta Crop Protection, Inc.
endosulfan	Phaser 3EC	AgroEvo USA Company
	Thiodan 3EC	FMC Corporation Ag Company
imidacloprid	Admire	Bayer Crop Protection
malathion	Malathion 57EC	United Agri Products
metaldehyde	Metaldehyde	Platte Chemical Company
methomyl	Lannate SP	DuPont Agricultural Products
oxamyl	Vydate 2L	DuPont Agricultural Product
permethrin	Ambush 2EC	Syngenta Crop Protection, Inc.
	Pounce 3.2EC	FMC Corporation
pyrethrin, piperonyl butoxide	Pyrenone	Aventis ES Professional Pest Control
pyrethrin, rotenone	Pyrellin EC	Webb Wright Corp.
spinosad	SpinTor 3EC	Dow AgroSciences
tebufenozide	Confirm 2F	Dow AgroSciences
NEMATICIDES		
telone	Telone II	Dow AgroSciences
metam	Busan 1020	Buckman
	Vapam	Syngenta Crop Protection, Inc.
oxamyl	Vydate 2L	DuPont Agricultural Product
FUNGICIDES		
azoxystrobin	Quadris	Syngenta Crop Protection, Inc.
benomyl	Benlate	no longer manufactured
chlorothalonil	Bravo	Syngenta Crop Protection, Inc.
	Echuus	Sipcam Agro USA, Inc.
copper ammonium carbonate	Copper Count N 8L	Mineral Research & Development Corp.
copper hydroxide	Champ	Agtrol International
	Kocide	Griffin L.L.C.
	Nu-Cop	Micro Flo Company
copper oxychloride	C-O-C-S WDG	United Agri Products
copper resinate	Tenn-Cop 5E	Griffin L.L.C.
copper sulfate	Basicop 53WP	Griffin L.L.C.

DCNA	Botran 75W	Gowan Company
iprodione	Rovral	Aventis CropScience
mefenoxam	Ridomil Gold Ultra Flourish	Syngenta Crop Protection, Inc. Agtrol International
neem oil	Trilogy	Thermo Trilogy Corporation
propiconazole	Tilt 3.6EC	Syngenta Crop Protection, Inc.
HERBICIDES		
clethodim	Select	Valent USA Corporation
glyphospate	Round-up	Monsanto Company
linuron	Lorox Linex	Griffin L.L.C.
metolachlor	Dual Magnum	Syngenta Crop Protection, Inc.
prometryn	Caparol	Syngenta Crop Protection, Inc.
trifluralin	Treflan Trilin	Dow AgroSciences Griffin L.L.C.
sethoxydim	Poast	BASF Corporation

Table 3. Unregistered Pesticides Tested on Celery in Michigan

Insecticides	Insects tested		
	Aphids	AL1	TPB
pymetrozone (Fulfill)	G-F[2]	-	-
thamethozam (Actara)	G	G-F	G

Fungicides	Pathogens tested		
	Early blight	Late blight	White/Pink Mold
fenbuconazole (Indar) (Dow Agro Sciences)	F-P	F-P	–
kresoxim-methyl (Sovran) (BASF)	E	E	–
pyraclostrobin (BAS 500) (BASF)	E	E	–
tebuconazol (Folicur) (Bayer Crop Protection)	F-P	F	–
trifloxystrobin (Flint) (Bayer Crop Protection)	E	E	–
vinclozolin (Ronilan) (BASF)	–	–	?

[1] Insect abbreviations: AL = aster leafhoppers, TPB = tarnish plant bugs.

[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 4. Description of Pests and Pathogens of Celery

Pest/Pathogen	Symptoms
INSECT PESTS	
Aphids (green peach aphid *Myzus persicae* and other aphids)	Numbers depend on seasonal conditions, location and control program. When abundant, they cause leaf distortion. Presence of their molted skins and honeydew can make celery unmarketable.
Aster leafhopper (*Macrosteles quadrilineatus*)	Economically important pest because it is the vector of the aster yellows disease.
Carrot weevil (*Listronotus oregonensis*)	Adults puncture and lay one to several eggs in the petioles of the celery. Larvae either tunnel in the petiole or move to the crown or roots to feed. Celery transplants are susceptible from the time of planting. Injury varies with the number of weevils present and in extreme cases, when soil moisture is low, severe wilting can occur due to reduced root mass.
Cutworms (Noctuidae)	Damage is primarily due to feeding on petioles.
Loopers (celery looper (*Anagrapha falcifera*) and cabbage looper (*Trichoplusia ni*))	Along with cutworms, these caterpillars can occasionally be a problem, however, the outer stalks that might be damaged in this way are usually removed prior to market.
Tarnished plant bug (*Lygus lineolaris*)	A pest on many fruit and vegetable crops, as well as alfalfa. Adults feeding early in the season may not be important since marketable petioles not present. However, damage nearer harvest (commonly called black joint) can be confused with black heart, a physiological disorder resulting from calcium deficiency. Damage to petioles can cause celery to be rejected and in extreme cases can lead to petiole death due to secondary organisms coming in on the wounds. It only takes a few petioles damaged to this extent to make the entire plant unmarketable.
Vegetable leaf miner (Agromyzidae)	An occasional problem in some areas, damage is mainly cosmetic. However, severe infestations can cause wilting when conditions are dry.
Wireworms (Elateridae)	Beetle larvae can occasionally be a problem. Their feeding via tunneling will damage petioles.
NEMATODE PESTS	
Northern root-knot nematode (*Meloidogyne hapla*)	Root-knot nematodes can severely reduce celery quality and yields by causing galls, forking and bunching
Pin nematode (*Paratylenchus negelectus*)	Severe infestations can cause wilting, stunting and yellowing of leaves and petioles.
Needle nematode (*Longidorus elongatus*)	Severe infestations can cause wilting, stunting and yellowing of leaves and petioles.
Root-lesion nematode (*Pratylenchus penetrans*)	Symptoms include wilting and stunting in patches of heavy infestation, yellowing leaves, and necrotic secondary roots with dry patches.

OTHER INVERTEBRATE PESTS	
Slugs	Feeding damage from slugs is occasionally a problem.
Spider mites (Acari)	Numbers depend on seasonal conditions, location and control program. When abundant, they cause leaf distortion and unsightly webbing.
PATHOGENS	
Bacterial blight (*Pseudomonas syringae* pv. *apii*)	Small, bright yellow, circular spots, 1 to 2 mm in diameter first occur on the leaves and later enlarge, turn rusty brown and usually are surrounded by a yellow halo. Numerous spots can give a blighted appearance.
Soft rot (*Erwinia 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.
Crater rot (*Rhizoctonia solani*)	Causes brown, oval, sharply delineated tan to brown lesions on the exterior of the outer petioles.
Damping off (*Pythium* sp. and *Rhizoctonia solani*)	Diseases caused by several fungi. Damping off occurs when infected seedlings wilt, turn brown and die, or develop a water soaked, discolored stem at the ground level and topple over, resulting in poor stands.
Foliar blight (*Cercospora apii* and *Septoria apiicola*)	*Cercospora apii* first appears as yellow spots visible on both sides of the foliage. These spots enlarge rapidly, become ashen-gray and do not have a distinct margin. *Septoria apiicola* looks very similar, however it has very small, widely separated back pycnidia within the spots. Both blights infect the leaves and petioles.
Fusarium yellows (*Fusarium oxysporum* f. sp. *apii*)	Plants tend to be brittle, stunted, yellow and taste bitter. As disease progresses, the crown and roots rot.
White or pink mold (*Sclerotinia sclerotiorum*)	Causes damping-off in infested seedbeds. Characterized by rapid development of basal crown and petiole rot. Plants appear to suddenly wilt and collapse in the field. Rotted area is watery, pinkish, and in moist conditions may become covered with white mold which contains hard black sclerotia.

Table 5. Advantages and Disadvantages of Pesticides for Celery

Active ingredient	Disease/Pest	Advantages/Disadvantages
INSECTICIDES		
abamectin	Spider mites Vegetable leafminer	• RUP; ground application only • highly effective against leafminer larvae • fits well into an IPM program because it is non-disruptive to beneficial insects • resistance management concerns • expensive
azinphos-methyl	Aster leafhopper Tarnish plant bug	• on EPA Phase 1 list; organophosphate • effective against multiple pests; longlasting residual • resistance issues • hard on beneficials; may increase aphid populations • no more than 3 applications allowed per season
acephate	Aphids Loopers	• systemic • on EPA Phase 1 list; organophosphate • frequently used in resistance rotation • long PHI=21 days • concerns about beneficial insects
Baccillus thuringiensis	Loopers	• limited effectiveness • slow acting; insect must ingest for activity • very safe; no pre-harvest interval • 4 hour REI • limited residual activity
carbaryl	Aster leafhopper Cutworms Tarnish plant bug	• on EPA Phase 1 list; carbamate • used on multiple crops; inexpensive and effective • broad spectrum, hard on beneficials • resistance issues • some processors will not accept it
cyromazine	Vegetable leafminer	• easy on beneficials • used in resistance management programs • effective, but highly toxic to aquatic organisms • expensive, multiple applications necessary and slow acting
endosulfan	Aphids Loopers	• organochlorine; highly toxic to fish and corrosive on iron • one application allowed per year • short pre-harvest interval = 4 days • limited efficacy, used in resistance management; non-toxic to bees

imidacloprid	Aphids	• newly registered on celery, efficacy unknown • systemic soil treatment • expensive
malathion	Aphids	• on EPA Phase 1 list; organophosphate • used in resistance management programs • losing effectiveness in some areas
metaldehyde	Slugs	• must avoid contact with plants • used between rows
methomyl	Aphids Aster leafhopper Cutworms Loopers	• on EPA Phase 1 list; carbamate • broad spectrum; short residual • used in resistance management programs • toxic to bees, fish and birds • short pre-harvest interval = 7 days • expensive, but very effective
oxamyl	Carrot weevil	• on EPA Phase 1 list; carbamate • 24C in Michigan for use against carrot weevil larvae • systemic used in resistance management • expensive • also used against nematodes • only insecticide registered for control of carrot weevil larvae
permethrin	Aster leafhopper Cutworms Loopers	• used in resistance management programs • broad spectrum; may increase aphid populations • inexpensive • pre-harvest interval = 1 day
pyrethrin, piperonyl butoxide	Aphids Loopers	• may increase aphid populations • no pre-harvest interval • non-toxic to humans and animals • minimally disruptive to beneficials • short residual • only 1-3 applications per season • not readily available in Michigan
pyrethrin, rotenone	Aphids Loopers	• may increase aphid populations • hard on beneficials
spinosad	Loopers Vegetable leafminer	• newly registered in Michigan • used in resistance management programs • expensive • short pre-harvest interval = 1 day
tebufenozide	Loopers	• insect growth regulator; safe around beneficials • activity specific to Lepidoptera • expensive

NEMATICIDES		
dichloropropene	Nematodes	• on EPA Phase 1 list; B1 or B2 carcinogen • fumigant • requires costly equipment • expensive • specific temperature requirements limit its use in Michigan • also can be used to control soil borne diseases and weeds • cannot be used in heavy soils
metam	Nematodes	• on EPA Phase 1 list; B1 or B2 carcinogen • expensive • fumigant or chemigant • used in other crops in Michigan, but not much in celery • also good against soil-borne diseases • toxic to fish
oxamyl	Nematodes	• on EPA Phase 1 list; carbamate • must be applied in low rate, multiple applications for efficacy • systemic used in resistance management • some resistance concerns • may be applied through trickle irrigation • expensive
FUNGICIDES		
azoxystrobin	Cercospora early blight Septoria late blight	• higher cost than protectant fungicides • 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 • some growers are concerned that growth regulator activity effects on yields
chlorothalonil	Crater rot Cercospora early blight Septoria late blight White or Pink Mold	• on EPA Phase 1 list; B2 carcinogen • broad spectrum foliar protectant • inexpensive, cost effective • most important tool against foliar blights in Michigan • very effective • used in resistance management programs

copper ammonium carbonate copper hydroxide copper oxychloride copper sulfate copper resinate	Bacteria blight Cercospora early blight Septoria late blight	• inexpensive • toxic to fish • limited efficacy under significant disease pressure from Cercospora early blight and Septoria late blight • broad spectrum bactericide/fungicide • not effective alone, must be used in rotation • pre-harvest interval = 0 days • effective against bacterial blight
DCNA	Crater rot White or Pink Mold	• effective, but expensive • specific to sclerotia-forming fungi; may also be effective on other soil-borne pathogens
mefenoxam	Damping off	• resistance concerns • long residual
neem oil	Cercospora early blight Septoria late blight	• efficacy data and use pattern lacking
propiconazole	Cercospora early blight Septoria late blight	• only four applications allowed per season • used in resistance management programs • long residual • variable efficacy
HERBICIDES		
clethodim	Grasses	• important grass herbicide • effective against annual grasses and clearing fields of cover crops • weak on quackgrass • no broadleaf or yellow nutsedge control • inexpensive • potential resistance issues
glyphospate	Grasses Broadleaf weeds	• no pre-harvest interval • broad spectrum, excellent on perennials • no residual activity • mildly toxic to birds • non-toxic to aquatic organisms
linuron	Grasses Broadleaf weeds	• C carcinogen • broad spectrum on annuals • some resistance issues • effective on most soil types • fast acting and cost effective • one application allowed per season • no control over composites, wild carrot and nutsedge

metolachlor	Grasses	• 24C in Michigan because of concerns about breakdown products – undergoing EPA cumulative assessment • one of the few products effective against nutsedge • short residual • high rates needed on muck soils
prometyrn	Grasses Broadleaf weeds	• only one application allowed per year • long pre-harvest interval = 45 days • long residual activity • also used on cotton • potential groundwater concerns • resistance concerns due to same mode of action as linuron
trifluralin	Grasses Broadleaf weeds	• C carcinogen • limited efficacy especially on muck soils • one application allowed per year • short residual • inexpensive • kills weed seeds • rainfall not required for activity • may cause phytotoxicity
sethoxydim	Grasses	• important grass herbicide • not effective at temperatures less than 60F • 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 Insect & Other Invertebrate Pests on Celery in Michigan

Management tool	Insect pests of celery[1]								
	Aphids	AL	Carrot weevil	CW Loopers[2]	TPB	VLM	WW	SM	Slugs
Carbamate insecticides registered									
carbaryl (Sevin)	-	F	-	-	G	-	-[3]	-	-
methomyl (Lannate)	G-F	G	-	G	G	-	-	-	-
oxamyl (Vydate)	-	-	G**	-	-	-	-	-	-
Organophosphate insecticides registered									
acephate (Orthene, Address)	G	E-G	-	G	G	-	-	-	-
azinphosmethyl (Guthion Solupak, Armor 2L)	-	G-F	-	-	G-F	-	-	-	-
malathion (Malathion)	P	-	-	-	-	-	-	-	-
Other insecticides registered									
abamectin (Agrimek)	-	-	-	-	-	?	-	G	?
Bacillus thuringiensis (many trade names)	-	-	-	G-F	-	-	-	-	-
cyromazine (Trigard)	-	-	-	-	-	G-F	-	-	-
endosulfan (Phaser, Thiodan)	F	-	-	G-F	-	-	-	-	-
metaldehyde (Metaldehyde)	-	-	-	-	-	-	-	-	-
imidacloprid (Admire)	E-G?	G	-	-	G	-	-	-	-
permethrin (Ambush, Pounce)	-	E	G***	G	G	-	-	-	-
pyrethrin and piperonyl butoxide (Pyrenone)*	-	-	-	G	-	-	-	-	-
pyrethrin and rotenone (Pyrellin)*	-	-	-	G	-	-	-	-	-
spinosad (SpinTor)	-	-	-	G	-	G?	-	-	-
tebufenozide (Confirm)	-	-	-	G-F?	-	-	-	-	-

Pipeline pest management tools									
methoxyfenozide (Intrepid)	-	?	-	-	-	-	-	-	-
pymetrozone (Fulfill)	G	-	-	-	-	-	-	-	-
thamethozam (Actara, Platinum)	G-F	E-G	-	-	G	-	-	-	-

* May increase aphid population.
** effective on larvae
*** effective on adults
[1] Insect abbreviations: AL = aster leafhoppers, CW = cutworms, TPB = tarnish plant bugs, VLM = vegetable leaf miner, WW = wireworms, SM = spider mites.
[2] Includes celery and cabbage loopers.
[3] 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 Nematode Pests on Celery in Michigan

Management tool	Nematode pests of celery			
	needle	pin	northern root-knot	root-lesion
B2 carcinogenic nematicides registered				
1,3-dichloropropene (Telone II)	[1]E	G	E	E
metham (Busan 1020, Vapam)	?	?	G	E
Carbamate nematicides registered				
oxamyl (Vydate)			G	
pre-plant application	P	?	F	F
planting application	P	?	F	G
post-plant application	P-F	?	V-G	V
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 8. Efficacy of Pest Management Tools for Control of Diseases on Celery in Michigan

Management tool	Diseases of celery[1]						
	BB	SR	CR	DO	FB	FY	WM
B2 carcinogenic fungicides registered in MI							
chlorothalonil (Bravo, Echo)	-	-	E-G	-	E-G	-	E-G
iprodione (Rovral)	-	-	-	F-P	-	-	-
mefenoxam (Ridomil Gold, Ultra Flourish)	-	-	-	E-G	-	-	-
Other fungicides registered in MI							
azoxystrobin (Quadris)	-	-	-	-	E	-	-
benomyl (Benlate)	-	-	-	-	E-G	-	-
copper ammonium carbonate (Copper Count N 8L)	G-F	-	-	-	G-P	-	-
copper hydroxide (Champ, Champion, Kocide, Nu-Cop)	G-F	-	-	-	G-P	-	-
copper oxychloride (C-O-C-S WDG)	G-F	-	-	-	G-P	-	-
copper resinate (Tenn-Cop)	G-F	-	-	-	G-P	-	-
copper sulfate (Basicop)	-	-	-	-	G-P	-	-
DCNA (Botran)	-	-	G	-	-	-	G
neem oil (Trilogy)	-	-	-	-	?	-	-
propiconazole (Tilt)	-	-	-	-	G-F	-	-
Pipeline pest management tools							
acibenzolar-S-methyl (Actigard)	?	-	-	-	-	P	-
fenbuconazole (Indar)	-	-	-	-	F-P	-	-
harpin protein (Messenger)	?	-	-	-	-	P	-
kresoxim-methyl (Sovran)	-	-	-	-	G	-	-
pyraclostrobin (BAS 500)	-	-	-	-	G	-	-

tebuconazole (Folicur)	-	-	-	-	F-P	-	-
thiophanate-methyl (Topsin-M)	-	-	-	-	?	-	-
trifloxystrombin (Flint)	-	-	-	-	G	-	-
vinclozolin (Ronilan)	-	-	-	-	-	-	?

[1] Disease abbreviations: BB = bacterial blight, SR = soft rot, CR = crater rot, DO = damping-off, FB = foliar leaf blights (early & late blight), FY = fusarium yellows, WM = white or pink mold.

[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 9. Efficacy of Pest Management Tools for Control of Weeds on Celery in Michigan

Management tool	Annual weeds		Perennial weeds	
	broadleaf	grass	broadleaf	grass
Pre-Plant				
glyphosate (Round-up)	[1]E	E	*E*	E
Pre-Emergence				
metolachlor (Dual Magnum)	-	G	-	G
trifluralin (Treflan, Trilin) [C carcinogen]	P	P	P	P
Pre- & Post-Emergence				
linuron (Lorox, Linex) [C carcinogen]	E-G*	G**	E-G*	G**
prometryn (Caparol)	E-G	G**	E-G	G**
Post-Emergence				
clethodim (Select)	-	E-G	-	E-G***
sethoxydim (Poast)	-	G	-	G***
Other Pest Management Practices				
cover crops				
wind breaks				
crop rotation				
fall tillage (in conjunction with herbicide treatment)				
herbicide rotation to reduce resistance				
Pipeline pest management tools				
flumioxazin (Valor)	E-G	G	P	P

[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.

* No control over composites, wild carrot and nutsedge. **Effective on only some grasses. *** Weak on quack grass and no nutsedge control.