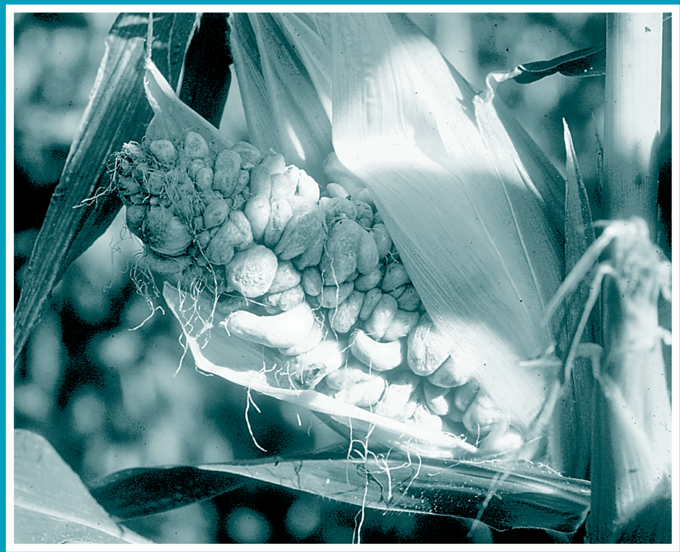
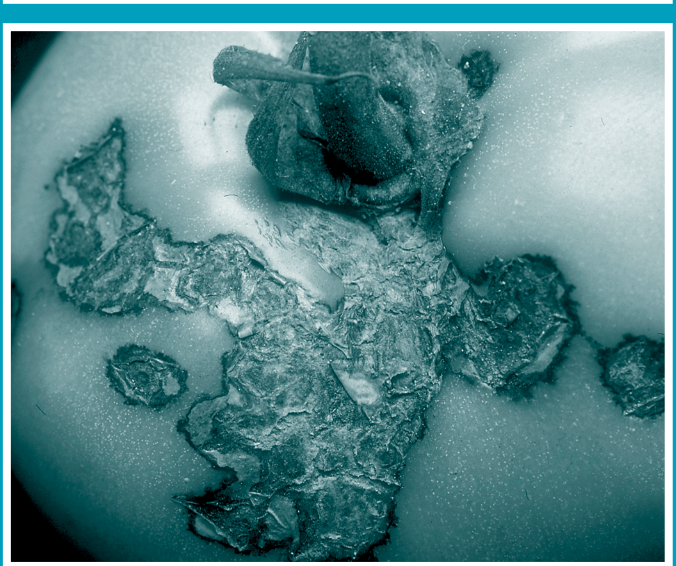
Vegetable Crop Pest Management

A Guide for Commercial Applicators Category 1B


Extension Bulletin E-2160 • March 2002, Major revision-destroy old stock • Michigan State University Extension

Vegetable Crop Pest Management

A Guide for Commercial Applicators
Category 1B

Editor:

Rebecca L. Hines
Academic Specialist
Pesticide Education Program
Michigan State University

Acknowledgements

We would like to express our thanks for the advice and technical assistance of the following reviewers: Dr. Chris DiFonzo, MSU Pesticide Education Program; Dr. Ed Grafius, MSU Department of Entomology; Dr. Bernard Zandstra, MSU Department of Horticulture; Dr. Mary Hausbeck and Sheila Linderman, MSU Department of Plant Pathology; Fred Warner, MSU Diagnostic Services; Becca Thompson, MSU Integrated Pest Management Program, and Joe Strazalka, Michigan Department of Agriculture

Special thanks go to:

Dr. George Bird, Department of Entomology, Michigan State University for providing the images of plant parasitic nematodes.

Steve Demming and Dr. Dale Mutch, Kellogg Biological Station, Michigan State University for graphics on page 4, 12, and 59.

Dr. Ed Grafius, Department of Entomology, Michigan State University and Dr. Bill Hutchison, Department of Entomology, University of Minnesota, for providing the images of vegetable insect pests.

Dr. Mary Hausbeck, Sheila Linderman and Dr. Willie Kirk, Department of Plant Pathology, Michigan State University, for providing the images of vegetable diseases.

Fred Warner, Diagnostic Services, Michigan State University, for writing Chapter 8, *Nematode Management*.

Vegetable Crop Pest Management

INTRODUCTION

How to Use This Manual

This manual contains the information needed to become a certified commercial applicator in Category 1B, Vegetables. This manual is intended for use in combination with the *Pesticide Applicator Core Training Manual* (Extension bulletin E-2195), available through the Michigan State University Bulletin Office. However, this manual would also be useful to anyone interested in learning more about vegetable pest management.

Category 1B, Vegetables, covers the management and control of common pests in asparagus, carrots, celery, cucurbits, cole crops, onions, potatoes, snap beans, sweet corn and tomatoes. The manual presents basic scientific information on pest life cycles and emphasizes protecting non-target organisms and preventing the development of resistance in pests.

The Category 1B certification exam is based on information found in this booklet. Each chapter begins with a set of learning objectives that help you focus on what you should understand from each chapter. The table of contents helps you identify important topics and understand how they relate to one another through the organization of headings and subheadings. As you prepare for the exam, read each chapter and answer the review questions. These questions are not on the certification exam, but are provided to help you prepare for the exam. Questions on the exam will pertain directly to the learning objectives.

The appendices and glossary, including an answer key (Appendix A), at the end of this manual provide supplemental information that will help you understand the topics covered in the chapters. Terms throughout the manual text that are bold or italicized can also be found in the glossary.

This certification manual benefits the applicator and the general public. By learning how to handle pesticides correctly, applicators can protect themselves, others, and the environment from pesticide misuse. For more specific information on how to become a certified applicator in Michigan, refer to the beginning of the core manual (E-2195) or the Michigan Department of Agriculture's Web site, <http://www.mda.state.mi.us>, or call the MDA at 1-800-292-3939.

CHAPTER 1

INTEGRATED PEST MANAGEMENT

LEARNING OBJECTIVES

After completely studying this chapter, you should:

- Be able to define integrated pest management.
- Understand the importance of an economic threshold.
- Know the basic principles of field scouting.
- Know the three ways that cultural control methods work.
- Be able to define and give examples of a natural enemy.
- Understand the various types of pesticides.
- Understand the importance of preharvest interval, residues, reentry interval, phytotoxicity, and pesticide resistance.

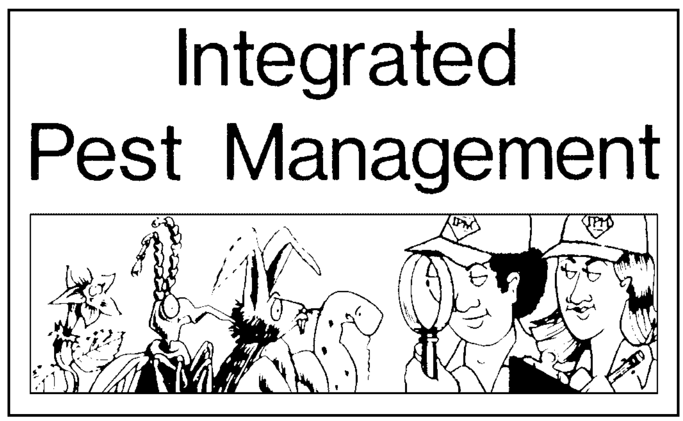
Vegetables are vulnerable to attack by pests. Pest damage can range from slight damage that has no effect on the value of the harvested product to severe damage that kills plants, significantly reduces crop yield, or reduces the crop's market value. Vegetable pests include insects and mites, weeds, diseases, and nematodes.

Effective management of pests is based on thorough consideration of ecological and economic factors. The pest, its biology, and the type of damage it causes are some of the factors that determine which control strategies and methods, if any, should be used. Pest management decisions largely determine the kind and amount of pesticides used.

Pest management decisions represent a compromise between the value of the product, the extent of the pest damage, the relative effectiveness and cost of the control measures, and the impact on the environment.

INTEGRATED PEST MANAGEMENT (IPM)

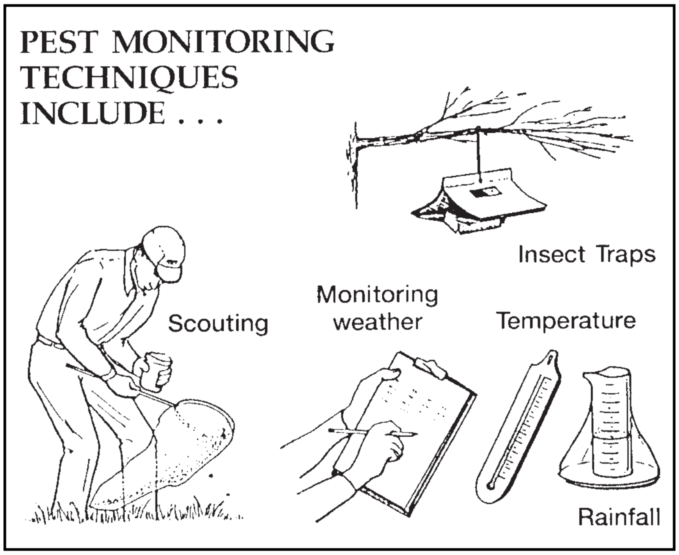
The goal of IPM is to use all appropriate tools and tactics to keep pest populations below economically damaging levels and to avoid adverse effects to humans, wildlife, and the environment. These tools include genetic resistance and cultural, biological, and chemical control methods. Management decisions are based on information gathered about the pest problem and the crop; then a combination of control measures that best suits the problem is used.



What are these IPM tools and how are they used?

FIELD SCOUTING, MONITORING

Field scouting is an important part of any IPM program because it helps define the pest problems. Correct identification and location of each pest in a crop are necessary for a successful pest management program. Regularly scouting fields can reveal: which pests are present, the growth stage of the pests and the growth stage of the crop; the location of the pests in the crop; whether the insect pests are healthy or diseased; the pest population and whether it is increasing or decreasing; and the crop condition. A scouting program should include accurately written records of field locations, field conditions, previous pest infestations, and control measures. With this information, you can determine what control measures are appropriate.



Remember the following basic principles when scouting:

- Take samples from several areas of the field.
- Select sample sites at random unless field conditions suggest uneven pest distribution.
- DO NOT sample in border rows or field edges unless indicated to do so for a particular pest.

Insect pests can be monitored in several ways. The most common methods are actually counting the number of insects present or estimating the amount of insect damage. Insect counts usually are expressed as the number of insects per plant or plant part (e.g., number of insects per leaf). Insect crop damage is often expressed as percentage of the plant damaged (e.g., percent leaf defoliation). Other insect monitoring methods include collecting insects with a sweep net, shaking crop foliage and counting dislodged insects, and trapping insects. Disease monitoring can be accomplished through scouting fields weekly and examining foliage for early disease symptoms. Also, monitoring the weather can indicate when conditions are favorable for disease development. Pest alerts and newsletters provided by MSUE county agents and other MSU personnel indicate pest pressure and outbreaks in the region and state.

ECONOMIC THRESHOLDS

An **economic threshold** is defined as the pest density at which action must be taken to prevent the pest population from increasing and causing economic damage. Economic thresholds are constantly changing and vary between fields, crop varieties, and crop growth stages. Economic thresholds are a function of crop value and cost of control. In general, a high-value crop will have a lower economic threshold; less pest damage will be accepted and control measures must be implemented sooner. If the control measures are expensive or the vale of the crop is low, the economic threshold is usually high. High control costs means it takes more crop loss to justify the control action.

Economic thresholds are often referred to as **action thresholds**. When the pest population reaches the threshold, action is taken to reduce the population. For insects, an economic or action threshold is typically expressed as the number of insects per plant or per leaf or the amount of crop damage.

CONTROL STRATEGIES

CULTURAL CONTROL

Cultural control uses farming practices to reduce pest populations by implementing a practice such as tillage or crop rotation at the correct time to kill or reduce pest numbers or slow pest development. Like all other control strategies, cultural control requires an understanding of the pest and the crop. Cultural control measures are usually applied at the weakest stage of the pest's life cycle and are generally preventive actions rather than curative actions.

Cultural control methods work in three ways:

1. Prevent the pest from colonizing the crop or commodity.
2. Create adverse conditions that reduce survival of the pest.
3. Reduce the impact of pest injury.

PREVENTING COLONIZATION

Control measures that prevent colonization physically exclude the pest, reduce pest populations, prevent the pest from finding the crop, or disrupt the timing between the pest and the crop.

A. Trap crop—planting a small area with a preferred host to attract the pest away from the crop. Once in the trap crop, the pest can be destroyed or controlled. For example, trap crops can help control striped cucumber beetles. The beetles are attracted to the oldest, most mature crop in an area. An early planting of pumpkins or cucumbers attracts early-season striped cucumber beetles, concentrating the population and preventing movement to the primary crop.

B. Physical barriers—separating a pest and host with an object such as a wall or a ditch to stop the pest from infesting—for example, covering the soil with black plastic to control weeds.

C. Crop rotation—a cycle in which different crops are planted in a field every year; the longer the rotation between crops susceptible to the same pests, the better the pest control. A crop rotation system helps control pests such as tomato diseases. Tomatoes should not be rotated with peppers, eggplant, or any cucurbits (pumpkins, zucchini, winter squash, cucumber, watermelon or muskmelon).

D. Delayed planting (timing)—changing the planting date so that the host is not available when the pest is present. Example: delaying the planting date of onions until after peak flight of onion maggot adults removes egg-laying sites and helps control onion maggots.

E. Cover crops—utilizing plant competition by planting a secondary crop to prevent weeds from becoming established. Example: using fall-planted rye as a living mulch for pumpkins. The rye is killed before seeding pumpkins and the rye residues suppress weeds.

Creating adverse pest conditions in the crop

Pests require specific living conditions. Cultural control methods can disrupt ideal pest conditions and decrease pest pressure. Adverse pest conditions can be created by destroying the host plant after harvest, physically moving the soil, changing water management practices and spatial arrangement, and using the plant's natural defense mechanisms.

A. Destroy crop residue, alternate hosts, and volunteer crops—eliminating the pest or pest habitat found in crop residue, or destroying alternate hosts of the pest found near or in the crop – for example, destroying corn debris after harvest to reduce overwintering European corn borers.

Pests, particularly plant pathogens, can survive in a field on volunteer crops and alternate hosts. The survival of these pathogens provides a source of **inoculum**. For example, aster yellows and its vector survive on volunteer crops and weeds. Both the phytoplasma and the insect population can build in the primary crop, increasing the likelihood of infection.

B. Tillage—physically moving the soil around the crop. Tillage can destroy an insect and uproot and cover weeds. All of these factors can reduce pest populations.

C. Water management—Water is needed for healthy plant growth but avoid water-related conditions that promote pest problems such as disease spread. For example, *Phytophthora* is a water mold that is favored by saturated soil conditions. Using raised beds for squash and cucumbers helps prevent loss from *Phytophthora*.

D. Spatial arrangement (seeding rate and row spacing)—changing the spatial arrangement of the crop to reduce pest populations. For instance, when plant spacing and row width are reduced, plants can outcompete weeds for light, water, and nutrients. On the other hand, close plant spacing may provide an environment favorable for disease development, such as white mold in snap beans.

E. Allelopathy—one plant species reducing competition from another plant species by releasing toxic chemical agents into the soil. Allelopathy has minimal potential in weed management. For example, in a conservation tillage system, leaving residues of some varieties of rye can reduce the number of weeds.

REDUCE PEST INJURY TO CROP

Cultural control also utilizes a plant's defense mechanisms to minimize pest damage. Planting pest-resistant crops, maintaining a healthy crop, timing harvest to reduce pest damage, and practicing pest-reducing storage techniques can reduce pest injury.

A. Host-plant resistance—the host plant's ability to tolerate pest pressure. Plants have defense mechanisms that allow them to either repel the pest or withstand the pest's damage.

B. Plant health—maintaining strong, healthy plants that are better equipped to out-compete weeds, fight disease, and withstand insect damage.

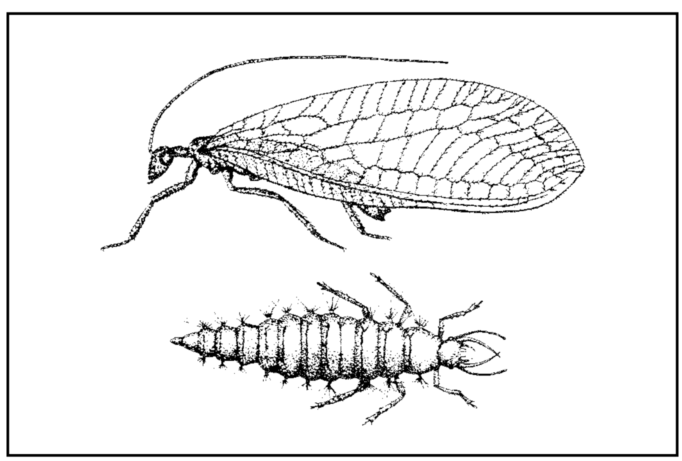
C. Harvest timing—changing the time when a crop is harvested to reduce pest impact on yield. For example, if a field is infested with *Phytophthora*, the vegetable crop should be harvested as soon as it is mature to decrease the time that the crop is exposed to the pathogen.

D. Storage practices—handling, curing, and storage practices to prevent the spread of disease during storage. For instance, controlled temperature and ventilation are essential to minimize losses in potatoes.

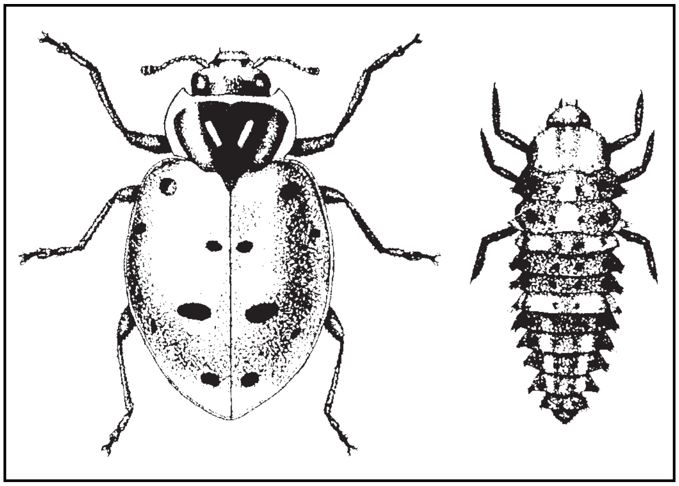
BIOLOGICAL CONTROL

Biological control is the use of living **organisms** to reduce a pest population. These beneficial organisms are referred to as natural enemies. Predators, parasitoids, and pathogens are the most common natural enemies.

- **Predators—**other organisms that eat the pest. Predators are usually not specific and will eat a variety of pests.

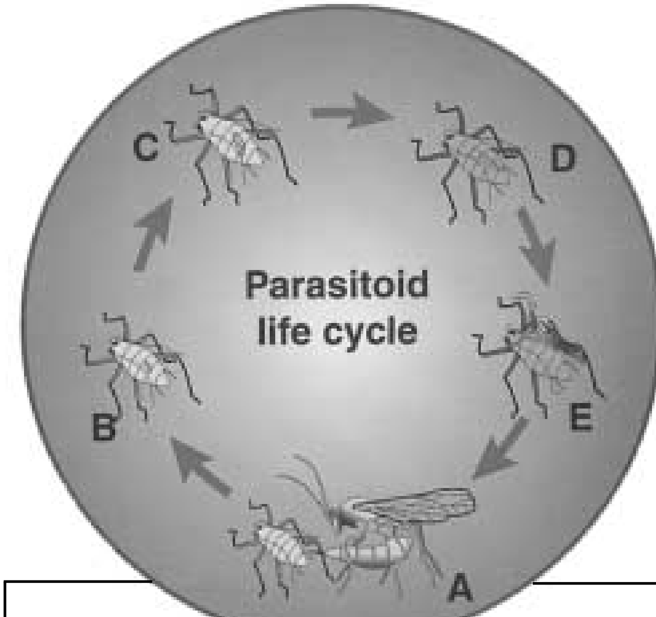


Green lacewing adult and insect eating larva.



Ladybird beetle adults and larvae consume large numbers of aphids and mites.

- **Parasitoids**—organisms that must live in or on another organism to complete their life cycle. A parasitoid is usually an insect that develops and feeds inside another insect. An adult parasitoid lays an egg in or on a host insect. When the parasitoid egg hatches, the parasitoid larva feeds on the host insect. Eventually, the developing parasitoid kills the host insect by eating it from the inside out. Parasitoids are usually host specific and include tiny wasps and flies.



A. Wasp lays egg in host (for example, an aphid).
B., C. As the host feeds and grows, so does the wasp larva.
D. Parasitoid kills then pupates within dead host.
E. An adult parasitoid emerges from the dead host.

Examples of insect biological control agents (natural enemies).

Natural Enemy	Pests Controlled
PREDATORS	
lady beetles	aphids, scale insects
green lacewings	aphids, mites, others
spined soldier bug	Colorado potato beetle, Mexican bean beetle
minute pirate bug	corn earworm eggs, mites
PARASITOIDS	
tachinid flies	beetles, caterpillars
ichneumonid wasps	caterpillars, leafrollers, weevils, others
braconid wasps	caterpillars, beetles, aphids
Trichogramma wasps	eggs of moths, such as European corn borer
PATHOGENS	
Bacillus thuringiensis	caterpillars, some beetle larvae, mosquito and blackfly larvae
nuclear polyhedrosis viruses (NPV)	caterpillars
Beauveria bassiana (fungus)	caterpillars, grasshoppers, aphids
Nosema (protozoan)	caterpillars, beetles, grasshoppers
Streptomyces griseoviridis strain K61 (Mycostop®) (fungus)	seed, root, and stem rot, and wilt caused by *Fusarium*, *Alternaria*, and *Phomopsis*
Trichoderma harzianum Rifai strain KRL-AG2 (PlantShield™) (fungus)	Plant pathogens such as *Pythium, Rhizoctonia, Fusarium, Botryis*, and powdery mildew.

- **Pathogens**—disease-causing organisms such as bacteria, viruses, and fungi that infect and kill the pest. Environmental conditions such as high humidity or high pest abundance allow naturally occurring pathogens to multiply and cause disease outbreaks (epizootic), which reduce a pest population. Some insect pathogens are manipulated to control specific pests. For example, the soil bacterium *Bacillus thuringiensis* (commonly known as Bt) can kill a variety of insects, including caterpillars and mosquito and beetle larvae.

CHEMICAL CONTROL

Chemical control reduces a pest population through the application of pesticides. The decision to use a pesticide as part of an IPM program should be based on a scouting program, pest identification, economic thresholds, and the crop/pest life stages. When used properly, pesticides provide effective and reliable control of most pest species.

TYPES OF PESTICIDES

Pesticides used to control vegetable crop pests are applied either to the soil or to the plant foliage.

- **Soil-applied pesticides**

  Chemigation—applying a pesticide or fertilizer to the soil by injecting it into the irrigation system.

  Insecticides—applied to prevent insect damage to the roots of corn and other crops. Insecticides can be applied by broadcast soil applications and soil incorporation before planting, applied in the seed furrow at planting, or broadcast before or after crop emergence.

  Fungicides—applied to soil to prevent damage to the roots caused by soilborne fungi. Fungicides can be applied by broadcast soil application and soil incorporation before planning, applied in the seed furrow at planting, or broadcast before or after crop emergence.

  Herbicides—applied to the soil surface and mixed into the soil before planting (**preplant incorporated**) or applied after planting but before crop emergence and not incorporated (**preemergence**).

  Soil fumigants or nematicides—applied to the soil to control nematodes before planting.

- Foliar-applied pesticides

  Foliar applications are applied directly to crop leaves. They can be applied before damage occurs (**preventive**) or in response to damage (**curative**).

  Insecticides—generally applied to control insects that are feeding above-ground on the crop.

  Herbicides—applied to the weed foliage after the crop and weeds have emerged (**postemergence**).

  Fungicides—applied to the crop before the disease appears to prevent disease (**protectant**) or to control disease after it appears (**eradicant**).

The following are special considerations to remember when using a pesticide to control your pest problem:

Preharvest interval—the minimum number of days needed between the last pesticide application and harvest. Preharvest intervals are established by the Environmental Protection Agency (EPA). The preharvest interval is based partly on how long it takes the pesticide to break down. Observing the preharvest interval reduces or eliminates pesticide residues on the commodity.

Residues—the pesticide that remains on the crop after an application. Ideally, a pesticide is present only long enough to kill the pest and then breaks down. Because many pesticides do not break down completely before harvest, for each pesticide registered for use on a food or feed crop, the EPA sets the amount of acceptable residue (**tolerance**) permitted on the harvested crop. The amount of residue relates to the preharvest interval and the pesticide application rate. Harvesting a crop during the preharvest interval or applying more pesticide than the label allows increases the risk of residues exceeding legal tolerance levels.

Reentry interval (REI)—the amount of time required after a pesticide application before a person can reenter a field without personal protective equipment (PPE). The reentry interval prevents unnecessary pesticide exposure. Only workers trained for early entry under the Worker Protection Standard (WPS) and wearing proper personal protection equipment may enter a treated area during the reentry interval. Refer to the Worker Protection Standard for the regulations on informing workers about pesticide applications.47

Phytotoxicity—when a pesticide damages the crop to which it is applied. Pesticide drift, excessive rates, mixing incompatible pesticides, adverse weather, using the wrong pesticide, and improper calibration of equipment can all cause phytotoxicity. Even using pesticides in accordance with the label can result in some phytotoxicity. Applying pesticides within recommended rates and following label instructions for mixing and applying help avoid this problem.

Pesticide resistance—the genetic ability of an organism to tolerate the toxic effects of a pesticide, such as malathion-resistant Indian mealmoths, atrazine-resistant common lamb's quarter, Mefenoxam-resistant *Phytophthora*, and ALS (acetolaclate synthase)-resistant ragweed. Resistance develops from overuse of the same pesticide or from overuse of a class of pesticides with a common mode of action, such as organophosphates or ALS herbicides. With overuse, only those pests resistant to the pesticide survive and reproduce, leading to a serious control problem. Therefore, it is important to use pesticides only when necessary and rotate pesticides and mode of action as much as possible.

CHAPTER 1

Review Questions

Chapter 1: Integrated Pest Management

Write the answers to the following questions and then check your answers with those in the back of the manual.

1. Define integrated pest management.

2. List three control strategies and give an example of each.

3. Define economic threshold.

4. A high-value crop will usually have a high economic threshold.
   A. True
   B. False

5. Field scouting is important because it helps determine pest:
   A. Presence.
   B. Location.
   C. Life stage.
   D. All of the above.

6. When scouting a field, you should sample only from:
   A. Border rows.
   B. One small area of the field.
   C. Randomly picked locations throughout the field.
   D. The edge of the field.

7. List three ways that cultural controls work.

8. Which of the following is an example of a biological control?
   A. Parasitoid
   B. Cover crop
   C. Pesticide
   D. Tillage

9. Host plant resistance is a form of:
   A. Biological control.
   B. Chemical control.
   C. Cultural control.

10. When plant species eliminate other plants by releasing toxic chemicals, it is called:
    A. Phytotoxicity.
    B. Allelopathy.
    C. Sanitation.
    D. Carryover.

11. After the growing season, destroying or removing crop residue can help reduce potential insect and disease problems the following year.
    A. True
    B. False

12. Pesticides are **not** part of an IPM program.
    A. True
    B. False

13. Herbicides that are applied and mixed into the soil before crop planting are called _______________ herbicides.
    A. Preemergence
    B. Postemergence
    C. Preplant incorporated
    D. Seed treatment

14-18. Match the following scenarios with the type of pesticide application you would perform to combat the problem.

A. Preventive
B. Curative

14. ___ Very weedy cornfield; the corn is knee-high.
15. ___ A neighboring field is infected with a disease and you don't want it in your field.
16. ___ The MSU Crop Advisory Team alerts you to potential pest outbreaks in your area.
17. ___ You apply a fungicide to get rid of a disease.
18. ___ When scouting a potato field, you find that the potato leafhopper population is above the economic threshold.

19. How are tolerance and pesticide residues related?

20-23. Match the following with their definitions.

A. Predators

B. Biological control

C. Pathogens

D. Parasitoids

20. ___ Typically a fly or tiny wasp that develops inside another insect.

21. ___ Generalist (organisms that eat almost anything).

22. ___Using living organisms to control a pest.

23. ___ Viruses or bacteria.

24-27. Match the following words with their definitions.

A. Pesticide resistance

B. Reentry interval

C. Preharvest interval

D. Phytotoxicity

24. ___ Reduces unnecessary exposure of workers to pesticides.

25. ___ Damage to a crop caused by pesticide application.

26. ___ Avoids harvesting pesticide-contaminated crops.

27. ___ Can result from the continued use of the same pesticide.

CHAPTER 2

MINIMIZING PESTICIDE IMPACT

LEARNING OBJECTIVES

After completely studying this chapter, you should:

- Understand pesticide labeling.
- Understand the difference between point and nonpoint source pollution.
- Understand management practices to reduce groundwater contamination.
- Understand how to protect non-target organisms from pesticides.
- Understand how pesticide resistance develops and how to delay or prevent resistance.

STATE AND FEDERAL LAWS

The *Pesticide Applicator Core Training Manual* (E-2195) discusses federal and state laws governing the use and handling of pesticides. These federal laws include the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), the Occupational Safety and Health Act (OSHA), the Endangered Species Act, and the Worker Protection Standard (WPS). Michigan pesticide laws include the Natural Resources and Environmental Protection Act (Act 451, P.A. 1994, Part 83, Pesticide Control), Regulation 636, Regulation 637, and the Michigan Occupational Safety and Health Act (MIOSHA). Pesticide applicators and technicians should keep up-to-date copies of the laws and review their contents periodically. Copies of Michigan pesticide laws can be obtained from Michigan Department of Agriculture (MDA) regional offices. Refer to the core manual (MSU Extension bulletin E-2195) to learn more about these and other laws affecting pesticide use.

GUIDELINES FOR SELECTING AND USING PESTICIDES

The most important law regulating pesticide registration, distribution, sales, and use in the United States is the Federal Insecticide, Fungicide, and Rodenticide Act, or FIFRA. The Environmental Protection Agency (EPA) and the Michigan Department of Agriculture (MDA) administer FIFRA.

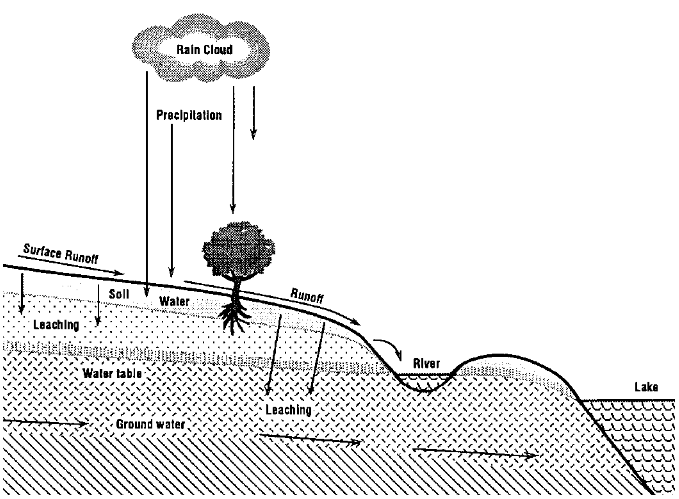
Pesticide labels provide use information such as safety precautions, application rates, sites where the pesticide can be applied, and target pests. They contain information to protect the applicator, the environment, and the crop while maximizing pest control. Pesticide labels are legal documents that must be followed. Always read the entire label and all supplemental labeling before using a pesticide. **Supplemental labeling** includes any information you receive from the manufacturer about how to use the product. It is considered part of the pesticide label and may be supplied at the time of purchase or requested from the dealer. If an applicator applies a pesticide according to a supplemental label, a copy of the supplemental label must be in the applicator's possession at the time of application. Supplemental labels include special local needs labels (24c), emergency exemption labels (section 18), and use information issued by the pesticide manufacturer.

Always:

- Select pesticides labeled for use on your crop.
- Read and understand the label instructions and limitations before each use.
- Follow the application directions on the pesticide label.
- Contact your county MSU Extension office if you have questions or concerns about a particular pesticide.

PROTECTING OUR GROUNDWATER

Groundwater is the water beneath the earth's surface. It is found in the cracks and pores of rocks and in the spaces between sand grains and other soil particles. Many people living in rural Michigan get their drinking water from wells. It is easy to see why you should be concerned about keeping pesticides out of groundwater.



Groundwater is always moving. Eventually, it reaches the earth's surface at natural places such as lakes, springs, and streams. Sometimes it is pumped to the surface from wells. Every year, rain and snow seep into the soil, replenishing the groundwater. The depth at which you first find groundwater is referred to as the **water table**. The water table depth changes during the year, depending on the amount of water added and removed from the ground.

Both **surface water**—visible bodies of water such as lakes, rivers, and oceans – and groundwater are subject to contamination by point and non-point source pollution. When a pollutant enters the water from a specific source, it is called **point source pollution**. For example, a factory that discharges chemicals into a river is a point source. **Non-point source pollution** refers to pollution from a generalized area or weather event, such as land runoff, precipitation, acid rain, or percolation rather than from discharge at a single location.

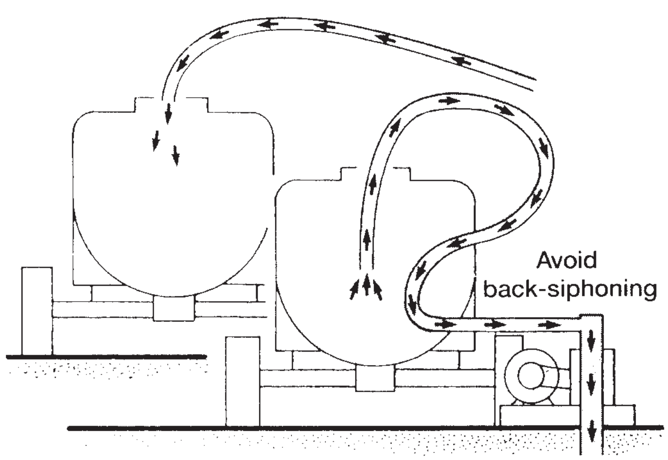
Keeping Pesticides Out of Groundwater and Surface Water

A pesticide that has not become a gas (volatilized), or been absorbed by plants, bound to soil, or broken down can potentially migrate through the soil to groundwater. Groundwater movement is slow and difficult to predict. Substances entering groundwater in one location may turn up years later somewhere else. A difficulty in dealing with groundwater contaminants is discovering the pollution source when the problem is occurring underground, out-of-sight. Also, microbial and photodegradation (by sunlight) do not occur deep underground, so pesticides that reach groundwater break down very slowly.

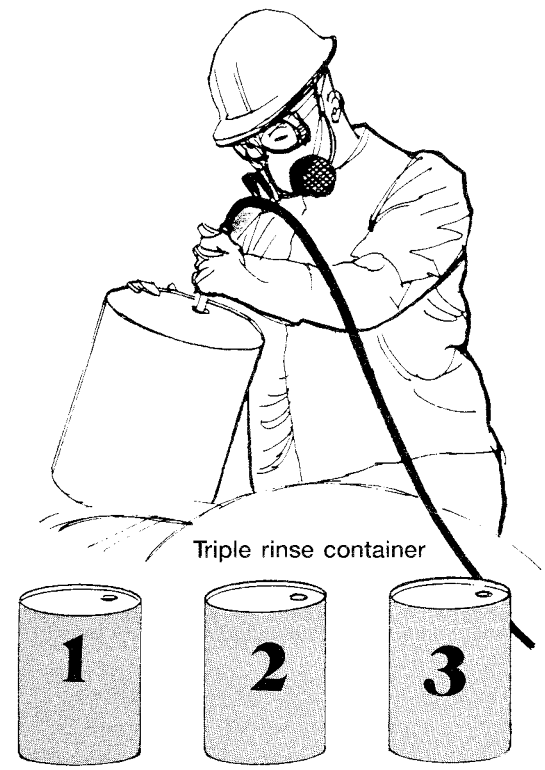
Cleaning contaminated groundwater or surface water is extremely difficult. Following certain practices can reduce the potential for pesticide contamination of groundwater and surface water:

- **Use integrated pest management.** Keep pesticide use to a minimum.
- **Consider the geology of your area** when locating wells, mix/load sites, or equipment washing sites. Be aware of the water table depth and how fast water moves in the geological layers between the soil surface and the groundwater.

- **Select pesticides carefully.** Choose pesticides that are not likely to leach (move downward) in the soil into groundwater or run off into surface water. Pesticides that are very water soluble and not easily bound to soil tend to be the most likely to leach. Read pesticide labels carefully, consult the MSU Extension pesticide application guides, or seek advice from an MSU specialist or a pesticide dealer to choose the best pesticide for your situation.
- **Follow pesticide label directions.** Container and supplemental pesticide labels are the law. Labels provide crucial information about application rates, timing, and placement of the pesticide. Consult all labels before using the pesticide.
- **Calibrate accurately.** Calibrate equipment carefully and often to avoid over- or underapplication.
- **Measure accurately.** Carefully measure concentrates before placing them into the spray tank. Do not "add a little extra" to ensure that the pesticide will do a better job.
- **Avoid back-siphoning.** Make sure the end of the fill hose remains above the water level in the spray tank at all times. This prevents back-siphoning of the pesticide into the water supply. Use an anti-backflow device when siphoning water directly from a well, pond, or stream. Do not leave your spray tank unattended.



- **Consider weather conditions.** If you suspect heavy rain will occur, delay applying pesticides.
- **Mix on an impervious pad.** Mix and load pesticides on an approved impervious mix/load pad where spills can be contained and cleaned up. If mixing in the field, change the location of the mixing area regularly. A portable mix/load pad is required if you fill at the same location 10 or more times per year.
- **Dispose of wastes and containers properly.** All pesticide wastes must be disposed of in accordance with local, state, and federal laws. Triple-rinse containers. Pour the rinse water into the spray tank for use in treating the labeled site or crop. After triple rinsing, perforate the container so it cannot be reused. Recycle all metal and plastic triple-rinsed containers or dispose of them in a state-licensed sanitary landfill. Dispose of all paper containers in a sanitary landfill or a municipal waste incinerator. Do not burn used pesticide containers. Burning does not allow for complete combustion of most pesticides, resulting in pesticide movement into the air; it is also a violation of state regulations administered by the Michigan Department of Environmental Quality. Contact your regional MDA office or local county Extension office for information on pesticide container recycling in your area.



- **Store pesticides safely and away from water sources.** Pesticide storage facilities should be situated away from wells, cisterns, springs, and other water sources. Pesticides should be stored in a locked facility that will protect them from temperature extremes, high humidity, and direct sunlight. The storage facility should be heated, dry, and well ventilated. It should be designed for easy containment and cleanup of pesticide spills and made of materials that will not absorb any pesticide that leaks out of a container. Store only pesticides in such a facility, and always store them in their original containers.

PROTECTING NON-TARGET ORGANISMS

The best way to avoid injury to **beneficial insects and microorganisms** is to minimize the use of pesticides. Use selective pesticides when possible. Apply pesticides only when necessary and as part of an integrated pest management program.

To reduce the chance of bee poisoning:

- **Do not treat near beehives.** Bees may need to be moved or covered before you use pesticides near hives.

- **Select the least hazardous pesticide formulation and lowest toxicity if bees are present.** Dusts are more hazardous to bees than sprays. Wettable powders are more hazardous than emulsifiable concentrates (EC) or water-soluble formulations. Microencapsulated pesticides are extremely dangerous to bees because the very small capsules can be carried back to the hive. Granular insecticides are generally the least hazardous to bees.
- **Do not apply pesticides that are toxic to bees if the site contains a blooming crop or weed.** Remove the blooms by mowing before spraying.
- **Minimize spray drift** by selecting appropriate nozzles, adding an **adjuvant**, or postponing the application to a less windy time.
- **Time pesticide applications carefully.** Evening applications are less hazardous than early morning ones; both are safer than midday applications.

Pesticides can also be harmful to **vertebrates** such as fish and wildlife. Fish kills may result when a pesticide (usually an insecticide) pollutes water or changes the pH of the water. Pesticides may enter water via drift, surface runoff, soil erosion, or leaching.

Pesticides may result in bird kills if birds ingest granules, baits, or treated seed; are exposed directly to the spray; drink and use contaminated water; or feed on pesticide-contaminated prey.

Endangered and threatened species are of special concern. Under the federal Endangered Species Act, every pesticide posing a threat to an endangered or threatened species or to its habitat must have a warning statement on the label. The warning provides instructions on how to safeguard the species when using the pesticide within its habitat.

POTENTIAL FOR PESTICIDE RESISTANCE

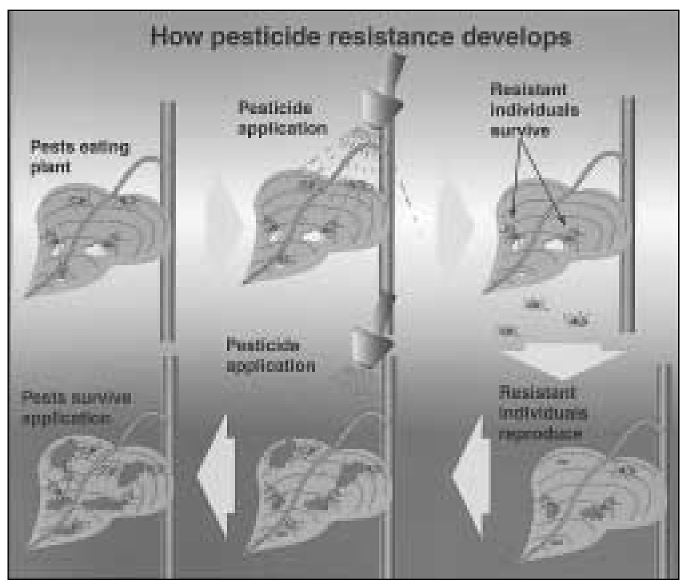
Pesticide resistance is a measurement of a pest's ability to tolerate the toxic effects of a particular pesticide. Intensive use of a product may allow only resistant individuals to survive. As the number of resistant individuals increases in a pest population, the original application rate or spray frequency no longer provides adequate control.

The Development of Resistance

Repeated applications of the same pesticide or of pesticides with a common mode of action give a pest population a chance to develop resistance. **Resistance** is an individual's (weed, crop, insect, etc.) ability to survive a specific pesticide application. There are three mechanisms of resistance. Resistant individuals:

1. May have a modified site of action so that the pesticide is no longer toxic.
2. Metabolize (detoxify) the pesticide. **Metabolism** is a biochemical process that modifies the pesticide to less toxic compounds.
3. Remove the pesticide from the site of action.

Resistant individuals have the genetic ability to survive when the pesticide is applied, and their offspring inherit the pesticide resistance. Because the pesticide kills most of the non-resistant individuals, the resistant organisms over time make up an increasingly larger percentage of the surviving pest population. With each use of the pesticide, this percentage increases until most of the pests are resistant and the chemical is no longer effective against the pest.



In most cases, pests that are resistant to one pesticide will show resistance to chemically related pesticides. This is called **cross-resistance**. Cross-resistance occurs because closely related pesticides kill pests in the same way—for example, all organophosphate insecticides kill by inhibiting the same enzyme in the nervous system, cholinesterase. If a pest can resist the toxic action of one pesticide, it can often survive applications of other pesticides that kill the same way.

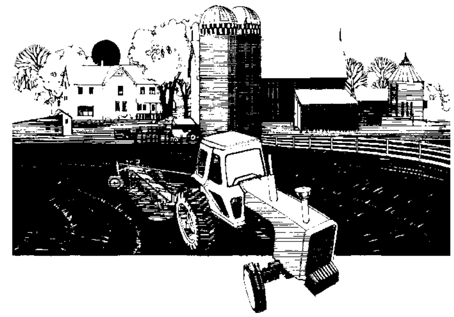
Resistance Management

Resistance management attempts to prevent or delay the development of resistance. A resistance management program includes:

- **Using integrated pest management.** Combine cultural, mechanical, biological, and chemical control measures into a practical pest management program. For example, crop rotation can reduce the buildup of pests in a particular crop, reducing the number of pesticide applications needed. This reduces the advantage that resistant individuals have over non-resistant individuals and delays or prevents the buildup of resistance in a population.
- **Using pesticides from different chemical families with different modes of action.** Try to do this whether you apply pesticides against a pest once a year or several times within a treatment season.
- **Using pesticides only when needed, and using only as much as necessary.**

NOTIFYING NEIGHBORS

Good public relations are extremely important when applying pesticides. It is the joint responsibility of landowner and applicator to see that neighboring landowners are not subjected to acts of trespass or exposed to spray drift. As a matter of courtesy, it is a good idea to inform adjacent landowners, neighbors, and beekeepers in advance of any large-scale pesticide application.



If off-target pesticide drift is expected, Michigan Regulation 637 requires a pesticide applicator to have a drift management plan. A drift management plan should contain:

- A map of all areas where pesticide applications occur.
- A list of pesticide-sensitive sites located near an application area – for example, schools, daycare facilities, or sensitive crops.
- Pesticide label and mandated restrictions that relate to setback provisions from sensitive areas.
- Information for persons in sensitive areas regarding the type of pesticide used, the method of application, and the applicator's plan to minimize pesticide drift.

A drift management plan should be used by private and commercial applicators as a communication tool to minimize adverse effects of off-target drift. For more information on drift management plans, contact the Michigan Department of Agriculture.

CHAPTER 2

Review Questions

Chapter 2: Minimizing Pesticide Impact

Write the answers to the following questions and then check your answers with those in the back of the manual.

1. A pesticide label is a legally binding document.
   A. True
   B. False

2. What is supplemental labeling? Give an example.

3. A certified pesticide applicator may apply a pesticide labeled for use on tomatoes to cucumbers only if:
   A. The same pest is present on both crops.
   B. Use for cucumbers is also on the pesticide label.
   C. A lower rate is applied to the cucumbers.
   D. The pest density is above the economic threshold.

4. Which of the following is **not** true about groundwater?
   A. It is always moving.
   B. It is measured by the water table.
   C. It is found at the earth's surface.
   D. It is used as drinking water.

5. When applying a pesticide according to the instructions on a supplemental label, you should have:
   A. A Michigan Department of Agriculture official with you.
   B. The dealer's phone number with you.
   C. A copy of the Michigan pesticide laws with you.
   D. The label with you.

6. The part of the government that regulates pesticides in the United States is the:
   A. Environmental Protection Agency (EPA).
   B. Food and Drug Administration (FDA).
   C. U.S. Department of Agriculture (USDA).
   D. Occupational Safety and Health Administration (OSHA).

7. The least hazardous pesticide formulation for bees and other pollinating insects is:
   A. Emulsifiable concentrates.
   B. Granular.
   C. Wettable powders.
   D. Dusts.

8. The water table depth changes:
   A. In the summer.
   B. In the winter.
   C. Never.
   D. Throughout the year.

9. Rain and melting snow do **not** affect the water table.
   A. True
   B. False

10. Non-point source pollution is generally easier to trace back to the origin than point source pollution.
    A. True
    B. False

11. List five ways you can reduce the risk of pesticides contaminating groundwater.

12. Which of the following is true about back-siphoning?

    A. It does not occur with an IPM program.
    B. It helps minimize pesticide drift.
    C. It can lead to contamination of water.
    D. It occurs when pesticides volatilize.

13. Which of the following is a proper method of disposing of an empty pesticide container?

    A. Burn it.
    B. Rinse and dispose in a licensed landfill.
    C. Use it to hold other pesticides.
    D. Bring to your local MDA office.

14. The impact of pesticides on bees and other pollinating insects can be reduced by applying:

    A. Pesticides under favorable weather conditions.
    B. When plants are in bloom.
    C. Microencapsulated pesticides.
    D. Broad-spectrum pesticides.

15. Pesticides are **not** harmful to fish and birds.

    A. True.
    B. False.

16. The ability of a pest to detoxify a pesticide and survive is a form of:

    A. Resistance.
    B. Phytotoxicity.
    C. Pollution.
    D. Pesticide drift.

17. A resistance management program will __________ the development of pesticide resistance.

    A. speed up
    B. slow down

18. The ability of a pest to develop resistance to similar pesticides is called:

    A. Mechanical control
    B. Cross-resistance.
    C. Cholinesterase.
    D. Resistance management.

19. In Michigan, a drift management plan is required if off-target pesticide drift is likely to occur.

    A. True.
    B. False.

20. List four items to include in a drift management plan.

CHAPTER 3

APPLICATION EQUIPMENT

LEARNING OBJECTIVES

After completely studying this chapter, you should:

- Know the various pesticide application methods and the factors that influence your choice of the appropriate method.
- Know special application methods that are used for vegetable crop weed control and when and how they are applied.
- Know the various sprayer components, how they operate, and what the desirable features are.
- Know the various sprayer types, how they operate, and what the desirable features are.
- Understand proper operation and maintenance of sprayers, before, during, and after spraying.
- Know the various types of granular applicators and application methods, when they are applied, and what they consist of.

METHODS OF APPLICATION

The method you choose to apply a pesticide will depend on the nature and habits of the target pest, the site, the pesticide, available application equipment, and the cost and efficiency of alternative methods. Some common application methods are described below.

Broadcast application is the uniform application of a pesticide to an entire area.

A **directed-spray application** targets pests in a specific area in an effort to minimize pesticide contact with the crop or beneficial insects.

Foliar application directs pesticide to the leafy portions of a plant.

Spot treatment is application of a pesticide to small, discrete areas.

Soil application places pesticide directly on or in the soil rather than on a growing plant.

Soil incorporation is the use of tillage equipment to mix the pesticide with the soil.

Soil injection is application of a pesticide beneath the soil surface.

TYPES OF SPRAYERS

When selecting a sprayer, be certain that it will deliver the proper rate of pesticide uniformly over the target area. Most pesticide applications in vegetable crops are done with a hydraulic sprayer at either high or low pressures.

Hydraulic Sprayers

Water is most often used with hydraulic spraying equipment as the means of carrying pesticide to the target area. The pesticide is mixed with enough water to obtain the desired application rate at a specific pressure and travel speed. The spray mixture flows through the spraying system under pressure and is released through one or more nozzles onto the target area.

Low-pressure Sprayers

Low-pressure sprayers normally deliver low to moderate volumes at low pressure—15 to 100 pounds of pressure per square inch (psi). The spray mixture is applied through a boom equipped with nozzles. The boom usually is mounted on a tractor, truck, or trailer, or the nozzle(s) can be attached to a hand-held boom.

Low-pressure sprayers do not deliver sufficient volume to penetrate dense foliage. They are most useful in distributing dilute pesticide over large areas.

High-pressure Sprayers

High-pressure sprayers deliver large volumes at high pressure. They are similar to low-pressure sprayers but deliver up to 50 gallons of spray per minute at pressures up to 800 psi. A boom delivers 200 to 600 gallons per acre.

High-pressure sprayers provide thorough coverage and can penetrate dense foliage, but they can produce large numbers of small spray droplets that can drift. These sprayers can provide low-pressure flow when fitted with proper pressure regulators.

PARTS OF A SPRAYER

To properly select, maintain, and operate your sprayer, you need to know its parts. The major components of a sprayer are tank, pump, agitator, flow control, and nozzles.

Sprayer tank, wand, pump and gauge.

Tanks

Suitable materials for spray tanks include stainless steel, polyethylene plastic, and fiberglass. Spray tanks made of aluminum, galvanized steel, and stainless steel are easily corroded by some pesticides and liquid fertilizers. The tank cover should form a watertight seal when closed to minimize spills. All tanks should have a drain plug at their lowest point and shut-off valves so that any liquid in the tank can be held without leaking if the pump, strainers, or other parts of the system need to be serviced.

Tank capacity markings must be accurate so that you can add the correct amount of water. A clear plastic tube (sight gauge) is mounted on metal tanks.

Agitators

Agitation is required to combine the components of the spray mixture uniformly and, for some formulations, to keep the pesticide in suspension. If agitation is inadequate, the application rate of the pesticide may vary as the tank is emptied. The two common types of agitation are hydraulic and mechanical.

The quantity of flow required for agitation depends on the chemical used. Little agitation is needed for solutions and emulsions, but intense agitation is required for wettable powders. For jet agitators, a flow of 6 gallons per minute for each 100 gallons of tank capacity is adequate. The jet should be submerged to prevent foaming. Wettable powder suspensions can wear the inside of the tank if the jet stream passes through less than 12 inches of liquid before hitting the tank wall.

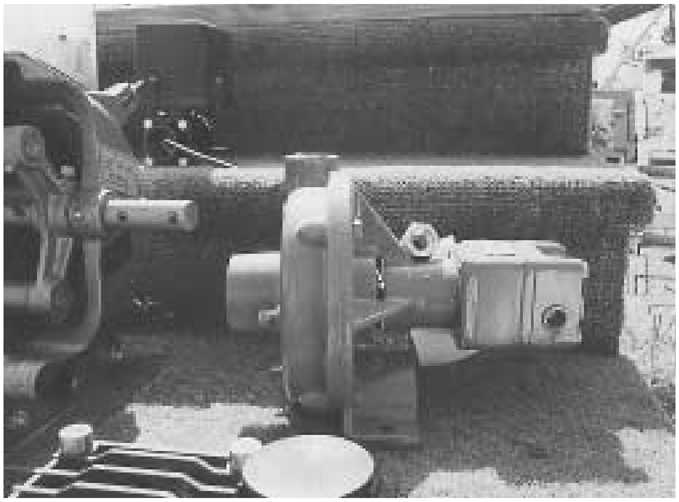
A mechanical agitator consists of a shaft with paddles and is located near the bottom of the tank. The shaft is driven by an electric motor or some other device powered by the tractor. This system is more costly than jet agitation. Mechanical agitators should operate at 100 to 200 rpm. Foaming will result at higher speeds.

Pumps

The pump must deliver the necessary flow to all nozzles at the desired pressure to ensure uniform distribution. Pump flow capacity should be 20 percent greater than the largest flow required by the nozzles.

When selecting a pump, consider resistance to corrosive damage from pesticides, ease of priming, and power source availability. The materials in the pump housing and seals should be resistant to chemicals, including organic solvents.

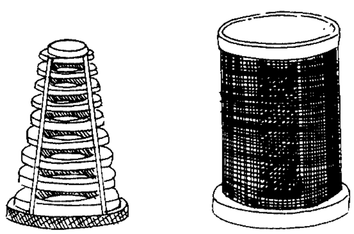
Pesticide sprayers commonly use roller, piston, diaphragm, and centrifugal pumps. Each has unique characteristics that make it well adapted for particular situations. Choose a pump that best fits your pesticide application program.



Centrifugal pump.

Strainers

Proper filtering of the spray mixture not only protects the working parts of the spray system but also avoids misapplication due to nozzle tip clogging. Three types of strainers commonly used on sprayers are tank filler strainers, line strainers, and nozzle strainers. As the mixture moves through the system, strainer openings should be progressively smaller. Strainer mesh size is determined by the number of openings per linear inch; a high strainer size number indicates smaller openings. Strainers need to be checked for clogs and rinsed frequently.



Strainers.

Hoses

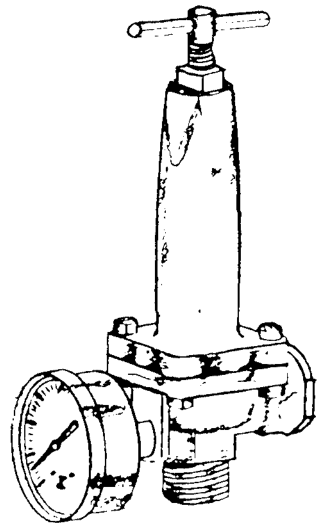
Use synthetic rubber or plastic hoses that have a burst strength greater than peak operating pressures, resist oil and solvents present in pesticides, and are weather resistant.

Sprayer lines must be properly sized for the system. The suction line, often the cause of pressure problems, must be airtight, non-collapsible, and as short as possible, and have an inside diameter as large as the pump intake.

Pressure Regulators

A pressure regulator is one of the most important parts of a sprayer. It controls the pressure and therefore the quantity of spray material delivered by the nozzles. It protects pump seals, hoses, and other sprayer parts from damage due to excessive pressure, and it bypasses excess spray material back to the tank.

There are two types of pressure regulators – simple relief valves and pressure unloaders. Relief valves are simple bypass valves that require the pump and engine to keep working just as though you were spraying. Pressure unloaders maintain working pressure on the discharge end of the system but move the overflow back into the tank at lower pressure, thus reducing strain on the engine and the pump.

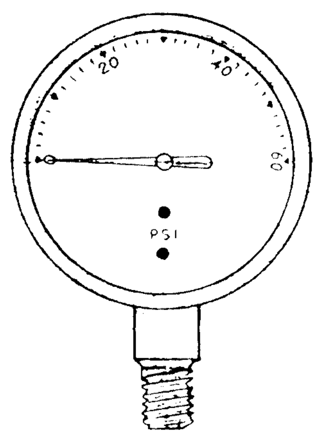


Pressure regulator.

Be certain that the flow capacity of the pressure regulator matches that of the pump being used.

Pressure Gauge

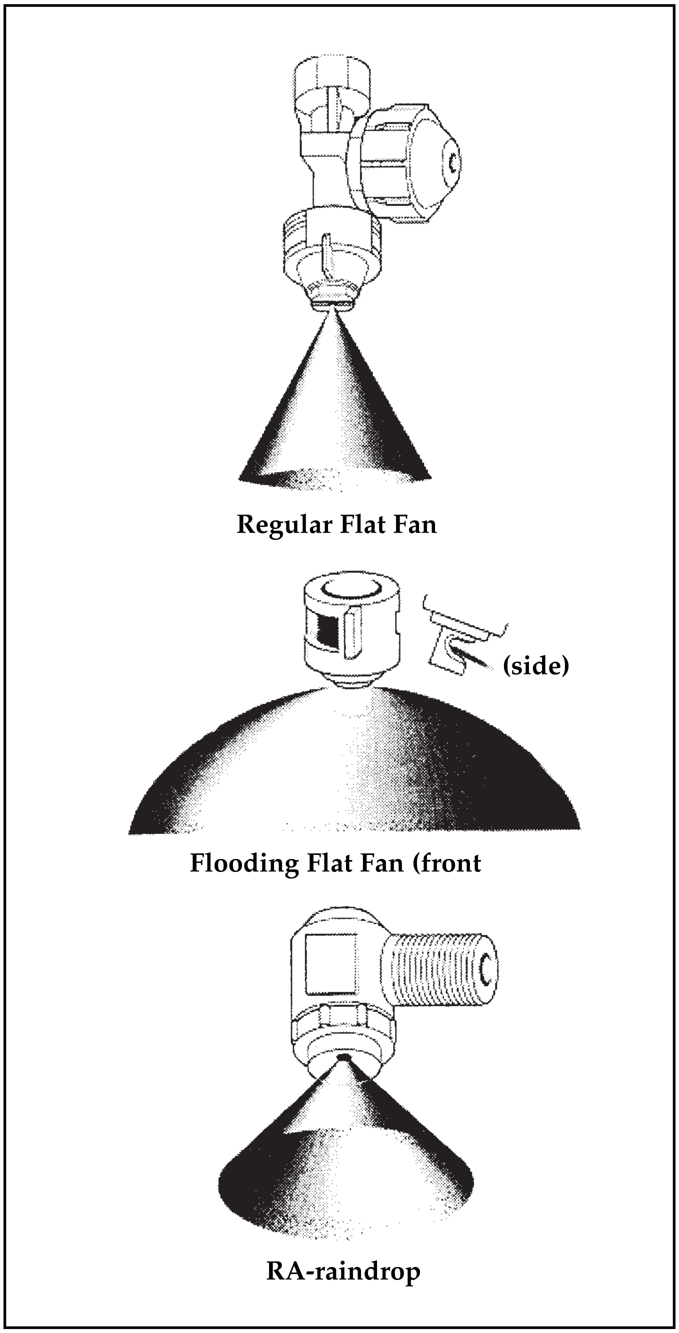
A pressure gauge is essential to every sprayer system to correctly indicate the pressure at the nozzle. Pressure directly affects the application rate and spray distribution. Pressure gauges often wear out because they become clogged with solid particles of spray material. A glycerine-loaded diaphragm gauge is more expensive but will last indefinitely.



Pressure gauge.

Nozzles

Nozzles are important to control the volume of pesticide applied, the uniformity of application, the completeness of coverage, and the degree of drift. Many types of nozzles are available, each one designed for a specific type of application. Regular flat-fan, flood, and whirl chamber nozzles are preferred for weed control. For minimum drift, flood and raindrop nozzles are preferred because they produce large droplets.



Types of nozzles.

Regular Flat-fan Nozzle

Regular flat-fan nozzles are designed for broadcast applications and are sometimes used on high-clearance and pickup sprayers. They are typically used for foliar applications and require a 30 to 50 percent pattern overlap to obtain uniform coverage. Flat-fan nozzles are recommended for herbicides and insecticides where foliage penetration and complete coverage are not necessary.

Regular flat-fan nozzles produce a narrow oval pattern and medium droplets at pressures of 15 to 20 psi; drift potential increases at pressures above 30 psi.

Flooding Flat-fan Nozzle

Flooding flat-fans are the most commonly used nozzles. They produce a wide-angle pattern that varies with pressure. At high pressure, the pattern is heavier in the center and tapers off toward the edges; at low pressures, they produce a uniform pattern.

Pressure also affects droplet size. Flooding flat-fan nozzles produce large spray droplets at low pressure and small droplets at high pressure. To control drift, flooding nozzles should be operated at between 8 and 25 psi.

Hollow-cone whirl chamber nozzle

The hollow-cone nozzle is used primarily to penetrate foliage for effective pest control when drift is not a concern. These nozzles produce small droplets at pressures of 40 to 80 psi that penetrate plant canopies and cover the undersides of leaves more effectively than spray from other nozzles.

Whirl chamber nozzles have two pieces. The first part is the whirl chamber, which squirts the material as it moves through the second piece, a disk. This results in a circular hollow-cone spray pattern.

Raindrop Nozzle

Raindrop nozzles are designed to reduce drift. This nozzle produces large droplets in a hollow-cone pattern when operated between 20 and 50 psi. The large droplets aid in drift control but may result in poor coverage by some foliar pesticides.

Nozzles are available in a variety of materials. Brass nozzles are inexpensive but wear rapidly. Stainless steel, nylon, and other plastic nozzles are wear resistant when used with corrosive or abrasive materials. Nozzles made of hardened stainless steel are the most wear resistant and expensive.

OPERATION AND MAINTENANCE OF SPRAYERS

Proper operation and maintenance of spray equipment will lead to safe and effective pest control, significantly reduce repair costs, and prolong the life of the sprayer.

Before Spraying

At the beginning of each spraying season, fill the tank with water and pressurize the system to be sure all the parts are working and there are no drips or leaks. All nozzles should be of the same type, size, and fan angle. If using nozzle strainers, make sure the check valves are working properly. Functioning check valves prevent dripping when flow to the nozzle drops below a specific pressure. Measure the distance between the nozzle tip and the target, and adjust the boom accordingly. In broadcast applications, nozzle height affects the uniformity of the spray pattern.

Fill the tank with water that does not have silt or sand in it. Keep the tank level when filling, to make sure the quantity in the tank is correctly indicated.

Calibrate the sprayer before using. (Calibration is discussed in Chapter 4 of this manual.)

During Spraying

Frequently check the pressure gauge to make sure the sprayer is operating at the same pressure and speed used during calibration. Operate the sprayer at speeds appropriate for the conditions. Bouncing and swaying booms can cause application rates to vary. Periodically check hoses and fittings for leaks, and check nozzles for unusual patterns. If you must make emergency repairs or adjustments in the field, wear the protective clothing listed on the pesticide label as well as chemical-proof gloves.

After Spraying

Always flush the spray system with water after each use. Apply this rinse water to sites for which the pesticide is labeled. Clean the inside and outside of the sprayer thoroughly before switching to another pesticide and before doing any maintenance or repair work. All parts exposed to a pesticide will normally have some residue, including sprayer pumps, tanks, hoses, and boom ends

GRANULAR APPLICATIONS

Granular applicators are designed primarily for soil applications and are available in various styles and sizes. Drop-through spreaders and rotary spreaders are the most common types of applications.

Granular applicators normally consist of a hopper for the pesticide, a mechanical-type agitator at the base of the hopper to provide efficient and continuous feeding, and some type of metering device, usually a slit-type gate, to regulate the flow of the granules.

Drop-through Spreaders

Drop-through spreaders are available in many widths. An adjustable sliding gate opens holes in the bottom of the hopper and the granules flow out by gravity feed. Normally, a revolving agitator is activated when the spreader is in motion to assure uniform dispensing.

Rotary Spreaders

Rotary spreaders distribute the granules to the front and sides of the spreader, usually by means of a spinning disk or fan. Heavy granules are thrown farther than lighter ones. A 6- to 8-foot swath width is common. Both power- and hand-driven rotary spreaders are available.

FIELD OPERATIONS

Pest control with pesticides relies on uniform application of the correct amount of product at the most efficient time. Clogged or worn nozzles, overlapping, and deviations in swath width can double applications or create skips in the treated area.

Dripping nozzles can cause crop damage during turns or when the sprayer is stopped for any reason. Use a positive shutoff, such as a high-capacity diaphragm check valve, to avoid dripping nozzles. Hydraulic and air-activated shutoff systems are more reliable but much more expensive.

GLOBAL POSITIONING SYSTEM (GPS) AND GEOGRAPHICAL INFORMATION SYSTEM (GIS)

Global positioning system (GPS) and geographical information system (GIS) technology has helped increase the accuracy of pesticide applications. This technology combines a tracking and guidance system with precise field mapping. Global positioning systems are based on the triangulation of worldwide satellite signals to determine exact field location. Geographic information systems are computer systems that interpret, manipulate, and display GPS information about a specific location. For example, a grower using a global positioning system can record the exact location of weedbeds in a field. A geographic information system can interpret this information and produce a map of the weed bed locations. This map can be used to apply pesticides directly to the weed beds the following year.

Geographic information systems can also be linked directly to application equipment and used to turn spray nozzles on and off. This results in pesticide applications only where necessary. Global positioning and geographical information systems are most frequently used with herbicide and fungicide applications.

Review Questions

Chapter 3: Application Equipment

Write the answers to the following questions and then check your answers with those in the back of the manual.

1. Which of the following methods of application mixes the pesticide into the soil?
   A. Soil treatment
   B. Soil application
   C. Soil fumigation
   D. Soil incorporation

2. What are some of the factors that influence the choice of pesticide application method?

3. What is one reason to use a directed-spray pesticide application?
   A. To minimize contact with beneficial insects.
   B. To get an evenly distributed application.
   C. To avoid flashback.
   D. All of the above.

4. Pesticides can corrode certain materials from which spray tanks are made.
   A. True
   B. False

5. A spray tank should have:
   A. An opening for filling.
   B. A shutoff before the pump.
   C. A drain plug at the lowest point.
   D. All of the above.

6. To compensate for pump wear, pump flow capacity should ______________ the largest flow required by the nozzles and hydraulic agitation.
   A. Be less than
   B. Be equal to
   C. Be greater than
   D. Not affect

7. All spray pumps are resistant to the corrosive effects of pesticides.
   A. True
   B. False

8. Which of the following formulations requires the most agitation?
   A. Wettable powders
   B. Solutions
   C. Emulsions
   D. Liquids

9. Hydraulic agitation is accomplished by a shaft with paddles in the spray tank.
   A. True
   B. False

10. With paddle agitation, foaming can result if the shaft motor is operated:
    A. Too slow.
    B. Too fast.
    C. Too long.
    D. Too little.

11. With hydraulic agitation, foaming can result if the jet is:

   A. Not operating.
   B. Above the liquid level in the tank.
   C. Below the liquid level in the tank.
   D. All of the above.

12. As liquid moves from the spray tank to the nozzle, the strainer mesh should:

   A. Remain the same.
   B. Become larger.
   C. Become smaller.
   D. Not matter.

13. Strainers within the spray system are cleaned automatically by the movement of the spray solution.

   A. True
   B. False

14. The burst strength of spray system hoses should be greater than the:

   A. Peak operating pressure.
   B. Volume of spray delivered.
   C. Length of the hose.
   D. Temperature during the application.

15. What does the pressure regulator do?

16. Relief valves and pressure unloaders are two types of:

   A. Pressure gauges.
   B. Nozzles.
   C. Pressure regulators.
   D. Hose fittings.

17. Nozzle types are specific to the types of applications.

   A. True
   B. False

18. Low-pressure sprayers and high-pressure sprayers are most efficient if they have the same type of pump.

   A. True
   B. False

19. Low-pressure sprayers are very useful for:

   A. Penetrating dense foliage.
   B. Delivering dilute pesticide over large areas.
   C. Spot treatment.
   D. All of the above.

20. High-pressure sprayers can:

   A. Provide high volume at high pressure.
   B. Penetrate dense foliage.
   C. Increase spray drift.
   D. All of the above.

21. What are the first two tasks when readying sprayers for the new season?

22. If a sprayer breaks down, it is **not** necessary to wear personal protective equipment while doing repairs.

   A. True
   B. False

23. After the inside of the spray tank has been rinsed with water, the water should be:

   A. Sprayed on any site as long as it has plant material growing on it.
   B. Sprayed on any bare soil.
   C. Sprayed on a site that appears on the pesticide label.
   D. Stored.

24. Granular applicators are designed primarily for:

   A. Foliar application.
   B. Soil application.
   C. Spot application.
   D. Basal application.

25. How can global positioning systems and geographical information systems aid a pesticide applicator?

CHAPTER 4

CALIBRATION

LEARNING OBJECTIVES

After completely studying this chapter, you should:

- Understand the purpose of calibration and why it is an essential process.
- Know the basic tools needed to calibrate sprayers and the variables that determine spray rate.
- Be able to check for and calculate nozzle output and know the guideline for determining when nozzles are worn out.
- Know what factors affect spray pattern uniformity and how to check for it.
- Understand how to calibrate a sprayer for ***broadcast application***.
- Be able to calculate how much pesticide to add to the spray tank for broadcast application.
- Know how to properly calibrate a hand sprayer on a per-acre basis and for a ***band application***.
- Know how to calibrate granular applicators, both drop-through spreaders and rotary spreaders.

INTRODUCTION

The purpose of **calibration** is to ensure that your equipment delivers the correct amount of pesticide uniformly over the target area. Calibration is the step in pesticide application that is most often neglected and misunderstood. Because virtually every sprayer is a unique combination of pumps, nozzles, and other equipment, calibration is an essential process for an applicator to learn.

For proper calibration, you will need a few basic tools, including a stopwatch, a collection container graduated in ounces, a tape measure, and flags or stakes for marking. Unless your sprayer is new, it will contain a certain amount of pesticide residue; therefore, a pair of chemical-proof gloves is also recommended. Additionally, a pocket calculator will help with calculations.

In this chapter, we provide formulas that are designed to make calibration easier for you. Some of these formulas have constants – i.e., numbers that remain the same whenever you use that formula. To make calibrations easier for you, we provide you with the constants.

CALIBRATION OF SPRAYERS

Calibrating a sprayer ensures that the sprayer is delivering the intended volume of spray mixture to the target area. You must determine each of the following:

- The amount of product the sprayer delivers per acre.
- The number of acres you can spray per tank.
- The recommended rate of pesticide application.
- The amount of pesticide to add to the spray tank.

Variables that Determine the Spray Rate

Two major variables affect the amount of spray mixture applied per acre (most commonly expressed in gallons per acre): the *nozzle flow rate* and the *ground speed* of the sprayer. You must understand the effect that each of these variables has on sprayer output to calibrate and operate your sprayer properly.

Nozzle Flow Rate

The flow rate through a nozzle varies with the nozzle pressure and the size of the nozzle tip. Increasing the pressure or using a nozzle tip with a larger opening will increase the flow rate (gallons per acre).

Increasing pressure will NOT give you a proportional increase in flow rate. For example, doubling the pressure will not double the flow rate – you must increase the pressure fourfold to double the flow rate.

Sprayer pressure (speed constant)	Sprayer output (gallons per acre)
10 psi	10
40 psi	20
160 psi	40

Pressure cannot be used to make major changes in spray rate, but it can be used to make minor changes. Keep in mind that operating pressure must be maintained within the recommended range for each nozzle type to obtain a uniform spray pattern and minimize drift.

The easiest and most effective way to make a large change in flow rate is to change the size of the nozzle tips. Depending on operating pressure, the speed of the sprayer, and nozzle spacing, small changes in nozzle size can significantly change sprayer output per acre. Use nozzle manufacturers' catalogs to select the proper tip size.

Ground Speed of the Sprayer

Provided the same throttle setting is used, as speed increases, the amount of spray applied per unit area decreases at an equivalent rate. For example, doubling the ground speed of a sprayer will reduce the amount of spray applied by one-half.

Sprayer speed (under constant pressure)	Sprayer output (gallons per acre)
1 mph	40
2 mph	20
3 mph	13.3
4 mph	10

To determine the new output after changing speed:

$$\text{New output} = \frac{\text{old output x old speed}}{\text{new speed}}$$

Some low-pressure sprayers are equipped with control systems that maintain a constant application rate over a range of travel speeds, provided the same gear setting is used. Pressure is automatically changed to vary the nozzle flow rate in proportion to changes in ground speed. Even so, do your calibration at a set ground speed. In the field, travel speed must be kept within certain limits to keep the nozzle pressure within the recommended range.

Precalibration Check of Nozzle Output

After making sure the system is clean, fill the tank approximately half full with water. Fasten a graduated container under each nozzle and operate the sprayer for one minute at a pressure within the recommended pressure range. Check to see that the flow rate from each nozzle is approximately the same; replace or clean any nozzle whose output differs by more than 5 percent from the average for all of the nozzles and again check the flow rates.

For example, the following flow rates are obtained for six nozzles:

Nozzle	Output (ounces per minute)
1	40.0
2	43.0
3	39.5
4	40.5
5	37.5
6	39.5
	Total 240.0 ounces

The average nozzle output is 40 ounces (240 ÷ 6).

Five percent of 40 ounces (40 x 0.05) is 2 ounces. Any nozzle whose output differs from 40 ounces by more than 2 ounces should be cleaned or replaced; that is, any nozzle whose output is greater than 42 or less than 38. Therefore, nozzle #5 should either be cleaned or replaced. The flow rate of nozzle #2 is too high. This indicates that the nozzle is worn and should be replaced.

When the average nozzle output varies by more than 10 percent from the manufacturer's specifications, the nozzles are worn enough to justify the purchase of a new set. This is particularly important when using flat-fan or flood nozzles because proper spray overlap becomes difficult to maintain with worn nozzles.

Spray Pattern Uniformity

A uniform spray pattern is crucial for an effective pesticide application. It's not enough to apply a pesticide only in its correct amount – you also must apply it uniformly over the target area. The effects of non-uniform application are most obvious when herbicide bands overlap and streaking results. Spray pattern uniformity is affected by boom height, spacing and alignment of nozzles on the boom, condition of nozzles (worn, damaged), and operating pressure. Check that all nozzles are of the same type. Also, a frequent cause of poor spray patterns is using nozzles with different spray angles on the same boom.

To check the uniformity of the spray pattern, adjust the boom height for the spray angle and nozzle spacing being used. Align flat-fan nozzles at a slight angle to the boom. Using water, operate the sprayer at the desired speed and pressure on clean, dry pavement or on another smooth surface. Observe the spray pattern as the water evaporates. Clean or replace nozzle tips that produce a poor spray pattern; if necessary, readjust boom height and recheck the spray pattern. If you replace any nozzles, recheck the flow rates.

Broadcast Sprayer Calibration

There are a number of equally effective calibration methods that vary in their basic approach and degree of difficulty. For the purposes of this manual, we have chosen a simple method that will allow you to calibrate quickly.

1. Fill the sprayer tank approximately half full with water.
2. Determine the nozzle spacing or band width in inches and stake out the appropriate distance in the field according to the following table:

Broadcast nozzle spacing or band width (inches)	Travel distance (feet)
8	510
10	408
12	340
14	291
16	255
18	227
20	204
22	185
24	170
26	157

For other nozzle spacings or band widths, determine the appropriate travel distance using the following formula:

$$\text{Travel distance (feet)} = \frac{4{,}080}{\text{nozzle spacing or band width (inches)}}$$

In this formula, 4,080 is a constant.

For example, if your nozzle spacing is 38 inches:

$$\text{Travel distance} = \frac{4{,}080 = 107 \text{ feet}}{38}$$

Measuring the appropriate travel distance is a critical step in calibration. To determine what volume your sprayer is delivering per acre, you must relate the average nozzle output to a smaller unit area of land. You could determine the volume output by physically spraying an entire acre, but this would be very time consuming. Therefore, we use a fraction of an acre.

3. With the sprayer turned off, drive the distance using the exact throttle setting and gear you plan to use during spraying. Be sure to *note the throttle setting and gear;* don't rely on a speedometer. Start the spray rig about 25 feet before the staked area so that you will be at typical field speed at the beginning of the measured distance. *Record your travel time in seconds.*
4. Adjust the pressure to the desired setting. Use slightly higher pressure when you use nozzle check valves and nozzle strainers.
5. With the sprayer stationary, collect and record the output (in ounces) from at least four nozzles for the travel time recorded in step 3. Because we already determined that the output of all nozzles is within 5 percent of one another in the precalibration check, it is not necessary to collect output from all nozzles.
6. *Determine the average nozzle output in ounces.*
7. The spray rate in gallons per acre is equal to the average nozzle output in ounces. For example, if the average nozzle output for the recorded travel time is 20 ounces, the spray rate is 20 gallons per acre.
8. If the spray rate is not reasonable for your particular spraying job, you can change output by one of three methods: adjust pressure, change speed, or replace nozzle tips. If only a minor change in output is needed, simply make an adjustment in pressure and determine the new average nozzle output. (Remember that operating pressure must be kept within the recommended range for the nozzle type so the spray pattern is not distorted.) If a large change in output is necessary, make a change in travel speed. However, you must drive the designated field distance and determine the new travel time before calculating the average nozzle output. If it is impossible to obtain the desired output at an appropriate pressure and ground speed, you will need to change nozzle tips; in this case, you must repeat the precalibration check of nozzle output.

The sprayer is now calibrated. When operated at the designated speed and pressure, it should deliver the desired spray volume. You should occasionally remeasure output to determine if changes in flow rate occurred as a result of nozzle wear or other variations. If you continue to use the same travel speed used during initial calibration, it will take only a few minutes to recheck your sprayer's output.

Example: You want to make a postemergence broadcast application of a herbicide at a spray volume of 20 to 30 gallons per acre using regular flat-fan nozzles spaced 40 inches apart on the boom:

1. Fill the sprayer tank approximately half full with water.
2. The appropriate travel distance for 40-inch nozzle spacing is 102 feet; measure and mark this distance in the field.
3. Using the throttle setting and gear you plan to use during spraying, you find that it takes 14 seconds to drive 102 feet.
4. Adjust the pressure to the desired setting within the recommended pressure range of 15 to 30 psi for regular flat-fan nozzles; your chosen setting is 25 psi.
5. With the sprayer stationary, you collect the following outputs from four nozzles in 14 seconds:

Nozzle	Output (ounces per 14 seconds)
1	15.5
2	16
3	15.5
4	16
	Total = 63 ounces

6. The average output of the nozzles for 14 seconds is:

$$\frac{63 \text{ ounces}}{4 \text{ nozzles}} = 16 \text{ ounces}$$

7. The spray rate, therefore, is equal to 16 gallons per acre.
8. The spray rate is lower than the recommended range of 20 to 30 gallons per acre stated on the label. The major change in output required should not be attempted by increasing pressure. You'll need to either decrease travel speed (in which case you'll also need to determine the new travel time) or increase nozzle tip size. Then determine the new average output.

Amount of Pesticide to Add to the Tank

Your next step is to determine the amount of pesticide to add to the spray tank. To do so, you need to know:

- The recommended rate.
- The capacity of the spray tank.
- The calibrated output of the sprayer.

You just learned how to determine the output of your sprayer.

The recommended rate is determined from the label. Rates are expressed either as the amount of pesticide product applied per acre (or area) or as the amount to mix with a certain volume of water (or other carrier).

Example: Broadcast application. Pesticide A is recommended as a broadcast application at a rate of 2 quarts per acre. Your sprayer has a 200-gallon tank and is calibrated to apply 20 gallons per acre. How much Pesticide A should you add to the spray tank?

1. Determine the number of acres you can spray with each tank, using the following formula:

$$\text{Acres per tank} = \frac{\text{tank capacity (gallons per tank)}}{\text{Spray rate (gallons per acre)}} = \frac{200}{20} = 10 \text{ acres}$$

2. Determine the amount of pesticide to add to each tank, using the following formula:

Amount per tank = acres per tank x rate per acre.

With each tank, you cover 10 acres and you want to apply 2 quarts of product per acre:

Amount per tank = 10 x 2 = 20 quarts.

You need to add 20 quarts (5 gallons) of Pesticide A to each tank load.

Example: Broadcast application. Pesticide B is an 80 percent wettable powder formulation. After reading the label, you decide to apply 12 pounds per acre for perennial weed control. The area to treat is 150 feet wide and 180 feet long. Your backpack sprayer is equipped with a three-nozzle boom, has a 4-gallon tank, and is calibrated to apply 40 gallons per acre of spray solution. How much water and product do you add to the tank? (43,560 sq ft = 1 acre)

1. Calculate the area to be treated as follows:

   150 x 180 feet = 27,000 square feet, which is equal to 0.62 acres (27,000 ÷ 43,560)

2. Calculate the amount of water needed to cover 0.62 acres, using this formula:

$$\frac{40 \text{ gallons}}{1 \text{ acre}} = \frac{Y \text{ gallons}}{0.62 \text{ acre}}$$

   which is read as "40 gallons is to one acre as Y gallons is to 0.62 acre."

   Cross-multiplying:

   (Y x 1) = (40 x 0.62) = 24.8 gallons to treat 0.62 acre

3. With a 4-gallon tank, we will need more than six loads of solution; let's plan to mix seven loads.

$$\frac{24.8 \text{ gallons}}{7 \text{ loads}} = 3.54 \text{ gallons per load}$$

4. If we were spraying an acre, we would need 12 pounds of pesticide per 40 gallons of water (the per-acre output of our sprayer). However, we will be spraying only 3.54 gallons at a time. To determine the amount of pesticide to add per tank load, use the following formula:

$$\frac{12 \text{ pounds}}{40 \text{ gallons}} = \frac{Y \text{ pounds}}{3.54 \text{ gallons}} =$$

$$Y = \frac{12 \times 3.54}{40} = 1.06 \text{ pounds of Pesticide B in each tank load of 3.54 gallons}$$

Liquid Application on a Percentage Basis

Occasionally pesticide recommendations are expressed as amount of product per a specified volume of water. Such rates are expressed as "volume/volume" equivalents or as a percentage of product in the spray solution.

Example: Rate expressed as volume per volume. Pesticide C is recommended as a sanitary bin spray to control stored grain insects. Four gallons of product are recommended per 100 gallons of water. You want to prepare 75 gallons of solution. How much Pesticide C do you mix with the 75 gallons of water?

$$\frac{4 \text{ gallons Pesticide C}}{100 \text{ gallons water}} = \frac{Y \text{ gallons Pesticide C}}{75 \text{ gallons water}}$$

By cross multiplying:

100 x Y = 75 x 4

100 x Y = 300

Y = 3 gallons of Pesticide C per 75 gallons of water

Granular Applicator Calibration

Occasionally, granular or pelleted pesticides are used for weed control. The need for accurate calibration is just as great for granular applicators as for sprayers.

The application rate of granular applicators depends on the size of the metered opening, the speed of the agitator or rotor, travel speed, the roughness of the site, and the flowability of the granules. The flow rate of granules depends on particle size, density, type of granule, temperature, and humidity. The manufacturer's suggested setting should be used only as the initial setting for verification runs by the operator prior to use. A different applicator setting may be necessary for each pesticide applied; variations in flow rate also can occur with the same product from day to day or from site to site. It is therefore important to calibrate frequently to maintain the proper application rate.

Apart from the actual setting of the metering opening, ground speed is the most significant factor affecting the application rate. You must use the same ground speed during calibration that you intend to use during the application, and the speed must remain constant. However, gravity-flow applicators use a rotating agitator, with speed varying with ground speed. The flow of granules through the opening is not necessarily proportional to speed. A speed change of 1 mile per hour may cause a significant variation in the application rate.

Drop-through Spreaders

Drop-through spreaders usually are calibrated using catch pans. Chain or wire catch pans beneath the spreader to collect granules as they are discharged. After covering a distance equivalent to 1/50 acre (871 sq. ft.), weigh the granules collected in the catch pan to determine the application rate. Use the table below to select the appropriate travel distance for your spreader.

Swath width (feet)	Travel distance (feet)
1.5	581
2	436
3	290
4	218
5	174
6	145
7	124
8	109
9	97
10	87
11	79
12	73
15	58

If your spreader has a different width, use this formula to calculate the travel distance:

$$\text{travel distance in feet} = \frac{871}{\text{swath width in feet}}$$

For example, if you have a spreader that covers a 6.5-foot swath, the distance to travel is:

$$\frac{871}{6.5} = 134 \text{ feet}$$

The step-by-step procedure for calibrating a drop-through spreader is:

1. Before starting, calculate how much material should be applied in the calibration area. You need to know only the recommended rate per acre and multiply this value by 1/50 (remember you will cover 1/50 acre in the calibration exercise).
2. Measure out the travel distance as determined by the swath width of the spreader.
3. Securely attach a collection pan to the spreader.
4. Set the feeder gate control to the setting recommended in the owner's manual or on the product label.
5. Calibrate with the same granules you intend to use during application.
6. Operate the spreader in the premeasured calibration area at the speed you intend to use during application.
7. Weigh the amount of granules in ounces in the collection pan. Be sure to use a scale that can accurately measure to the nearest ounce.
8. Compare the amount of product collected in the calibration area with the amount calculated in Step 1 above. If they are within 5 percent of each other, the applicator is properly calibrated; if not, you need to adjust the feeder gate control and recalibrate.

Example: A broadcast application of Pesticide D is to be made at a rate of 60 pounds of product per acre. Your equipment broadcasts granules in a 15-foot swath width. After covering a distance of 58 feet, you collect 16 ounces of granules. Is your applicator properly calibrated?

1. Determine the amount of product in ounces that should be applied to the calibration area:

   (60 pounds) x (1/50) = 1.2 pounds x 16 ounces per pound = 19.2 ounces

2. Determine if the amount actually applied (16 ounces) is within 5 percent of the recommended rate (19.2 ounces):

   19.2 ounces x 0.05 (5%) = 0.96 ounces

If your applicator was properly calibrated, it should have applied between 18.2 and 20.2 ounces of product to the calibration area. It actually applied less. You therefore need to adjust the feeder gate control to apply more material and then recalibrate.

CHAPTER 4

Review Questions

Chapter 4: Calibration

Write the answers to the following questions and then check your answers with those in the back of the manual.

1. Why is calibration of various spray systems essential?

2. Calibration ensures that the correct amount of pesticide is delivered uniformly over the target area.

   A. True

   B. False

3. What happens to the flow rate if you increase the nozzle pressure or use a larger nozzle tip opening?

   A. Has no effect of the flow rate.

   B. Increases the flow rate.

   C. Decreases the flow rate.

4. To double the flow rate, you must increase the pressure:

   A. Twofold.

   B. Threefold.

   C. Fourfold.

   D. Fivefold.

5. If the throttle setting remains constant, and the speed doubles, the amount of spray per acre:

   A. Remains constant.

   B. Doubles

   C. Is reduced by half.

   D. Is reduced by one quarter.

6. Measuring and comparing the output of each nozzle to the average output of all the nozzles allows you to determine if:

   A. The pump is functioning properly.

   B. Any nozzle is worn or clogged.

   C. It is the right nozzle for the job.

   D. The pressure is accurate.

7. If the spray pattern is not uniform, you should:

   A. Check the boom height.

   B. Check the spacing and alignment of the nozzles on the boom.

   C. Check the operating pressure.

   D. Do all of the above.

8. You determine the distance to travel for calibration by:

   A. Using a formula with a constant and the nozzle spacing.

   B. Reading it from the pesticide label.

   C. Reading it from the tractor handbook.

   D. Setting an arbitrary distance based on the type of pesticide.

9. Why is there an operating pressure range for each type of nozzle?

   A. To prevent nozzle clogging.

   B. To relieve strain on the pump.

   C. To keep the spray pattern from distorting.

   D. To calculate the travel distance.

10. In a broadcast sprayer calibration, if the nozzle spacing is 30 inches, what is an appropriate distance to stake out in the field?

    A. 101 feet

    B. 136 feet

    C. 256 feet

    D. 1 acre

11. In Question 10, it took 20 seconds to travel the appropriate distance. What does this travel time tell you?

    A. How long you should measure the output from nozzles.

    B. How long it will take to spray the entire field.

    C. How long it will take to empty the tank.

    D. Whether the sprayer is properly calibrated.

12. When calibrating a broadcast sprayer, you find that the average nozzle output is 25 ounces for the recorded travel time. What is the spray rate in gallons per acre?

    A. 25 gallons per acre
    B. 30 gallons per acre
    C. 35 gallons per acre
    D. 40 gallons per acre

13. What can you do if your calibrated spray rate is less than the recommended rate stated on the label?

    A. Increase the pressure.
    B. Decrease travel speed.
    C. Increase nozzle tip size.
    D. B and/or C.

14. In a broadcast sprayer application, if the spray tank capacity is 150 gallons and the spray rate is 30 gallons per acre, how many acres can be sprayed per tank?

    A. 0.2 acres
    B. 0.5 acres
    C. 3 acres
    D. 5 acres

15. In Question 14, how much pesticide will you need to add per tank if the label recommends 4 quarts of product per acre?

    A. 10 quarts
    B. 20 quarts
    C. 30 quarts
    D. 40 quarts

16. How do you determine what rate of pesticide to apply?

    A. Use a formula.
    B. Read it off the spray tank.
    C. Read the pesticide label.
    D. All of the above.

17. The flow rate of dry granular pesticide products:

    A. Varies because of many factors such as particle size and humidity.
    B. Remains constant from product to product.
    C. Prevents accurate calibration.
    D. Allows for less frequent calibration than liquid products.

18. A broadcast application of granular pesticide is to be made at the rate of 30 pounds of product per acre. Your equipment broadcasts granules in a 10-foot swath. How many feet do you travel to calibrate your spreader?

    A. 218 feet
    B. 145 feet
    C. 87 feet
    D. 58 feet

CHAPTER 5

INSECT MANAGEMENT

LEARNING OBJECTIVES

After completely studying this chapter, you should:

- Understand how insects grow and develop.
- Understand the difference between simple and complete metamorphosis.
- Be able to identify the major pests of asparagus, carrots, celery, cucurbits, cole crops, onions, potatoes, snap beans, sweet corn, and tomatoes.
- Be able to describe the life cycles and habitats of the major vegetable insect pests.

Insect damage reduces crop yield, quality, or contaminates the final product. Insects can also transmit disease. To effectively control insect pests, you need to understand how insects grow and develop.

GROWTH AND DEVELOPMENT

Growth

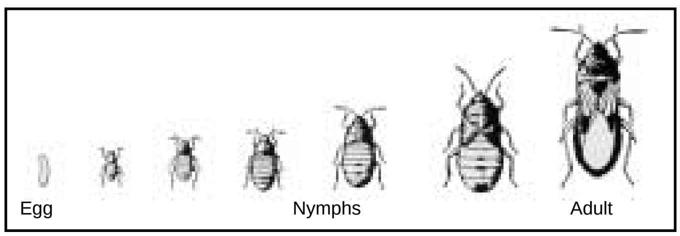
An insect's body is confined in a protective **exoskeleton**. This hard outer covering does not grow continuously. A new, soft exoskeleton is formed under the old one, and the old exoskeleton is shed in a process called molting. The new skeleton is larger and allows the insect to grow a little more. The new exoskeleton is white at first, but it hardens and darkens in a few hours. After the molting process, which usually takes place in hiding, the insect resumes its normal activities.

Development

Insects are divided into groups according to the way they change during their development. The technical term for this change is **metamorphosis**, which means "change in form." Pests of vegetables undergo either simple or complete metamorphosis.

Group 1. Simple Metamorphosis

Insects developing by simple metamorphosis hatch from an egg and resemble the adult insects except that the immatures, or **nymphs**, do not have wings. Nymphs periodically molt, growing larger. After the final molt, nymphs become adults and generally have wings. Many pests of vegetables, such as aster leafhopper, aphids, and tarnished plant bug, develop by simple metamorphosis. Nymphs and adults are often found together in the crop and usually eat the same food.

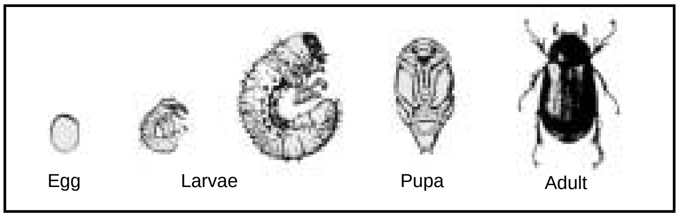


A plant bug is an example of an insect with simple metamorphosis.

Group 2. Complete Metamorphosis

Insects that develop by complete metamorphosis make a radical change in appearance from immature to adult. This group includes beetles, moths, butterflies, flies, bees, and wasps.

In complete metamorphosis, newly hatched insects are called **larvae**. Grubs, maggots, and caterpillars are types of larvae. The job of larvae is to eat and grow; they usually molt four to six times, and then they change into **pupae**. A pupa is an inactive stage of insect development. During pupation, the insect's body rearranges itself, resulting in a complete change in form from the immature to an adult insect. Insects undergoing complete metamorphosis have very different larval and adult stages. Larvae and adults are often so different that they do not eat the same food and need different habitats.



Development with complete metamorphosis (example: beetle).

CONSIDERATIONS FOR PEST MANAGEMENT

The developmental stages of insects with complete metamorphosis often support rather than compete with each other. It's as if there are two or three completely different animals with different needs and habits, instead of a single species. The larvae feed and live in one habitat and sometimes leave that area to pupate a short distance away. The adult emerges and often eats a different food and lives in another area, returning to the larval feeding site only to lay eggs. One example is the cabbage maggot - the larva is a maggot living and feeding in the roots of cole crops, and the adult is a fly. Species with complete metamorphosis are managed differently according to life stage, where each lives, and what each does. You will want to pay special attention to sections that discuss the life cycle and behavior of each insect pest.

INSECT PESTS OF ASPARAGUS

ASPARAGUS BEETLES

There are two different asparagus beetles in Michigan. The **common asparagus beetle** (*Crioceris asparagi*) is 1/4 inch long, black, red and yellow with a metallic blue head. The adult female lays dark brown, bullet-shaped eggs on asparagus spears. The gray, slug-like larvae and adults feed on tender spear tips until foliage emerges. They will also eat stems and foliage. This feeding weakens plants in a young stand.

Spotted asparagus beetle (*Crioceris duodecimpunctata*) is reddish orange with six black spots on each wing cover. When the asparagus berries appear, the adult female beetles lay eggs. The cream-colored larvae feed only on the berries, not the foliage. Damage to asparagus berries does not cause any economic loss, so the spotted asparagus beetle is not an important pest.

Damage: Asparagus beetles overwinter as adults in crop debris and along field edges. The common asparagus beetle emerges in early spring, slightly before the spotted asparagus beetle. The beetles begin to feed as soon as they emerge and egg laying by the common asparagus beetle starts several days after emergence. Eggs or adults feeding on spears can contaminate the crop and cause consumer rejection. In Michigan, there are typically two to four generations of asparagus beetles per year.

Spotted asparagus beetles cause damage to asparagus berries, not foliage.

Control strategies:

- Many beneficial insects feed on or parasitize asparagus beetles, eggs, and larvae but do not often provide sufficient control in commercial fields.
- Chemical control may be required to reduce contamination and injury to spears or to protect foliage after harvest.

ASPARAGUS MINER (*Ophiomyia simplex*)

The adult asparagus miner is a small, shiny black fly. At the end of May, the female fly lays eggs in the asparagus stalk. Legless larvae tunnel or mine into the stem near the base of the plant. After feeding on the stalks for two to three weeks the larvae pupate near the soil surface. The second generation of adult asparagus miners emerges in mid July. They overwinter as pupae. There are two or three generations per year.

Damage: Feeding by asparagus miner larvae damages asparagus plants. Plants with heavy infestations of miners may become infected with *Fusarium* spp. which causes root rot.

Control strategies:

- Chemical control is not usually necessary to reduce the population.

CUTWORMS

White cutworm feeding on asparagus spear.

Two cutworms commonly feed on asparagus, the **white cutworm** (*Euxoa scandens*) and the **dark-sided cutworm** (*Euxoa messoria*). White cutworms overwinter as larvae, and then emerge in spring to climb the spears and feed on the growing tips from April to May. Dark-sided cutworms overwinter as eggs. Larvae hatch in May and feed on the spears at or near the soil surface. Dark-sided cutworm damage can result in twisted or crooked spears. Cutworm larvae also feed on weeds and volunteer asparagus.

Control strategies:

- Remove weeds and incorporate crop residues to help reduce the cutworm population.
- Cutworm infestations are limited and sporadic. Searching the soil around the plants in the fall and watching for damage during harvest will identify areas needing treatment. Granular insecticide applications in the fall can help reduce the overwintering population of white cutworms.

INSECT PESTS OF CARROTS

ASTER LEAFHOPPER (*Macrosteles quadrilineatus*)

Aster leafhoppers are 1/8-inch-long, yellowish green, wedge-shaped insects with sucking mouthparts. Leafhopper nymphs resemble adults without fully developed wings (simple metamorphosis). In Michigan, aster leafhoppers overwinter as eggs in grasses and small grains and also migrate into Michigan from the southern United States on storm fronts. Aster leafhoppers have many host plants, both weeds (Queen Anne's lace, pineapple weed, and horse weed) and crops (carrots, celery, and alfalfa). In Michigan, there are up to five generations a summer.

Aster leafhopper adults (top) and nymphs (bottom) are pests of carrots and celery.

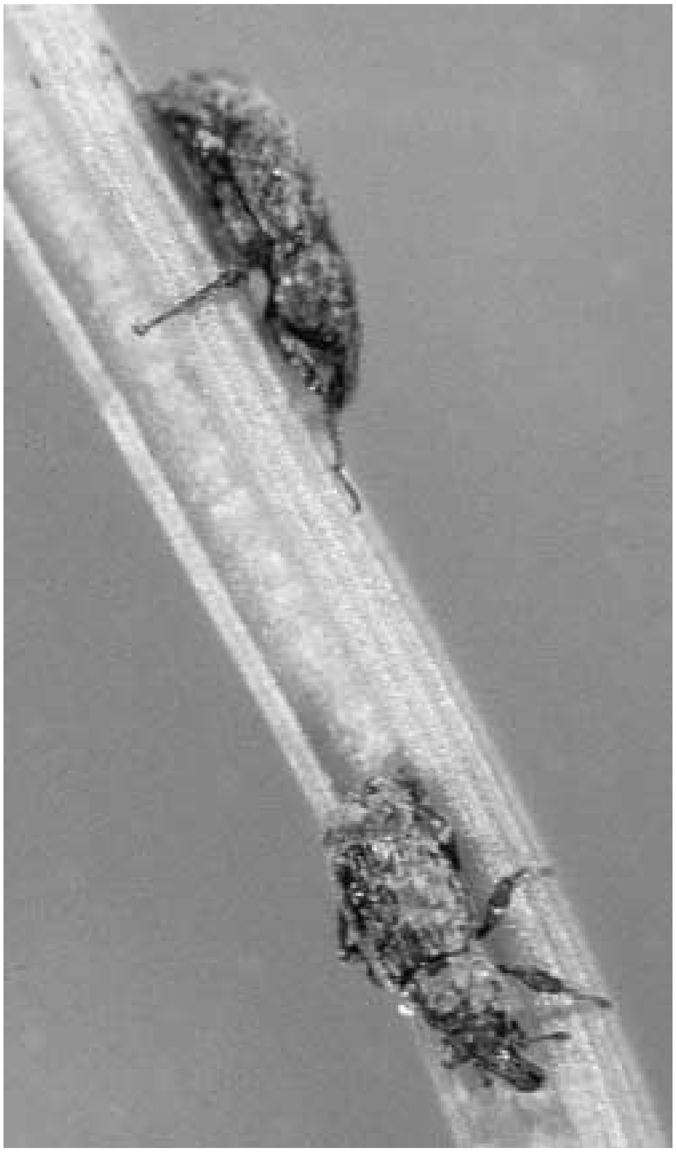
Damage: Aster leafhoppers transmit the mycoplasma-like organism that causes the disease **aster yellows**. (For more information on aster yellows, see Chapter 7 Disease Management.) Early symptoms of aster yellows disease are yellowing of younger leaves, progressing to red or purple, twisted petioles, and dense shoot growth. Carrots affected with aster yellows are dwarfed, abnormally shaped, covered with hairy growth of secondary roots, and bitter tasting. Aster yellows may also kill plants and reduce carrot size, leading to yield losses.

Control strategies:

- Use a sweep net and scout fields regularly, one to two times per week. The action threshold commonly used is 20 aster leafhoppers per 100 sweeps.

CARROT WEEVIL (*Listronotus oregonensis*)

The adult carrot weevil is a snout beetle about 1/4 inch long. Adult weevils overwinter in the soil, emerging in April to May. Female weevils lay eggs in leaf petioles. When larvae hatch, they tunnel into the petiole, then down into the crown and eventually into the carrot, and feed for two to four weeks. Larvae pupate in the soil, and adults begin to emerge in mid-June. Alternate hosts include celery, parsley, Queen Anne's lace, and some broadleaf weeds.



Adult carrot weevils do not fly.

Damage: Adult carrot weevils do not cause serious damage to carrots. They feed on foliage, making small holes in leaf petioles. However, carrot weevil larvae feed by tunneling in the upper third of the carrot, making the carrot unmarketable for either fresh or processing. Carrot weevil tunnels also create a route of entry for secondary infections by plant pathogens.

Control strategies:

- Practice crop rotation with non-host crops, such as onions or potatoes. This provides control because adult carrot weevils do not fly.
- Control alternate weed hosts (e.g., Queen Anne's lace, plantain).
- Monitor carrot weevil populations with traps baited with carrot. If pesticide applications are made, they can be targeted toward newly hatched larvae with a systemic insecticide or toward molts using a standard insecticide in the spring or early summer when the adults are active. See Extension bulletin E-890, Detection and Control of Carrot Weevil, for detailed information on trapping.

INSECT PESTS OF CELERY

Aster leafhoppers and **carrot weevils** can also attack celery. Please refer to the carrot insect section for information about these pests.

APHIDS

Green Peach Aphid (*Myzus persicae*) and Sunflower Aphid (*Aphis helianthi*)

Aphids are generally characterized by a pear-shaped body with two cornicles or "tailpipes" on the hind end. Adult green peach aphids may vary in color from yellow to light green to pink. Sunflower aphids are green with black cornicles and black legs. There are wingless and winged forms of both aphids. Winged green peach aphids have dark patches on the head, thorax and abdomen.

Adult female aphids reproduce without mating, creating genetically identical offspring. They do not lay eggs but give birth to tiny aphids. Aphids overwinter as eggs on host plants or as adults in greenhouses. They also migrate into Michigan from the southern United States. There are five to ten generations per year.

Damage: Aphids use their sucking mouthparts to drink plant sap and also transmit viruses. Aphid damage can twist and distort new plant growth, and aphids can contaminate the harvested product.

Control strategies:

- Aphids have many natural enemies; lady beetles, lacewings, spiders, parasitic wasps, and fungal diseases help maintain low aphid populations.
- Chemical control for aphids is not usually necessary unless other pesticide applications have eliminated all natural enemies. Aphids can rapidly develop pesticide resistance because aphid offspring are genetically identical.

CELERY LOOPER (*Syngrapha falcifera*) CABBAGE LOOPER (*Trichoplusia ni*)

Celery and cabbage looper larvae are green caterpillars with white stripes on their sides and are up to one inch long. The larvae move like inchworms, bringing their back legs forward and creating a loop with their body. Celery loopers overwinter in Michigan as pupae and emerge as adults in May. Cabbage loopers migrate into Michigan from the southern United States in late June to early July. The adult moths lay white, round eggs about the size of a pinhead. The larvae feed for approximately two to three weeks, then pupate. Looper pupae are wrapped in a delicate cocoon of white threads that makes them difficult to remove from plant material.

Damage: Looper larvae feed on leaves and petioles of the celery plant, creating small holes. Pupae contaminate product and are of more concern than foliage damage because pupae are difficult to wash off the plant.

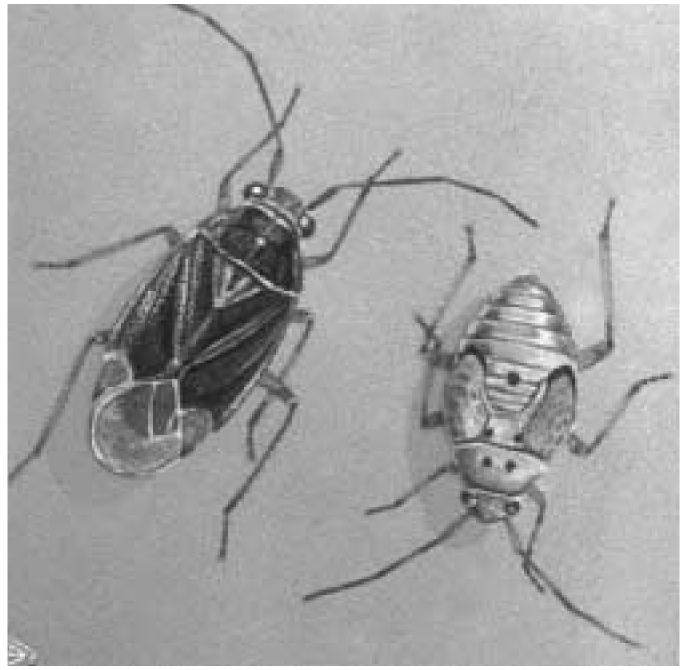
Control strategies:

- Regularly scout fields for caterpillars. If marketable petioles are present, insecticide applications may be needed. Remember, pesticides are more effective against small, young loopers, and loopers need to be controlled before they pupate.

Celery loopers (top) overwinter in Michigan but adult cabbage loopers (bottom) migrate into Michigan every year.

TARNISHED PLANT BUG (*Lygus lineolaris*)

Tarnished plant bugs are green (immature) or brown (mature) and shield-shaped. They feed and reproduce on many host crops and weeds. Eggs are usually laid on leaf midribs, and young nymphs generally remain on the new growth on the plant upon which they hatched. Adults are strong fliers and can easily move between fields, from wild habitats, or from other crops into celery.



Adult tarnished plant bug (left) and nymph (right).

Tarnished plant bug adults and nymphs have sucking mouthparts and produce toxic saliva, which causes the area around the feeding site to die. Feeding creates brown spots on leaves and petioles, can cause new growth to twist, and creates entry points for plant pathogens.

Control strategies:

- Tarnished plant bugs have many host plants and are therefore difficult to control using cultural control methods.
- Because they are strong fliers, tarnished plant bug adults can move quickly from field to field, making effective pesticide applications difficult. Frequent scouting is critical.

VARIEGATED CUTWORM (*Peridroma saucia*)

The variegated cutworm can cause severe stalk damage in celery. As early as May, the adult gray-brown moths begin to lay eggs on the undersides of celery leaves. The larvae feed primarily on celery leaves and petioles, creating holes in the stalks. As they grow, larvae begin to move down the plant and feed on the inner surface of the petioles. A small unmanaged population of variegated cutworms can cause extensive damage. Variegated cutworm caterpillars can also contaminate the crop at harvest.

Control strategies:

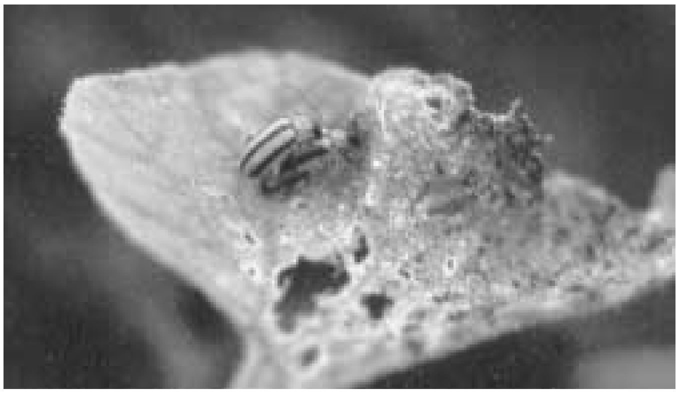
- Scouting the field and visually monitoring for eggs and larvae provide an early warning of caterpillar infestations.
- Monitor for variegated cutworm adults with pheromone lures and traps. Preventive pesticide applications may be necessary once marketable petioles are present (within four weeks of harvest).

INSECT PESTS OF CUCURBITS (CUCUMBER, MELON, PUMPKIN, SQUASH)

APHIDS

Aphids also attack cucurbits. Please refer to the celery insect section for information on the aphids.

CUCUMBER BEETLES



Striped cucumber beetle.

Spotted cucumber beetle.

The **striped cucumber beetle** (*Acalymma vittatum*) and the **spotted cucumber beetle** (*Diabrotica undecimpunctata howardi*) are found on cucurbits in Michigan. The striped cucumber beetle is yellow with black stripes on its wing covers. The spotted cucumber beetle (also called the southern corn rootworm) is yellow or green with black legs, antennae, and head, and 12 black spots on its wing covers. In the spring, striped cucumber beetles emerge from overwintering sites along fencerows and ditch banks to begin feeding on new plants. Spotted cucumber beetles migrate into Michigan each year from the southern United States. Both striped and spotted female beetles lay their eggs in the soil at the base of cucurbit plants. Larvae emerge and feed on the roots and underground portions of the plant stems. Larvae pupate in the soil and when the adults emerge they feed on the foliage, flowers and fruits of cucurbits. The spotted cucumber beetle can feed on more than 200 common plants, including corn, peas, beans and tomatoes, but the striped cucumber beetle feeds only on cucurbits.

Striped cucumber beetles are easily confused with the western corn rootworm. Striped cucumber beetles have faint yellow markings on their legs; the western corn rootworm has solid black legs. Also, striped cucumber beetles have black abdomens; western corn rootworm, yellow. It is important to distinguish between these two beetles because the western corn rootworm does not injure or transmit disease to cucurbits.

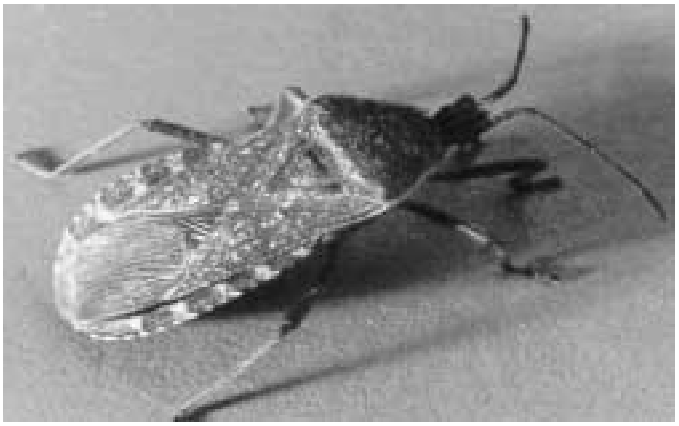
Damage: Root feeding by striped cucumber beetle larvae can cause serious damage to undeveloped vines. Adult beetle feeding can completely defoliate young plants or girdle the stems and kill the plants. Cucumber beetle adults also transmit bacterial wilt, a major disease of cucurbits. (See Chapter 7 for more information on bacterial wilt.) In Michigan, the spotted cucumber beetle rarely occurs in high numbers and is not a major pest. Striped cucumber beetles, however, can be a severe problem.

Control strategies:

- Row covers act as a barrier and prevent striped cucumber beetle infestations. However, row covers must be removed for pollination, are not practical for large acreage, and must not have holes that could allow beetles to enter and go unnoticed.
- Trap crops help control early-season beetle infestations. Any cucurbit variety that is extremely attractive to the striped cucumber beetle can be used as a trap crop. Plant the attractive cucurbit along the field border before the primary crop. Striped cucumber beetles attack the most mature cucurbit crop in a given area, so the beetle population will build in the trap crop. This allows limited, effective insecticide applications to prevent beetle movement to the primary crop.
- Cucurbits are very sensitive to pesticides - read the label carefully. Treatment with a systemic insecticide at planting provides excellent control of early-season cucumber beetles without affecting honeybees. When cucurbit crops are in bloom, making foliar insecticide applications in the early morning or late evening reduces insecticide contact with honeybees. Yields can be reduced if the insecticide application harms pollinators.

SQUASH BUG (*Anasa tristis*)

Squash bugs feed on all cucurbits but are more of a problem in squash and pumpkins. Adult squash bugs are dark grayish brown with gold and brown stripes on their abdomens. Females lay eggs in clusters on the undersides of leaves between leaf veins. Newly hatched squash bugs do not have wings (simple metamorphosis) and are pale green to white with reddish brown heads and legs. As they mature, they become grayish white with black legs, and look more like adult squash bugs. Immature squash bugs are commonly found in groups.



Adult squash bug (top) and squash bug eggs (bottom).

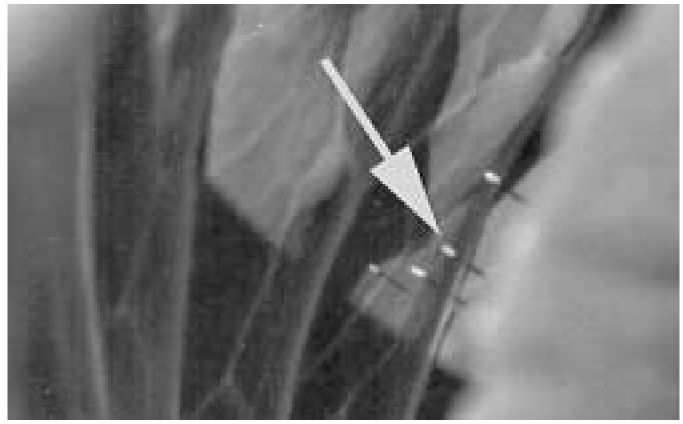
Damage: Nymph and adult squash bugs use their sucking mouthparts to consume plant juices from leaves and fruit. Damaged leaves wilt, turn black and die. In hot, dry weather, large populations of squash bugs can cause plants to wilt. If squash bug problems are detected and controlled early, plants will recover. Late in the season, especially after a killing frost, squash bugs begin to feed on the fruit. Fruit feeding causes the tissue in damaged areas to collapse and makes the product unmarketable.

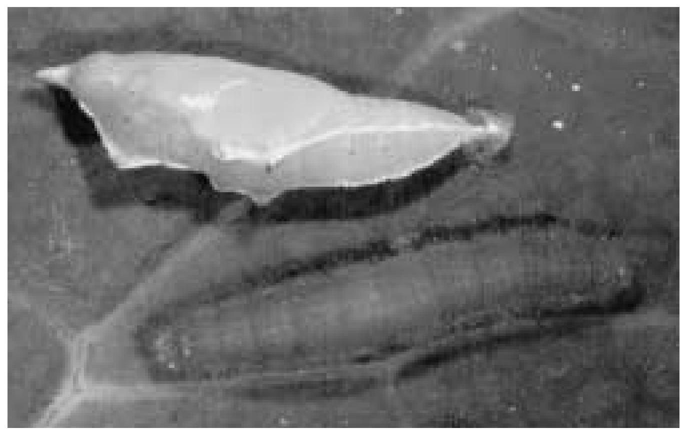
Control strategies:

- Plant resistant hybrids to reduce young squash bug populations.
- Cultivate immediately after harvest to remove crop debris, and eliminate overwintering sites.
- Natural enemies do not provide adequate control of the pest.
- Insecticide applications targeted at nymphs are more effective than later applications to control adults.

INSECT PESTS OF COLE CROPS (BROCCOLI, CAULIFLOWER, AND CABBAGE)

IMPORTED CABBAGEWORM (*Pieris rapae*)





Imported cabbageworm eggs (top) and larva and pupa (bottom).

The imported cabbageworm is the most common pest of cole crops in Michigan. These white butterflies begin to fly in late April or early May after overwintering as pupae in crop debris. Female butterflies lay bullet-shaped, yellow eggs on the foliage. Imported cabbageworm larvae are velvet green caterpillars with a faint yellow stripe along each side. Larvae usually pupate on the undersides of leaves near the soil surface. The pupae are bright green. The imported cabbageworm completes its development in four to five weeks; in Michigan, there are three generations per year.

Damage: Imported cabbageworm larvae feed on foliage, creating large, irregular holes in leaves. Cabbage plants can tolerate some feeding damage before head formation. Broccoli and cauliflower can withstand some foliar damage. However, as imported cabbageworm larvae grow, they move to the center of the plant, boring into the cabbage head or feeding on the broccoli and cauliflower florets. Imported cabbageworm injury to the growing tip in broccoli can result in head deformation. Feeding damage also increases the plants' susceptibility to diseases. Imported cabbageworms can also contaminate yield and reduce product marketability.

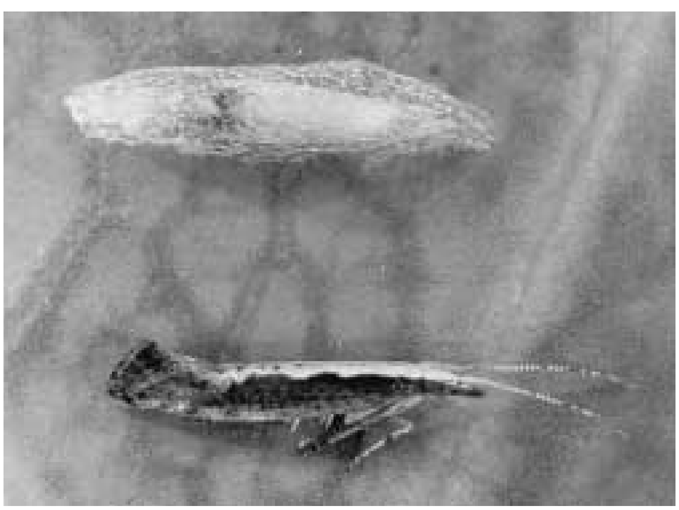
CABBAGE LOOPER (*Trichoplusia ni*)

Cabbage looper larva.

Beginning in late June or early July, cabbage looper adults migrate into Michigan from the southern United States. The adult cabbage looper is a gray and brown moth with a characteristic white/gray figure-eight marking on the wing. The adults are active at night and on cloudy days, laying single white eggs on the undersides of leaves. Cabbage looper larvae move with an inchworm motion - they bring their back legs forward, creating a loop with their bodies. Cabbage loopers pupate on the undersides of leaves, wrapping the brown pupae in cocoons of white threads. There are typically two to three generations per year.

Damage: Cabbage looper larvae feed on foliage, creating large, irregularly shaped holes in the leaves similar to the damaged caused by the imported cabbageworm. Cabbage loopers can contaminate the harvest. They are also pests of celery and tomatoes.

DIAMONDBACK MOTH (*Plutella xylostella*)



Diamondback moth adult and pupa.

Worldwide, the diamondback moth is the major pest of cole crops, but in Michigan, it usually does not cause serious damage. The adults are small, grayish brown moths. The diamondback moth may overwinter in Michigan in crop debris, migrate into Michigan from warmer climates, or be brought in on transplants. Female moths lay very small eggs, which are difficult to see, on leaves and leaf petioles. Diamondback moth larvae are small (1/3 inch long) and yellow-green. When frightened or touched, the larvae squiggle very rapidly and drop off the leaf, hanging from a silk thread (similar to a spider silk). Diamondback moth pupae are small, green, and enclosed in lace-like cocoons. There are multiple generations a year.

Damage: Like imported cabbageworms and cabbage loopers, diamondback moth larvae damage foliage and contaminate the harvest. Larvae feed on the underside of a leaf, leaving a "windowpane" of transparent tissue; where the imported cabbageworm and cabbage looper larvae create irregularly shaped holes in the leaves. Because of their small size, it takes approximately 20 diamondback moth larvae to defoliate as much as one cabbage looper or two imported cabbageworm larvae.

Control strategies for the caterpillar complex:

Cultural:

- Plant broccoli and cauliflower early to help reduce cabbage looper infestation damage.

Biological:

- Several parasitoids attack the imported cabbageworm and cabbage looper.
- Birds and spiders also help control these caterpillars.
- In Michigan, diamondback moth populations are controlled primarily by a very effective parasitoid. This tiny wasp may kill 70 to 80 percent of the diamondback population; however, it is easily killed by most insecticides.

Chemical:

- Regular scouting of cole crops is extremely important. Cabbage looper and diamondback moth adults can be monitored using pheromone (sex attractant) lures and traps. Plants are visually sampled for eggs and larvae of imported cabbageworms and cabbage loopers.
- Biological insecticides such as *Bacillus thuringiensis* are effective against the imported cabbageworm and do not harm biological control agents.
- Cabbage loopers are more difficult to control with insecticides than imported cabbageworms. Insecticide applications are more effective when cabbage looper larvae are small.
- Diamondback moth larvae and adults in some locations have developed resistance to a number of insecticides, including *Bacillus thuringiensis*. *Bacillus thuringiensis* is recommended for diamondback moth control because it does not affect the highly susceptible parasitoid. Insecticides (including *Bacillus thuringiensis*) used to control the imported cabbageworm or cabbage looper may fail to control diamondback moth and actually result in an increased diamondback moth population because the pesticide killed the natural enemies.

CABBAGE MAGGOTS (*Delia radicum*)

Cabbage maggot adults are flies that look very similar to houseflies. Cabbage maggots overwinter as pupae in the soil and emerge in spring. Immediately after emerging, the female flies begin to lay small, white, oval eggs at the bases of cole crop plants in or near the soil. Larvae, otherwise known as maggots for flies, burrow into the soil and attack plant roots. Cabbage maggots have many host plants, including crops (broccoli, cabbage) and weeds (wild mustard). There are three generations per year in Michigan.

Damage: Cabbage maggots feed on young, susceptible transplants and seedlings in early spring, killing or stunting plants. On hot days, damaged plants may wilt. Cabbage maggot damage also creates an entrance for secondary infections such as bacterial soft rot and blackleg (See Chapter 7 – Disease Management). Cabbage maggots can be more of a problem in cool, wet weather.

Control strategies:

- Destroy crop residue to reduce overwintering cabbage maggot pupae.
- Plant cole crops after peak adult flight (mid-to late June) to reduce the number of eggs laid on the crop.
- Several natural enemies, including a parasitic wasp and a nematode, attack cabbage maggots. Ground beetles also eat cabbage maggot eggs. The natural enemy population does not usually provide adequate control in heavily infested fields, however.
- Scouting for adults or eggs of cabbage maggots is difficult. The adults look much like many other common flies, including houseflies. Eggs are very small and difficult to find in the soil. Therefore, preventive soil treatments are commonly used in areas where cabbage maggot has been a problem in the past.

INSECT PESTS OF CORN (SWEET)

CORN FLEA BEETLE (*Chaetocnema pulicaria*)

The adult corn flea beetle is very small—1/16 inch long—shiny, and black, with enlarged hind legs. It jumps like a flea when plants are disturbed. In Michigan, flea beetles overwinter in plant debris along field edges. In the spring, they emerge and feed on grasses and winter wheat if no corn is available. Eggs are deposited in the soil, and the larvae develop in the soil feeding on corn roots.

Damage: Adult corn flea beetles strip off the top layer of cells on a leaf, giving the leaf a scratched appearance. The most severe injury occurs during cold springs, when slow plant growth allows the beetle more time to feed. Corn flea beetles may also transmit a bacterial disease, Stewart's wilt, which can dramatically reduce yields of susceptible hybrids. Disease symptoms may appear at any stage of corn development in certain corn varieties. (Refer to Michigan State University Extension Bulletin E-2034, Chapter 7, Field Crops—Disease, for more information).

Control strategies:

- Plant wilt-resistant sweet corn hybrids.
- Avoid planting susceptible hybrids early in the season.
- Remove crop residue and control weeds to remove corn flea beetle overwintering sites.
- Areas where corn flea beetle and Stewart's wilt have been a problem may require insecticide seed treatment. Foliar insecticides applied to control corn rootworm also offer some control of corn flea beetle. See Chapter 7, diseases of corn, for further information.

EUROPEAN CORN BORER (*Ostrinia nubilalis*)

European corn borer larva (top) and adult (bottom).

The European corn borer is the most serious pest of Michigan sweet corn. European corn borers overwinter as full-grown larvae in corn debris, usually field corn. Beginning in mid-June, the first generation of adult moths emerge and mate in tall grasses. The adult moths are cream to light brown. The female moth lays her eggs, which look like fish scales, on the undersides of corn leaves. The larvae hatch and feed on the leaf, eventually moving into and feeding down in the whorl. As the larvae mature, they enter the stalk to feed and pupate. Second-generation European corn borer adults mate and the females deposit eggs on the leaves in the ear zone of silking corn. The larvae feed on the developing ears, causing kernel damage, or enter the stalk, ear shank, or cob. Depending on the temperature, there are two or three generations of European corn borer per year.

Damage: First-generation European corn borers feed primarily in the whorl, giving the leaves a “shot-hole” appearance. Larger larvae feed within the midrib and burrow into the stalk. Both of these feeding activities disrupt normal movement of plant nutrients and water, potentially reducing yield.

Second-generation corn borers feed on the stalks, tassels, ear shanks, leaves, and kernels. Feeding on the kernels contaminates the crop, and feeding on the ear shank causes the ear to drop. Stalk boring breaks the stalk, making it difficult to harvest and creating entry wounds for stalk-rot fungi.

Control strategies:

A number of factors affect the potential economic loss caused by European corn borer damage. A series of cool evenings (below 65 degrees F) or a heavy rain can reduce the number of eggs laid or the survival of small larvae. In addition, young larvae can dehydrate and blow away on hot, windy days. Thus, conditions present during European corn borer mating, egg laying, and development are critical in determining the population from year to year.

- Destruction of overwintering sites (corn debris) in the fall kills many European corn borer larvae, but, it does not reduce the population enough to provide adequate control the following year.
- Planting early in the season and using resistant hybrids and early-season hybrids are all useful in managing the European corn borer. Tall corn is more attractive to egg-laying females and, therefore, first-generation damage. Likewise, the second generation tends to attack late silking and pollen-shedding corn. Avoid extremely early and late plantings or plant such fields with resistant hybrids. Scouting efforts should be concentrated on fields as they begin to tassel and continue through harvest.

Biological:

A large number of natural enemies attack all life stages of the European corn borer.

- Generalist predators such as lady beetle larvae and adults, lacewing larvae, and minute pirate bugs feed on egg masses and small larvae. Other insects and birds eat large larvae, pupae and adults.
- Though parasitoids have been imported from Europe to control the European corn borer, only a few have been successfully established. The amount of control from these parasitoids varies from year to year and depends on the location and shape of each field.
- Two main pathogens affect European corn borer populations. *Beauvaria bassiana* is a naturally occurring fungus that can kill overwintering larvae. Dead larvae are white and furry-looking. Most epidemics of *B. bassiana* occur during and after periods of rainfall late in the season when temperatures are in the mid-80s F.
- *Nosema pyrausta* is a protozoan-like microbe that reduces European corn borer egg laying, kills some larvae, and increases overwintering mortality. An increase in stress caused by other factors increases the mortality caused by *N. pyrausta.*

Chemical:

Timing is critical to control the European corn borer because once larvae enter the stalk or ear, insecticide applications become less effective. Thus, scouting is crucial. Scout for first-generation corn borers by examining plants for shot-holing. Scout for second-generation corn borers by looking for egg masses on the undersides of leaves, especially in the ear zone. Pheromone traps in grassy field borders help determine presence and abundance of adult European corn borers.

- Insecticide applications during the whorl stage can be effective against first-generation European corn borers. Though they’re not commonly used in Michigan sweet corn, research and field corn experience show that granular insecticides control first-generation corn borers more efficiently than liquid insecticides.
- *Bacillus thuringiensis* subspecies *kurstaki* (Berliner), usually known as Bt, is effective against larvae feeding in the whorl, sheath, and collar. Bt kills the corn borer only when it is ingested and is more effective on smaller larvae. Therefore, once the larvae have burrowed into the stalk, Bt is not effective. Though Bt kills the European corn borer and other caterpillars, it is much less toxic to other organisms (including beneficial insects and humans) than most broads-pectrum insecticides.
- A few varieties of transgenic Bt sweet corn are available. Transgenic Bt corn has had the gene that produces the same toxin as the bacterium *Bacillus thuringiensis* inserted into its genetic structure. When a corn borer larva feeds on a transgenic Bt corn plant, the larva ingests the toxin and dies. Like Bt insecticide applications, transgenic Bt corn is much less toxic to beneficial insects and growers than conventional insecticides.

CORN EARWORM *(Helicoverpa zea)*

The corn earworm is also known as the tomato fruitworm. Each year, sometime between June and early August, the adult moth migrates into Michigan. Female moths lay small, yellow eggs on corn silks. When the larvae hatch, they begin feeding on the tip of the ear. Corn earworm larvae vary in color from pink, green, and maroon to brown and tan and can be 1¾ inches long. Mature caterpillars drop from the plant and pupate in the soil. There are two to three generations per year in Michigan.

Damage: Corn earworms feed on corn kernels. As they develop, they can eat the entire tip of a corn ear and then move to other parts of the plant or other ears. A fully grown larva will create a large hole in the husk of the ear it has been feeding on when it exits to pupate. Damaged ears are unmarketable, and corn earworm feeding damage creates an entry point for secondary fungal infections.

Control strategies:

Corn earworm adults can be monitored using pheromone lures and traps placed near cornfields. Scout fields to monitor ear feeding. Correct identification is important because corn earworms are more difficult to control than European corn borers.

- Naturally occurring biological control agents such as parasitic wasps and flies, lady beetles, and other predators help control the corn earworm.
- Timing of insecticide treatments and application to the corn silks, where corn earworm eggs are laid, are critical—once corn earworms enter the ear, insecticide applications are not effective.

Corn earworm eggs are laid in corn silks (top) and the larvae vary in color (bottom).

FALL ARMYWORM (*Spodoptera frugiperda*)

Fall armyworms cannot overwinter in areas where the ground freezes and, therefore, arrive in Michigan from the Gulf Coast states late in the growing season. The adult moth is dark gray with light and dark mottled wings and a white spot near the tip of the forewing. Eggs are deposited in clusters on leaves. The female covers her egg clusters with hairs and wing scales. The 1½-inch larvae vary in color, but all have three yellowish white lines running from head to tail and darker stripes on the sides of the body. Scattered along the body are black bumps (tubercles) with spines. A white inverted Y on the head capsule of the fall armyworm distinguishes it from other corn pests. Fall armyworm completes one to three generations per year.

Damage: Fall armyworm larvae feed on developing leaves deep inside the whorl, occasionally killing the tassel before it emerges, though usually a plant will outgrow fall armyworm whorl damage. Late in the season, larvae feed on developing ears, causing damage similar to that of corn earworm. Fall armyworm damage is generally more severe in late-planted corn and is uncommon in early plantings.

Control strategies for armyworm and fall armyworm:

- Eliminate grassy weeds from fields and field edges to reduce armyworm egg-laying sites.
- Avoid late-season plantings to reduce the risk of fall armyworm damage; fall armyworms can be more abundant in long-season hybrids.
- In warm, dry weather, natural enemies usually keep armyworm populations under control and provide some suppression of fall armyworms.
- If armyworms deplete the grassy weed hosts and larvae migrate into a cornfield, an insecticide application may be necessary. Spot treatment of infested areas can provide sufficient control for a confined infestation.
- Timing of insecticide treatments and application to the corn silks, where eggs are laid, are critical—once fall armyworms enter the ear, insecticide applications are not effective.

INSECT PESTS OF ONIONS

ONION MAGGOT (*Delia antiqua*)

Adult onion maggots emerge in mid-May and resemble houseflies. They feed on pollen from dandelions and other flowers. Female flies lay eggs in or on the soil near the bases of onion plants. When the eggs hatch, the maggots (larvae) burrow into the soil and feed on onion roots and bulbs. Onion maggots feed only on onion plants and prefer cool, wet weather. After feeding for two to three weeks, the maggots pupate in the soil. Adults emerge in a couple of weeks. There are three generations of onion maggots in Michigan each year.

Damage: Onion maggots feed on roots and bulbs. First-generation larvae cause the most damage, feeding on onion seedlings. Late in the season, adults prefer to lay eggs near already damaged plants. Maggots have a difficult time feeding on healthy bulbs.

Control strategies:

- Remove or plow under volunteer onions after harvest to reduce third-generation populations.
- Do not pile up old bulbs on field edges in the spring. This attracts adult females to lay eggs in the field.
- Plant onions as late as possible to reduce the time they are available for adult egg laying.
- Interplanting rye or barley strips in onion fields helps protect young seedlings from wind and attracts natural enemies.
- Avoid injuring plants when cultivating, fertilizing, or working in the field—onion maggots are attracted to injured plants.

- Natural enemies such as ground beetles, lady beetles, rove beetles, and tiny parasitic wasps attack and kill onion maggots. A fungal disease called *Entomophthora* kills adult flies.
- Onion maggots have developed resistance to nearly all available insecticides. Foliar applications aimed at killing the adults are ineffective, and, the application of foliar insecticides kills natural enemies and aids in resistance development.
- A soil insecticide application at planting protects against onion maggot.

ONION THRIPS (*Thrips tabaci*)

Onion thrips damage.

Thrips are small insects, measuring one mm in length, with two pairs of fringed, feathery wings. They have mouthparts developed for rasping and sucking – they shred plant tissue (rasp) and then withdraw the juices (suck). They feed on foliage, buds, and flowers of many host plants. Onion thrips prefer hot, dry conditions and require two to four weeks for complete development. There are several generations per year.

Damage: Thrips feed on the leaves and new growth in the center of the plant near the bulb. Damaged leaves have a silvery appearance. In heavy infestations, thrips can also be found feeding on the outer leaf surfaces, causing leaf tips to turn brown. Feeding injury reduces yield, decreases bulb size, and affects market price.

Control strategies:

- Thrips can be knocked off the plant or drowned by rain or overhead irrigation.
- Check plants regularly for early detection of thrips. They are usually found within the folds of leaves, where they are difficult to control with insecticides, and they have developed resistance to many common insecticides.
- When applying insecticides, use high pressures and high gallonage to improve coverage in the center of the plant.

INSECT PESTS OF POTATOES

COLORADO POTATO BEETLE (*Leptinotarsa decemlineata*)

Colorado potato beetle larva (top) and adult (bottom).

Adult Colorado potato beetles are easily recognized by their yellow orange color and five narrow, black strips on each wing cover. Adults overwinter buried in the soil in fields and field borders. In the spring, they emerge and begin to feed, mate, and lay eggs. Typically, the yellow, oblong eggs are laid on the undersides of leaves in groups of 10 to 30. Red to orange larvae emerge and begin to feed on foliage. After two to three weeks of feeding, larvae pupate in the soil. Depending on the temperature, Michigan has one to three generations of Colorado potato beetle a year.

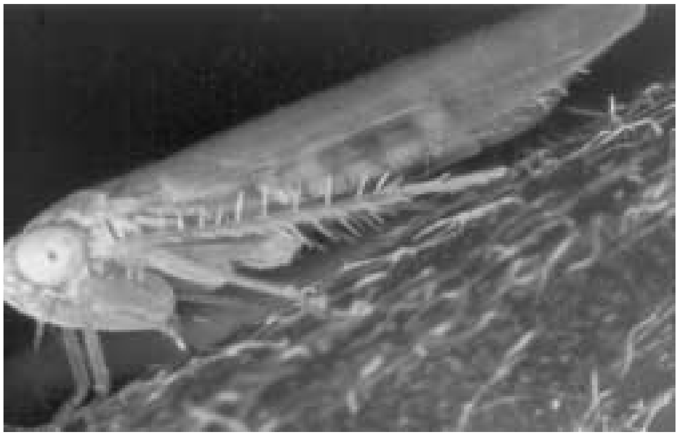
Damage: Colorado potato beetle adults and larvae feed on potato foliage. If left uncontrolled, they can easily defoliate entire plants.

Control strategies:

- Crop rotation to delay or reduce spring infestations is a highly effective management practice.
- Trap crops of early-planted potatoes along field edges concentrate adults migrating to the field. This high concentration of Colorado potato beetles makes flaming or vacuuming a successful control option.

- Several natural enemies aid in suppressing the Colorado potato beetle, but none provides adequate suppression.
- Soil- or foliar-applied insecticides can be used, though many Colorado potato beetle populations have developed insecticide resistance to almost all insecticides available.

POTATO LEAFHOPPER (*Empoasca fabae*)



Potato leafhooper adult.

Every year, potato leafhoppers migrate to Michigan from their overwintering sites in the southern United States, arriving in May. Potato leafhoppers are wedge-shaped, lime-green insects with sucking mouthparts. Potato leafhopper nymphs look like adult leafhoppers without fully developed wings. In warm weather, it takes only 21 days for a potato leafhopper to develop, so populations can increase quickly. There are multiple generations a year in Michigan.

Damage: Adults and nymphs damage plants by sucking plant sap from leaves; nymphs cause more damage than adults. Potato leafhoppers inject toxic saliva when they feed that causes the edges of damaged leaves to turn yellow and curl; eventually they die and drop from the plant. This damage is called “hopperburn.” Potato leafhopper damage disrupts the plant’s ability to transport nutrients and so reduces yield. A plant does not have to show obvious potato leafhopper damage, however, to suffer substantial yield loss.

Control strategies:

- Weekly scouting for potato leafhopper nymphs and adults is extremely important because low populations can cause significant yield reductions without obvious damage. Adults can be sampled by sweeping the field with a sweep net. To sample for nymphs, remove a single leaf and count the number of nymphs on the leaf. (Nymphs don’t have wings and can’t fly away). Randomly sample 25 leaves throughout the field.
- Foliar insecticides provide control. Choose foliar insecticides that do not promote Colorado potato beetle or green peach aphid resistance.

APHIDS

Green Peach Aphid (*Myzus persicae*) and Potato Aphid (*Macrosiphum euphorbiae*)

Green peach aphids are common pests of many vegetable crops. To learn more about the life cycle and crop damage caused by green peach aphids, see the carrot insect section.

The **potato aphid** has a similar life cycle as the green peach aphid. However, potato aphids overwinter in Michigan as eggs on plants of rose and related species. Beginning in June and July, winged potato aphids migrate to potato fields.

Damage: Aphids use sucking mouthparts to take plant juices from leaves and stems. If populations are large, they cause leaves to turn yellow and brown. Many aphid species can vector potato virus Y (PVY) and green peach aphids transmit potato leafroll virus (PLRV) (see Chapter 7-Disease Management).

Control strategies:

- Many common predators, including lady beetle adults and larvae, lacewing larvae, and syrphid fly larvae, feed on aphids. There are also a number of parasitic wasps. For seed potato producers, natural enemies usually do not provide sufficient aphid control because of the zero tolerance for virus infection.
- Sample for aphids by examining the undersides of leaves on plants throughout the field. Yellow sticky cards or water traps can also be used, but because many other insects can be trapped, correct pest identification can be difficult. Action thresholds differ for fresh market, processing, and seed potatoes.
- Aphids develop resistance quickly from repeated use of foliar insecticides with similar modes of action.

INSECT PESTS OF SNAP BEANS

POTATO LEAFHOPPERS

Potato leafhoppers are common pests of several vegetable crops. To learn more about their life cycle and the crop damage they cause, see the potato insect section.

TARNISHED PLANT BUG (*Lygus lineolaris*)

Adult tarnished plant bugs are 1/4 inch long and light brown with a tarnished appearance—relatively long antennae and legs, and a white triangle between their shoulders. Beginning in late April or May, tarnished plant bugs emerge from overwintering sites in leaf litter. Female bugs deposit eggs into plant stems and midribs. Eggs hatch, and nymphs, which are similar to the adults but smaller and without wings, begin to feed. There are three to five generations per year.

Damage: Tarnished plant bug adults and nymphs use their needlelike mouths to suck plant juices from leaves, flowers, and pods. Tarnished plant bugs inject a saliva that is toxic to some plants when they feed. In beans, they feed on flower petioles and cause blossom drop and reduced yields. They feed on a wide variety of plants, including alfalfa, and can rapidly move from crop to crop. They may migrate into snap beans after the cutting of nearby alfalfa.

Control strategies:

- Begin scouting fields using a sweep net when plants are in bloom and continue through small pod development.
- With their wide host range (dozens of crops and weeds), there are no practical non-chemical control options at this time.
- Insecticide applications for potato leafhoppers also reduce tarnished plant bug populations, which move about freely, resuming feeding soon after an application.

EUROPEAN CORN BORER (*Ostrinia nubilalis*)

The European corn borer is a pest of snap beans. European corn borers overwinter as full-grown larvae in corn debris, usually field corn. Beginning in mid-June, the first generation of adult moths emerge and mate in tall grasses. The adult moths are cream to light brown. The female moth lays her eggs, which look like fish scales, on the undersides of corn leaves. The larvae hatch and feed on the leaf, eventually moving into and feeding down in the whorl. As the larvae mature, they enter the stalk to feed and pupate. After second-generation European corn borers adults mate, the females deposit eggs on the leaves in the ear zone of silking corn. The larvae feed on the developing ears, causing kernel damage, or enter the stalk, ear shank or cob. Depending on the temperature, there are two or three generations of European corn borer per year.

Damage: Young larvae feed on leaves, buds and flowers; mature larvae burrow into stems and beans. The greatest risk of European corn borer contamination is from bud to pin bean stage. Eggs laid 14 days or less before harvest will generally not result in damage or contamination. A very small proportion of European corn borer eggs survive long enough to lead to pod damage, but the tolerance for injury for processing is zero, and management is required.

Control strategies:

***Non-chemical*—**A number of factors affect European corn borer populations but they are out of your control. A series of cool evenings (below 65 degrees F), or a heavy rain can reduce the number of eggs laid or the survival of small larvae. In addition, young larvae can dehydrate and blow away on hot, windy days. Thus, conditions present during European corn borer mating, egg laying, and development of eggs and small larvae are critical in determining the population from year to year.

***Biological*—**A large number of natural enemies attack all life stages of European corn borer. Generalist predators such as lady beetle larvae and adults, lacewing larvae, and minute pirate bugs feed on egg masses and small larvae. Other insects and birds eat large larvae and pupae. In locations with large populations of predators, their role in controlling European corn borer should be taken into consideration when determining a management strategy.

Though parasitoids have been imported from Europe to control European corn borer, only a few have been successfully established. The amount of control from these parasitoids varies from year to year and depends on the location and shape of each field.

Two main pathogens affect European corn borer populations. *Beauvaria bassiana* is a naturally occurring fungus that usually kills overwintering larvae; dead larvae look white and furry. Most epidemics of *B. bassiana* occur late in the season during and after periods of rainfall when temperatures are in the mid-80’s F. *Nosema pyrausta* is a protozoan-like microbe that reduces European corn borer egg laying, kills some larvae, and increases overwintering mortality.

***Chemical*—**Timing is critical for a successful pesticide application. Larvae will be controlled only when they are moving on the plant and NOT after they are feeding inside the pods or stems. The treatment window for European corn borers is from bud stage to 14 days before harvest. Preventive insecticide applications are recommended for processing snap beans during this period.

INSECT PESTS OF TOMATOES

COLORADO POTATO BEETLE (*Leptinotarsa decemlineata*)

Colorado potato beetles feed on plants in the family Solanaceae, which includes potato, tomato, eggplant, nightshade, and horsenettle. For detailed information on their life cycle, see the section on potatoes.

Damage: Colorado potato beetle adults and larvae feed on tomato foliage and fruit. Though they prefer to feed on potatoes, they can easily defoliate an entire tomato plant in three to four days.

Control sÏtrategies:

- Crop rotation helps delay and reduce spring infestations.
- Trap crops of potatoes planted along field edges attract migrating Colorado potato beetle adults and delay tomato infestation for a few days.
- Several natural enemies aid in controlling the Colorado potato beetle, though they seldom provide sufficient larval or adult control.
- Foliar insecticides can be applied to trap crops or “hot spots,” small isolated areas of infestation, to avoid treating an entire field. Insecticides are most effective on small larvae.

TOMATO HORNWORM (*Manduca quinquemaculata*)

Tomato hornworms can quickly defoliate plants because the larvae are large (up to four inches long). Larvae are pale green caterpillars with white markings and a horn at the rear end. In May or June, tomato hornworms emerge from their overwintering sites as adult hawk moths. Single light green eggs are laid on the undersides of leaves. When eggs hatch, larvae feed on leaves and fruit before pupating in the soil. In Michigan, there may be two to three generations a year.

Tomato hornworm larva (top) and adult (bottom).

Damage: With their chewing mouthparts, these large caterpillars eat leaves of tomatoes, eggplants, and peppers and can also bore into tomato fruit. Tomato hornworm damage can cause 100 percent of the product to be unmarketable.

Control strategies:

- Small infestations of tomato hornworms can be hand picked from plants. Look closely when scouting plants for tomato hornworms -- they are well camouflaged and difficult to see until they are large enough to defoliate plants.
- A number of natural enemies help control tomato hornworms. For example, caterpillars parasitized by a tiny wasp will have tiny, white wasp cocoons on them. Parasitized larvae do not develop into adult hornworms, but they do continue to feed.
- Many foliar insecticides control tomato hornworms.

TOMATO FRUITWORM (*Heliocoverpa zea*)

The tomato fruitworm is also known as the corn earworm. The adult moth migrates into Michigan each year beginning in late June. Moths are active at night, and female moths are attracted to flowering and fruiting tomato plants. Small, yellow eggs are laid near or on the tomato. Newly hatched larvae vary in color from pink and green to maroon, brown, and tan and begin at once to feed on the tomato. A fully mature larva can grow to 1 3/4 inches long. Mature caterpillars drop from the plant and pupate in the soil. There are two to three generations per year in Michigan.

Damage: Tomato fruitworm caterpillars attack green tomatoes. They bore into the fruit, creating a deep, watery cavity. The cavity creates an entry point for secondary fungal infections. Damaged fruit is unmarketable and usually falls from the vine.

Control strategies:

- Naturally occurring biological control agents such as parasitic wasps and flies are very important in the control of tomato fruitworm.
- Tomato fruitworm adults can be monitored using pheromone lures and traps placed near tomato plants or cornfields. Scout fields to monitor fruit feeding. It is important to treat when the larvae are small, because once they enter the fruit, insecticide applications will not be effective.

GENERAL VEGETABLE INSECT PESTS

SEEDCORN MAGGOT (Delia platura)

Seedcorn maggots have a wide host range including corn, snap beans, and cucurbits. They overwinter in the soil as small, brown pupae. Beginning in early April, adult seedcorn maggots emerge. The adult is a small, gray fly, similar to a housefly. Female flies deposit eggs in the soil and are attracted to soil high in organic matter, either plowed-down crop residue or animal manure. Larvae or maggots feed on decomposing plant material and seeds. Seedcorn maggots favor cold, wet weather. There are multiple generations a year, but only the first generation is of economic concern.

Damage: Larvae feed on decomposing plant matter and seeds. Seeds can be attacked before or after germination. Damaged seeds may not sprout or produce malformed, stunted plants. Attacked seedlings will wilt and die within a few days.

Control strategies:

- If planting into a field that has a cover crop, plow down the cover crop three to four weeks before planting. This provides enough time for decomposition.
- Insecticide seed treatments are an effective way to control seedcorn maggot.

Review Questions

Chapter 5: Insect Management

Write the answers to the following questions and then check your answers with those in the back of the manual.

1. Insect damage can result in:
   A. An unmarketable product.
   B. Disease transmission.
   C. Yield reduction.
   D. All of the above.

2. Molting is the process of shedding an old skeleton to reveal a new, larger exoskeleton.
   A. True.
   B. False.

3. Define metamorphosis.

4-8. Match the following forms of metamorphosis with the correct statement.

A. Simple

B. Complete

C. Both simple and complete

4. ___ Immature insects resemble adults.

5. ___ Adults and nymphs usually live in the same environment.

6. ___ Adult insects have wings.

7. ___ Immature insects do not look like the adults.

8. ___ Immature insects are referred to as larvae.

9. During which insect life stage does an insect undergo a complete change?
   A. Nymph
   B. Larva
   C. Pupa
   D. Adult

10. The asparagus miner goes through which type of metamorphosis?
    A. Simple
    B. Complete

11. The leafhopper goes through which type of metamorphosis?
    A. Simple
    B. Complete

12. Why is it important to understand an insect's life cycle for pest management?

13-17. Match the following insects with the correct statement below. Answers can be used more than once.

A. Diamondback moth
B. Aster leafhopper
C. Corn flea beetle
D. Onion thrips
E. European corn borer

13. ___ Transmits aster yellows.
14. ___ Pest of cole crops that can be resistant to *Bacillus thuringiensis*.
15. ___ Has rasping/sucking mouthparts.
16. ___ Transmits Stewart's wilt.
17. ___Feeds on leaves and burrows into cornstalks.

18. Larvae of the striped cucumber beetle damage cucumbers by feeding on the:

A. Fruit.
B. Root hairs and root tips.
C. Vines.
D. Foliage.

19. Which pest of asparagus feeds on the berries?

A. Common asparagus beetle
B. Asparagus miner
C. Spotted asparagus beetle
D. Cutworms

20. First generation European corn borers feed primarily in the:

A. Ear.
B. Shank.
C. Whorl.
D. Roots.

21. European corn borer feeding can result in:

A. Ear drop.
B. Stalk breakage.
C. Grain reduction.
D. All of the above.

22. The squash bug has what type of mouthparts?

A. Chewing.
B. Sucking.
C. Rasping.

23. Aphids and leafhoppers can spread plant disease.

A. True
B. False

24. Which insect pest of celery is also one of the main pest of cole crops?

A. Aster leafhopper
B. Cabbage looper
C. Tarnished plant bug
D. Variegated cutworm

25. Larvae of which of the following are common predators of aphids?

A. Lacewing
B Monarch
C. Housefly
D. None of the above

26. Which insect pest is easily confused with the striped cucumber beetle?

A. Bean leaf beetle.
B. Western corn rootworm
C. Corn flea beetle
D. Colorado potato beetle

27-30. Match the following insects with the characteristics given below.

A. Aphids
B. Armyworm
C. Tomato hornworm
D. Onion maggot

27. ___ Defoliates tomatoes, eggplants, and peppers.
28. ___ Vectors potato virus Y.
29. ___ Feeds on roots and bulbs.
30. ___ Damages corn and small grains.

31. Aphids must mate to produce offspring.

A. True
B. False

32. Which of the following insects does **not** have chewing mouthparts?

A. Tarnished plant bug
B. Diamondback moth larvae
C. Carrot weevil
D. Cutworms

CHAPTER 6

WEED MANAGEMENT

LEARNING OBJECTIVES

After completely studying this chapter, you should:

- Be able to define a weed and its four stages of development.
- Understand the differences between annual, biennial, and perennial weeds.
- Be able to give examples of cultural weed controls.
- Know the advantages and disadvantages of the various methods of herbicide applications.
- Understand herbicide carryover and how to prevent it.
- Know what herbicide adjuvants are.

Weeds are plants growing where they are not wanted. They can reduce yields by competing with crops for water, nutrients, and light. Some weeds release toxins that inhibit crop growth; others may harbor insects, diseases, or nematodes that attack crops. Weeds often interfere with harvesting operations, and at times contamination with weed seeds or other plant parts may render a crop unfit for market. Profitable crop production depends on effective weed control.

DEVELOPMENT STAGES

Most crop plants and weeds have four stages of development:

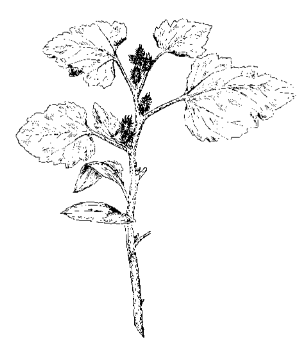
- SEEDLING—small, delicate, newly emerged plants.
- VEGETATIVE—plant grows quickly, producing stems, roots, and leaves.
- SEED PRODUCTION—plant's energy is directed into producing flowers and seeds.
- MATURITY—plant produces little or no energy. Some plants begin to dry out or **desiccate**.

LIFE CYCLES OF WEEDS

Weeds can be classified according to their life cycle. The three types of plant life cycles for weeds are annual, biennial, and perennial.

ANNUAL

Plants that complete their life cycle in one year are **annuals**. They germinate from seed, grow, mature, produce seed, and die in one year or less. Annuals reproduce by seed only and do not have any vegetative reproductive parts. Summer annuals may germinate from seed in the spring, flower and produce seed during the summer, and die in the summer or fall. Winter annuals germinate from seed in the fall and reproduce and die the following year. Annual weeds are easiest to control at the seedling stage.



Cocklebur.

BIENNIAL

Biennials complete their growth cycle in two years. The first year, the plant produces leaves and stores food. The second year, it produces fruits and seeds. Biennial weeds are most commonly found in no-till fields, pastures, and unmowed fencerows. They are easiest to control in the seedling stage.

Bull thistle is a biennial.

PERENNIAL

Perennials are plants that live for two or more years. Perennials can reproduce by seed or vegetatively. The plant parts that allow perennials to spread without producing seeds are **stolons** (creeping aboveground stems—e.g., white clover and strawberries), **rhizomes** (creeping belowground stems—e.g., milkweed, quackgrass), **tubers** (enlarged underground stems—e.g., potato, yellow nutsedge), and **bulbs** (underground stem covered by fleshy leaves—e.g., tulip). Because perennial weeds can propagate (spread) underground, they can be the most difficult weeds to control. Removing the aboveground vegetation will not stop the weed from spreading.

Johnsongrass is a creeping perennial.

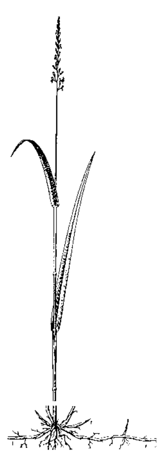
Annuals, biennials, and perennials can reproduce from seed. Many weeds produce large quantities of seeds. Seeds are easily dispersed across a field by wind, rain, machinery, animals, and people. Weed seeds can germinate after being dormant for long periods of time. They can also tolerate extremes in weather such as temperature and moisture. To prevent seed dispersal, you should control weeds before they produce seeds.

COMMON WEEDS IN MICHIGAN

GRASS AND GRASSLIKE WEEDS

Annuals

- Barnyard grass
- Large crabgrass
- Smooth crabgrass
- Giant foxtail
- Yellow foxtail
- Green foxtail
- Fall panicum
- Wild-proso millet
- Witchgrass



Monocot or Grass plant.

Perennials

- Johnsongrass
- Yellow nutsedge
- Quackgrass

Yellow Nutsedge.

BROADLEAF WEEDS

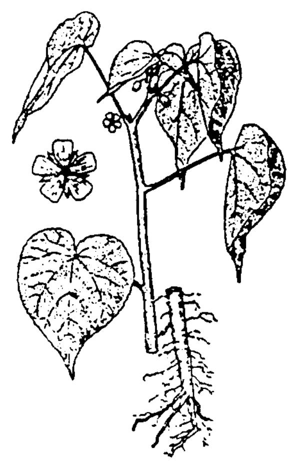
Annuals

- Ladysthumb
- Pennsylvania smartweed
- Wild buckwheat
- Common lambsquarters
- Redroot pigweed
- Eastern black nightshade
- Common cocklebur
- Jimsonweed
- Common purslane
- Common ragweed
- Giant ragweed
- Velvetleaf
- Common chickweed
- Shepherd's purse
- Horseweed (Marestail)
- Prickly lettuce
- Wild mustard
- Yellow rocket

Redroot Pigweed.

Biennials

- White campion
- Wild carrot
- Bull thistle



Velvetleaf.

Perennials

- Milkweed
- Hemp dogbane
- Canadian thistle
- Dandelion
- Field bindweed
- Perennial sow thistle
- Swamp smartweed
- Goldenrod
- Plantain

WEED CONTROL

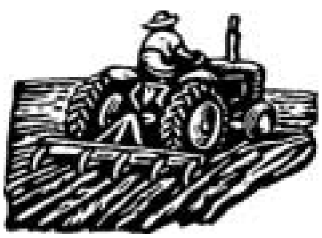
CULTURAL CONTROL

Crop competition is a very useful method of weed control. Production practices that optimize crop growth enable the crop plants to compete effectively with weeds. Crop management practices that can improve the competitive ability of the crop are crop and variety selection, planting date, population, soil fertility, drainage, etc. Recommended crop production practices are also beneficial weed control practices.

Crop rotation may also be helpful in maintaining adequate weed control. Many weeds cannot tolerate crop rotation.

MECHANICAL CONTROL

Tillage buries weeds or destroys their underground plant parts. Small annual and biennial seedlings are more effectively controlled with tillage. Disturbing the soil, however, can bring new weed seeds near the soil surface and create more weed problems.



CHEMICAL CONTROL

The first step in successful chemical weed control is the correct identification of the weeds. Annual weeds are easier to kill when they are small seedlings and when conditions favor rapid growth, but, crop plants are also easily injured under these conditions. Selective herbicides should control the weeds with little or no injury to the crop.

Timing and rate of herbicide application are very important in chemical weed control. Applying herbicides at the wrong time often results in poor weed control and crop injury.

TYPES OF HERBICIDES

Chemical weed control can be obtained with herbicides applied either preplant incorporated, preemergence, or postemergence. Many herbicides can be applied by more than one of these methods.

Preplant Herbicide Soil Applications and Incorporation

Preplant incorporation applications are herbicides applied and incorporated into the soil before planting. Incorporation of some herbicides is required to prevent them from volatilizing (becoming a gas) into the air or decomposing in the sun.

Advantages of preplant soil applications and incorporation:

- Early weed control reduces weed competition with the crop.
- Wet weather will not delay cultivation or herbicide application to control weeds.
- Preplant soil application and incorporation is less dependent on rainfall for herbicide activation than preemergence herbicide applications.

Disadvantages of preplant soil applications and incorporation:

- Incorporating the herbicide too deep in the soil can reduce weed control.
- A streaking pattern of good and poor weed control can result from incomplete soil incorporation.
- Growers apply herbicide without identifying the weeds. They are preventive applications.
- It is incompatible with a no-till system.

Preemergence Herbicide Applications

Preemergence herbicide applications are applied to the soil surface after the crop has been planted but before the crop or weeds emerge. Typically, preemergence herbicide applications require rainfall within one week following the application to ensure that the herbicide moves into the soil.

Advantages of preemergence applications:

- Early control of weeds reduces weed competition with crop.
- They can be used in all tillage systems.
- Planting and herbicide application may be done at the same time.

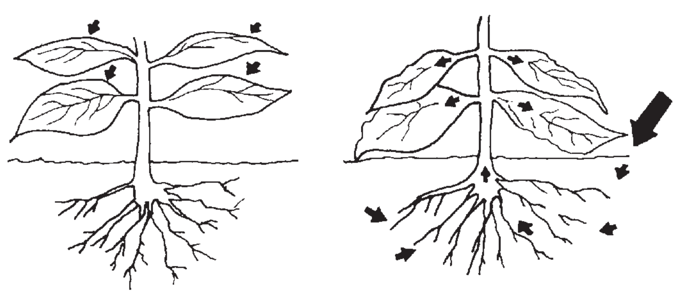
Disadvantages of preemergence applications:

- They depend on rainfall and are ineffective in dry soil conditions.
- On sandy soil, heavy rains may move the herbicide down in the soil to the germinating crop seed and cause injury.
- Growers apply herbicide without identifying the weeds. They are preventive applications.

Postemergence Herbicide Applications

Postemergence herbicide applications are applied to the foliage of the weeds after the crop and weeds have emerged. There are two types of postemergence herbicides: contact and systemic. **Contact herbicides** kill only the plant parts that they touch. Typically, the aboveground parts of a weed, such as the leaves and stems, turn brown and die. Contact herbicides are commonly used to control annuals.

Systemic or translocated herbicides are absorbed by the weed's roots or leaves and moved throughout the plant. Translocated herbicides are more effective than contact herbicides against perennial weeds because the herbicide reaches all parts of the plant, but, translocated herbicides may take up to three weeks to kill the weeds.



Advantages of postemergent applications:

- Herbicide is applied after the weed problem occurs (remedial application).
- They are less susceptible to environmental conditions after the herbicide application than preemergent herbicides.
- They are useful for spot treatments.
- Postemergent herbicide applications have short or no soil residual.

Disadvantages of postemergent applications:

- Postemergent herbicides are environmentally sensitive at the time of application.
- Weeds must be correctly identified.
- Timing of the application is critical for effective weed control.
- Postemergent herbicides should not be applied to wet foliage.
- Weather may not permit a herbicide application at the proper time.

HERBICIDE CARRYOVER

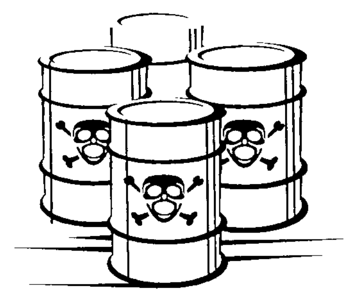
A potential problem of herbicide applications is **herbicide carryover**. This occurs when a herbicide does not break down during the season of application and persists in sufficient quantities to injure succeeding crops. The breakdown of herbicides is a chemical and/or microbial process. Generally the rate of breakdown increases with soil temperature. Very dry conditions during the summer and early fall often increase the potential for carryover of many herbicides.

Herbicide carryover is also influenced by the rate of application, herbicide distribution across a field, soil type, and time. When herbicides are used above the labeled rate and/or not uniformly distributed, herbicide carryover problems may result. Poor distribution is generally the result of improper calibration or agitation, sprayer overlapping, or non-uniform soil incorporation.

Vegetable and ornamental crops are often more sensitive to herbicide carryover than field crops. To reduce the potential of herbicide carryover, read and follow all pesticide label directions. Herbicide labels contain restrictions on the interval between application and planting of various crops. Consult the current version of MSU Extension bulletin E-433, *Weed Control Guide for Vegetable Crops*, for more information on herbicides.

HERBICIDE COMBINATIONS

Herbicides are commonly combined and applied as a tank mix. Combinations are used to give more consistent control or a broader spectrum weed control, to decrease herbicide carryover, or to obtain adequate season-long weed control. Proper application methods must be followed for each herbicide detailed on the EPA-approved pesticide label. Always remember to read the pesticide label before combining or applying herbicides.



HERBICIDE ADDITIVES (ADJUVANTS)

An **adjuvant** is any substance added to a herbicide to enhance its effectiveness. Many commercially available herbicide formulations contain their own particular set of adjuvants to optimize the performance, mixing, and handling of the active ingredient. Sometimes additional additives are required for specific applications or herbicide combinations. The pesticide label will explain how and when to use the necessary adjuvants.

Additives are used primarily with postemergence herbicide applications to improve the coverage of leaf surfaces and increase herbicide penetration into the leaf. Additives do not increase the effectiveness of soil-applied herbicides.

HERBICIDE COMPATIBILITY PROBLEMS

Compatibility problems in tank mixing herbicides usually occur when applicators do not follow mixing directions. Some common causes of compatibility problems are: mixing two herbicides in the wrong order (for example, adding an emulsifiable concentrate to the spray tank before suspending a wettable powder), insufficient agitation, excessive agitation, and air leaks. Problems can also occur when the carrier is a fertilizer such as 28 percent nitrogen or other non-water substances. You should test for herbicide compatibility in a small container before mixing a large tank. If compatibility problems occur, adding compatibility agents may help.

CHAPTER 6

Review Questions

Chapter 6: Weed Management

Write the answers to the following questions and then check your answers with those in the back of the manual.

1. Define a weed.

2. Plants that complete their life cycle in one year are:
   A. Biennials.
   B. Annuals.
   C. Perennials.
   D. None of the above.

3. An aboveground creeping stem is called a:
   A. Rhizome.
   B. Stolon.
   C. Tuber.
   D. Bulb.

4. Weeds are easiest to control at the:
   A. Reproductive stage.
   B. Vegetative stage.
   C. Seedling stage.
   D. Mature stage.

5. Which of the following is an example of a broadleaf weed?
   A. Quackgrass.
   B. Green foxtail.
   C. Wild-proso millet.
   D. Common ragweed.

6. An example of a perennial grass weed is:
   A. Quackgrass.
   B. Wild carrot.
   C. Barnyard grass.
   D. Smooth crabgrass.

7. Reducing the competition between a crop and weeds by changing the planting population of the crop is an example of:
   A. Biological weed control.
   B. Cultural weed control.
   C. Chemical weed control.
   D. Mechanical weed control.

8. Preemergence herbicides generally require rainfall within a week of application to incorporate the herbicide in the soil.
   A. True
   B. False

9. Which of the following is true of preplant incorporated herbicide applications?

   A. They provide early weed control.

   B. They can be used in all tillage systems.

   C. They typically cause more crop injury than postemergence herbicide applications.

   D. They are not affected by soil composition and moisture.

10. List two advantages and two disadvantages of postemergence herbicide applications.

11. Systemic herbicides kill weeds on contact.

    A. True.

    B. False.

12. A preventive herbicide application occurs ______ weeds have emerged.

    A. before

    B. after

13. A grower has a quackgrass problem in a cucumber field where the plants have three leaves. Which type of herbicide application would you use to control the quackgrass?

    A. Preplant soil incorporated

    B. Postemergent

    C. Preemergent

    D. None of the above

14. The best way to reduce the potential of herbicide carryover is to follow the pesticide label directions.

    A. True

    B. False

15. What is a herbicide adjuvant?

16. It is **not** necessary to test for herbicide compatibility before mixing a large tank.

    A. True

    B. False

CHAPTER 7

DISEASE MANAGEMENT

LEARNING OBJECTIVES

After completely studying this chapter, you should:

- Be able to define non-infectious and infectious disease.
- Understand how fungi, bacteria, and viruses produce disease.
- Understand the disease triangle and the disease cycle.
- Understand control methods specific to disease management.
- List the major diseases affecting asparagus, carrots, celery, cole crops, cucurbits, corn (sweet), onions, potatoes, tomatoes, and snap beans.

INTRODUCTION

Diseases are the most difficult type of plant injury to diagnose and manage. A plant **disease** is any condition that does not allow the plant to function normally. **Noninfectious plant diseases** are caused by nonliving agents or cultural and environmental factors such as drought, soil compaction, hail, wind, toxic chemicals, nutrient deficiency, and temperature or moisture extremes. Noninfectious disease cannot reproduce and spread from plant to plant.

Symptoms such as wilting, stunting, and yellowing of leaves may appear suddenly on a plant with a non-infectious disease. Few noninfectious diseases can be corrected or avoided, and often the symptoms resemble those of infectious diseases. For example, nutrient deficiency symptoms often resemble symptoms of root rot. The remainder of the manual focuses on infectious plant diseases and their management.

An **infectious plant disease** is caused by an agent that attacks and feeds on the host plant. The disease-causing agent is called a **pathogen**. In Michigan, fungi, bacteria, and viruses are pathogens for vegetable crops. Pathogens are spread from diseased plants to healthy plants by wind, rain, soil, people, machinery and insects.

FUNGI

Fungi are the largest and most familiar group of plant pathogens. The best known fungi are mushrooms and yeast. Most fungi are extremely small and cannot be seen without a microscope. Fungi cannot convert sunlight into food and therefore feed on dead or decaying organic matter (dead trees) or living matter (e.g., tomatoes, cole crops and corn plants).

Most fungi are made up of delicate, threadlike structures called **hyphae**. Hyphae grow and form masses called **mycelium**, which is the fuzzy growth that sometimes appears on the surface of the plant. Hyphae absorb nutrients and water needed for fungal growth and reproduction.

Most fungi reproduce by forming microscopic **spores** (sometimes called conidia). Spores come in many shapes and sizes. Some spores are produced on structures called **fruiting bodies**. Others appear on the plant surface as mold growth (powdery mildew and rust). Each fungus has a unique spore or fruiting body structure which is often used for identification.

Wind, splashing rain, insects, workers' hands, and clothing and equipment can easily transport spores from one location to another. Harsh environmental conditions will kill some spores, but other spores can be dormant for several months or years before germinating.

Some fungi survive harsh environmental conditions by producing specialized structures, such as **sclerotia**, which are masses of hyphae and food that can withstand long periods of extreme hot or cold temperatures and lack of water. When environmental conditions turn more favorable, the fungus again produces spores to infect hosts.

BACTERIA

Bacteria are very small, microscopic, one-celled organisms. Some bacteria are harmful to humans and animals because they cause diseases such as pneumonia, tuberculosis, typhoid fever, and anthrax. Bacteria also cause diseases in plants but most bacteria are harmless or beneficial (for example, the nitrogen-fixing bacteria of legumes). It is important to point out that the bacteria that are plant pathogens are **not** human pathogens.

Bacteria enter plants through wounds, natural openings in the plant, or direct penetration, usually in the leaf but sometimes roots and stems. Once inside the plant, bacteria begin to multiple rapidly and live in the spaces between plant cells. The life cycle of a bacterium may be only 20 minutes, so a population of bacteria may increase its numbers rapidly.

Bacteria do not produce spores or fruiting bodies; they reproduce by simple cell division. A cell splits into approximately two equal halves, and each half forms a new fully developed bacterium. Bacteria, like fungi, rely on their host plant for food. In the absence of a host plant, a bacterial population may decline rapidly.

Bacteria are spread primarily by wind-driven rain, but driving or walking through a field wet from dew will also spread bacteria. Insects spread some bacterial diseases, such as Stewart's wilt of corn. Typical symptoms of bacterial disease include leaf spots, soft rot of tissues, and water-soaking of tissue.

VIRUSES

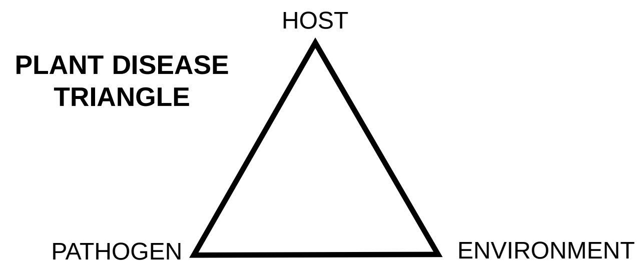
A **virus** is a very small non-living pathogen that cannot reproduce by itself. Viruses multiply by tricking the host cells into making more viruses. They are most familiar to us as the cause of human and animal diseases, such as polio, influenza, chickenpox, and warts. Viruses can also cause diseases in plants. Like bacteria, viruses infecting plants do **not** infect humans.

Plants infected with a virus can show any of the following symptoms: yellow to dark-green mottling, stunting of the leaves, early leaf fall, loss of plant vigor, mosaic patterns on leaves, deformation of plant tissues, and reduced yield. Sometimes a virus disease is mistaken for nutrient deficiency, pesticide or fertilizer injury, insect or mite activity, or other types of disease.

Because viruses can survive only in living cells, they need to enter a plant by means of a **vector**, usually an insect. Insect with piercing-sucking mouthparts, such as leafhoppers and aphids, are usually responsible for transmitting viruses. Pollen, soil-borne fungi, or nematodes can transmit a few viruses. Viruses can also be transmitted by vegetative means, such as tubers, bulbs, and root cuttings, and can be a serious problem for crops that are propagated from cuttings (for example, potatoes).

DISEASE TRIANGLE

Plant diseases occur when a pathogen attacks a susceptible plant (the host) under environmental conditions that favor infection and growth of the pathogen. Plant diseases are the result of a complex interaction between the host, the pathogen, and the environment. This interaction is often pictured as the disease triangle. By changing any side of the disease triangle, such as adding an unfavorable environment or using a disease-resistant variety, you can reduce the disease development.



The role of the environment in this interaction is important because diseases need specific conditions to develop. Temperature and moisture are two of the most important environmental conditions that influence plant diseases.

Air or soil temperature affects the growth of the host plant or pathogen. If the host plant is stressed or grows poorly, it may be more susceptible to disease. Temperature may also change the speed of growth of a pathogen.

Pathogens and host plants are also affected by moisture. Most fungal spores need moisture to germinate. A host plant experiencing moisture stress may be more susceptible to some pathogens. Also, many pathogens are spread by wind-blown rain or require moisture to infect the plant.

A successful disease management program takes into account the interactions of the environment, the disease, and the host plant. Disease management emphasizes reducing pathogen survival and limiting pathogen dispersal. For example, planting resistant varieties, improving soil drainage, and destroying or removing infected plants reduce the interaction between the three parts of the disease triangle.

DISEASE CYCLE

All plant pathogens have a basic chain of events involved in disease development called the **disease cycle**.

The basic steps are:

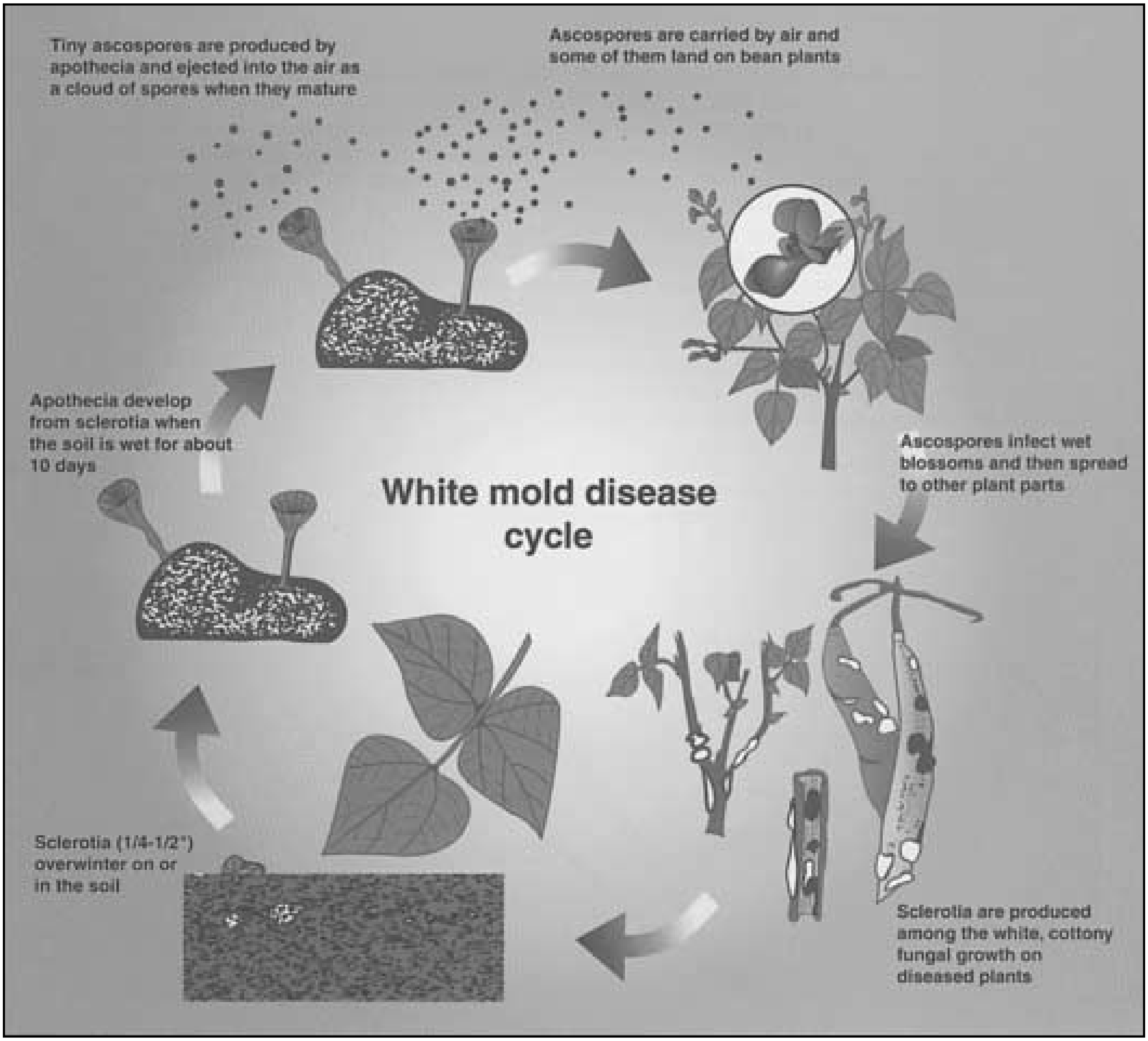
1. **Production of inoculum. Inoculum** is a source of a pathogen that infects and causes a disease (for example, fungal spores, bacterial cells, and virus particles). Inoculum can be present in soil, seed, weeds, crop residue, or other crops, or carried by the wind, rain, insects, animals, people, and machinery.
2. **Spread of inoculum.** The inoculum must disperse to the host plant. There are two types of spore movement:

active and passive. **Active movement** occurs when the inoculum is carried to a host by another organism (for example, insects, machinery or worker). One example is the spread of potato virus Y (PVY) by aphids from plant to plant. **Passive movement** is movement of the inoculum to a new host plant by wind or water. Most fungal and bacterial foliar pathogens disperse this way.

3. **Infection.** Infection occurs when the plant pathogen becomes established in the host. A successful plant pathogen grows, spreads within the host plant and produces new inoculum. As the pathogen grows in the host plant, symptoms begin to appear. The time period between infection and appearance of the first symptoms is called the **incubation period**, which can be several days to months.

4. **Pathogen survival between susceptible crops.** In Michigan, pathogens need to survive the winter between growing seasons and periods when no host is present. Disease pathogens survive non-host periods by:

   - Surviving on crop residues left in the field.
   - Producing structures that resist microbial and environmental breakdown.
   - Infecting seeds.
   - Infecting alternate hosts. A pathogen with a large host range has an increased chance of survival. Some plant pathogens may survive in alternate hosts without causing disease.



A good example of the disease cycle can be seen by looking at the fungus that causes white mold.

DISEASE MANAGEMENT

Options for disease management are limited. The best available disease management strategies concentrate on preventing disease. Chapter 1 of this manual deals with general aspects of IPM; this section will address control options specific to diseases.

Cultural Control

Changing crop production practices can help reduce the incidence and impact of many vegetable crop diseases. Cultural practices can disrupt the disease cycle, create unfavorable environmental conditions for the pathogen, reduce the pathogen population in the field, and improve crop growth and vigor.

CROP ROTATION. Many plant pathogens survive from one growing season to the next in the soil or on crop residues. To reduce disease, avoid planting the same crop in a field year after year. Alternating to non-host crops provides time to reduce pathogen populations. Some pathogens have a wide host range and are not affected by the sequence of the crop rotation. The fungus, *Sclerotinia sclerotiorum*, responsible for white mold in soybeans, can also infect many other crops, including dry beans, potatoes, tomatoes, and canola. A rotation that includes two of these crops can increase the pathogen population faster than a rotation that includes only one host.

TILLAGE. Incorporating crop residue permits soil microorganisms to decompose the residue, prey directly on the pathogen, or outcompete the pathogen for resources, resulting in a decrease in the pathogen population. Corn residues left on the soil surface in combination with periods of high daytime temperatures and relative humidity are the favored growing conditions for the fungal pathogen *Cercospora zeae-maydis*, which causes corn gray leaf spot.

ROW SPACING. Soil moisture changes with row spacing. Wider row spacing allows the surface of the soil to dry out faster and increases the amount of time needed to create a closed row. For example, wider row spacing can reduce the incidence of white mold in snap beans.

VARIETY SELECTION. The use of resistant varieties or hybrids is the least expensive, easiest, and most effective way to control plant diseases. Plant varieties express varying degrees of resistance to many diseases. A resistant variety can act as a non-host crop for a specific pathogen. Partially resistant varieties may not prevent the spores of a pathogen from germinating and growing but may reduce the number of new spores produced. This helps keep the pathogen from reaching yield-reducing thresholds.

SEED QUALITY. Certified seed is high-quality seed selected from healthy, relatively disease-free plants of known origin and genetic makeup. Poor seed quality may be associated with fungal or bacterial pathogens that use seed for survival and dispersal. Plants infected with seed-transmitted pathogens should not be used for seed.

Biological Control

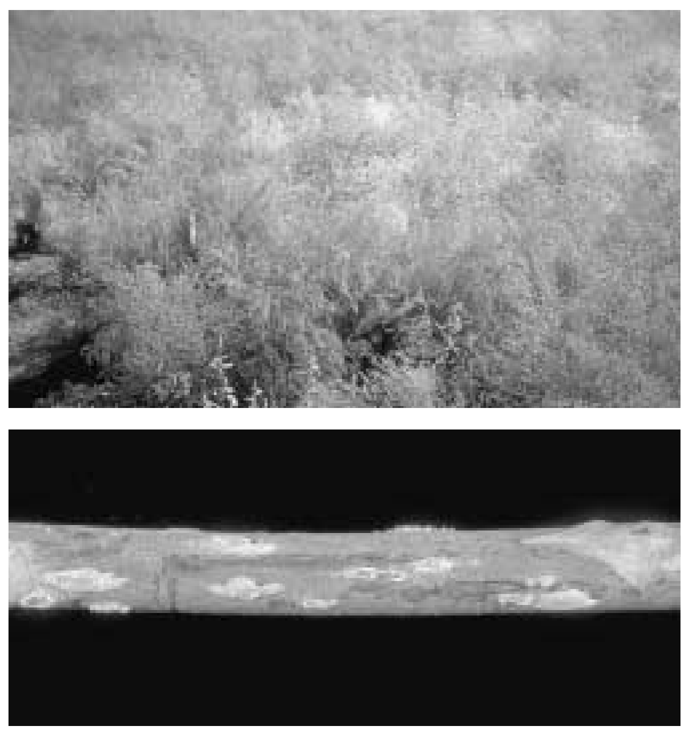
Biological control including bacteria or fungi have been developed primarily for soilborne pathogens. Once a pathogen has become established in a field, there is little opportunity to use biological control. Rotation and tillage contribute to biological control by giving natural enemies time to reduce pathogen populations.

Chemical Control

Chemical seed or foliar treatments are often used to control pathogens. Seed treatments can effectivly control pathogens that live or disperse by seed. For control of diseases of vegetable crops using pesticides, see Michigan State University Extension bulletin E-312, *Insect, Disease and Nematode Control for Commercial Vegetables*. Foliar fungicides are important in managing rust and purple spot on asparagus fern, Cercospora and Alternaria leaf blight on carrots, and early and late blight of celery.

DISEASES OF ASPARAGUS

RUST



Asparagus plants infected with rust appear yellow (top); rust on an asparagus stem (bottom).

Pathogen type: fungus (*Puccinia asparagi*)

Disease symptoms: This fungus attacks all aboveground plant parts. Plant symptoms include red or brown, elongated spots on spears, shoots, or needles; reduced plant vigor; increased water loss; and premature death. Severe rust infections can stunt or kill young shoots and defoliate plants; repeated defoliation leads to reduced yields.

Environmental conditions favoring disease: Spores remain in crop debris during the winter. In the spring, fungal spores are dispersed by wind and penetrate asparagus plant tissue. Disease development is more likely with heavy dews.

Control strategies:

- Plant moderately resistant asparagus varieties in well drained areas.
- Orientate rows with the prevailing wind to allow for free air movement. This keeps moisture levels low and helps prevent fungal spores from penetrating plant tissue.
- Apply fungicides when weather is favorable for disease development.

PURPLE SPOT

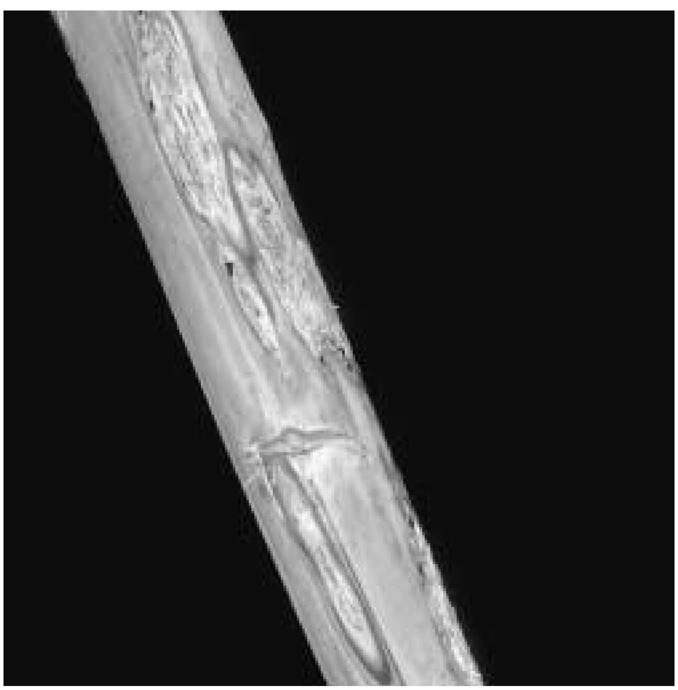
Pathogen type: fungus (*Stemphylium vesicarium*)

Disease symptoms: Small, elliptical, purple lesions with brown centers occur on all aboveground plant parts. Severe disease results in defoliation and dieback. Repeated defoliation can lead to reduced yields.

Environmental conditions favoring disease: The fungus enters the plant through wounds and stomata. It requires moisture from dew or rain to develop. Purple spot is worse when the weather is cool and wet during spear emergence.

Control strategies:

- Good field sanitation is important. Remove last season's fern growth, the primary inoculum source, before new spears emerge.
- Apply fungicides according to the TOM-CAST disease forecaster.



Lesions caused by purple spot on asparagus stem.

FUSARIUM WILT AND CROWN ROT

Pathogen type: fungus (*Fusarium oxysporum* f. sp. *asparagi* and *F. proliferatum*)

Disease symptoms: Infected plants have weak, spindly spears in the spring followed later in the season by shoots with a brilliant yellow coloration and perhaps limited vascular discoloration. Feeder roots are frequently discolored and rotted. The discoloration may also extend into the storage roots, with pinpoint reddish lesions occurring where the fungus has entered the root. Crowns of infected plants may show internal discoloration extending from stems into the interior crown tissue. *Fusarium* fungi inhibit water uptake and food transportation within the plant. They may also cause damping-off of seedlings in crown nurseries, poor stand establishment in young asparagus fields, and a slow decline in productivity of mature fields.

Environmental conditions favoring disease: Fusarium proliferatum is spread from plant to plant via airborne spores that infect asparagus plants near the base of the stem. *Fusarium oxysporum* f. sp. *asparagi* is soilborne. The optimum temperature for the disease is between 75 and 86 degrees F. Excessive and insufficient levels of soil moisture increase the severity of decline. Attacks by the asparagus miner, rust, or purple spot weaken the plants and make them more susceptible to Fusarium infections. Plants stressed by adverse environmental factors, excessive cutting periods, or other organisms decline much sooner than non-stressed plants.

Control strategies: *Fusarium* is extremely persistent and difficult to control.

- Choose well-drained sites for asparagus fields.
- To minimize disease impact, minimize overcutting, drought, overwatering, insect injury, weeds and soil compaction.
- Destroy crop residue from the previous year in late fall or winter to reduce inoculum.
- Control rust, purple spot and insect pests.

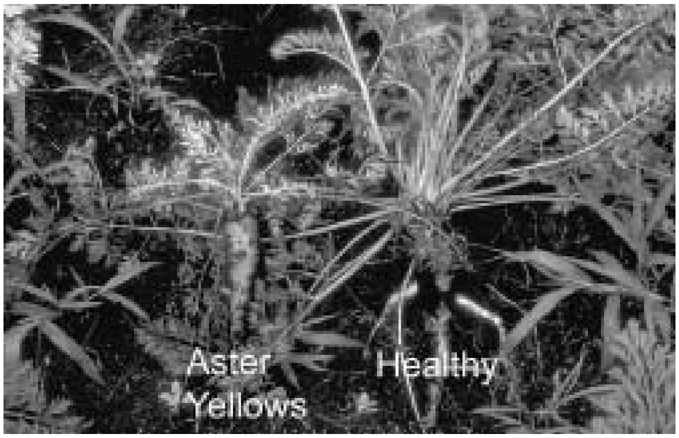
DISEASES OF CARROTS

ASTER YELLOWS

Pathogen type: phytoplasma—a very small organism intermediate in size between bacteria and viruses.

Disease symptoms: Infected plants are twisted, stunted, and yellow. Many more feeder roots and shoots than normal develop, and bronzing of foliage is common. Diseased carrots often have an unpleasant taste.

Environmental conditions favoring disease: The aster yellows organism is transmitted to healthy plants by infected leafhoppers, which infect the plant by penetrating the vascular tissue and injecting the mycoplasma through their saliva while feeding. It takes 11 days for healthy leafhopppers to acquire the ability to transmit the disease after they feed on infected plants. Only a small proportion of the leafhopper population will be infected —usually less than five percent—but a level of infection above one percent is considered a serious threat.



Aster yellows stunts and discolors foliage.

Control strategies:

- Control leafhopper populations to prevent disease transmission.
- Control weeds. Weed and grass hosts near the target crop can harbor aster yellows and leafhopper eggs.
- Plant tolerant/resistant carrot varieties.
- Plant early to establish the crop prior to possible infection.
- Remove infected plants, if feasible, to prevent the spread of an existing infection.

ALTERNARIA LEAF SPOT

Carrots infected with Alternaria.

Pathogen type: fungus (*Alternaria dauci*)

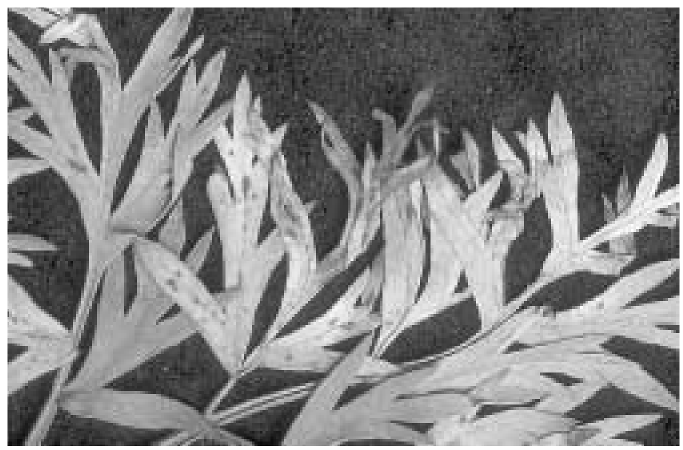
Disease symptoms: Dark brown/black spots with yellow margins appear on older leaves. The leaves may begin to curl at the edges as the plant matures. This can result in weak foliage or defoliation and make harvest impossible. The disease can also cause damping-off of seedlings and often occurs concurrent with Cercospora leaf spot.

Environmental conditions favoring disease: Alternaria fungus overwinters in soil and plant debris and in volunteer carrots. Pathogens are blown by the wind, carried by water or equipment, or introduced within the seed. Outbreaks occur first as isolated patches but quickly spread throughout the rest of the field. Favorable conditions such as overhead irrigation and rainy, windy weather increase the rate of spread of Alternaria.

Control strategies:

- Postharvest tilling helps reduce the overwintering inoculum. Turning under carrot residue will accelerate decomposition.
- Avoid continuous carrot cropping. Growers in Michigan frequently rotate a minimum of two years, but this does not seem to deter the disease.
- Do not plant new fields near infested fields.
- Use clean seed and resistant cultivars.
- Regular fungicide applications control Alternaria leaf spot.

CERCOSPORA LEAF SPOT



Leaves with lesions in a Cercospora infected carrot plant.

Pathogen type: fungus (*Cercospora carotae*)

Disease symptoms: The first symptoms are circular spots about 1/16 to 1/8 inch in diameter on both leaves and petioles. Spots resemble a target with a tan center, a dark brown ring, and an outer yellow ring, which will be inconspicuous on some plants. As the fungus grows, lesions encircle petioles, causing defoliation. Plants show symptoms as soon as three days after infection. Cercospora often occurs concurrent with Alternaria leaf spot.

Environmental conditions favoring disease: Cercospora produces spores during warm, humid weather. The spores are transported primarily by wind. Healthy carrot tissue can be infected when leaves remain wet for eight or more hours. The fungus can survive in seed, in carrot debris in soil, or in wild carrot.

Control strategies:

- Plant disease-free seed and disease-tolerant cultivars.
- Practice a two-year crop rotation and plow under carrot residue to decompose (the fungus dies after the debris decomposes).
- Chemical controls can be applied.

DAMPING OFF

Pathogen type: fungus (*Pythium* spp., *Phytophthora* spp.)

Disease symptoms: Damping off is a seedling disease that may be caused by several fungi, most commonly *Pythium*. Symptoms of damping off include wilting, browning and death. Seedlings are attacked at the ground level and develop water-soaked, discolored stems. Infected plants topple over and seldom recover. Yield loss due to Pythium damping off can be as severe as 100 percent.

Environmental conditions favoring disease: Infection rates can be high, particularly during periods of cool, wet weather. The fungus enters plant cells and consumes all cellular material, killing the cells and the plant. If the infection occurs in a mature plant, the host may be able to resist fungal growth but may exhibit stunting and a yield reduction.

Control strategies:

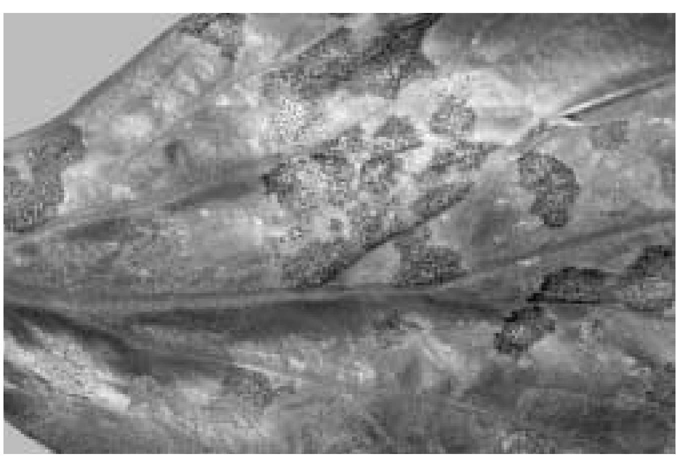
- Control soil moisture. Do not overwater seedlings (although this is not always in your control). Good drainage is important in limiting disease development. Compost and other soil amendments may help to improve drainage and air circulation and thereby decrease disease occurrence.
- Plant at times conducive to rapid plant growth to minimize the opportunity for infection.
- Crop rotation helps to decrease the incidence of damping off.
- Chemical controls are sometimes recommended for difficult cases, but they may not be cost effective.

DISEASES OF CELERY

ASTER YELLOWS

Aster yellows also infects celery. Please refer to the carrot disease section for information on aster yellows.

SEPTORIA LEAF BLIGHT (Late Blight)



Late blight in celery causes leaf spots that contain small, spore-filled black bodies.

Pathogen type: fungus (*Septoria apiicola*)

Disease symptoms: Somewhat circular spots on leaves and petioles can cause defoliation in severe cases. Lesions are tan to gray and contain small, black bodies resembling small grains of pepper to the unaided eye. These are actually black, flask-shaped structures that are embedded in diseased leaf tissue and contain the spores that spread the disease. Over time, leaf spots merge and kill the leaf.

Environmental conditions favoring disease: When the spore-filled structures become wet from rainfall or dew on leaves, spores are forcibly pushed onto the leaf surface. They are then spread by spattering raindrops or by clinging to machinery or skin or clothing of workers passing through the field. Spores within water droplets can be spread by strong winds during thunderstorms. It takes 12 days under normal conditions for symptoms to appear after an infection has occurred.

Control strategies:

- Plant disease-free seed and transplants.
- Plow under infected celery after harvest.
- Practice crop rotation with at least one year out of celery.
- Limit movement of machinery and workers in fields to reduce the spread of the disease.

BACTERIAL LEAF BLIGHT

Pathogen type: bacterium (*Pseudomonas apii*)

Disease symptoms: Irregular, circular, rusty-red spots up to five millimeters (0.20 inch) in diameter appear on the leaves.

Environmental conditions favoring disease: Disease development is favored by warm, moist conditions. The bacteria require ten hours of continuous leaf wetness and moderate temperatures to infect foliage. Bacterial leaf blight is a seedborne bacterium that spreads rapidly in a greenhouse because of the dense plant canopy and high humidity. In the field, bacterial spread is enhanced by overhead irrigation. The bacteria overwinter in undecomposed celery residue.

Control strategies:

- Hot water seed treatment will reduce seedborne inoculum but may also reduce seed germination.
- To minimize disease development and spread in greenhouses, space plants to allow adequate air movement, water early enough in the day to allow foliage to dry by evening, and utilize heating and venting to maintain the relative humidity below 85 percent.
- Do not plant diseased transplants.
- Avoid overhead irrigation to minimize the spread of the disease.
- Copper-based fungicides applied on a regular basis can limit disease spread.

FUSARIUM YELLOWS

Fusarium yellows causes the water-conducting tissue of a celery plant to turn brown.

Pathogen type: fungus (*Fusarium oxysporum* f. sp. *apii*)

Disease symptoms: Plants may become stunted and yellow and exhibit poor growth. The water-conducting tissues of the crown, petiole, and roots turn brown. Leaves become brittle and rough and curl upward.

Environmental conditions favoring disease: Symptoms are most severe when soil temperatures are warm. Fusarium yellows can be spread readily by movement of infested soil or transplants. The fungus infects common weeds such as lamb's quarters, smartweed, barnyard grass, and purslane, and can survive for long periods in soil as dormant spores. This allows the fungal population to grow in the absence of a celery crop.

Control strategies:

- Plant resistant or tolerant celery cultivars.
- Avoid planting celery into fields with known histories of Fusarium yellows.
- To avoid infestation of clean fields, keep equipment free of infested soil.
- Control weeds that serve as alternate hosts.

DISEASES OF COLE CROPS (cabbage, broccoli, cauliflower)

BLACK LEG

Pathogen type: fungus (*Phoma lingam*)

Disease symptoms: Dark, sunken cankers at the stem base or light brown, circular spots on the leaves are the early symptoms of black leg. Eventually, the cankers girdle the stem and move down to infect the roots. Small black specks—spores—can also be seen inside the cankers and spots.

Environmental conditions favoring disease: The fungus overwinters in crop debris and is easily spread. The fungus is most active in cool temperatures.

Black leg on cabbage.

BLACK ROT

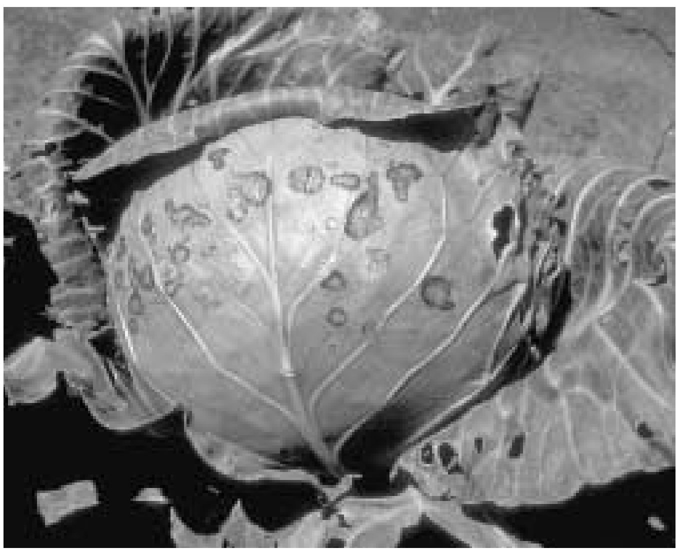
Cabbage infected with black rot (top); inside of a cauliflower stem infected with black rot (bottom).

Pathogen type: bacterium (*Xanthomonas campestris* pv. *campestris*)

Disease symptoms: Infected seedlings turn yellow and die. Symptoms on older plants include yellow, wedge-shaped areas at the leaf margins. The affected areas expand toward the center of the leaf, turn brown, and die. The veins become discolored at the leaf margins and the discoloration extends toward the base of the plant. The head is stunted, and symptoms are frequently more severe on one side of the head.

Environmental conditions favoring disease: The optimum temperature for disease development is 80 to 86 degrees F, and either rain or persistent dew is required. The bacteria overwinter on and in seed and debris from diseased plants left in the field. They spread by splashing water, on wind blown leaves, or by handling infected plants.

ALTERNARIA LEAF SPOT



Alternaria can also cause head rot in cabbage.

Pathogen type: fungus (*Alternaria* spp.)

Disease symptoms: Spots with dark, concentric circles form on lower leaves. In moist weather, a dusty fungal growth occurs on the spots.

Environmental conditions favoring disease: Disease development is favored by cool, wet weather. The fungus overwinters in seed and diseased crop residues.

CLUBROOT

Clubroot causes wilting (top) and enlarged plant roots (bottom).

Pathogen type: fungus (*Plasmodiophora brassicae*)

Disease symptoms: Infected plants yellow and wilt. The roots are enlarged and "clubbed." Young plants can be killed; mature plants will not produce a marketable crop.

Environmental conditions favoring disease: Clubroot thrives in cool, wet soils. This soilborne fungus can remain viable indefinitely in the soil.

DOWNY MILDEW

Plants infected with downy mildew can have a white, fuzzy appearance.

Pathogen type: fungus (*Peronospora parasitica*)

Disease symptoms: Downy mildew begins as small, yellow spots on the leaves, which later turn brown. White fungal growth appears on the lower leaf surface during periods of moist weather.

Environmental conditions favoring disease: Downy mildew is worse in cool, wet weather in spring and fall. Plants infected with downy mildew are often more susceptible to secondary pathogens, such as soft rot bacteria. The fungus overwinters on seed and in cruciferous weeds (for example, Shepherd's purse and mustard).

Control strategies for diseases of cole crops:

- Plant disease-free or certified seed and transplants.
- Avoid dipping transplants in water before planting to reduce the spread of disease.
- Practice at least a three-year crop rotation out of cole crops for most diseases.
- Plant disease-resistant cultivars.
- Maintain good weed control.

DISEASES OF CORN

COMMON RUST

Blisters on corn leaf infected with common rust.

Pathogen type: fungus (*Puccinia sorghi*)

Disease symptoms: Oval or elongated, brick-red blisters appear on the leaf surfaces, husks, leaf sheaths, and stalks. Severe infections result in leaf death. Killing the leaves of young plants reduces plant vigor and yield.

Environmental conditions favoring disease: The fungal spores are wind dispersed every year, usually late in the season. Rust develops under cool temperatures (60 to 73 degrees F) and high humidity and bright days.

Control strategies: Planting resistant hybrids is the best way to control rust. Fungicides are used, especially in seed corn.

CORN SMUT

Ear of corn infected with corn smut.

Pathogen type: fungus (*Ustilago zeae*)

Disease symptoms: Galls are formed on aboveground young growing parts of the plant, typically the ear, tassel, leaves, and stalk. The young galls have a greenish white covering, which turns silver-gray with age. Mature galls are full of black, powdery fungal spores that disperse into the air when the gall ruptures.

Environmental conditions favoring disease: Corn smut is most prevalent under dry conditions and temperatures of 78 to 94 degrees F and on stressed plants. Fungal spores overwinter in the soil and prefer high levels of soil nitrogen.

Control strategies:

- The best management strategy is to plant corn hybrids that have some level of resistance.
- Rotating crops and burying crop residue may be helpful.

STEWART'S WILT

Corn leaf showing symptoms of Stewart's wilt.

Pathogen type: bacterium (*Erwinia stewartii*)

Disease symptoms: Symptoms appear first on leaves and are more severe on young plants than on older plants. Pale green to yellow streaks with irregular margins extend the length of the leaf and turn brown. Infected young plants may show brown discoloration; cavities may form in the center of the stem near the soil line. If plants are infected after tasseling, leaf lesions develop. Light green to yellow, water-soaked streaks with wavy, irregular margins are formed parallel to leaf veins. The streaks turn tan, enlarge and coalesce (merge) with age, resulting in blighting. When these leaves are held up to the light, insect feeding scars can be observed in these lesions. The bacteria spread through the host via the vascular system and may enter the kernels. When infected stalks or leaves are cut open, droplets of yellow bacterial ooze may extrude from the vascular tissue.

Environmental conditions favoring disease: The bacterium overwinters in corn flea beetles and is spread to corn when corn flea beetles feed on corn plants. (Corn flea beetles carrying the bacterium can be expected if the sum of the average monthly temperatures [in degrees F] for December, January and February exceeds 90 degrees.) Stewart's wilt is most severe when temperatures are high (88 to 98 degrees F).

Control strategies:

- Plant resistant hybrids.
- Control the pathogen vector, corn flea beetles.

DISEASES OF CUCURBITS (cucumbers, melons, pumpkins, squash)

ALTERNARIA LEAF SPOT

Alternaria causes leaf spot.

Pathogen type: fungus (*Alternaria cucumerina*)

Disease symptoms: Small, circular, tan spots with a concentric ring pattern form on the leaves. Spots coalesce, causing defoliation.

Environmental conditions favoring disease: The disease develops best under bright sunshine, frequent dews or showers, and temperatures between 60 and 90 degrees F. Fungus spores are spread by rain, wind, and splashing water. The fungus overwinters on and in seed, as well as in residue from diseased plants.

Control strategies:

- Destroy volunteer cucurbit crops and weeds that may harbor fungal spores.
- Practice crop rotation out of cucurbits to reduce the risk of Alternaria leaf spot and other diseases.
- Apply fungicides as needed.

MOSAIC VIRUSES

Cucumber field damaged by virus (top); zucchini fruit damage by virus (bottom).

Pathogen type: virus

Disease symptoms: Mosaic viruses cause plant leaves to be mottled dark and light green and crinkled. The disease is more noticeable on young leaves. Older leaves have V-shaped dead areas extending from the leaf margins to the middle vein. The fruits of diseased plants are mottled, warty and misshapen.

Environmental conditions favoring disease: Many weeds act as hosts. The virus is spread primarily by aphids.

Control strategies:

- Plant disease-resistant varieties.

POWDERY MILDEW

Powdery mildew on cucumber.

Pathogen type: fungus (*Erysiphe cichoracearum, Sphaerotheca fuliginea*)

Disease symptoms: Powdery mildew causes a white, powdery growth on leaves and stems. The white, powdery areas may expand and merge. The crown leaves are the first to become infected and may die. Yield is reduced in infected plants, and fruit quality is poor. Powdery mildew infection renders the plant and fruit more susceptible to other diseases.

Environmental conditions favoring disease: Leaves are most susceptible 16 to 23 days after unfolding. The fungus reproduces under dry conditions and will not grow when the leaf surface is wet. The optimum temperature is about 81 degrees F. Powdery mildew is spread by spores generally carried by wind.

Control strategies:

- Plant disease-resistant varieties.
- Scout for the first sign of disease and then apply a fungicide.

PHYTOPHTHORA ROOT, CROWN, AND FRUIT ROT

Phytophthora fruit rot on pickles and watermelon.

Pathogen type: fungus (*Phytophthora capsici*)

Disease symptoms: Phytophthora attacks fruits lying on the soil. The fungus causes partial or complete rotting of the fruit. Infected roots and stems are soft, water-soaked and brown.

Environmental conditions favoring disease: The fungus prefers moist, humid, warm conditions and is favored by saturated soil conditions. The soilborne fungus is spread readily by splashing water.

Control strategies:

- Crop rotation.
- Water management.
- Good drainage and eliminate excess moisture.

DISEASES OF ONIONS

PURPLE BLOTCH

Purple blotch on onion leaf.

Pathogen type: fungus (*Alternaria porri*)

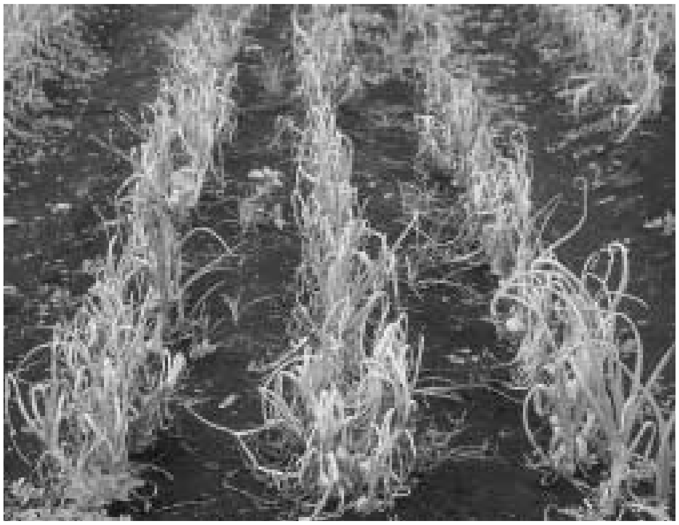
Disease symptoms: Small, white, sunken lesions with purple centers appear on leaves. These spots enlarge to encircle the leaf, resulting in premature senescence. Darkened zones with the characteristic purple color appear on leaf surfaces as the plant matures.

Environmental conditions favoring disease: Fungal spores develop in high humidity, rain, or persistent dew with an optimum temperature range of 77 to 85 degrees F. Purple blotch infections are more severe following injury caused by thrips, hail, or wind-blown soil.

Control strategies:

- Plant top-quality seed and disease-free transplants.
- Dispose of onion culls by incorporating them into the soil immediately after harvest.
- Practice a three- to four-year crop rotation.
- Apply fungicides when weather conditions favor disease development.

DOWNY MILDEW



Severe downy mildew infections result in stand decline (top); downy mildew on onion leaves (bottom).

Pathogen type: fungus (*Peronospora destructor*)

Disease symptoms: Disease symptoms appear on older leaves as elongated spots. Under humid conditions, the fungus produces purplish spores on the leading edge of the lesion. Eventually, affected leaves turn yellow and collapse.

Environmental conditions favoring disease: Fungal spores develop under high humidity, either from rain or persistent dew, at an optimum temperature range of 77 to 85 degrees F.

Control strategies:

- Plant high-quality seed and disease-free transplants.
- Dispose of onion culls by incorporating them into the soil immediately after harvest.
- Practice a three- to four-year crop rotation.
- Apply fungicides when weather conditions favor disease development.

SMUT

Onion smut.

Pathogen type: fungus (*Urocystis magica*)

Disease symptoms: Gray streaks appear on leaves, leaf sheaths and bulbs. These streaks are filled with a dark brown, powdery mass of spores. Affected leaves become twisted and deformed and eventually may die.

Environmental conditions favoring disease: Cool weather delays plant growth, thereby extending the period an onion is susceptible to onion smut. This soilborne fungus can serve as an infection source for 15 years. Spores are spread whenever soil, water, and plant parts are moved from one place to another.

Control strategies:

- Plant disease-free seed and transplants.
- Use treated seed.
- Use an in-furrow fungicide treatment for problem fields.

BOTRYTIS LEAF BLIGHT

Botrytis leaf blight on leaves (top) and the onion fruit (bottom).

Pathogen type: fungus (*Botrytis squamosa*)

Disease symptoms: The first symptoms are numerous white specks on the leaves. The spots expand, causing the leaves to die, starting at the leaf tip.

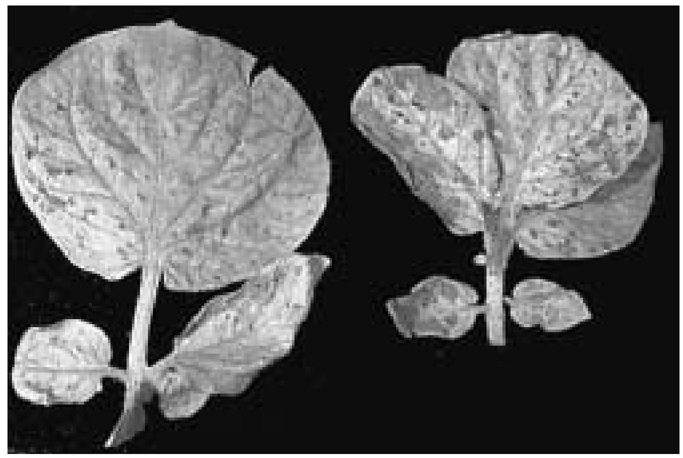
Environmental conditions favoring disease: Plants may become infected where leaf tissue has been injured by thrips, blowing sand, or other agents. Fungal spores are spread by wind and develop best under warm, wet weather conditions.

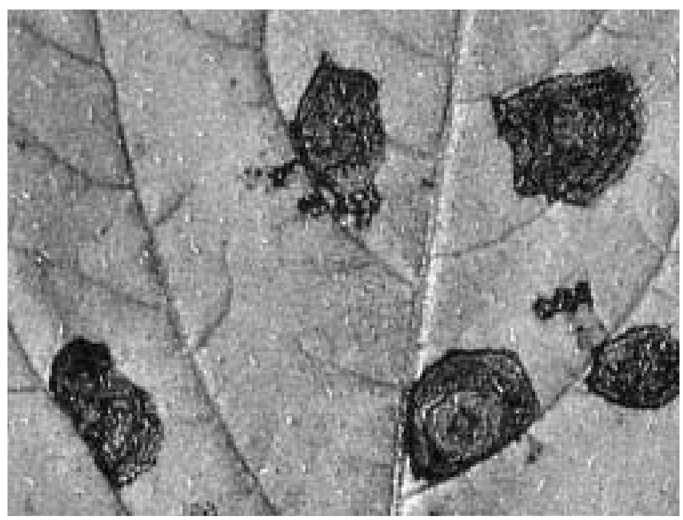
Control strategies:

- Plant high-quality seed and transplants free of disease.
- Dispose of onion culls by incorporating them into the soil immediately after harvest.
- Practice a three- to four-year crop rotation to reduce the incidence of infestation.
- Apply fungicide when weather conditions favor disease development.

DISEASES OF POTATOES

EARLY BLIGHT



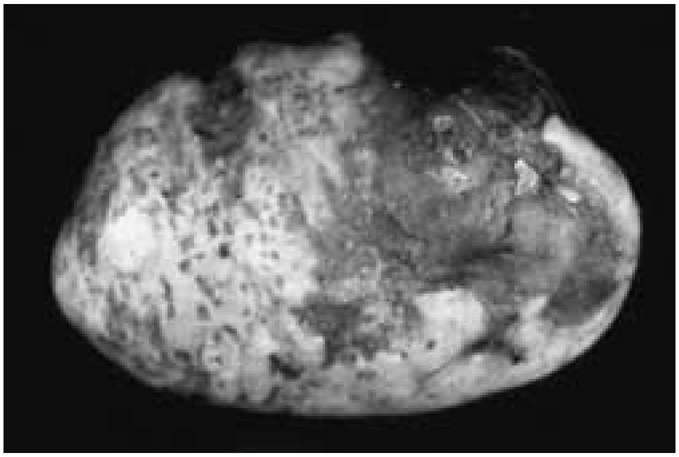


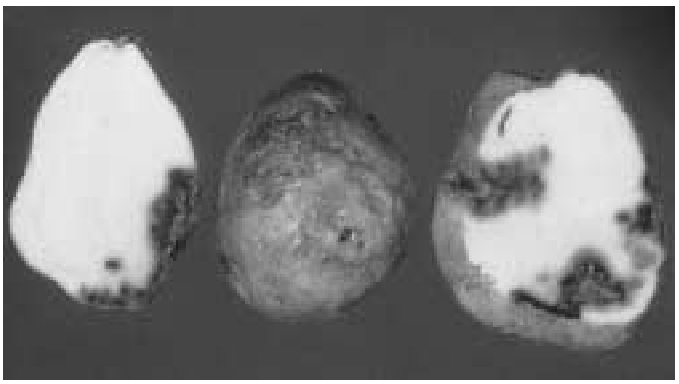
Early blight symptoms on potato foliage.

Pathogen type: fungus (*Alternaria solani*)

Disease symptoms: Small, angular, brown spots with concentric rings that create a target pattern occur on lower leaves. Several spots may run together and kill the leaf. In severe infections, upper leaves and stems may have brown lesions.

Environmental conditions favoring disease: Spores are spread by the wind and favored by warm weather (68 to 86 degrees F), heavy dews or rain, and high relative humidity. The disease is more likely to develop on older or stressed foliage and on plants with poor mineral nutrition. The fungus survives the winter on tubers and crop residue and in the soil.





Early blight also infects tubers on the surface (top) and the interior (lbottom).

Control strategies:

- Crop rotation helps reduce overwintering fungus.
- Begin fungicide applications when the first lesions are visible on the lower leaves. Fungicide applications will not kill the existing infection but should stop the fungus from spreading.

LATE BLIGHT

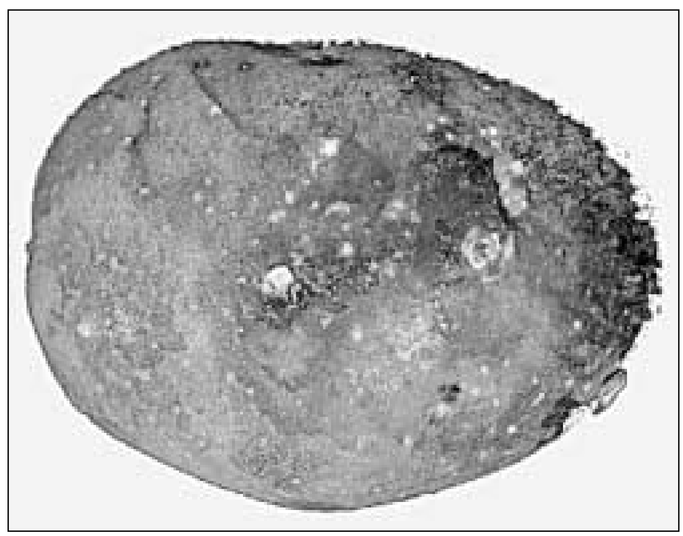
Late blight symptoms on potato foliage.

Late blight symptoms on potato foliage (close-up).

Pathogen type: fungus (*Phytophthora infestans*)

Disease symptoms: Leaf lesions consist of large (1/2 to 1 inch in diameter), black, water-soaked areas. Leaves quickly dry and leaf and stem tissues die. A white mycelial growth on the leaves and stems is characteristic of this disease. Tubers exhibit a reddish brown dry rot.

Environmental conditions favoring disease: Late blight can develop from seed tubers, volunteers in the field or cull piles, and infected tubers sprouting in the spring. The fungal spores are carried by wind to healthy potatoes. The pathogen will continue to reproduce and spread on potatoes during favorable conditions (cool to warm, humid, rainy weather).



Potato tuber infected with late blight.

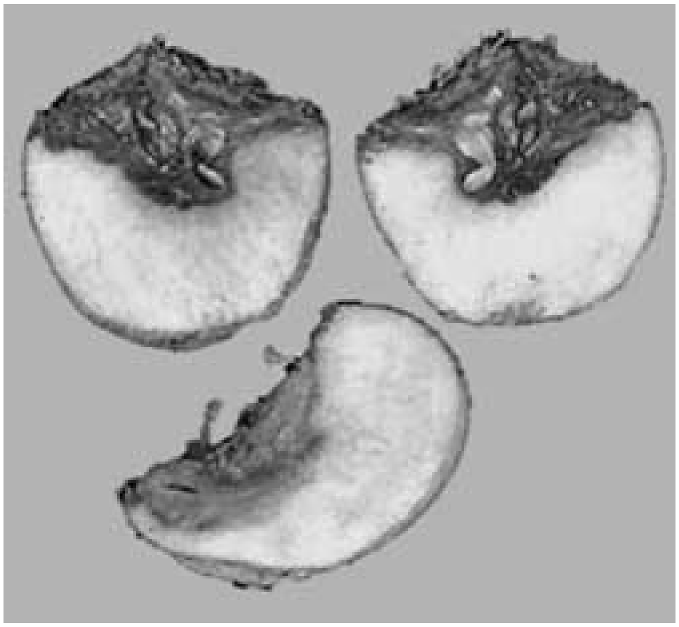
Control strategies:

Below are a few general tactics used to control late blight. For more specific control information, contact the potato disease lab at Michigan State University or refer to MSU Extension bulletins.

- Plant resistant varieties and carefully inspect all seed before planting.
- Remove cull piles.

- Practice crop rotation to reduce the potential for carryover of the late blight fungus.
- Scout fields regularly for late blight, and as soon as plants show symptoms of infection, begin applications of labeled fungicides according to MSU Extension recommendations.

FUSARIUM DRY ROT



Potato tuber infected with dry rot.

Pathogen type: fungus (*Fusarium sambucinum*)

Disease symptoms: Fusarium dry rot affects potato tubers. Tubers become infected when wounds occur in the skin during harvest and handling. Infected tubers may appear wrinkled or have sunken areas. The internal tissue of the tuber has sharply defined brown, rotten areas. Potatoes that appear normal at harvest can develop disease symptoms after a few weeks.

Environmental conditions favoring disease: *Fusarium fungi* are common soil fungi. Fusarium dry rot does not usually spread from tuber to tuber in storage, but under high humidity, secondary infections of bacterial soft rot may develop.

Control strategies:

- Clean and disinfect all harvest and storage equipment before the beginning of the harvest season.
- Handle tubers carefully to minimize bruising when harvesting.
- Do not wash tubers before placing them in storage—this can increase infections and rot.

COMMON SCAB

Potato tubers infected with common scab.

Pathogen type: bacteria-like organism (*Streptomyces scabies*)

Disease symptoms: Common scab affects potato tubers. Tiny, dark spots develop on the tuber and rapidly expand, producing brown areas with a cork-like texture—scabs. The scabs may be raised, pitted, or shallow, depending on environmental conditions, the strain of bacterium, and the potato variety.

Environmental conditions favoring disease: Scab development is favored by dry soil conditions and alkaline soils. The disease organism enters the plant through wounds or natural openings such as stomata or lenticels. It is spread by infected seed potatoes, wind and soil.

Control strategies:

- Use scab-free certified seed.
- Maintain a low soil pH and healthy soil.
- Maintain adequate soil moisture during tuber initiation to minimize scab development.

BLACK SCURF/STEM CANKER

Rhizoctonia solani **causes tuber and stem damage in potatoes.**

Pathogen type: fungus (*Rhizoctonia solani*)

Disease symptoms: This pathogen is both seed- and soil-borne. On tubers, irregularly shaped, black, canker-like masses appear—black scurf. The pathogen causes brown to black lesions on belowground stems of immature plants. Eventually, these lesions sink into the stem surface, causing cankers that can girdle and kill stolons or stems. This results in pruning and loss of tuber development sites.

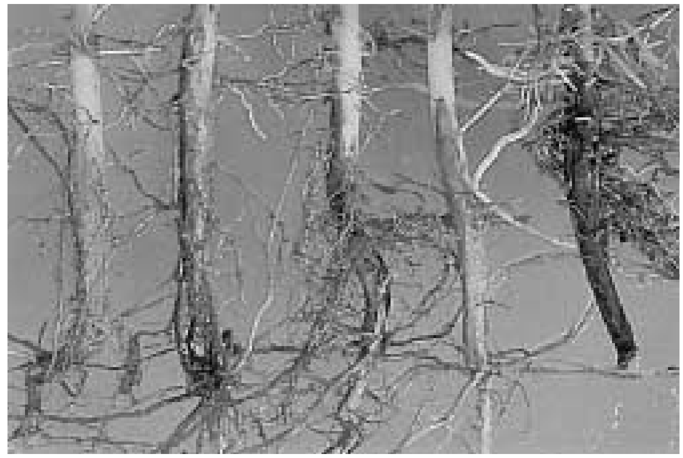
Environmental conditions favoring disease: Disease development is enhanced during cool, wet weather and in cold, wet soil.

Control strategies:

- Practice crop rotation with non-host crops.
- Encourage rapid plant development of sprouts to reduce the disease severity.
- Remove plant residue to allow soil to dry out and warm up in the early spring.
- Plant disease-free seed. Seed treatment effectively controls the seed-borne pathogen.

DISEASES OF SNAP BEANS

FUSARIUM ROOT ROT



Fusarium root rot in snap beans.

Pathogen type: fungus (*Fusarium solani* f. sp. *phaseoli*)

Disease symptoms: Two to three weeks after planting, reddish brown streaks appear on the stem just below the soil surface. The lesions may extend upward to the soil surface and become brown with age. Severely infected roots die. Plants appear stunted with yellow leaves, but the fungal infection seldom kills the entire plant.

Environmental conditions favoring disease: Early planting in cool, moist soil favors the disease. Any conditions reducing root growth increase the likelihood of infection with Fusarium root rot. The pathogen can survive for years in the soil in the absence of beans.

Control strategies:

- Avoid plant stress. The disease causes little damage to healthy plants. A three-year crop rotation out of beans reduces the chance of a Fusarium infection.

WHITE MOLD

White mold kills branches and stems, giving them a white appearance.

Pathogen type: fungus (*Sclerotinia sclerotiorum*)

Disease symptoms: Leaves may become slightly chlorotic but typically wilt and take on a gray-green cast, although the veins remain green. Eventually, leaves become tan, curl, and die but remain attached to the stems. The fungus often girdles the main stem or its branches, usually 6 to 12 inches from the soil line. Branches and stems killed by the fungus generally have a white, bleached appearance. Infected pods are soft and mushy but later become dry, light-colored and shriveled. White, fluffy mold covers the diseased plant tissue during periods of high relative humidity.

Environmental conditions favoring disease: Small, hard bodies called sclerotia survive in soil or inside debris from diseased plants. Sclerotia germinate best when soil temperatures are 55 to 65 degrees F and soils are moist for seven to 10 days. Light stimulates the germinated sclerotia to form mushroom-like structures. Spores released from the mushroom-like structures may land on dead flower petals sticking to recently formed pods, where they may germinate and penetrate host tissues if free water from dew or rain is present.

Control strategies:

- Plant wider rows to allow the soil to dry out. This changes the environmental factors necessary for the pathogen to infect the plant.
- Prevent the introduction of the pathogen by thoroughly cleaning equipment to minimize the spread between fields.
- Practice crop rotation. The severity of white mold infections can be reduced by long crop rotations. Be aware that the fungus attacks other vegetables such as tomatoes, potatoes, and cucumbers, and field crops including dry beans and canola.

HALO BLIGHT

Pathogen type: bacterium (*Pseudomonas syringae* pv. *phaseolicola*)

Disease symptoms: Numerous small, dead leaf spots with yellow haloes appear. Cool, wet weather favors this disease and results in relatively large haloes (up to 1/2 inch in diameter). During periods of high relative humidity, a cream-colored ooze is produced in pod spots. When temperatures are high, the bacteria move systemically in the plant, resulting in the absence of halos and death of the entire leaf.

Environmental conditions favoring disease: Water from rain or irrigation, dust, machinery, and humans can all contribute to disease spread. Disease development is most rapid in wet weather.

Control strategies:

- Use disease-free seed.
- Practice crop rotation.
- Promptly incorporate old plant debris.
- Keep equipment out of field when plants are wet.

DISEASES OF TOMATOES

EARLY BLIGHT OF TOMATO

Early blight on tomato fruit (top) and leaves (bottom).

Pathogen type: fungus (*Alternaria solani*)

Disease symptoms: On established plants, symptoms include dark brown spots up to 1/2 inch in diameter with dark, concentric rings that develop first on oldest leaves and progress upward on the plant. Affected leaves may die prematurely, resulting in substantial early defoliation, fruit sunscald, and poor fruit color. Typically, fruit spots occur at the stem end as a rot that radiates out from the area of attachment between the calyx and the fruit. The spot is usually brown to black, up to 1 inch in diameter, firm, and depressed, with distinct concentric rings.

Environmental conditions favoring disease: The fungus overwinters in soil or in plant debris, where it can persist for a year or more. The fungus may also be introduced into a field on seed and transplants. Spores are disseminated by wind and running water. During periods of free moisture on the leaves, the fungus penetrates the plant. The disease occurs under a wide range of weather conditions and is favored by heavy dew and rainfall and is especially severe on plants with poor vigor.

Control strategies:

- Plant disease-free transplants.
- Practice crop rotation with crops other than potato, eggplant, and pepper.

- Remove or destroy crop residue immediately after harvest.
- Maintain fertility and moisture levels, but do not overfertilize with nitrogen.
- Avoid planting near windbreaks and in shady areas.
- Fungicides are essential to tomato production in Michigan and are applied on a calendar schedule or according to a disease forecaster.

SEPTORIA LEAF SPOT

Septoria leaf spot on tomato.

Pathogen type: fungus (*Septoria lycopersici*)

Disease symptoms: Small, circular, gray spots with dark borders form on the leaves. Black specks (reproductive structures of the fungus) can be seen within the spots.

Environmental conditions favoring disease: The disease develops and spreads most rapidly in wet weather—spores are dispersed by splashing water. The fungus survives in crop residue and on/in seed.

Control strategies:

- Avoid planting near windbreaks and in shady areas.
- Remove or destroy crop residue immediately after harvest.
- Practice a two- to three-year crop rotation to reduce potential outbreaks.
- Apply fungicides when needed.

ANTHRACNOSE

Lesions caused by anthracnose on tomato.

Pathogen type: fungus (*Colletotrichum coccodes*)

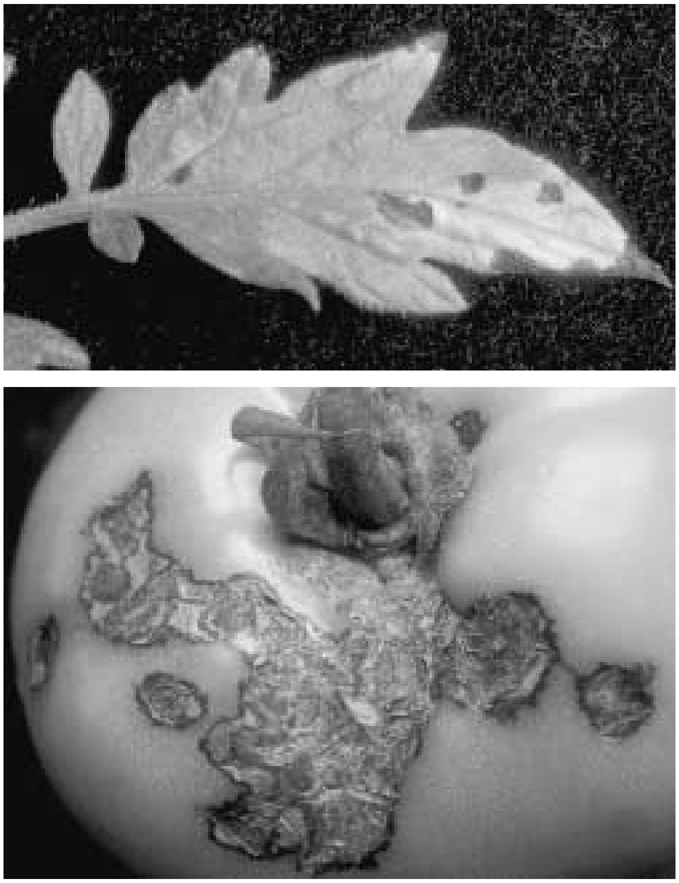
Disease symptoms: Symptoms on ripening fruit are small, slightly depressed, water-soaked, circular spots that increase in size (up to 1/2 inch in diameter), become more sunken, and typically develop concentric rings. Lesions may merge, resulting in large rotted areas on the fruit. The lesions may darken and small, black fruiting structures appear in the center. These fruiting bodies exude masses of slimy, tan or salmon-colored spores during warm, humid weather.

Environmental conditions favoring disease: The fungus overwinters in soil and infected plant debris. Splashing water spreads spores. The fungus can penetrate the outer layer of the fruit directly and may also enter through wound sites. On ripe fruit, a lesion can develop within five to six days following spore contact. The fungus can cause infection when temperatures range from 55 to 95 degrees F, though lesions develop most rapidly at 80 degrees F. Wet, rainy weather increases disease development.

Control strategies:

- Practice a two- to three-year crop rotation.
- Remove or destroy crop residue immediately after harvest.
- Fungicides are essential to tomato production in Michigan and are applied on a calendar schedule or according to a disease forecaster.

BACTERIAL SPOT



Bacterial spot can affect the leaf (top) and the fruit (bottom).

Pathogen type: bacterium (*Xanthomonas axonopodis* pv. *vesicatoria*)

Disease symptoms: Small, dark, greasy-looking spots develop on leaves and stems. On green fruit, small, dark, raised spots occur and may be surrounded by water-soaked margins. Spots enlarge up to 1/4 inch in diameter and are brown and scabby.

Environmental conditions favoring disease: Abundant rainfall and high humidity are requirements for spread and infection. Maximum growth of the bacteria is associated with temperatures between 75 and 86 degrees F. The bacteria can be carried on the surface of the seed and may overwinter in the soil in association with roots of non-hosts. Penetration of plant tissue occurs through wounds caused by broken plant hairs, insects, and windblown sand and soil.

Control strategies:

- Plant disease-free seed and transplants or chemically treated seed.
- Practice a three-year crop rotation with nonsusceptible hosts.
- Control solanaceous weeds, such as black nightshade.
- Apply copper-based fungicide.

Review Questions

CHAPTER 7

Chapter 7: Disease Management

Write the answers to the following questions and then check your answers with those in the back of the manual.

1. Which of the following can cause a non-infectious disease?

   A. Drought

   B. Insects

   C. Viruses

   D. Bacteria

2. An organism that causes disease is a:

   A. Parasitoid.

   B. Predator.

   C. Pathogen.

   D. Parasite.

3. Infectious plant diseases can be spread from diseased plants to healthy plants.

   A. True

   B. False

4. Which of the following is a living microscopic one-celled organism?

   A. Virus

   B. Fungus

   C. Bacterium

   D. Fruiting body

5. Which of the following uses spores to reproduce?

   A. Virus

   B. Bacterium

   C. Fungus

   D. Nematode

6. Draw a picture of the disease triangle and label its three parts.

7. By changing an environmental factor such as soil moisture, you can influence plant diseases.

   A. True

   B. False

8. List the four basic steps of the disease cycle.

9. A plant pathogen that is dispersed by wind to unaffected plants is said to move by:

   A. Active movement.

   B. Passive movement.

10. The source of a plant pathogen that causes a disease is called a(n):

    A. Infection.

    B. Parasite.

    C. Inoculum.

    D. Host.

11. The time period between infection and appearance of the first plant symptoms is the:

A. Preharvest interval.

B. Restricted entry interval.

C. Incubation period.

D. Disease period.

12. Cultural control methods can disrupt the disease cycle by:

A. Creating unfavorable conditions.

B. Improving crop growth.

C. Reducing the plant pathogen population in a field.

D. All of the above.

13. Which of the following is **not** a cultural control?

A. Planting high-quality seed.

B. Treating seeds with a fungicide.

C. Increasing the row spacing.

D. Practicing crop rotation.

14. Which of the following diseases of asparagus is more likely to develop if the weather is cool and wet during spear emergence?

A. Crown rot.

B. Fusarium wilt.

C. Purple spot.

D. Rust.

15. An asparagus plant infected with purple spot or rust is more susceptible to Fusarium infections.

A. True.

B. False.

16. Which of the following diseases of carrots and celery is transmitted by leafhoppers?

A. Aster yellows.

B. Damping off.

C. Leaf blight.

D. Leaf spot.

17. Which of the following is **not** a symptom of a carrot plant infected with damping off?

A. Wilting.

B. Browning of foliage.

C. Purple spots on foliage.

D. Death of plant.

18-21. Match the following celery diseases with the characteristic disease symptoms.

A. Aster yellows

B. Bacterial leaf blight

C. Septoria leaf blight (late blight)

D. Fusarium yellows

18. ___ Plants are stunted and yellow, and the water-conducting tissue of the crown and roots turns brown.

19 ___ Leaf spots contain small, black bodies that contain spores.

20. ___ Plants are stunted and wilted.

21. ___ Rusty-red spots up to 5 mm in diameter appear on leaves.

22. Which of the following diseases of cole crops results in enlarged roots?

A. Damping off.

B. Downy mildew.

C. Black Leg.

D. Clubroot.

23. Yellow, wedge-shaped areas starting at leaf margins are a characteristic of which cole crop disease?

A. Alternaria leaf spot.

B. Black leg.

C. Black rot.

D. Downy mildew.

24. Which of the following diseases of corn results in parts of the plant being covered with spore-filled galls?

A. Ear rot.

B. Rust.

C. Smut.

D. Stewart's wilt.

25. Stewart's wilt is spread from corn plant to corn plant by:

A. Insect.

B. Rain.

C. Soil.

D. Wind.

26-29. Match the following cucurbit diseases with the characteristic disease symptoms.

A. Alternaria leaf spot

B. Mosaic viruses

C. Powdery mildew

D. Phytophthora fruit rot

26. ___ Leaves and stems have a white, snow-like growth.
27. ___ Attacks fruit lying on the soil surface.
28. ___ Fruits are mottled, warty and misshapen.
29. ___ Concentric ring pattern develops on leaves.

30. Which of the following is **not** a disease of onions?

A. Botrytis leaf blight.

B. Downy mildew.

C. Purple blotch.

D. Stewart's wilt

31. A potato tuber that has odd-shaped cankers on the outer surface is infected with:

A. Black scurf.

B. Early blight.

C. Fusarium dry rot.

D. Late blight.

32. Which of the following potato diseases does **not** affect the foliage?

A. Early blight.

B. Common scab.

C. Late blight.

D. Mosaic virus.

33. The snap bean disease halo blight is caused by a bacterium.

A. True.

B. False.

34-37. Match the following tomato diseases with the characteristic disease symptoms.

A. Bacterial spot

B. Anthracnose

C. Septoria leaf spot

D. Early blight

34. ___ Leaves have small, gray spots with dark borders.
35. ___ Small water-soaked sunken spots appear on the fruit.
36. ___ Spots appear on the fruit at the stem end as the rot moves from foliage to fruit.
37. ___ Small, greasy spots develop on leaves; green fruits have small, dark, raised spots that enlarge and become brown and scabby.

CHAPTER 8

NEMATODE MANAGEMENT

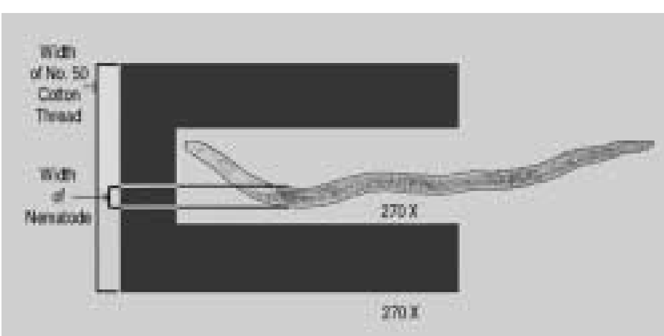
LEARNING OBJECTIVES

After completely studying this chapter, you should:

- Understand the basic biology of plant-parasitic nematodes.
- Be familiar with nematodes of importance in vegetable production.
- Know the importance of monitoring nematode population densities.
- Understand the strategies and tactics used to manage plant-parasitic nematodes.

INTRODUCTION

Nematodes are animals. More specifically, nematodes are non-segmented roundworms, which separates them from their close relatives the segmented roundworms, more commonly known as earthworms. Adult nematodes can vary in length from 1/30 inch to nearly 9 feet. Nematodes are commonly found in soil or water, including oceans. They may be the most numerous multicellular organisms on earth. A shovelfull of garden soil typically includes more than 1 million nematodes.



Nematodes are extremely small. Here a nematode is laid on top of a cotton thread to compare size.

The majority of nematode species are regarded as beneficial. They feed on bacteria, fungi, and other soil-inhabiting or aquatic animals. Some are quite specific in the types of foods they feed on; others are considered omnivores and potentially feed on a wide range of foods.

The life stages of a female (top) and male (bottom) cyst nematode.

Some species of nematodes are parasites of plants and animals. The focus of this chapter will be plant-parasitic nematodes. Plant-parasitic nematodes share three common characteristics. First, they are all microscopic, with adults ranging in length from about 1/30 to 1/4 inch in length. Secondly, they are obligate parasites of plants, meaning they must have living plant tissue to feed on to grow and reproduce. Finally, they all possess stylets, which are structures similar to hypodermic needles that nematodes use to puncture plant cells and obtain the cell's contents. All plant-parasitic nematodes spend at least part of their life cycles in soil, though many are principally found in root or leaf tissue.

PLANT-PARASITIC NEMATODES

Plant-parasitic nematodes are microscopic animals that attack plants. Every species of plant has at least one species of nematode that parasitizes it. The majority of plant-parasitic nematodes (about 95 percent of the described species) feed on roots, either within the root tissue as endoparasites or outside as ectoparasites. Some nematodes feed within leaves. Plant-parasitic nematodes must have living host tissue to feed on to grow and reproduce. If the host dies, nematodes will disperse and search for other plants to invade.

Feeding by plant-parasitic nematodes, in general, does not result in the development of characteristic symptoms. For this reason, nematode problems often go undiagnosed. Typical aboveground symptoms of nematode infections include stunting, yellowing, wilting, and, most importantly from an economic standpoint, reduced yields. A few types of nematodes do produce characteristic symptoms or signs; these will be discussed when specific nematodes are described.

Nematodes are similar to insects in that they possess an exoskeleton. This skin must be shed or molted for a nematode to grow. A typical plant-parasitic nematode life cycle consists of an egg, four preadult stages (referred to as juveniles) and an adult. Females are often more destructive; males typically do not feed. In many species of plant-parasitic nematodes, males are rare or not known to exist. The life cycle of a plant-parasitic nematode may be completed in as little as two weeks or as long as two years, depending on the species and the temperature.

Because of their size, plant-parasitic nematodes do not move long distances on their own. They are usually transported over long distances on machinery, in nursery stock, on transplants or seed, or by animals. Anything that moves soil moves nematodes, including water and wind. Some nematodes are known to move a few feet vertically in the soil during a growing season when environmental conditions are adverse.

NEMATODES OF IMPORTANCE IN VEGETABLE PRODUCTION

Northern Root-Knot Nematode
(*Meloidogyne hapla*)

HOST PLANTS: Very wide host range, including virtually all vegetables.

BIOLOGY: The northern root-knot nematode overwinters in the soil as eggs. As soil temperatures increase in the spring, second-stage juveniles emerge, migrate through the soil, and penetrate the roots of host plants. The nematodes establish feeding sites behind the root cap. As the infected root continues to grow, the vascular tissue slips in the area where the nematodes have fed.

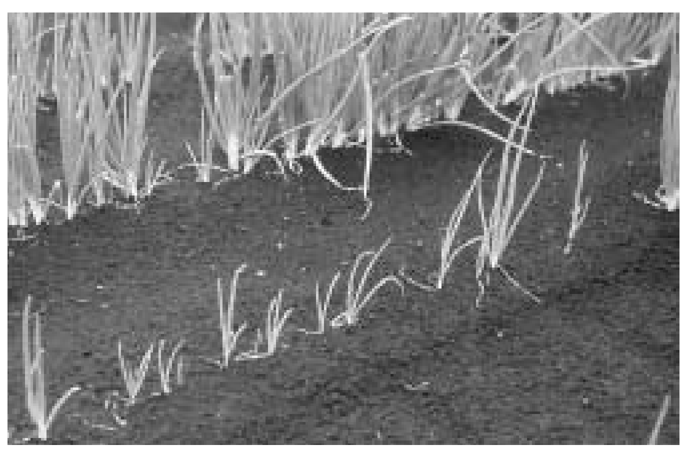
Shortly after successfully establishing a feeding site, the second-stage juvenile begins to swell and soon molts to a third-stage juvenile. Eventually, following two more molts, it matures to become an adult female or male nematode. Females are round and incapable of movement. Males are worm-like and generally exit the root because they do not feed. Female NRKN produce large numbers of eggs, up to 3,000, in a gelatinous matrix secreted by the anus.

The northern root-knot nematode can complete its life cycle in a month at optimal soil temperatures. Therefore, the nematode can complete multiple generations per growing season.

SYMPTOMS: The northern root-knot nematode, like many other nematode species that feed on vegetables, does not cause characteristic foliage symptoms. Typical symptoms are stunting, yellowing, and reduced yields. Severely infested plants usually wilt during periods of hot, dry weather because the nematodes disrupt the plant tissue.

Invasion of roots by northern root-knot nematode will result in the production of small swellings on the roots called **galls**. Galls will vary in size, depending on the numbers of nematodes feeding within them. Carrots are highly susceptible to the northern root-knot nematode, which causes losses due to forking or stubbing of the taproots.

A healthy (left) and a northern root-knot nematode-damaged (right) celery root.



Northern root-knot nematode damage on onion.

MANAGEMENT

Avoidance: Once established, root-knot nematodes are virtually impossible to eradicate. Therefore, attempts should be made to keep sites clean of northern root-knot nematode for as long as possible. This is accomplished primarily by using nematode-free transplants and by not contaminating fields with northern root-knot nematode-infested soil.

Population Reduction

CULTURAL CONTROLS: Sites with histories of root-knot nematode problems should be kept out of vegetable production for a period of two to four years. NRKN non-host crops such as corn or small grains should be grown to reduce population densities. Weed control is important because many weeds serve as hosts for the northern root-knot nematode.

GENETIC CONTROLS: Some varieties of vegetables are reported to be resistant or tolerant to root-knot nematodes.

CHEMICAL CONTROLS: Sites should be routinely sampled for plant-parasitic nematodes before vegetables are planted, especially those extremely susceptible to NRKN. If nematode population densities are recovered at damage threshold levels, use of a nematicide may be advised.

Lesion Nematode (*Pratylenchus penetrans*)

HOST PLANTS: Virtually all species of cultivated plants.

BIOLOGY: Lesion nematodes overwinter as juveniles and adults within roots or in soil. These nematodes penetrate young roots. Once inside the root, they migrate between and through cells, often killing them.

Lesion nematode females lay eggs singly in root tissue or in soil. Females typically produce fewer than 100 eggs. Life cycles can be completed in three to four weeks, depending on soil temperatures. They can complete multiple generations per growing season.

SYMPTOMS: Aboveground symptoms are virtually the same as those produced by the NRKN. Penetration of roots by lesion nematodes results in very small lesions. These wounds create a point of entry for other soil pathogens, such as the fungi *Verticillium, Cylindrocarpon, Rhizoctonia, Colletotrichum*, and possibly others.

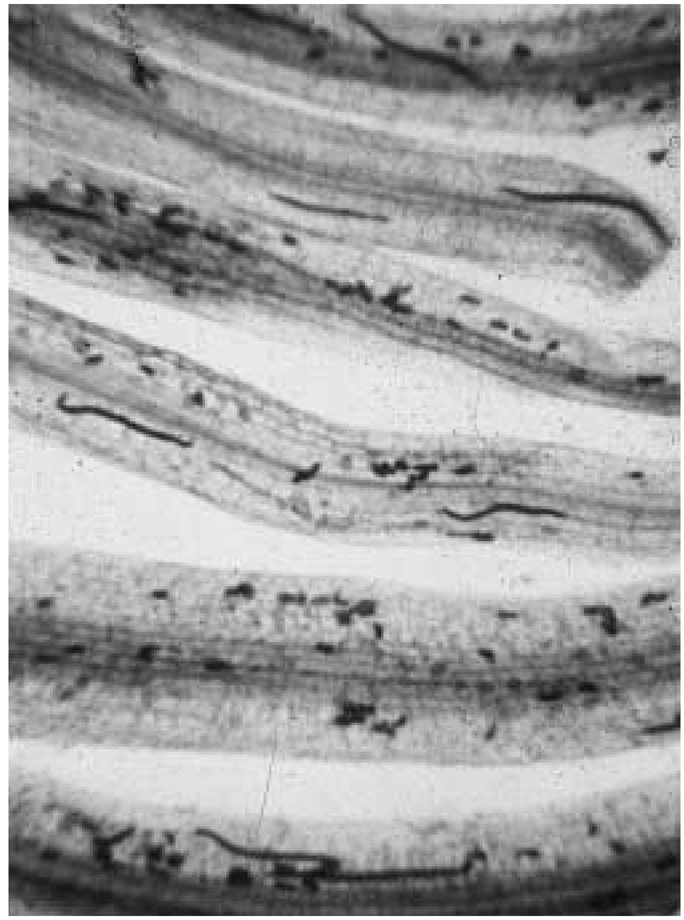
Lesion nematode-infected plants typically have reduced root volumes and weights. Feeding and migration by these organisms kills cells. Feeder roots are usually destroyed.

MANAGEMENT

Avoidance: Plant lesion nematode-free transplants.

Population Reduction

CULTURAL CONTROLS: Lesion nematodes feed on virtually all species of cultivated plants, so they are difficult to manage with rotation. Asparagus is a very poor host. Fields with histories of lesion nematode problems should be kept fallow before planting. Maintaining a clean fallow is important because many weeds serve as hosts. Utilizing sorghum or sudax as a rotational crop may help to reduce population densities of lesion nematode.



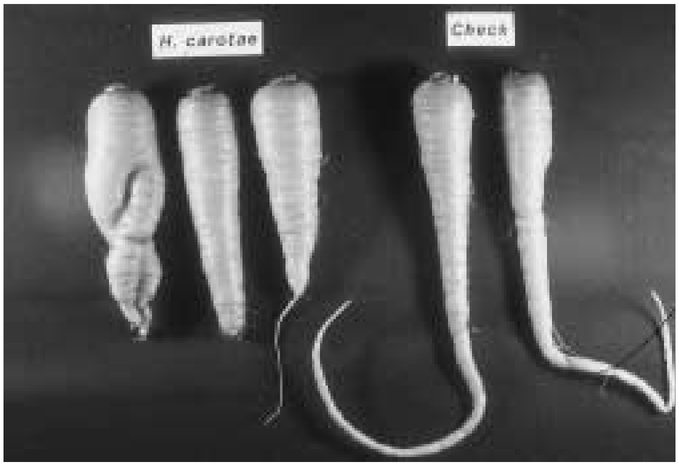
Lesion nematodes in roots.

CHEMICAL CONTROLS: See the section on nematicides.

Cyst Nematode (*Heterodera* spp.)

HOST PLANTS: Four species of cyst nematodes feed on vegetable crops in Michigan. The carrot cyst nematode, *Heterodera carotae*, has carrot as its only host. The soybean cyst nematode, *H. glycines*, feeds on green beans and peas. The sugar beet cyst nematode, *H. schachtii*, feeds on a variety of vegetables, including beets, broccoli, cauliflower, cabbage, Brussels sprouts, turnips and spinach. The clover cyst nematode, *H. trifolii*, is reported to feed on some vegetables but is not regarded as a serious pest of these crops in Michigan.

BIOLOGY: Cyst nematodes overwinter as eggs within cysts in the soil. Cysts are the dead remains of female nematodes. They are lemon-shaped and about the size of a pinhead. Eggs hatch and second-stage juveniles emerge from the cysts, migrate through the soil, and enter roots to feed. They swell as they grow, eventually becoming large enough that they rupture the root and are exposed to the soil. If cyst nematode-infected roots are examined closely after gently removing the soil, these females can be seen with the naked eye. They are white or yellow, depending on age. Males are worm-like and usually exit the root to mate with females.



Carrot damage by the carrot cyst nematode, *Heterodera carotae*.

Female cyst nematodes are visible without a microscope on plant roots.

Female cyst nematodes produce approximately 50 to 100 eggs in a gelatinous matrix outside their bodies, and many more eggs remain within their bodies. The eggs produced in the matrices typically hatch soon after production, whereas the ones contained within the females may not hatch for 10 years or more. The numbers of eggs produced by cyst nematodes vary by species.

SYMPTOMS: Feeding by cyst nematodes results in areas of stunted and yellow plants. Yields can also be significantly reduced. The severity of the symptoms varies according to host and the population densities of the cyst nematodes.

Female cyst nematodes can be observed with an unaided eye on infected plants during the growing season. Females are white or yellow and roughly the size of the period at the end of this sentence. Cyst nematode-infected plants often have reduced root systems.

Aerial view of damage caused by cyst nematodes.

Cyst nematode damage causes plants to wilt.

MANAGEMENT

Avoidance: Cyst nematodes can survive in the soil for 10 to 15 years in the absence of host crops. Do not contaminate fields with cyst nematode-infected soil. Growing host plants in long rotations with non-host crops also minimizes the risks of severe cyst nematode problems developing in the future. If cyst nematodes become established in a field, growers must learn to optimize yields in the presence of these nematodes.

Population Reduction

CULTURAL CONTROLS: Sites with histories of cyst nematode problems should be kept free from host plants for two or more years. Crop rotation is the most effective tactic to reduce population densities of cyst nematodes. Most of these nematodes have narrow enough host ranges that at least one or more non-host crops could be rotated into the cropping system.

CHEMICAL CONTROLS: Cyst nematodes are difficult to control with nematicides, though use of these materials can result in declines in cyst nematode population densities.

Stem and Bulb Nematode (*Ditylenchus dipsaci*)

HOST PLANTS: Many, including onion, beet, carrot, celery, cucumber and tomato.

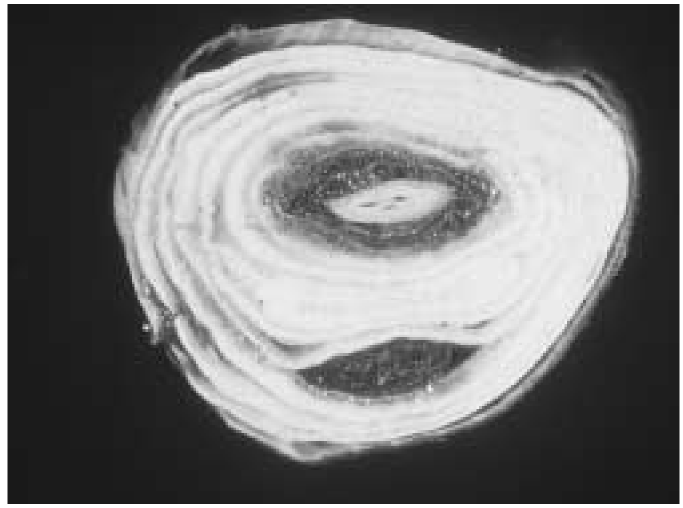
Stem and bulb nematode damage on onions.

BIOLOGY: Stem and bulb nematodes overwinter as fourth-stage juveniles and adults. They spend the winter in plant tissue or soil. When moisture is adequate, the nematodes migrate from their overwintering sites onto the leaves and stems of young plants. Females will produce up to 500 eggs and can survive 10 weeks or longer. The life cycle can be completed in about three weeks in optimal conditions. They are active very early in the spring, and egg laying can occur at temperatures below 40 degrees F. Vegetables produced in hot, dry summer conditions are less likely to suffer severe damage from stem and bulb nematodes.

Stem and bulb nematodes can persist for long periods. They are quite resistant to drought and cold temperatures. These nematodes will often form aggregates of large numbers of individuals (sometimes called “eelworm wool”) to survive during adverse conditions. Population densities often decline rapidly in the absence of host plants in fields.

SYMPTOMS: Deformed leaves and bulbs are the most common symptoms of stem and bulb infestations in onions. Leaves yellow and develop blisters. Young plants often are deformed or may be killed by high infestations. Older infected bulbs show swelling of the scales. These bulbs are often soft and, when cut open, reveal concentric rings of brown leaf scales. Infected bulbs often rot in storage because they are invaded by soft rot bacteria.

Other plants infested with stem and bulb nematodes are stunted and distorted. In beets, the growing point of the plant is often killed and multiple crowns may develop. For many vegetables infested with stem and bulb nematodes, severe crown rot may develop late in the growing season.



Stem and bulb nematode damage creates entry points for secondary pathogen infections that can cause bulbs to rot.

MANAGEMENT

Avoidance: Do not plant stem and bulb nematode-infested bulbs or seeds.

Population Reduction

CULTURAL CONTROLS: Crop rotation or the use of fallow can reduce population densities of stem and bulb nematodes. A few weeds are host plants, so good weed control is essential.

Disinfecting onion sets and bulbs in hot water dips kills nematodes. The temperature and time of dipping must be carefully controlled. Often temperatures of 110 to 115 degrees F for one to two hours are required to kill cyst nematodes.

These nematodes typically move on the surfaces of plants in water. Therefore, attempts should be made to minimize leaf wetness.

Common Needle Nematode (*Longidorus elongatus*)

HOST PLANTS: Celery, onion, mint, and other vegetables.

BIOLOGY: Needle nematodes overwinter as juveniles and adults in the soil. Eggs are laid in the spring and early summer when soil temperatures are cool and new roots are being produced. Females produce relatively few eggs—20 per year. Needle nematode adults live for several years and may require more than a year to complete a generation.

As temperatures rise and soil moisture levels decrease in the summer, needle nematodes move deep into the soil. They often rest 2 to 4 feet below the soil surface. During the fall, they move up to return to the root zones. It is best to sample for needle nematodes in the spring or fall when they are near the soil surface.

SYMPTOMS: The most characteristic symptom of feeding by needle nematodes is root swelling, especially of younger roots. Often these roots are killed and stunted root systems develop.

Needle nematode feeding can result in serious stunting or death of young plants. The damage is often very evident early in the growing season, and stunted plants remain in this condition throughout the year.

Needle nematode feeding can stunt plants.

MANAGEMENT

Avoidance: Do not plant stem and bulb nematode-infested bulbs or seeds.

Population Reduction

CULTURAL CONTROLS: Rotation to non-host crops is recommended to reduce population densities of common needle nematodes. Because these nematodes are often present in fairly low numbers and produce few eggs, a year without a host plant may be sufficient to adequately reduce their numbers.

CHEMICAL CONTROLS: Soil fumigation is effective for control of needle nematodes. Nonfumigant nematicides are generally not effective.

Pin Nematode
(*Paratylenchus hamatus* and *P. projectus*)

HOST PLANTS: Carrot and celery are susceptible to pin nematodes. Other vegetables serve as hosts but appear quite tolerant to pin nematodes.

BIOLOGY: Pin nematodes typically feed on roots but do not enter the root. We know little about their biology and life cycles.

SYMPTOMS: Feeding by pin nematodes can result in stunted, unthrifty plants. In carrots, taproots are stunted and discolored.

MANAGEMENT

Population Reduction

CULTURAL CONTROLS: Pin nematodes can be managed with rotation, though these nematodes do feed on a wide range of plants. Small grains are often used as covers in the fall to minimize soil erosion in fields where vegetables are produced. These cover crops can serve as hosts for pin nematodes. However, pin nematodes are not regarded as serious pest of most plants.

SAMPLING NEMATODE POPULATIONS

Plant-parasitic nematodes are microscopic organisms with concentrated distributions in a field. They tend to occur in clumps, so symptoms occur in circular or elliptical patterns. If aboveground symptoms are uniformly distributed in any given field, the cause of the problem is typically not nematodes.

Points to remember when sampling for nematodes:

- Because of their microscopic size, the only way to diagnosis a plant-parasitic nematode problem is to collect soil and/or plant tissue samples and send them to a nematode diagnostic lab for analysis.
- It is impossible to provide specific recommendations for the management of plant-parasitic nematodes unless they are properly identified.
- When collecting soil samples for plant-parasitic nematodes, the more soil cores gathered, the better the sample. However, it is necessary to submit only a pint to a quart of soil to a lab.
- For more complete instructions on sampling for nematodes, please refer to MSU bulletin E-2199, *Detecting and Avoiding Nematode Problems.*

MANAGEMENT OF PLANT-PARASITIC NEMATODES

The best defense against nematodes is to avoid them. Once fields or plant tissues are infected with nematodes, eradication is usually possible. Nematodes are usually transported over long distances by machinery, in plant material, on animals, or by water or wind. Natural disasters such as floods are uncontrollable, but the patterns in which machinery is moved and the sanitation of this equipment can be controlled. These tactics should be considered when trying to avoid nematodes. The bottom line is that anything that moves soil moves nematodes.

Often, fields do become infested with nematodes. If samples indicate the presence of pest nematodes at damage threshold levels, then steps should be taken to reduce the nematode population. Many tactics can be utilized to accomplish this.

Biological controls: The majority of nematodes present in the soil are considered beneficial. They typically feed on bacteria, fungi, or small animals, including other nematodes. Research results indicate that as the abundance of beneficial nematodes increases, the numbers of plant-parasitic nematodes decrease. Steps can be taken to increase the diversity and numbers of beneficial nematodes in fields. This type of approach is outlined in other MSU bulletins on crop ecology.

Many organisms are parasites or pathogens of nematodes. Most of these occur naturally in soils but often do not provide sufficient control of plant-parasitic nematodes.

Some biological nematicides products are available, but their use has not resulted in consistent control of nematodes in Michigan.

Biotechnological controls: Plants have not been genetically modified at this time to control plant-parasitic nematodes.

Chemical controls: Nematicides are compounds that kill nematodes. Nematicides are either **fumigants** or non-fumigants. Fumigants are typically compounds sold as liquids that react with water in the soil to produce gases that kill a wide variety of organisms, including plants. They are usually applied to the soil in the fall or spring when soil temperatures are adequate. Fumigant nematicides are labeled for use in vegetable production in Michigan. Please consult MSU bulletin E-312, *Insect, Disease and Nematode Control for Commercial Vegetables,* for specific recommendations.

Non-fumigant nematicides are also labeled for use in Michigan vegetable production. Unlike fumigants, they do not volatilize in soil water. They can be applied before, at, or even after planting in some situations. These compounds are not as broad spectrum as killing agents as fumigant types. They will control problem nematodes, but their use will often result in decreases in numbers of beneficial as well as parasitic nematodes. See MSU bulletin E-312 for information on use of these materials.

Cultural controls: Tactics that affect nematode populations include the species of plants grown, planting dates, presence or absence of companion crops, etc. Most of these tactics have been covered in detail in the sections on specific nematodes.

Genetic controls: Very few cultivars of vegetables are resistant to plant-parasitic nematodes, though many varieties of tomato have resistance to root-knot nematodes. Varieties of vegetables will differ in their susceptibility to nematodes, but this information is not always readily available. These data can be obtained with on-farm testing or screening of selected vegetable varieties.

Physical controls: These include the use of heat, steam or water (flooding) to reduce population densities of nematodes. In field situations, these types of controls are limited. In glasshouse or poly-house production of plants, heat or steam is typically used to sterilize growing media.

CHAPTER 8

Review Questions

Chapter 8: Nematode Management

Write the answers to the following questions and then check your answers with those in the back of the manual.

1. 1. Nematodes are best described as:

   A. Aliens.

   B. Animals.

   C. Bacteria.

   D. Earthworms.

   E. Fungi.

2. 1. Plant-parasitic nematodes typically range in length from approximately:

   A. 1/3000 to 1/300 inch.

   B. 1/30 to 1/4 inch.

   C. 1/4 to 4 inches.

   D. 4 inches to 4 feet.

   E. None of the above.

3. Which of the following is not a characteristic shared by all plant-parasitic nematodes?

   A. Complete their life cycles in usually 7 days

   B. Microscopic

   C. Obligate parasites of plants

   D. Stylet-bearing

4. How are nematodes similar to insects?

   A. They have compound eyes.

   B. They have three primary body segments.

   C. They possess an exoskeleton.

   D. They have legs and wings.

5. To reduce population densities of northern root-knot nematodes, you should:

   A. Grow carrots year after year.

   B. Rotate onions with celery.

   C. Grow corn or small grains.

   D. Fertilize crops with nitrogen.

6. Cyst nematodes spend the winter:

   A. In condominiums in Florida

   B. In cysts in the soil.

   C. As second-stage juveniles within leaf tissue.

   D. None of the above

7. Which female nematodes, of those listed below, would potentially produce the largest number of eggs?
   A. Common needle
   B. Lesion
   C. Northern root-knot
   D. Stem and bulb

8. Which of the nematodes listed below is not a pathogen of onion?
   A. Common needle
   B. Lesion
   C. Northern root-knot
   D. Soybean cyst

9. To diagnose a nematode problem, you should:
   A. Collect a soil sample and place the soil in a paper cup on the windowsill and count the nematodes as they migrate to the top.
   B. Collect soil and plant tissue samples and send them to a nematode diagnostic lab for analysis.
   C. Ask an expert.
   D. Consult with a fortune teller.

10. Lesion nematodes would not be transported over long distances in which of these situations?
   A. By moving machinery from field to field.
   B. By planting vegetable transplants started in contaminated soil.
   C. By applying leaf mulch.
   D. By soil erosion caused by flooding of the local river.

APPENDIX A

ANSWERS TO REVIEW QUESTIONS

Chapter 1 Integrated Pest Management

(1) Integrated pest management is a planned pest control program that combines control strategies to keep the pest population below economically damaging levels and to avoid adverse effects to humans, wildlife, and the environment.

(2) Cultural control—examples: host-plant resistance, maintaining healthy plants, changing the timing of harvest or planting, cultivation, field management, water management.

Biological control—examples: pathogens, parasitoids, predators.

Chemical control—examples: insecticide, herbicide, fungicide.

(3) Economic threshold – the number of pests (pest density) that requires a control action to prevent the pest population from increasing and causing economic damage.

(4) B. (5) D. (6) C.

(7) Cultural controls work by preventing the pest from colonizing the crop or commodity, creating adverse conditions that reduce survival of the pest, and reducing the impact of injury by the pest.

(8) A. (9) C. (10) B. (11) A. (12) B.

(13) C. (14) B. (15) A. (16) A. (17) B. (18) B.

(19) Tolerance is the amount of acceptable pesticide residue permitted by the Environmental Protection Agency (EPA) on a harvested crop.

(20) D. (21) A. (22) B. (23) C. (24) B. (25) D.
(26) C. (27) A.

Chapter 2. Minimizing Pesticide Impact

(1) A.

(2) A supplemental label is any information from the manufacturer about how to use the product. Examples: special local needs labels (24c), emergency exemption labels (section 18), and use information issued by the manufacturer.

(3) B. (4) C. (5) D. (6) A. (7) B. (8) D.

(9) B. (10)B.

(11) Any five of the following are correct: use integrated pest management, consider the geology of the area, carefully select pesticides that are not likely to leach, follow pesticide label directions, calibrate your equipment, measure accurately, avoid back-siphoning, consider weather conditions at the time of application, mix on an impervious pad, properly dispose of all pesticide wastes, and store pesticides away from water sources.

(12) C. (13) B. (14) A. (15) B. (16) A. (17) B.

(18) B. (19) A.

(20) 1. A map of all areas where pesticide applications occur.

2. A list of pesticide-sensitive sites near an application area.

3. Pesticide label and mandated restrictions.

4. Information for persons in sensitive areas on the type of pesticide used, the method of application, and the applicator's plan to minimize pesticide drift.

Chapter 3 Application Equipment

(1) D.

(2) The method of a pesticide application is influenced by target pest, the site of application, the available application equipment, and the cost and efficiency of alternative control methods.

(3) A. (4) A. (5) D. (6) C. (7) B. (8) A.

(9) B. (10) B. (11) C. (12) C. (13) B. (14) A.

(15) A pressure regulator controls the pressure in the spray system and therefore the amount of spray material delivered by the nozzles.

(16) C. (17) A. (18) B. (19) B. (20) D.

(21) 1. Check the spray system for leaks and drips by filling the tank with water and pressurizing the system.

2. Check the nozzles and strainers, making sure they are all the same type and are clean.

3. Measure the distance between the nozzle tip and the target and adjust, if necessary.

(22) B. (23) C. (24) B.

(25) Global positioning systems and geographical information systems help map fields and increase the accuracy of pesticide applications.

Chapter 4 Calibration

(1) Calibration of various systems is important because each system is a unique combination of pumps, nozzles, and other equipment.

(2) A. (3) B. (4) C. (5) C. (6) B. (7) D.

(8) A. (9) C. (10) B. (11) A. (12) A.

(13) D. (14) D. (15) B. (16) C. (17) A. (18) C.

Chapter 5 Insect Management

(1) D. (2) A.

(3) Metamorphosis is defined as the change in shape or form of an animal. An insect is said to under go metamorphosis when it changes from the larval to pupal to adult life stage.

(4) A. (5) A. (6) C. (7) B. (8) B. (9) C.

(10) B. (11) A.

(12) It is important to understand an insect's life cycle for pest management because each life stage is managed differently on the basis of its food source and habitat.

(13) B. (14) A. (15) D. (16) C. (17) E. (18) B.

(19) C. (20) D. (21) D. (22) B. (23) A. (24) B.

(25) A. (26) B. (27) C. (28) A. (29) D. (30) B.

(31) B. (32) A.

Chapter 6 Weed Management

(1) A weed is a plant growing where it is not wanted.

(2) B. (3) B. (4) C. (5) D. (6) A. (7) B.

(8) A. (9) A.

(10) Advantages—base herbicide selection on weeds present; soil type and moisture do not affect herbicide activity.

Disadvantages—greater risk of crop injury; should not be applied to wet foliage; time the application for effective control; weather may delay time of application.

(11) B. (12) A. (13) B. (14) A.

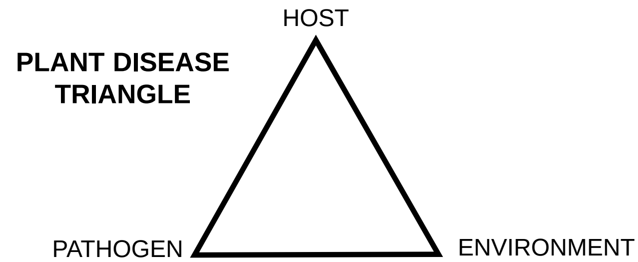
(15) A herbicide adjuvant is any substance that is added to a herbicide to enhance its effectiveness.

(16) B.

Chapter 7 Disease Management

(1) A. (2) C. (3) A. (4) C. (5) C.

(6)



(7) A.

(8) 1. Production of inoculum.

3. Spread of inoculum.

4. Infection.

5. Pathogen survival between susceptible crops.

(9) B. (10) C. (11) C. (12) D. (13) B. (14) C.

(15) A. (16) A. (17) C. (18) D. (19) C. (20) A.

(21) B. (22) D. (23) C. (24) C. (25) A. (26) C.

(27) D. (28) B. (29) A. (30) D. (31) A. (32) B.

(33) A. (34) C. (35) B. (36) D. (37) A.

Chapter 8 Nematode Management

(1) B. (2) B. (3) A. (4) C. (5) C.

(6) B. (7) C. (8) D. (9) B. (10) C.

APPENDIX B

CONVERSION TABLES

Area

144 square inches	1 square foot
9 square feet	1 square yard
43,560 square feet	1 acre
4,840 square yards	1 acre
160 square rods	1 acre
640 acres	1 square mile
2.5 acres	1 hectare

Length

1 inch	2.54 centimeters	5.5 millimeters	
1 foot	12 inches		
1 yard	3 feet		
1 rod	5.5 yards	16.5 feet	
1 mile	320 rods	1,760 yards	5,280 feet
1 meter	39.4 inches	1.09 yards	
1 kilometer	1,000 meters	0.62 mile	

Volume

1 tablespoon (tbsp or T)	3 teaspoons (tsp or t)	
1 fluid ounce	2 tablespoons	
8 fluid ounces	16 tablespoons	1 cup
16 fluid ounces	2 cups	1 pint
32 fluid ounces	4 cups	1 quart
128 fluid ounces	4 quarts	1 gallon
1 liter	33.9 ounces	1.06 quarts

Weight

1 ounce	28.3 grams	
1 pound	16 ounces	453.6 grams
2.2 pounds	1 kilogram	1,000 grams
1 ton	2,000 pounds	907 kilograms
1 metric ton	1,000 kilograms	2,205 pounds

APPENDIX C

GLOSSARY

ABDOMINAL PROLEGS—The false, peglike legs on the abdomen of a caterpillar.

ABSORPTION—The movement of a chemical into plants, animals (including humans), and/or microorganisms.

ACARICIDE—A pesticide used to control mites and ticks. A miticide is an acaricide.

ACTIVE INGREDIENT—The chemical or chemicals in a pesticide responsible for killing, poisoning, or repelling the pest. Listed separately in the ingredient statement.

ACTION THRESHOLD—see ***economic threshold***

ACUTE TOXICITY—The capacity of a pesticide to cause injury within 24 hours following exposure. LD_{50} and LC_{50} are common indicators of the degree of acute toxicity. (See also ***chronic toxicit***y).

ADJUVANT—A substance added to a pesticide to improve its effectiveness or safety. Same as additive. Examples: penetrants, spreader-stickers, and wetting agents.

ADSORPTION—The process by which chemicals are held or bound to a surface by physical or chemical attraction. Clay and high organic soils tend to adsorb pesticides.

AGGREGATION PHEROMONE—See ***pheromone***.

AEROSOL—A material stored in a container under pressure. Fine droplets are produced when the material dissolved in a liquid carrier is released into the air from the pressurized container.

ALLELOPATHY—When one plant species releases toxic chemicals that eliminate a completing species.

ANAL PROLEGS—The false, peglike legs near the anus of a caterpillar.

ANNUAL—A plant that completes its life cycle in one year.

ANTI-SIPHONING DEVICE—A device attached to the filling hose that prevents backflow or back-siphoning from a spray tank into a water source.

ANTIBIOSIS—A relationship between two or more organisms that negatively affects one of the organisms involved (example: plant characteristics that affect insect behavior).

ANTIDOTE—A treatment used to counteract the effects of pesticide poisoning or some other poison in the body.

ANTIXENOSIS—A relationship between two or more organisms that changes the behavior of one of the organisms involved (example: plant characteristics that drive an insect away).

ARACHNID—A wingless arthropod with two body regions and four pairs of jointed legs. Spiders, ticks, and mites are in the class Arachnida.

ARTHROPOD—An invertebrate animal characterized by a jointed body and limbs and usually a hard body covering that is molted at intervals. For example, insects, mites, and crayfish are in the phylum Arthropoda.

ATTRACTANT—A substance or device that will lure pests to a trap or poison bait.

AUGMENTATION—A periodic release of natural enemies to increase the present population; a method of biological control.

AVICIDE—A pesticide used to kill or repel birds. Birds are in the class Aves.

BACK-SIPHONING—The movement of liquid pesticide mixture back throught the filling hose and into the water source.

BACTERIUM (plural BACTERIA)—Microscopic organisms, some of which are capable of producing diseases in plants and animals. Others are beneficial.

BACTERICIDE—Chemical used to control bacteria.

BAIT—A food or other substance used to attract a pest to a pesticide or to a trap.

BAND APPLICATION—The application of a pesticide in a strip or band of a certain width.

BARRIER APPLICATION—Application of a pesticide in a strip alongside or around a structure, a portion of a structure, or any object.

BENEFICIAL INSECT—An insect that is useful or helpful to humans; usually insect parasites, predators, pollinators, etc.

BIENNIAL—A plant that requires two growing seasons to complete its life cycle.

BIOLOGICAL CONTROL—Control of pests using predators, parasites, and disease-causing organisms. May be naturally occurring or introduced.

BIOMAGNIFICATION—The process whereby one organism accumulates chemical residues in higher concentrations from organisms it consumes.

BOTANICAL PESTICIDE—A pesticide produced from chemicals found in plants. Examples are nicotine, pyrethrins, and strychnine.

BRAND NAME—The name or designation of a specific pesticide product or device made by a manufacturer or formulator; a marketing name.

BROADCAST APPLICATION—A uniform pesticide application to a field or site.

CALIBRATE, CALIBRATION OF EQUIPMENT, OR APPLICATION METHOD—The measurement of dispersal or output and adjustments made to control the rate of dispersal of pesticides.

CARBAMATES (N-methyl carbamates)—A group of pesticides containing nitrogen, formulated as insecticides, fungicides and herbicides. The N-methyl carbamates are insecticides and inhibit ***cholinesterase*** in animals.

CARCINOGENIC—The ability of a substance or agent to induce malignant tumors (cancer).

CARRIER—An inert liquid, solid, or gas added to an active ingredient to make a pesticide dispense effectively. A carrier is also the material, usually water or oil, used to dilute the formulated product for application.

CARRYOVER (**HERBICIDE**)—When a herbicide is not broken down during the season of application and persists in quantities large enough to injure succeeding crops.

CERTIFIED APPLICATORS—Individuals who are certified to use or supervise the use of any restricted-use pesticide covered by their certification.

CHEMICAL NAME—The scientific name of the active ingredient(s) found in the formulated product. This complex name is derived from the chemical structure of the active ingredient.

CHEMICAL CONTROL—Pesticide application to kill pests.

CHEMTREC—The Chemical Transportation Emergency Center has a toll-free number (800-424-9300) that provides 24-hour information for chemical emergencies such as a spill, leak, fire, or accident.

CHLORINATED HYDROCARBON—A pesticide containing chlorine, carbon, and hydrogen. Many are persistent in the environment. Examples: chlordane, DDT, methoxychlor.

CHLOROPHYLL—The green pigment in plant cells that enables the plant to convert sunlight into food.

CHOLINESTERASE, ACETYLCHOLINESTERASE—An enzyme in animals that helps regulate nerve impulses. This enzyme is depressed by N-methyl carbamate and organophosphate pesticides.

CHRONIC TOXICITY—The ability of a material to cause injury or illness (beyond 24 hours following exposure) from repeated, prolonged exposure to small amounts. (See also ***acute toxicity***.)

CLASSES— See ***taxonomy***.

COMMERCIAL APPLICATOR—A certified applicator who uses or supervises the use of any pesticide classified for restricted use for any purpose or on any property other than that producing an agricultural commodity.

COMMON NAME—A name given to a pesticide's active ingredient by a recognized committee on pesticide nomenclature. Many pesticides are known by a number of trade or brand names, but each active ingredient has only one recognized common name.

COMMUNITY—The various populations of animal species (or plants) that exist together in an ecosystem. (See also ***population*** and ***ecosystem***).

CONCENTRATION—Refers to the amount of active ingredient in a given volume or weight of formulated product.

CONTACT PESTICIDE—A compound that causes death or injury to insects when it contacts them. It does not have to be ingested. Often used in reference to a spray applied directly on a pest.

CONTAMINATION—The presence of an unwanted substance (sometimes pesticides) in or on plants, animals, soil, water, air, or structures.

COTYLEDONS—The first leaf or pair of leaves of a seedling.

CROSS-RESISTANCE—When a pest develops resistance to one type of pesticide and all other pesticides with a similar mode of action.

CULTURAL CONTROL—A pest control method that includes changing human habits—e.g., sanitation, work practices, cleaning and garbage pickup schedules, planting and harvest times, etc.

CURATIVE—The application of a control tactic after the pest has arrived.

CYST (**NEMATODES**)—The body of the dead adult female nematode of the genus *Heterodera* or *Globodera*, which may contain eggs.

DAMPING-OFF—A disease that destroys seedlings near the soil line, resulting in the seedlings falling to the ground.

DECONTAMINATE—To remove or break down a pesticidal chemical from a surface or substance.

DEGRADATION—The process by which a chemical compound or pesticide is reduced to simpler compounds by the action of microorganisms, water, air, sunlight, or other agents. Degradation products are usually, but not always, less toxic than the original compound.

DEPOSIT—The amount of pesticide on treated surfaces after application.

DERMAL TOXICITY—The ability of a pesticide to cause acute illness or injury to a human or animal when absorbed through the skin. (See ***exposure route***.)

DESICCANT—A type of pesticide that draws moisture or fluids from a pest, causing it to die. Certain desiccant dusts destroy the waxy outer coating that holds moisture within an insect's body.

DETOXIFY—To render a pesticide's active ingredient or other poisonous chemical harmless.

DIAGNOSIS—The positive identification of a problem and its cause.

DILUENT—Any liquid, gas, or solid material used to dilute or weaken a concentrated pesticide.

DISEASE—A disturbance of normal plant function; caused by bacteria, fungi, virus, or environmental conditions.

DISEASE CYCLE—The basic chain of events involved in disease development.

DISINFECTANT—A chemical or other agent that kills or inactivates disease-producing microorganisms. Chemicals used to clean or surface-sterilize inanimate objects.

DOSE, DOSAGE—Quantity, amount, or rate of pesticide applied to a given area or target.

DRIFT—The airborne movement of a pesticide spray or dust beyond the intended target area.

DRIFT MANAGEMENT PLAN—A written plan required of commercial and private applicators by Michigan Regulation 637 whenever there is a chance of a spray application drifting from the target onto non-target and off-site sensitive areas.

DUST—A finely ground, dry pesticide formulation containing a small amount of active ingredient and a large amount of inert carrier or diluent such as clay or talc.

ECONOMIC DAMAGE—The amount of injury that will justify the cost of applied control measures.

ECONOMIC INJURY LEVEL (EIL)—The smallest pest population that will cause economic loss to the crop.

ECONOMIC THRESHOLD (ET, ACTION THRESHOLD)—The pest density at which a control tactic should be taken to prevent the pest population from increasing to the economic injury level.

ECOSYSTEM—The pest management unit. It includes a community (of ***populations***) with the necessary physical and biotic (food, hosts) supporting factors that allow an infestation of pests to persist.

EMULSIFIABLE CONCENTRATE—A pesticide formulation produced by mixing or suspending the active ingredient (the concentrate) and an emulsifying agent in a suitable carrier. When it's added to water, a milky emulsion is formed.

EMULSIFYING AGENT (EMULSIFIER)—A chemical that aids in the suspension of one liquid in another that normally would not mix together.

EMULSION—A mixture of two liquids that are not soluble in each other. One is suspended as very small droplets in the other with the aid of an emulsifying agent.

ENCAPSULATED FORMULATION—A pesticide formulation with the active ingredient enclosed in capsules of polyvinyl or other materials; principally used for slow release.

ENDANGERED SPECIES—A plant or animal species whose population is reduced to the extent that it is near extinction and that a federal agency has designated as being in danger of becoming extinct.

ENTRY INTERVAL—See ***re-entry interval***.

ENVIRONMENT—All of our physical, chemical, and biological surroundings, such as climate, soil, water, and air, and all species of plants, animals, and microorganisms.

ENVIRONMENTAL PROTECTION AGENCY (EPA) — The federal agency responsible for ensuring the protection of humans and the environment from potentially adverse effects of pesticides.

EPA ESTABLISHMENT NUMBER—A number assigned to each pesticide production plant by the EPA. The number indicates the plant at which the pesticide product was produced and must appear on all labels of that product.

EPA REGISTRATION NUMBER—An identification number assigned to a pesticide product when the product is registered by the EPA for use. The number must appear on all labels for a particular product.

ERADICATION—The complete elimination of a (pest) population from a designated area.

EXOSKELETON—The external hardened covering or skeleton of an insect to which muscles are attached internally; periodically shed.

EXPOSURE ROUTE OR COMMON EXPOSURE ROUTE—The manner (dermal, oral, or inhalation/respiratory) by which a pesticide may enter an organism.

FAMILY—See ***taxonomy***

FIFRA—The Federal Insecticide, Fungicide, and Rodenticide Act; a federal law and its amendments that control pesticide registration and use.

FLOWABLE—A pesticide formulation in which a very finely ground solid particle is suspended (not dissolved) in a liquid carrier.

FORMULATION—The pesticide product as purchased, containing a mixture of one or more active ingredients, carriers (inert ingredients), and other additives making it easy to store, dilute, and apply.

FRUITING BODY—The part of a fungus that contains spores.

FUMIGANT—A pesticide formulation that volatilizes, forming a toxic vapor or gas that kills in the gaseous state. Usually, it penetrates voids to kill pests.

FUNGICIDE—A chemical used to control fungi.

FUNGUS (plural **FUNGI**)**—**A group of small, often microscopic, organisms in the plant kingdom that cause rot, mold and disease. Fungi need moisture or a damp environment (wood rots require at least 19 percent moisture). Fungi are extremely important in the diet of many insects.

GENERAL-USE (UNCLASSIFIED) PESTICIDE—A pesticide that can be purchased and used by the general public. (See also **restricted-use pesticide**.)

GEOGRAPHIC INFORMATION SYSTEM (GIS)—An organized collection of computer hardware, software, geographic data and personnel designed to capture, manipulate, analyze and display geographically referenced data.

GENUS—See t***axonomy***

GLOBAL POSITIONING SYSTEM (GPS)—Portable, satellite-based system which will establish the real-world location (position) of the GPS receiver.

GRANULE—A dry pesticide formulation. The active ingredient is either mixed with or coated onto an inert carrier to form a small, ready-to-use, low-concentrate particle that normally does not present a drift hazard. Pellets differ from granules only in their precise uniformity, larger size, and shape.

GROUNDWATER—Water sources located beneath the soil surface from which springwater, well water, etc., are obtained. (See also ***surface water***.)

HAZARD—See ***risk***.

HERBICIDE—A pesticide used to kill plants or inhibit plant growth.

HOPPERBURN—A V-shaped yellow marking resulting from feeding of leafhoppers.

HOST—Any animal or plant on or in which another lives for nourishment, development, or protection.

HOST RESISTANCE—The defense mechanism of an animal or plant against a pest; sometimes host-plant resistance. See **RESISTANCE**.

HYPHA (plural HYPHAE)—A single, delicate threadlike structure of fungus.

IGR, INSECT GROWTH REGULATOR, JUVENOID— A pesticide constructed to mimic insect hormones that control molting and the development of some insect systems affecting the change from immature to adult. (See ***juvenile hormone***.)

INCUBATION PERIOD—The time between first exposure to a pathogen and when symptoms begin to appear.

INERT INGREDIENT—In a pesticide formulation, an inactive material without pesticidal activity.

INFECTION—The establishment of a pathogen with a host.

INFECTIOUS DISEASE—Disease caused by pathogens such as bacteria, viruses, and fungi; can be spread from plant to plant.

INGREDIENT STATEMENT—The portion of the label on a pesticide container that gives the name and amount of each active ingredient and the total amount of inert ingredients in the formulation.

INHALATION—Taking a substance in through the lungs; breathing in. (See ***exposure route***.)

INOCULUM—A pathogen source that can infect and cause disease.

INSECT GROWTH REGULATOR—See **IGR**.

INSECTICIDE—A pesticide used to manage or prevent damage caused by insects. Sometimes generalized to be synonymous with pesticide.

INSECTS, INSECTA—A class in the phylum Arthropoda characterized by a body composed of three segments (head, ***thorax***, and abdomen) and three pairs of legs.

INTEGRATED PEST MANAGEMENT— See **IPM**.

IPM—Integrated pest management. A planned pest control program in which various methods are integrated and used to keep pests from causing economic, health-related, or aesthetic injury. IPM includes reducing pests to a tolerable level. Pesticide application is not the primary control method but is an element of IPM—as are cultural, mechanical, and biological methods. IPM programs emphasize communication, monitoring, inspection, and evaluation (keeping and using records).

JUVENILE—The immature or larval stage of nematodes; commonly referred to as J1, J2, J3, and J4.

JUVENILE HORMONE—A hormone produced by an insect that inhibits change or molting. As long as juvenile hormone is present, the insect does not develop into an adult but remains immature.

LABEL—All printed material attached to or on a pesticide container.

LABELING—The pesticide product label and other accompanying materials that contain directions that pesticide users are legally required to follow.

LARVA (plural **LARVAE**)**—**An early developmental stage of insects with complete metamorphosis. Insects hatch out of eggs as larvae before becoming ***pupae*** (resting stage), and then adults.

LC_{50}—Lethal concentration. The concentration of a pesticide, usually in air or water, that kills 50 percent of a test population of animals. LC_{50} is usually expressed in parts per million (ppm). The lower the LC_{50} value, the more acutely toxic the chemical.

LD_{50}—Lethal dose. The dose or amount of a pesticide that can kill 50 percent of the test animals when eaten or absorbed through the skin. LD_{50} is expressed in milligrams of chemical per kilogram of body weight of the test animal (mg/kg). The lower the LD_{50}, the more acutely toxic the pesticide.

LEACHING—The movement of a substance with water downward through soil.

MESOTHORAX—The second segment of an insect's ***thorax***. One pair of legs and usually one pair of wings are attached.

METAMORPHOSIS—A change in the shape, or form, of an animal. Usually used when referring to insect development.

METATHORAX—The third segment of an insect's ***thorax***. One pair of legs and often one pair of wings are attached.

MICROBIAL DEGRADATION—Breakdown of a chemical by microorganisms.

MICROBIAL PESTICIDE—Bacteria, viruses, fungi, and other microorganisms used to control pests. Also called biorationals.

MICROORGANISM—An organism so small it can be seen only with the aid of a microscope.

MITICIDE—A pesticide used to control mites. (See ***acaricide***.)

MODE OF ACTION—The way in which a pesticide exerts a toxic effect on the target plant or animal.

MOLLUSCICIDE—A chemical used to control snails and slugs.

MOLT—Periodic shedding of the outer layer (e.g., an insect's ***exoskeleton*** is shed periodically).

MONITORING—On-going surveillance. Monitoring includes inspection and record keeping. Monitoring records allows technicians to evaluate pest population suppression, identify infested or non-infested sites, and manage the progress of the management or control program.

MYCELIUM—A mass of hyphae; has a fuzzy appearance.

NECROSIS—Death of plant or animal tissues that results in the formation of discolored, sunken, or necrotic (dead) areas.

NEMATODE—A small, slender, colorless roundworm; nematodes live in soil and water or as parasites of plants or animals.

NEMATICIDE—A chemical used to control nematodes.

NON-INFECTIOUS DISEASE—Disease caused by nonliving agents such as drought, soil compaction, temperature or moisture extremes, nutrient deficiency, etc.; cannot reproduce and spread.

NON-POINT SOURCE POLLUTION—Pollution from a generalized area or weather event.

NON-RESIDUAL PESTICIDE—Pesticides applied to obtain effects only during the time of treatment.

NON-TARGET ORGANISM—Any plant or animal other than the intended target(s) of a pesticide application.

NOZZLE FLOW RATE—The amount of material that passes through the nozzle for a specific amount of time; dependent on pressure and tip size.

NYMPH—The developmental stage of insects with gradual metamorphosis that hatches from the egg. Nymphs become adults.

ORAL TOXICITY—The ability of a pesticide to cause injury or acute illness when taken by mouth. One of the common exposure routes.

ORDER—See ***taxonomy***.

ORGANOPHOSPHATES—A large group of pesticides that contain the element phosphorus and inhibit ***cholinesterase*** in animals.

PARASITE—A plant, animal, or microorganism living in, on, or with another living organism for the purpose of obtaining all or part of its food.

PARASITOID—An organism that lives during its development in or on the body of a single host organism, eventually killing it.

PATHOGEN—A disease-causing organism.

PERENNIAL—A plant that lives for more than two years.

PERSONAL PROTECTIVE EQUIPMENT (PPE)—Devices and clothing intended to protect a person from exposure to pesticides. Includes such items as long-sleeved shirts, long trousers, coveralls, suitable hats, gloves, shoes, respirators, and other safety items as needed.

PEST—An undesirable organism (plant, animal, bacterium, etc.); any organism that competes with people for food, feed, or fiber, causes structural damage, is a public health concern, reduces aesthetic qualities, or impedes industrial or recreational activities.

PESTICIDE—A chemical or other agent used to kill, repel, or otherwise control pests or to protect from a pest.

PETIOLE—The stalk of a leaf.

pH—A measure of the acidity/alkalinity of a liquid—acid below pH7; basic or alkaline above pH7 (up to 14).

PHEROMONE—A substance emitted by an animal to influence the behavior of other animals of the same species. Examples are sex pheromones (to attract mates) and aggregation pheromones (to keep members of the same species together in a group). Some pheromones are synthetically produced for use in insect traps.

PHOTODEGRADATION—Breakdown of chemicals by the action of light.

PHYSICAL CONTROL—Habitat alteration or changing the infested physical structure—e.g., caulking holes, sealing cracks, tightening around doors and windows, moisture reduction, ventilation, etc.

PHYTOTOXICITY—Injury to plants caused by a chemical or other agent.

POINT OF RUNOFF—The point at which a spray starts to run or drip from the surface to which it is applied.

POINT SOURCE POLLUTION—Pollution from a specific source.

POISON CONTROL CENTER—A local agency, generally a hospital, that has current information on the proper first aid techniques and antidotes for poisoning emergencies. Centers are listed in telephone directories.

POPULATION—Individuals of the same species. The populations in an area make up a community. (See ***ecosystem***.)

POSTEMERGENT HERBICIDE—Herbicide applied after weeds have emerged to kill them by contacting the foliage.

PREEMERGENT HERBICIDE—Herbicide applied before emergence of weeds to kill them as they develop (sprout).

PREHARVEST INTERVAL—The minimum amount of time (in days) between the last application and harvest.

PRECIPITATE—A solid substance that forms in a liquid and settles to the bottom of a container; a material that no longer remains in suspension.

PREDATOR—An animal that attacks, kills, and feeds on other animals. Examples of predaceous animals are hawks, owls, snakes, many insects, etc.

PRONOTUM—The area just behind an insect's head (i.e., the upper plate of the ***prothorax***).

PROPELLANT—The inert ingredient in pressurized products that forces the active ingredient from the container.

PROTECTANT—A chemical applied to a plant or animal to prevent a pest problem.

PROTHORAX—The first segment of an insect's thorax. One pair of legs is attached.

PUPA (plural **PUPAE**)**—**The developmental (resting) stage of insects with complete metamorphosis during which major changes from the larval to the adult form occur.

RATE OF APPLICATION—The amount of pesticide applied to a plant, animal, unit area, or surface; usually measured as per acre, per 1,000 square feet, per linear foot, or per cubic foot.

REENTRY INTERVAL—The length of time following a pesticide application when entry into the treated area is restricted.

REGISTERED PESTICIDES—Pesticide products that have been registered by the Environmental Protection Agency for the uses listed on the label.

REPELLENT—A compound that keeps insects, rodents, birds, or other pests away from humans, plants, domestic animals, buildings, or other treated areas.

RESIDUAL PESTICIDE—A pesticide that continues to remain effective on a treated surface or area for an extended period following application.

RESIDUE—The pesticide active ingredient or its breakdown product(s) that remain in or on the target after treatment.

RESISTANCE—The inherited ability of a pest to tolerate the toxic effects of a particular pesticide.

RESTRICTED-USE PESTICIDE (RUP)—A pesticide that can be purchased and used only by certified applicators or persons under their direct supervision; pesticide classified for restricted use under FIFRA, Section 3(d)(1)(C).

RHIZOME—An underground stem capable of sending out roots and leafy shoots.

RISK—A probability that a given pesticide will have an adverse effect on humans or the environment in a given situation.

RODENTICIDE—A pesticide used to control rodents.

RUNOFF—The movement of water and associated materials on the soil surface. Runoff usually proceeds to bodies of surface water.

SANITATION—The removal of infected plant parts, decontamination of tools, equipment, hands, etc.

SCLEROTIA—A mass of hyphae and food that allows the fungus to survive long periods of extreme hot or cold temperatures and lack of water.

SCOUTING—Regular monitoring of a crop or site to determine possible pest problems.

SCUTUM—Shield-like structure located near the front part of the ***mesothorax*** of an insect.

SIGNAL WORDS—Required word(s) that appear on every pesticide label to denote the relative toxicity of the product. Signal words are DANGER-POISON, DANGER, WARNING, and CAUTION.

SITE—Areas of pest infestation. Each site should be treated specifically or individually.

SOIL DRENCH—To soak or wet the ground surface with a pesticide. Large volumes of the pesticide mixture are usually needed to saturate the soil to any depth.

SOIL FUMIGANT—A toxic gas or volatile substance that is used to kill soil microorganisms.

SOIL INJECTION—The placement of a pesticide below the surface of the soil; common application method for nematicides.

SOIL INCORPORATION—The mechanical mixing of a pesticide product with soil.

SOLUTION—A mixture of one or more substances in another substance (usually a liquid) in which all the ingredients are completely dissolved. Example: sugar in water.

SOLVENT—A liquid that will dissolve another substance (solid, liquid, or gas) to form a solution.

SPECIES—See ***taxonomy***.

SPORE—The reproductive stage of a fungus.

SPRAY DRIFT—Movement of airborne spray from the intended area of application.

STOMACH POISON—A pesticide that must be eaten by a pest to be effective; it will not kill on contact.

STOLONS—An aboveground creeping stem that can root and develop new shoots.

STYLET—A long, slender, hollow feeding structure of nematodes and some insects.

SUPPLEMENTAL LABELING—Pesticide label information that appears on a separate piece of paper and contains information regarding the site, pest, rate, etc. Supplemental labeling may be supplied at the time of purchase or requested from the dealer.

SURFACE WATER—Water on the earth's surface: rivers, lakes, ponds, streams, etc. (See also ***groundwater***.)

SUSPENSION—Pesticide mixtures consisting of fine particles dispersed or floating in a liquid, usually water or oil. Example: wettable powders in water.

TARGET—The plants, animals, structures, areas, or pests at which the pesticide or other control method is directed.

TAXONOMY—The classification of living organisms into groups: kingdom, phylum, class, order, family, genus, and species.

TECHNICAL MATERIAL—The pesticide active ingredient in pure form as it is manufactured by a chemical company. It is combined with inert ingredients or additives in formulations such as wettable powders, dusts, emulsifiable concentrates, or granules.

THORAX—The middle part of an insect's body, between the head and the abdomen. It is divided into three segments**—*prothorax***, ***mesothorax***, and ***metathorax***. A pair of legs is attached to each thoracic region.

THRESHOLD—A level of pest density at which the pest or its damage becomes unacceptable and control measures are required.

TOXIC—Poisonous to living organisms.

TOXICANT—A poisonous substance such as the active ingredient in a pesticide formulation.

TOXICITY—The ability of a pesticide to cause harmful, acute, delayed, or allergic effects; the degree or extent to which a chemical or substance is poisonous.

TOXIN—A naturally occurring poison produced by plants, animals, or microorganisms. Examples: the poison produced by the black widow spider, the venom produced by poisonous snakes, and the botulism toxin produced by bacteria.

UNCLASSIFIED PESTICIDE—See ***general-use pesticide***.

USE—The performance of pesticide-related activities requiring certification include: application, mixing, loading, transport, storage, or handling after the manufacturing seal is broken; care and maintenance of application and handling equipment; and disposal of pesticides and their containers in accordance with label requirements. Uses not needing certification: long-distance transport, long-term storage, and ultimate disposal.

VAPOR PRESSURE—The property that causes a chemical to evaporate. The higher the vapor pressure, the more volatile the chemical or the easier it will evaporate.

VECTOR—A carrier, an animal (e.g., insect, nematode, mite) that can carry and transmit a pathogen from one host to another.

VERTEBRATE—Animal characterized by a segmented backbone or spinal column.

VIRUS—Ultramicroscopic parasites composed of proteins. Viruses can multiply only in living tissues and cause many animal and plant diseases.

VOLATILITY—The degree to which a substance changes from a liquid or solid state to a gas at ordinary temperatures when exposed to air.

VOMITOXIN—A toxin produced by the fungus, *Fusarium graminearm*, wheat scab, that contaminates wheat; toxic to mammals.

WATER TABLE—The upper level of the water-saturated zone in the ground.

WETTABLE POWDER—A dry pesticide formulation in powder form that forms a suspension when added to water.

For the further definition of terms consult:

Pesticide Applicator Core Training Manual, E-2195, Michigan State University Extension.

The Federal Insecticide, Fungicide, and Rodenticide Act as amended. Public Law 92-516 October 21, 1972 as amended by Public Law 94-140 November 28, 1975, and Public Law 95-396 September 30, 1978.

Federal Register, November 7, 1990, Part II Environmental Protection Agency 40, CFR Part 171 Certification of Pesticide Applicator; Proposed Rule.

Region V Office of the EPA, Chicago, Ill.

Michigan Department of Agriculture State Plan for Commercial and Private Applicators.

Federal Agency Secretary's Office (for federal employees using restricted pesticides in performance of official duties).

Local, state, and national pest control associations.

APPENDIX D

SELECTED BIBLIOGRAPHY

Pesticides

Cheremisinoff, Nicholas P., and J. A. King. 1994. *Toxic Properties of Pesticides.* Marcel Dekker, Inc. New York.

Kamrin, Michael A. 1997. *Pesticide Profiles Toxicity, Environmental Impact, and Fate.* CRC Lewis Publishers. New York.

Ware, George W. 1994. *The Pesticide Book (4th Edition)*. Thomson Publications. Fresno, California.

Selected Subject References (subjects are in **bold print**)

Agrios, George N. 1988. ***Plant Pathology*** *(3rd Edition)*. Academic Press, Inc. San Diego, California.

Bird, George, B. Bishop, E. Grafius, M. Hausbeck, L. Jess, W. Kirk, and W. Pett. ***2001 Insect, Disease and Nematode Control for Commercial Vegetables***. Bulletin E–312. East Lansing, Michigan: Michigan State University Extension.

Carey, J. B., J. J. Kells, and K. A. Renner. 1993. *Common* ***Weed*** *Seedlings of Michigan*. Bulletin E-1363. East Lansing, Michigan: Michigan State University Extension.

Cavigelli, M. A., S. R. Deming, L. K. Probyn, and D. R. Mutch (eds.). 2000. *Michigan Field Crop* ***Pest*** *Ecology and Management*. Bulletin E-2704. East Lansing, Michigan: Michigan State University Extension.

Chomas, Andrew J., J. J. Kells, and J. B. Carey. 1998. *Common* ***Weed*** *Seedlings of the North Central State*s. North Central Regional Extension Publication No. 607. East Lansing, Michigan: Michigan State University Extension.

Flint, Mary Louise, and P. Gouvei. 2001. ***IPM*** *in Practice: Principles and Methods of Integrated Pest Management*. Publication 3418. Davis, California: University of California.

Foster, Rick, and B. Flood (eds.) 1995. ***Vegetable Insect*** *Management with emphasis on the Midwest*. Meister Publishing Co. Willoughby, Ohio.

Gunsolus, Jeffery L., and W. S. Curran. 1994. ***Herbicide*** *Mode of Action and Injury Symptoms*. North Central Regional Extension Publication No. 377. St. Paul, Minnesota: University of Minnesota.

Gunsolus, Jeffery L. 1994. ***Herbicide Resistant Weeds***. North Central Regional Extension Publication No. 468. University of Minnesota, St. Paul, Minnesota.

MacNab, A. A., A. F. Sherf, and J. K. Springer. 1994. *Identifying Diseases of Vegetables*. University Park, Pennsylvania: Pennsylvania State University.

Mason, Charles E., M. E. Rice, D. D. Calvin, J. W. Van Duyn, W. B. Showers, W. D. Hutchison, J. F. Witkowski, R. A. Higgins, D. W. Onstad, and G. P. Dively. 1996. ***European Corn Borer*** *Ecology and Management*. North Central Regional Extension Publication No. 327. Ames, Iowa: Iowa State University.

Nickle, William R. 1991. ***Manual of Agricultural Nematology***. Marcel Dekker, Inc. New York.

Ostlie, K. R., W. D. Hutchison and R. L. Hellmich. 1997. ***Bt Corn*** *and European Corn Borer*. North Central Regional Extension Publication No. 602. St. Paul, Minnesota: University of Minnesota.

Pedigo, Larry P. 1989. ***Entomology and Pest Management***. Macmillan Publishing Company. New York.

Steffey, K. L., M. E. Rice, J. All, D. A. Andow, M. E. Gray, and J. W. Van Duyn (eds.). 1999. *Handbook of* ***Corn*** *Insects*. Entomological Society of America. Lanham, Md.

Zandstra, Bernard H. ***2001 Weed Control Guide for Vegetable Crops***. Bulletin E-433. East Lansing, Michigan: Michigan State University Extension.

Zimdahl, Robert L. 1993. *Fundamentals of* ***Weed*** *Science (2nd Edition)*. Academic Press. San Diego, California.

Internet Reference Sites

Michigan State University Integrated Pest Management Program: http://www.msue.msu.edu/ipm/

Michigan State University Pesticide Education Program: http://www.pested.msu.edu/

Michigan Department of Agriculture: http://www.mda.state.mi.us/

National Pesticide Information Center: http://npic.orst.edu (pesticide information)

The Extension Toxicology Network: http://ace.ace.orst.edu/info/extoxnet/ (pesticide information)

Environmental Protection Agency (EPA): http://www.epa.gov/

Radcliffe's IPM World Textbook: http://ipmworld.umn.edu/

University of California Statewide Integrated Pest Management Project, Pest Management and Identification: http://www.ipm.ucdavis.edu/PMG/crops-agriculture.html

USDA Office of Pest Management Policy & Pesticide Impact Assessment Program: http://ipmwww.ncsu.edu/opmppiap/proindex.htm (crop profiles)

VegEdge (University of Minnesota): http://www.vegedge.umn.edu

Vegetable Grower News Online: http://www.vegetable growers news.com/

Notes

PESTICIDE EMERGENCY INFORMATION

For any type of an emergency involving a pesticide, immediately contact the following emergency information centers for assistance.

Current as of February 2002

Human Pesticide Poisoning

POISON CONTROL

From anywhere in the United States, call

1-800-222-1222

Special Pesticide Emergencies

Animal Poisoning

Your veterinarian:

____
Phone No.

or

Animal Health Diagnostic Laboratory (Toxicology) Michigan State University:

(517) 355-0281

Pesticide Fire

Local fire department:

____
Phone No.

and

Fire Marshal Division, Michigan State Police:
M – F: 8 – 12, 1 – 5

(517) 322-1924

Traffic Accident

Local police department or sheriff's department:

____
Phone No.

and

Operations Division, Michigan State Police:

****(517) 336-6605***

Environmental Pollution

District Michigan Department of Environmental Quality (MDEQ) Office Phone No.

____
Phone No.

and

MDEQ Pollution Emergency Alerting System (PEAS):

****1-800-292-4706***

also

****1-800-405-0101***

Michigan Department of Agriculture Spill Response

Pesticide Disposal Information

Michigan Clean Sweep, Michigan Department of Agriculture Environmental Stewardship Division.

Monday – Friday: 8 a.m.–5 p.m.

(517) 335-6529

**** Telephone Number Operated 24 Hours***

National Pesticide Information Center

Provides advice on recognizing and managing pesticide poisoning, toxicology, general pesticide information and emergency response assistance. Funded by EPA, based at Oregon State University

7 days a week; excluding holidays

6:30 a.m. – 4:30 p.m. **Pacific Time Zone**

1-800-858-7378

FAX: 1-541-737-0761

Revised by Carolyn J. Randall, *Pesticide Education Program, Michigan State University Extension*

Produced by Pesticide Education Program and printed using vegetable-based inks.

Major revision (destroy old) 3:02-1.5M-KMF-BRD, Price $16.00, for sale only. (Pesticide Applicator Certification)