Chapter 1
Integrated Pest Management

Integrated Pest Management (IPM) has been developed as a way to control pests without relying solely on pesticides. IPM is a systematic plan which brings together different pest control tactics into one program. This Chapter defines IPM, the various pest control methods used in IPM, and how to set up an IPM program, and provides information to help pesticide applicators manage insects, plant diseases, weeds, and vertebrate pests.



Integrated Pest Management provides farmers with choices about how to manage pests safely and effectively. Photo: NRCS

Notes Page

Section 1: What Is Integrated Pest Management?

With IPM, a farmer uses pesticides as one tool in an overall pest-control program. Let's look at what each of the words in the term Integrated Pest Management means:

- **Integrated:** a focus on interactions of pests, crops, the environment, and various control methods. This approach considers all available tactics and how these tactics fit with other agricultural practices used.
- **Pest:** an organism that conflicts with our profit, health, or convenience. If a species does not exist in numbers that seriously affect these factors, it is not considered a pest.
- **Management:** a way to keep pests below the levels where they can cause economic damage. Management does not mean eradicating pests. It means finding tactics that are effective and economical, and that keep environmental damage to a minimum.

Integrated Pest Management, or IPM, is managing crops using many tactics to keep pest levels below an economic threshold.

This Section describes the development of IPM and the cultural, biological, mechanical, physical, chemical, and legal control methods used in IPM.

Learning Objectives:

1. Describe the difference among the Economic Damage, Economic Injury Level, and Economic Threshold.
2. Identify the three elements of a successful IPM program.
3. Provide two reasons why pest management has shifted from routine pesticide application to IPM.

Terms to Know:

- Economic damage (ED)
- Economic injury level (EIL)
- Economic threshold (ET)
- Host
- Integrated pest management (IPM)
- Pest
- Pest signs
- Pest symptoms

Integrated Pest Management (IPM)

Almost all farmers do at least some IPM through normal crop production practices. Integrated pest management is a balanced, tactical approach to pest control. It involves taking action to anticipate pest outbreaks and to prevent potential damage. IPM utilizes a wide range of pest control strategies or tactics. The goal of this strategy is to prevent pests from reaching economically or aesthetically damaging levels with the least risk to the environment.

IPM programs are very site-specific. IPM is based on the identification of pests, accurate measurement of pest populations, assessment of damage levels, and knowledge of available pest management strategies or tactics that enable the specialist to make intelligent decisions about control. IPM offers the possibility of improving the effectiveness of pest control programs while reducing some of the negative effects. Many successful IPM programs have reduced pesticide use and increased protection of the environment.

Pesticide use is and will continue to be significant in food and fiber production, forestry, turf and landscape maintenance, and public health. Pest management has shifted from relying heavily on pesticides to using an integrated approach based on pest assessment, decision making, and evaluation.

Why Practice IPM?

Why have pest managers shifted to IPM when chemical pesticides so often succeed at controlling pests? There are many reasons to broaden pest management beyond the use of chemicals.

- **IPM helps to keep a balanced ecosystem.** Every ecosystem, made up of living things and their non-living environment, has a balance; the actions of one kind of organism in the ecosystem usually affect other species. Introducing chemicals into the ecosystem can change this balance, destroying certain species and allowing other species (sometimes pests themselves) to dominate. Pesticides can kill beneficial insects that consume pests, leaving few natural mechanisms of pest control.
- **Pesticides can be ineffective.** Chemical pesticides are not always effective. Pests can become resistant to pesticides. In fact, some 600 cases of pests developing pesticide resistance have been documented to date, including many common weeds, insects, and disease-causing fungi. Furthermore, pests may survive in situations where the chemical does not reach pests, is washed off, is applied at an improper rate, or is applied at an improper life stage of the pest.

- **IPM can save money.** IPM can avoid crop loss caused by pests and prevent unnecessary pesticide expense. Applicators can save on pesticide costs because the need for control, rather than routine application triggered by the calendar, is the basis for applying pesticides.

- **IPM promotes a healthy environment.** We have much to learn about the persistence of chemicals in the environment and their effect on living creatures. Cases of contaminated groundwater appear each year, and disposal of containers and unused pesticides still pose challenges for applicators. Make sure that environmental impacts are considered in any pest management decisions. Using IPM strategies helps keep adverse effects to a minimum.

- **IPM maintains a good public image.** IPM is now demanded by many sectors of our society. IPM has been implemented to grow our food, to manage turf and ornamentals, to protect home and business structures, to manage school grounds, and to protect humans, pets, and livestock health.

Components of an Integrated Pest Management Program

Scouting is the Key Feature of IPM

Planning is at the heart of an IPM program. Every crop has pests that need to be considered. If you wait until problems arise during a growing season, you'll end up relying on pesticides more and more.

A good Integrated Pest Management program has three components:

1) identifying and monitoring pest problems;

2) selecting the best pest management tactics;

3) recordkeeping and evaluating the program.

By considering each of these components, applicators can set up an IPM program for insects, plant diseases, weeds, and vertebrate pests.

Pest monitoring by using a sweep net.
Photo: ***National Pesticide Applicator Certification Core Manual*****, NASDARF**



Identify and Monitor Pests

You have to know what's happening in your fields before you can make good management decisions. Never classify an organism as a pest or treat it as a pest until it is clearly determined to be one. You should scout your crops often and on a regular basis to identify and monitor pest populations and/or the resulting damage or losses, track crop growth and field conditions, and find other problems. Scouting is, in fact, the key feature of any IPM program.

By scouting, you will be able to detect potential problems early. The earlier you discover a problem, the better your chances are of avoiding economic losses. The procedures for monitoring vary with the pest and the situation. Weather and temperature data are particularly helpful in following a pest's life cycle or in predicting how long it takes a certain pest to develop. Models have been developed for a number of insects and plant diseases to predict the need for and timing of pesticide applications.

To scout effectively, you have to:

- **Know** the crop's growth characteristics to recognize abnormal or damaged plants.
- **Identify** the cause of the problem to know what kind of pest you are dealing with. If you encounter something you cannot identify, contact your county Extension educator.
- **Determine** the stage of growth of the pest and the crop. This is essential for proper timing of control methods.
- **Decide** whether the infestation is increasing or decreasing.
- **Assess** the condition of the crop.
- **Map** problem areas. It may be possible to limit the area that needs treatment.
- **Use** the right scouting method for the specific pest.

Identification is important whether you are dealing with an insect, weed, plant disease, or vertebrate. Be certain any injury or observed damage is actually due to the identified pest and not some other cause. Misidentification and lack of information about a pest could cause you to choose the wrong control method or apply the control at the wrong time—these are the most frequent causes of pest-control failure. Keep in mind that plants may be damaged by non-living agents, such as weather extremes, air pollutants, road salt, and inadequate or excessive fertilization. Sometimes this damage is mistaken for that caused by living pests.

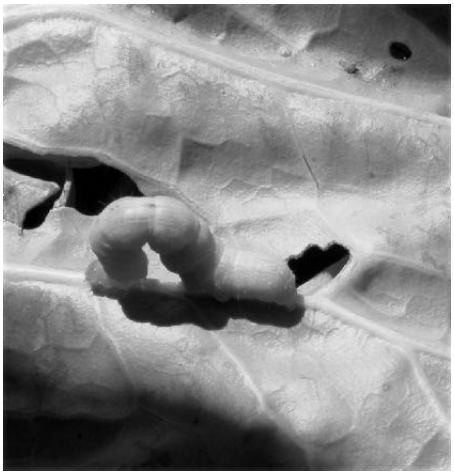
The Four Main Groups of Pests

- **Weeds –** undesirable plants.
- **Invertebrates –** insects, mites, ticks, spiders, snails, and slugs.
- **Disease agents or pathogens –** bacteria, viruses, fungi, nematodes mycoplasmas, and other microorganisms.
- **Vertebrates –** birds, reptiles, amphibians, fish, and rodents and other mammals.



Photo: ***National Pesticide Applicator Certification Core Manual*****, NASDARF**

Once you have identified the pest and confirmed that it is causing damage, become familiar with its life cycle, growth, and reproductive habits. Because IPM focuses not just on the pest, but also on underlying causes that increase pest numbers, look at such factors temperature, cultural practices, and soil moisture that may affect a pest's life cycle, behavior, or ability to reproduce. The more you know about a pest, the easier and more successful pest management becomes.



The cabbage looper looks much different here, in its mature larval stage, than in its immature or pupal stages.
Photo: Iowa State Extension

Pests may leave signs of their presence or symptoms of characteristic damage on hosts and can help you in pest identification. **Pest symptoms** include such things as insect feeding indicators, discoloration from diseases, or reduced plant growth due to competition with weeds for nutrients. **Pest signs** are parts of the pest itself or other evidence of their presence.

Rodents and some other mammals dig distinctive burrows in the ground and often leave identifying gnaw marks on tree trunks or other objects. Insect and rodent droppings also are distinctive and important identification aids. Fruiting bodies of some fungi are easily seen. Weeds may have unique flowers, seeds, fruits, or growth habits. Fungi and other pathogens often cause specific types of damage, deformation, or color changes in host tissues.

Identification books, Extension bulletins, field guides, and reference materials are available that contain pictures and biological information on pests and pest identification. Another option is to have pests examined and identified by pest-management consultants or specialists.

When having pests identified, always collect several specimens. Have plastic bags, vials, or other suitable containers available when collecting samples in the field. Be sure to include the location and date of the collection. Often the pest's host (the animal or plant on which an organism lives) and location are important to making a positive identification. Information on the environmental conditions at the collection site and the season of collection provides additional clues to the pest's identity.

Kill insects first and send them to the specialist in a manner that will not damage body parts that aid in identification. The small size of certain insects and most mites, nematodes, and plant pathogens poses a difficulty in identifying them in the field. Accurate identification often requires use of a hand lens or microscope, special tests, or careful analysis of damage.

Note:
For plant diseases, submit undamaged specimens, such as healthy foliage, along with the damaged foliage. For more information about submitting plant disease samples, contact the University of Minnesota Plant Disease Clinic: http://pdc.umn.edu/

Pest species may have different physical forms depending on their life cycles or the time of year. Weed seedlings, for example, often do not resemble the mature plant. Many insect species undergo changes in appearance as they develop from eggs through immature stages (nymph, larva, and pupa) to the adult form.

Select the Best Management Tactics

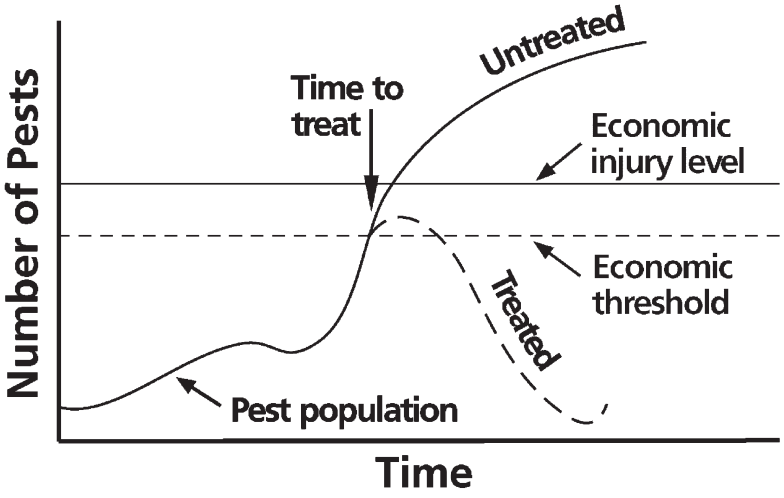
Your goal in selecting pest management tactics is to use methods that are effective, practical, economical, and environmentally sound. To select the best control tactics, you have to:

- **Understand** the life cycle and habits of the pest. Some control methods will work only if they are used at the right time.
- **Decide** whether the infestation is serious in terms of economic loss.
- **Compare** the costs and benefits of various control methods.
- **Make** plans for the future. Not every part of an IPM program can be put into effect immediately. Some tactics, such as planting resistant varieties or rotating crops, require long-range planning.

The presence of a pest does not always cause a loss in quality or quantity of an agricultural product. To justify the cost of control, pest populations must be large enough to cause significant damage. Using IPM can help agricultural producers to determine if the benefits of pesticides and other pest-management tactics exceed the costs of control. If benefits don't exceed costs, time and money are wasted. A number of economic concepts are helpful in determining the point at which it pays to use pesticides or other treatment:

- **Economic damage (ED)** occurs when the cost of preventable crop damage exceeds the cost of control. For example, if corn is worth $2.00 a bushel and an insecticide costs $14.00 an acre, then economic damage occurs when insect damage causes a yield loss of seven or more bushels an acre (ED = cost of treatment/crop value = $14/A/$2/bushel = 7 bushel).
- **Economic injury level (EIL)** is the lowest pest population that will cause economic damage. For many pests it is important to use control measures before this level is reached.
- **Economic threshold (ET)** is the pest population level at which a control tactic should be started to keep the pest population from reaching the EIL. (The ET is also called the action threshold.) Economic thresholds have been established for a number of crop/pest systems, in particular those involving insects. This information is available from the University of Minnesota Extension. Research is being done to develop ETs for weeds and diseases.

Economic thresholds are available for many pests and crops. Several factors can influence an economic threshold. These factors include the current value of the agricultural or ornamental product, its stage of development, the degree of damage caused under various environmental conditions, the cost and effectiveness of control measures, and the anticipated yield. For example, even slight damage may reduce the value of certain fruits and vegetables, so the economic threshold must be set low.



To make a control practice profitable, or at least break even, it is necessary to set the economic threshold (ET) below the economic injury level (EIL). Graphic: *National Pesticide Applicator Certification Core Manual*, NASDARF

Record and Evaluate Results

It is very important to record and evaluate the results of your control efforts. Keeping crop and pest records is easier than ever with the many factsheets, booklets, and software programs now available. Some control methods, especially non-chemical procedures, are slow to yield measurable results. Other methods may be ineffective or even damaging to the target crop, animal, treated surface, or natural predators and parasites. Consider how well your IPM strategies work and their impact on the environment before implementing them again.

Evaluation means deciding how effective a program is and whether any changes are needed. To evaluate an IPM program, you should:

- **Monitor** your fields and keep records. Each time you visit your fields, make a note of crop and pest conditions—record crop yields and quality, and record any counts on pest populations.
- **Record** control measures. Records should include dates, weather conditions, pest levels, application rates and timing, and costs. Good records are a guide if the same problem occurs. They are also a good legal safeguard.
- **Compare** effectiveness. Whatever control tactics are chosen, use a different method on some strips. That way you can compare methods: which worked better, taking into account costs and environmental impacts?



At the end of each growing season, evaluate how well your IPM program worked. Photo: NRCS

Section 2: Pest Management Methods

The goal of most IPM programs is to maintain pest damage at economically acceptable levels while protecting the environment and human health. Prevention and suppression techniques are often combined in an effective IPM program. In rare instances, pest eradication may be needed. The strategy for a sound IPM program is to coordinate the use of multiple tactics into a single integrated system. Pesticides are just one method for controlling pests, and this Section describes the various options. Non-chemical methods may provide longer and more permanent control of a pest and should always be considered when developing a pest management strategy. Evaluate the costs, benefits, and liabilities of each control tactic.

Learning Objectives:

1. Describe the differences between natural and applied controls.
2. Give an example of each method of pest control: biological, mechanical, cultural, genetic, chemical, and regulatory.
3. Explain how government may stop the spread of pests.
4. Identify the stage in the life cycle of an annual, biennial, and perennial plant when it is most susceptible to pesticide use.

Terms to Know:

- Contact pesticide
- Mode of action
- Pesticide
- Pesticide resistance
- Residual pesticide
- Selective pesticide
- Systemic pesticide

Pest Control Goals

There are many tactics that are effective in controlling pests, and each one (or combinations) will give pesticide applicators the best strategy for a specific goal.

Prevention

Prevention, suppression, and eradication are three approaches to maintain pest damage below economic levels. Prevention includes such things as planting weed- and disease-free seed and growing varieties of plants resistant to diseases or insects, sanitation, using cultural controls to prevent weedy plants from seeding, and choosing planting or harvesting times that minimize pest problems. Pesticides are sometimes used for pest prevention as well.

Suppression

Suppressive pest-control methods are used to reduce pest population levels. The methods chosen usually do not eliminate all pests, but reduce their populations to a tolerable level or to a point below an economic injury level; additional suppressive measures may be required if the first attempt does not achieve the management goal.

Eradication

Eradication is the total elimination of a pest from a designated area. Over larger areas eradication may be very expensive and often has limited success. Large eradication programs are usually directed at exotic or introduced pests posing an immediate area-wide public health or economic threat.

Pest Management Methods

The pest control strategy or tactics you choose depends on the nature of the pest, the environment of the pest, and economic or tolerance considerations. The combination of prevention and suppression techniques usually enhances a pest-management program. When implementing the IPM program, try to select the methods that are the most effective and the least harmful to people and the environment. Use several methods whenever possible, and be sure to use them correctly. It is also important to observe all state and federal regulations regarding the methods chosen or combined in an IPM program.

Natural controls are the measures that check or destroy pests without depending on humans for their continuance or success. Natural controls include climatic factors such as wind, temperature, sunshine, and rain. Topographic features such as rivers, lakes, and mountains can influence pest movement. Naturally occurring predators, parasites, and pathogens can regulate pest populations.

When natural controls have not held pests in check, humans must intervene and apply pest-management controls. Maintaining populations of natural enemies by avoiding damaging cultural practices or the indiscriminate use of pesticides can be one of the most economical means of control. If pesticides are part of your control program, select types that are known to be less toxic to natural enemies or, if recommended, apply pesticides at lower-than-label rates to avoid harming natural enemies. Sometimes it is possible to modify certain parts of the environment, such as by planting crops or ground covers, to maintain or enhance natural enemies.

Biological Control

Most pests have natural enemies that control or suppress them effectively in some situations. Natural enemies, including pathogens and insects, are being used successfully as biological control agents to manage certain

insect, mite, fungus, animal, and weed pests. Biological control is often directed against pests that are not native to a geographical area. Introduced pests often cause problems in their new locations because they lack natural enemies to help control them. Laws have been enacted that strictly control the importation of all organisms, including biological control agents, into the United States, to prevent these organisms from also becoming pests.

Biological control also involves the mass release of large numbers of natural enemies into fields, orchards, greenhouses, or other locations to control specific pests. This method usually does not have long-term results, so these natural enemies must be released periodically. Several natural enemies are reared or cultured commercially. Predatory mites are used to control plant-feeding spider mites. Parasitic wasps and lacewings are used to control various insect pests. Nematodes and fungi are being studied as biological control agents for certain weeds and some insects. General predators, such as praying mantids and lady beetles, are sold with claims made for biological control. In many cases, however, their effectiveness has not been established.

Mechanical Control

Mechanical control involves the use of devices, machines, and other physical methods to control pests or alter their environment. Traps, screens, barriers, fences, and nets are examples of devices used to prevent pest activity or remove pests from an area.

Cultivation

Cultivation is one of the most important methods of controlling weeds. It is also used for some insects and other soil-inhabiting pests. Devices such as plows, disks, mowers, cultivators, and bed conditioners physically destroy weeds or control their growth and disrupt soil conditions suitable for the survival of some microorganisms and insects.

Exclusion



Bird netting is used to protect fruits and other crops from bird damage. Photo: U.S. Fish and Wildlife Service

Exclusion is a mechanical control technique that consists of using barriers to prevent pests from getting into an area. Window screens, for example, exclude flies, mosquitoes, and other flying insects. Patching or sealing cracks, crevices, and other small openings in buildings can exclude insects, rodents, bats, birds, or other pests. Fences and ditches make effective barriers against many vertebrate pests. Wire or cloth mesh excludes birds from fruit trees. Sticky material painted onto tree trunks, posts, wires, and other objects prevents crawling insects from crossing.

Trapping

Traps physically catch pests within an area or building. Several types of traps are commonly used. Some kill animals that come in contact with the trap; others snare animals so they can then be relocated or destroyed. Traps are either mechanical devices or sticky surfaces.

Cultural Control

The goal of cultural control is to alter the environment, the condition of the host, or the behavior of the pest to prevent or suppress an infestation. It disrupts the normal relationship between the pest and the host and makes the pest less likely to survive, grow, or reproduce. Cultural practices and sanitation are two examples of cultural control.

Cultural Practices

Many cultural practices influence the survival of pests. In agricultural crops, selection of crop plant varieties, timing of planting and harvesting, irrigation management, crop rotation, and use of trap crops help reduce populations of weeds, microorganisms, insects, mites, and other pests. Weeds also can be managed by mulching (with plastic, straw, shredded bark, or wood chips) and by using cover crops.

Sanitation

Sanitation, or source reduction, involves eliminating food, water, shelter, or other necessities important to the pest's survival. In crop production, sanitation includes such practices as removing weeds that harbor pest insects or rodents, eliminating weed plants before they produce seed, destroying diseased plant material or crop residues, and keeping field borders or surrounding areas free of pests and pest breeding sites. Animal manure management is an effective sanitation practice used for preventing or reducing fly problems in poultry and livestock operations.

Host Resistance or Genetic Control

Sometimes plants and animals can be bred or selected to resist specific pest problems. For example, particular livestock breeds are selected for physical characteristics that prevent attack by some pests or provide physiological resistance to disease or parasitic organisms. Resistance also is enhanced by maintaining the host's health and providing for its nutritional needs. Certain plant varieties are naturally resistant to insects, pathogens, or nematodes. Many plants actually repel various types of pests, and some contain toxic substances. Plant resistance to insect pests can sometimes be achieved by transferring genetic material from certain insect-destroying microorganisms to hybrid seed. Genetic control has been widely used in the past and offers great promise for the future, especially when combined with new gene-manipulation techniques.

Chemical Controls

Chemical controls are pesticides that are either naturally derived or synthesized. Pesticides often play a key role in pest management programs

and frequently may be the only control method available. Major benefits associated with the use of pesticides are their effectiveness, the speed and ease of controlling pests, and, in many instances, their reasonable cost compared with other control options. Usually pest damage stops or pests are destroyed within a few hours (for insects) to a few days (for weeds) after application of a pesticide. Using a fungicide may provide immediate, short-term protection against microorganisms.

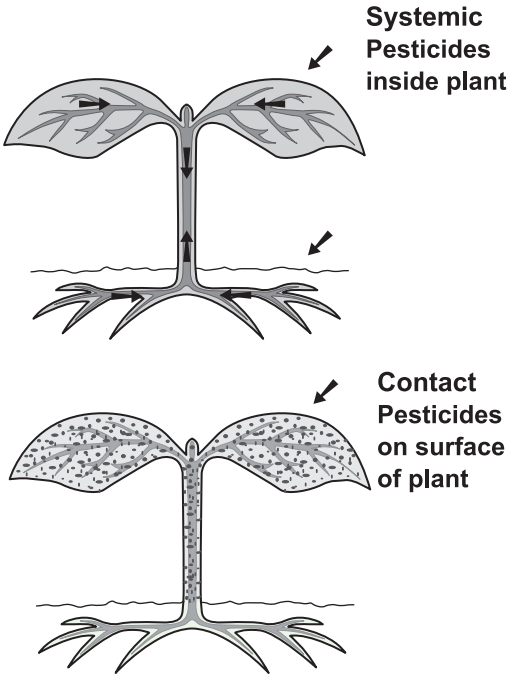
A **pesticide** is defined as any material that is applied to plants, the soil, water, harvested crops, structures, clothing and furnishings, or animals to kill, attract, repel, regulate or interrupt the growth and mating of pests, or to regulate plant growth. Pesticides include a wide assortment of chemicals with specialized names and functions. They are commonly grouped according to the type of pest they control.

- **Avicides** control pest birds.
- **Bactericides** control bacteria.
- **Disinfectants (antimicrobials)** control microorganisms.
- **Fungicides** control fungi.
- **Herbicides** control weeds and other undesirable plants.
- **Insecticides** control insects and related arthropods.
- **Miticides (acaricides)** control mites.
- **Molluscicides** control snails and slugs.
- **Nematicides** control nematodes (roundworms).
- **Predacides** control predatory vertebrates.
- **Piscicides** control pest fish.
- **Repellents** repel insects, related invertebrates, birds, and mammals.
- **Rodenticides** control rodents.
- **Defoliants** cause leaves or foliage to drop from plants.
- **Desiccants** promote drying or loss of moisture from plant tissues.
- **Growth regulators** are substances (other than fertilizers or food) that alter the growth or development of a plant or animal.

Each group of pesticide includes several classes or families. For example, the classes of insecticides include, among others, the organophosphates, organochlorines, carbamates, pyrethroids, botanicals, insecticidal soaps, and microbials. The pesticides within a particular class have similar chemical structures or properties or share a common **mode of action.** The mode of action of a pesticide is how the pesticide works. In other words, it is what specific system(s) in the pest are affected by the pesticide. The various classes of chemicals work in different ways and present different risks and problems.

Pesticides also vary in their selectivity. Fumigants, for example, are non-selective, controlling a wide variety of pests—fungi, insects, weeds, nematodes, etc. Some non-selective herbicides control any plant given a sufficient dose. In contrast, **selective pesticides** control only certain species of pests or affect only a certain stage of pest development. For example, certain herbicides control broadleaf weeds while not harming grasses, and ovicides kill only the eggs of certain insects, mites, and related pests.

Pesticides may move in various ways after they come in contact with a host. **Systemic pesticides** are absorbed through leaves or roots and then transported within the treated plant. Similarly, systemic insecticides can be eaten by or injected into livestock to control certain pests. By contrast, **contact pesticides** are not absorbed by treated plants or animals. These pesticides must directly touch the pest or a site the pest frequents to be effective.



Systemic and contact pesticides on treated plants. Adapted from Penn. State *Pesticide Education Manual.*

Pesticides also vary in their persistence, or how long they remain active to control pests. Some **residual pesticides** control pests for weeks, months, or even years. Others provide only short-term control, sometimes lasting only a few hours.

The production, sale, use, storage, and disposal of all pesticides are regulated at both the federal and state levels. The federal laws and regulations governing all aspects of pesticide use and handling are covered in Chapter 2.

Regulatory Pest Control

Some pest problems cannot be controlled successfully at a local level. These problems involve pests that seriously endanger public health or are likely to cause widespread damage to agricultural crops, animals, forests, or ornamental plants. Government agencies are authorized to destroy weeds and plants that cause fire hazards, harbor harmful pathogens or animals, or are noxious to people or livestock in and around agricultural areas. Similar authority applies to diseased or infected livestock or poultry and to weeds and nuisance plants in residential, commercial, and industrial areas. Mosquito abatement is an important pest-control function undertaken to protect public health. Under the authority of mosquito abatement laws, state agencies drain or treat standing water that provides breeding sites for mosquitoes.

Quarantine or eradication programs directed by governmental agencies according to federal and state laws are used to prevent the introduction and spread of such pests.

Quarantine

Quarantine is a pest-control process designed to prevent entry of pests into pest-free areas. Some states maintain inspection stations at all major entry points to intercept pests or materials that might harbor pests. Regulatory agencies monitor airports and ocean ports. Quarantine also prevents movement of designated pests within a state. Produce and other identified items being shipped from a quarantine area must be fumigated to destroy pests before shipment. Nursery stock, plant cuttings, and budding and grafting material are also regulated to prevent the spread of pests to non-infested areas.

Eradication

Eradication is the total elimination of a pest from a designated area; often, these pests are under quarantine restrictions. When eradication is required, the geographical extent of pest infestation is determined and control measures are taken to eliminate this pest from the defined area. Procedures may include an area-wide spray program, releasing sterile insects, using mechanical and cultural practices, and intensive monitoring for pests within and around the borders of the infested area.

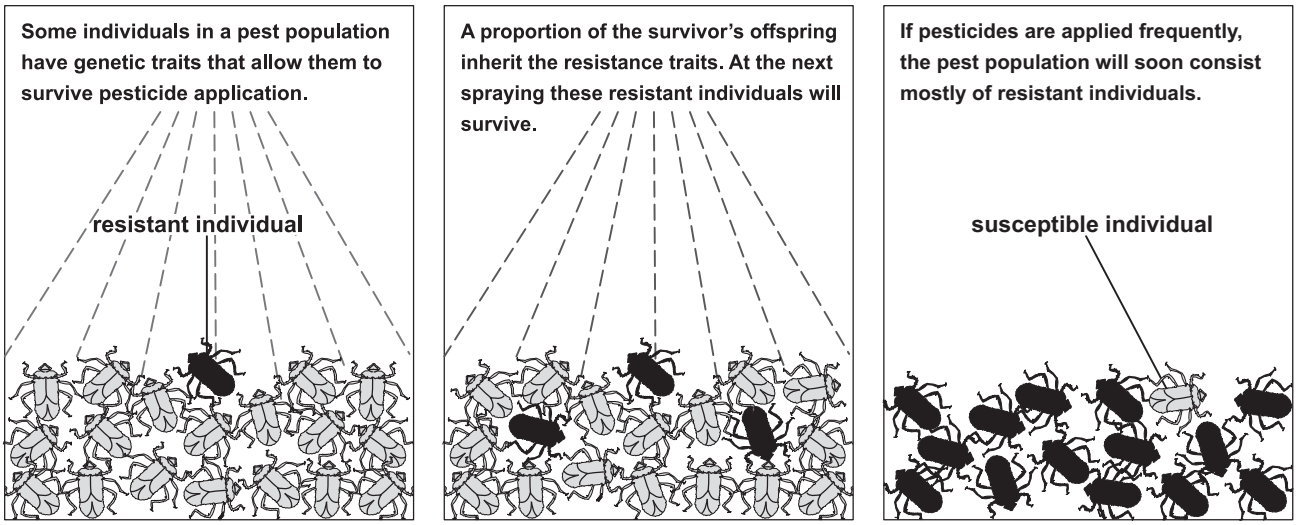
Effective Pest Management Programs

Sometimes a pesticide application fails to control a pest because the pest was not identified correctly and the wrong pesticide was chosen. Other applications fail because the pesticide was not applied at the correct time—the pest may not have been in the area during the application, or it may have been in a life-cycle stage or location where it was not susceptible to the pesticide. Also, remember that the pests that are present may be part of a new infestation that developed long after the chemical was applied.

Even non-chemical pest management tactics become ineffective if the pest and the susceptible stage(s) of its life-cycle are not identified correctly. Successful pest-management programs do not happen by accident—they depend on careful observation, a thorough knowledge of the pest and the damage it causes, an understanding of all available pest control options, and a caring, professional attitude.

Pesticide Resistance

Pesticide resistance can be defined as the ability of an insect, fungus, weed, rodent, or other pest to tolerate a pesticide that once controlled it. Resistance develops because intensive pesticide use kills the susceptible individuals in a population, leaving only the resistant ones to reproduce. Initially, higher labeled rates and more frequent applications are needed to control resistant pests. Eventually, however, the pesticide will have little or no effect on the pest population.



Pesticide resistance develops over time as resistant individuals survive to reproduce. Adapted from the University of California, *The Safe and Effective Use of Pesticides*

Resistance may develop to only a single insecticide, fungicide, herbicide, or rodenticide. More often, however, pest populations become resistant to all chemically related pesticides in a class of compounds. It is also possible for a pest to develop resistance to pesticides in two or more classes of compounds with unlike modes of action.

Continual use of pesticides from the same chemical class, such as all organophosphate or all pyrethroid insecticides, increases the likelihood that resistance will develop in pest populations. Frequent applications and persistence of the chemical further increase the chances of resistance occurring. Finally, the spread of resistance through a pest population can occur much more rapidly in pests that have many generations per year and many offspring per generation, such as insects, fungi, and rodents.

Several pest-management tactics help prevent or delay the occurrence of pesticide resistance. One approach involves the use of new or reformulated pesticides. Using new compounds with different modes of action will lessen the likelihood of resistance developing in a population. Unfortunately, new replacement products are often quite complex, difficult to synthesize, and very costly to develop. They have very specific modes of action, which can rapidly lead to the development of resistant pest populations even after very limited use in the field.

Changing pesticide use patterns is an important step in preventing resistance. When dosages are reduced, fewer pests are killed, so the pressure to develop resistant pest populations is decreased. Applying pesticides over limited areas reduces the proportion of the total pest population exposed to the chemical, thereby maintaining a large pool of individuals still susceptible to the pesticide. This tactic has a tendency to delay the development of a resistant population because pesticide-susceptible individuals in the population continue to interbreed with

resistant ones, thus diluting the resistance in the population. Also, treating alternate generations of pests with pesticides that have different modes of action decreases the selection pressure for resistance.

Managing pesticide resistance is a very important aspect of integrated pest management. Pesticide-resistant weeds and insects is a growing concern. Monitor pest populations carefully and treat only when necessary, rather than treating on a calendar basis. Good pesticide application records are an important component of resistance management. Pesticides are more effectively managed when treatment history is known. Resistance must be detected when it is at a very low level and then controlled by using all available pest management techniques to extend the useful life of our current pesticides.

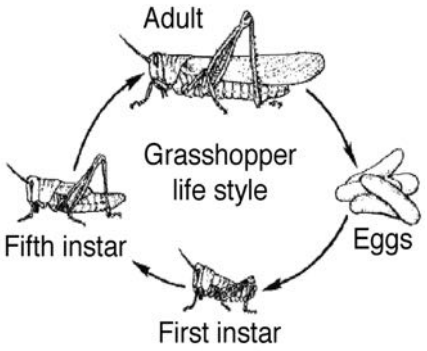
Managing Insects

There are more insects in the world than any other living creature. More than one million species have been identified. Of these, fewer than 1 percent of insect species can be considered pests, and very few of them are serious agricultural pests. Many insects are important as scavengers, predators, parasites, and plant pollinators.

How Insects Grow and Reproduce

Before trying to control insect pests, understand how they grow and reproduce. Knowing pest life cycles and development allows you to plan when to scout fields and when to apply control measures.

Insects grow through a process of change called metamorphosis. Insects have an external skeleton (exoskeleton) and can only grow in steps by shedding the old exoskeleton and forming a new, larger one. This process is called molting. Stages between molts are called instars.



Private Pesticide Applicator Guide, **Iowa State University, University Extension**

Some insects, like grasshoppers and leafhoppers, change gradually. Their eggs hatch into nymphs, which look like the adults except that they are sexually immature and lack wings. Other insects, like beetles, moths, and butterflies, undergo a drastic change in body form—from eggs to larvae to the adult form. In different stages, the insect's habitat and food sources may change completely. For example, corn rootworm larvae feed on corn roots in the soil, but the adults feed on corn silks and the pollen of many plants.

Temperature has a direct effect on the growth and development of insects. Each species has a temperature range in which it develops. Within this range, the higher the temperature, the faster the insect develops and grows. But at very low or very high temperatures, insect development stops. The insect may die, or may resume development when the temperature returns to its normal range. Knowing the temperature ranges of an insect can help you predict pest development, so you will know the best time to scout and to use control measures.

Some insects overwinter in Minnesota by suspending development and entering a resting state called diapause. Insects can **diapause** in any stage, but it is most common in egg and larval stages. Some insects cannot overwinter in Minnesota. They migrate to the south and return to Minnesota each spring and summer.

In the adult stage, insects have three main functions: to reproduce, to spread to new areas, and to search out homes for their offspring.

- **Reproduction.** To find a mate, some insects use chemical cues released from a prospective mate or from a host plant or animal. A chemical released to attract a mate is called a pheromone. Insects have amazing reproductive capacities. One female may lay anywhere from a few to several thousand eggs in her lifetime. For example, the western corn rootworm lays from 500 to 1,500 eggs. In addition, some species produce two or more generations in one season.
- **Spreading to new areas.** Wings enable adult insects to move to new habitats, an important ingredient in the survival of the species. The distance each species can travel ranges from a few feet to thousands of miles. For example, a female gypsy moth cannot fly at all, European corn borer and corn rootworm beetles can fly several miles, and monarch butterflies migrate from Minnesota to Mexico.
- **Selecting a site for laying eggs** is perhaps the most important thing a female insect does. Young nymphs or larvae cannot move very far, so where the female chooses to lay eggs determines whether the offspring will survive. Female insects use all their senses—sight, smell, taste, and touch—to pick the right spot.
- **Limits on reproduction.** Despite their amazing capacity to reproduce, insect populations are usually kept in check by such limiting factors as weather, natural enemies, and relative lack of food. Major pest outbreaks occur when the balance between the limiting factors and the insect's reproductive capacity shifts in favor of the insect. One of the ways this imbalance occurs is when humans create specialized environments, such as farms and lawns. When we confine livestock or plant large acreages of single crops, we create settings favorable to some insects and, at the same time, reduce or eliminate those insects' natural enemies.

When Is an Insect a Pest?

Insects are considered pests when they cause economic or aesthetic losses or when they create inconvenience, annoyance, or health problems. Before using control measures, you need to know whether the insect really is a pest and whether the damage it causes is serious enough to justify control tactics.

Unfortunately, people often try to control insects because the damage is easy to see, not because of the economic impact. For example, insects that feed on leaves, like the Colorado potato beetle, sunflower beetle, and green cloverworm, are often unnecessarily treated with insecticide because the damage is so visible.

Insects can cause injury to plants, animals, and humans in several ways. Insects injure plants by reducing the yield or quality of crops, spread plant diseases or harm the beauty and economic value of horticultural crops. Common symptoms of insects on plants include:

- Chewing on leaves, fruits, seed, and roots.
- Tunneling in stems, leaves, or roots.
- Sucking plant juices from leaves, stems, roots, fruits, and flowers.
- Initiating galls or other plant malformations.

Even after plants are harvested, insects can cause further losses by:

- Feeding on stored products.
- Contaminating raw or processed agricultural commodities.

Important injury to livestock and pets occurs when insects:

- Chew skin, fur, or feathers.
- Suck blood.
- Invade body tissues.
- Annoy or irritate.
- Transmit diseases.

Finally, insects cause injury to humans by transmitting diseases, such as Western equine encephalitis and West Nile disease (from mosquitos) and Lyme disease (from deer ticks).

Identifying Insect Pests

An effective IPM program begins with identifying the problem. This means knowing your crop or livestock pests and scouting fields.

- **Know key pests.** There's no substitute for knowing the enemies that crops and livestock face. Certain insect problems are predictable for each crop and livestock species in your area. These insects are called "key pests." Learning about their life cycles, identifying characteristics, injury symptoms, and management is the foundation of your IPM program. This knowledge will also allow you to recognize unusual situations that require further attention.

- **Scout fields.** Because insects can reproduce so rapidly, it is essential to detect insect infestations promptly. Know which insect problem you're facing and how severe it is or may become. You can only do this by scouting your fields on a regular basis. Some insects can be monitored by using pheromones in traps, for example, black cutworms.

Management of Insect Pests

Most of the tactics for managing insects require planning. The goal is to avoid or minimize insect outbreaks. Unfortunately, even with planning, some insect outbreaks may require short-term rescue tactics, such as early harvest or insecticides. But these short-term tactics also require planning because, with insects, timing is so important.

Cultural Control Methods

- **Sanitation** removes existing infestations or the resources needed for a pest buildup. (Examples: cleaning grain bins and the surrounding area of infested grain and grain debris; removing manure breeding sites for filth flies; controlling weeds to minimize seed production and dispersal).
- **Tillage** directly affects survival of insects that live in soil or crop debris. Indirectly it influences how attractive and suitable the environment is to insects. (Example: reduced tillage systems suffer more frequent and severe damage from black cutworms).
- **Resistant varieties** are a low-cost, highly effective control that has minimal impact on the environment. Some varieties may prevent a pest from becoming established or may kill it (Example: young corn contains a chemical that prohibits the European corn borer from feeding). Some varieties may be less attractive than others to insects (Example: slower-growing varieties suffer less damage from first generation European corn borers if they are near faster-growing varieties). Some varieties may tolerate injury and still yield well (Example: differences among varieties in strength of corn stalks or ear shanks can affect losses from second- and third-generation European corn borers).
- **Crop rotation** makes it harder for a pest to know when or where a crop will appear. This strategy is very effective against pests that overwinter as eggs or larvae and against pests that have limited ability to disperse (Example: crop rotation is extremely effective against corn rootworms that overwinter as eggs). Crop rotation is useless against insects that disperse readily during the growing season, such as potato leafhoppers, armyworms, or European corn borers.

Biological Control Methods

- **Protect natural enemies** of insect pests by avoiding unnecessary insecticide use, targeting insecticides, and using selective insecticides. Example: thiodicarb (Larvin) is effective against various defoliating caterpillars of soybean but does not affect many of the caterpillar's natural enemies.
- **Use natural enemies** or their products the same way you would use an insecticide. Example: the bacteria Bacillus thuringiensis produces a toxin which in one strain is effective only against caterpillars, while another strain is effective only against mosquitoes and black flies.
- **Release natural enemies from other areas.** This is a tactic that is used by entomologists (scientists who study insects). Most of the insect pests in this country were introduced from other areas, but not always with their natural enemies. Entomologists search the areas of origin for natural enemies that can be released successfully in the U.S. and that can be controlled here. Example: natural enemies have been introduced into Minnesota to help control alfalfa weevil and European corn borer.

Mechanical and Physical Control Methods

These methods, which include cold or heat to kill insects or slow down activity, screens to keep insects out, and bug zappers that attract and kill insects, are not effective for crop pests; however they are widely used against insect pests of livestock and stored grain and for nuisance pests around the home.

Chemical Control Methods

Insecticides are the main type of chemical used in insect control. Other chemical control measures include use of pheromones, insect growth regulators, and sterilants. These are sometimes thought of as biological controls, because they are related to the natural biology of the insect.

The advantages and disadvantages of insecticides were discussed in the first part of this section on Integrated Pest Management. Despite their drawbacks, insecticides are often the only option available when insect outbreaks threaten economic losses. Remember, though, that scouting and using economic thresholds will help avoid unnecessary yield loss and unnecessary insecticide use.

Managing Plant Diseases

A plant disease is an abnormal condition that affects the structure or function of a plant. A diseased plant may be shorter or have fewer leaves than normal; it may not produce flowers or fruit; it may wilt and die prematurely. Unlike an injury, which occurs instantly, a disease is progresses over time. It is caused by a disease-producing agent and is

harmful in some way, even though the harm may not always be detected immediately.

The three steps in managing plant diseases are: 1) detecting symptoms of the disease, 2) identifying the cause of the disease, and 3) using appropriate control measures.

Symptoms of Plant Diseases

The first step in controlling plant disease is to examine your crops for symptoms of disease. There are five types of plant disease symptoms:

- **Necrosis** is the death of cells or entire portions of the plant. Necrotic tissue is usually discolored, often appearing brown or black. There may be extensive decay (Examples: dry rots, soft rots, brown rots, and white rots) or only small areas may be affected (Examples: leaf spots, fruit spots, blotches, scabs, stripes, and streaks).
- **Overdeveloped tissue** includes galls, clubroot, leaf curls, and warts.
- **Underdeveloped tissue** includes stunting, dwarfing, and some malformations.
- **Discoloration of tissue** is usually due to a lack of chlorophyll, unless it is the discoloring that results from necrosis. The usual symptom is yellowing (chlorosis) of normally green tissue, but sometimes there may be a red discoloration. Chlorosis is an early symptom of many diseases.
- **Wilt** is the loss of rigidity and drooping of plant parts. Wilt may be due to low soil moisture, necrosis of the roots or stems, or a disease agent plugging the plant's water transport tissue.

Plant diseases are often classified according to the symptoms they produce, for example: blights, mildews, rots, or mosaics.

Identifying Plant Diseases

The symptoms described above can be caused by several different diseases. The next step is to identify the cause of the symptoms. There are two parts to this process: 1) determining if the disease is parasitic or non-parasitic, and 2) identifying the specific cause.

Parasitic and Abiotic Diseases

Generally there are two types of disease: parasitic diseases caused by pathogens (disease-causing agents), such as viruses, and non-parasitic or abiotic diseases caused by something in the environment, such as lack of water. Ask the following questions to help decide whether your crop's disease is parasitic or non-parasitic:

- **How is the disease distributed in your fields?** Is there a pattern? Are all of the plants in the field affected? Are the affected plants distributed in spots or in a particular row or rows? Definite

patterns, such as along the edges of a field, roadway, fence, or in low spots, suggest that climate, soil factors, or toxic chemicals are the cause, but pathogens (disease-causing organisms) should not be ruled out. If most of the plants in a field are affected, consider an environmental problem (for example, an excess or lack of soil nutrients, adverse weather, toxic chemicals, or poor cultural practices). If affected plants are limited to a particular row, this might indicate errors in cultivating, fertilizing, or application of pesticides.

- **How did the disease develop?** Parasitic diseases usually spread slowly, rather than appear all at once. If a condition starts at one point and then spreads slowly, it is probably due to a pathogen. If a disease appears overnight, it is probably due to an environmental factor, for example, hail or lightning.
- **Is there a common disease problem for the crop or area?** It's easier to identify a disease if you are familiar with the kinds of problems that are likely to affect your crops.
- **Have you thoroughly examined all symptoms?** If you diagnose a disease early, you will get the most benefit from a control treatment. Be sure the plant is really diseased. Always compare a plant you think is diseased with a normal one. Sometimes normal structures and characteristics are mistaken for disease symptoms. The symptoms should be well defined—don't rely only on symptoms that appear during the early stage of a disease. On the other hand, don't rely on a plant that has deteriorated so badly that characteristic symptoms cannot be identified. Always examine the entire plant.

  Some aboveground symptoms, especially chlorosis and wilting, are often due to root damage. Always examine the roots of a diseased plant if you are at all unsure of the cause. It can also be helpful to cut into or through portions of diseased plants. For example, vascular wilts may cause a browning inside the stem; you can often see this discoloration if you cut through portions of the stem. A small hand lens, a pocket knife, and a shovel are important tools for plant disease diagnosis.
- **Are there signs that indicate the cause?** Such signs include: fungus spores, nematodes or eggs, and bacterial ooze. Signs are harder to see than symptoms. You may need a microscope or magnifying glass to see them. More training is needed to find and identify signs than to observe symptoms.

The Life Cycle of Parasites

Environmental conditions, especially temperature and moisture, greatly influence the life cycle of parasites. These conditions also affect the plant's ability to fight off a disease.

The first step in a parasitic disease cycle occurs when a fungus spore, nematode egg, bacterial cell, or virus particle (an inoculum) arrives at a part of the plant where infection can occur. This step is called inoculation.

If environmental conditions are favorable, the parasite will begin to develop. This step is called incubation, and at this stage control is most effective. The next stage occurs when the parasite gets into the plant; this step is called infection. When the plant responds to the invasion of the pathogen in some way, it is considered **diseased**.

Control Measures for Plant Diseases

The main goal is to prevent plant diseases from occurring. Once a plant is infected, it is usually too late to prevent its death or to prevent serious reductions in crop yields. When only part of a crop is diseased, eradication may prevent further spread. Eradication can be done with cultural as well as chemical methods. Always weigh the cost carefully before making treatment decisions. Chemical treatment, such as with fungicides, should be regarded as a last resort.

Cultural Control Methods

- Choose planting sites and dates of planting.
- Use resistant varieties.
- Use sanitation, crop rotation, and primordium tip-culture techniques fallowing fields.
- Use proper soil, water, pH, and fertilizer applications to ensure maximum plant vigor.
- Remove infected plants or plant parts.

Biological Control Methods

- Use organisms that are antagonistic to the disease, such as hyperparasites or microorganisms.
- Use cross-protection techniques for viruses.

Mechanical and Physical Control Methods

- Treat soil or plant parts with heat.
- Use proper storage or curing methods for plants and plant products.

Legal Control Methods

- Use certified disease-free seed and nursery stock.
- Obey quarantine regulations with inspections to prevent pathogens from being introduced via plants or equipment into areas where they do not already exist.

Chemical Control Methods

- Use chemicals to protect the host plant before it is infected.
- Use the correct chemical for the pest: fungicides for fungi; antibiotics for bacteria; viricides for viruses; nematicides for nematodes.

The use of a pesticide to eradicate the pathogen after it has infected the host plant is not common.

Managing Weeds

Weeds are plants that reduce crop yields and quality, result in less efficient land use, and diminish enjoyment of turf, ornamental plants, and outdoor recreation areas.

Certain plants have legally been declared noxious weeds. In Minnesota, state regulations list marijuana, poison ivy, bull thistle, perennial sow thistle, musk thistle, plumeless thistle, Canada thistle, field bindweed, leafy spurge, and purple loosestrife as "noxious weeds." Noxious weeds must be cut or controlled so that they do not produce seeds. Some local governments require control of additional weeds.

The weeds that are the most serious problems are those that resemble the crop in physical characteristics, growth habits, and requirements for soil, water, nutrients, and light. Broadleaf weeds are often most difficult to control in broadleaf crops, and grass weeds in grass crops. Another problem with controlling weeds is that some production methods, especially cultivation, favor some weeds.

Most weeds have common names like cocklebur or crabgrass. The trouble with common names is that people in different places may use different names for the same plant. Herbicide labels and publications that give weed-control information generally use standardized common names. You need to know the standardized common name of a weed so you can choose the proper control method.

Summer Annuals:
- Crabgrass
- Foxtails
- Cocklebur
- Pig weed
- Lambsquarter
- Kochia
- Black nightshade
- Velvet leaf
- Common ragweed
- Wild oat

Winter Annuals:
- Field pennycress
- Shepherd's purse
- Annual bluegrass
- Peppergrass

Biennials:
- Burdock
- Musk thistle
- Bull thistle

Perennials:
- Quackgrass
- Canada thistle
- Field bindweed
- Yellow nutsedge
- Sowthistle

How Weeds Grow and Reproduce

To control weeds, you need to know something about how they grow and reproduce.

Life Cycles

Weeds can be classified as annuals, biennials, and perennials. **Annuals** are plants with a one-year life cycle. They grow from seed, mature, and produce seed for the next generation in one year or less. **Summer annuals** are plants that result from seeds that germinate in the spring, produce seed, and die before winter each year. **Winter annuals** are plants that grow from seeds that germinate in the fall, overwinter, produce seeds in the spring and die before summer each year.

Biennials require two years to complete their life cycles. They grow from seed that germinates in the spring. They develop heavy roots and compact rosettes or clusters of leaves the first summer. Biennials remain dormant through the winter; in the second summer they mature, produce seed, and die before winter.

Perennials are plants that live more than two years—sometimes indefinitely. They may grow from seed, but many produce tubers, bulbs, rhizomes (belowground stems), and stolons (aboveground stems). The aboveground parts of these plants may die back each winter, but the plants develop new above-ground parts each spring. **Simple perennials** produce seeds each year as their normal means of reproduction; in some instances, following mechanical injury during cultivation, root pieces may produce new plants (Examples: dandelions and plantain). **Creeping perennials** produce seeds, but also produce rhizomes and stolons.

Seeds

One key to weed control is preventing the production of weed seeds. This is true whether you are trying to control annuals, biennials, or perennials. Weed seeds have certain characteristics which make them very difficult to control:

- **Large numbers.** Weed species often produce enormous numbers of seeds. For example, a single pigweed plant may produce 100,000 seeds.
- **Tolerant of extreme conditions.** Weed seeds are notably tolerant of extremes in temperature, precipitation, and variations in oxygen supply.
- **Long-lived.** Weed seeds may remain alive in the soil for a great many years. Only a small percentage germinate in any single year; the remaining seeds stay dormant and germinate in future years, when temperature and oxygen conditions are more favorable.
- **Easily spread.** Weed seeds are effectively spread by wind, water, animals (including humans), or machinery, and in crop seed, feed grain, hay, straw, and manure.

Control Methods for Weeds

The most effective ways to control weeds are through cultural and chemical means. Biological control methods, using natural enemies of weeds such as insects or diseases, have not been highly successful thus far in Minnesota. But this method offers some potential for the future. Researchers continue to search for natural enemies and attempt to introduce them into areas where a particular weed is prevalent.

A weed-control program should be planned well in advance of the growing season. Your plan should be based on a thorough knowledge of weed problems, soil, soil characteristics, future cropping plans, and all available methods of control. As crop production practices change—for example, tillage—so do weed problems; a good weed-control program must be flexible. Control of a particular weed should be just one part of a total weed-control program.

Annuals and biennials depend exclusively on seed for reproduction and survival. Therefore, an effective way to control them is by destroying

the top of the plant—by mowing, tillage, or herbicides. It is important to destroy the growing point to prevent seed production. Perennials are more difficult to control by simply destroying the top growth. It is more effective to destroy the underground parts of the plant, either through tillage or with herbicides. Perennials have specialized underground parts that help the plant to survive and reproduce. Even simple perennials, such as dandelions (which reproduce only by seeding), store energy for re-growth in the roots. Destroying the top growth can only be effective if it is done repeatedly or in conjunction with other control methods.

Cultural Control Methods

Cultural control of weeds—hand weeding, plowing, harrowing, etc.—has been practiced for centuries. Many of the methods of weed control used today have changed very little over the years. They include:

- **Clean seed.** It is often easier to prevent weeds from being introduced than it is to control them. Use only tested and tagged seed; certified seed ensures high-quality seed free of noxious weeds.
- **Clean feed.** Weed seeds in feed grains and forages survive and germinate after passing through farm animals; manure spread on fields may be spreading weed seeds. Screenings containing weed seeds are sometimes used in mixed feeds; they must be finely ground or heated or else the seeds will remain alive.
- **Tillage.** Burial of weeds can be effective for small annuals and biennials, but will not control most perennials if it is done beyond the seedling stage, unless it is done repeatedly. For perennials, it is more effective to destroy underground parts, using sweeps, knives, harrows, rotary hoes, and other shallow cultivation equipment. This type of control is most effective in dry soils where roots have little chance of becoming established.

  One problem with tillage is that it brings weed seeds up near the soil surface, resulting in germination of a new population of weeds. These can be controlled, especially if they are annuals, by cultivating a second time. Plant the crop immediately after the last cultivation to allow sufficient growth before weeds again become a problem.
- **Mowing** is effective only for tall-growing weeds. Certain tall perennials can be mowed to the point where regrowth is no longer possible, but this requires repeated and frequent mowing.
- **Crop competition** means growing your crops so well that they crowd out the weeds. To make sure your crops compete effectively with weeds, always select the best variety and use the best crop-production methods.
- **Rotating crops** with different life histories or growth habits can control weeds associated with a particular crop. For example, many

summer annual weeds associated with corn will not do well under the cultural practices of fall-planted small grains.

- **Fallowing fields**, or allowing intervals for chemical treatment, may partially solve some special weed problems.
- **Companion crops**, usually annuals that germinate quickly and grow rapidly, can be planted with a perennial crop to compete with weeds and allow the major crop to become established. The companion (or nurse) crop is then removed to allow the perennial crop to take over. Example: oats are used as a companion crop in Minnesota to aid in establishing alfalfa.

Chemical Control

Chemical control through the use of herbicides is the most common method of weed control in agriculture. Herbicides work in different ways. Here are the most common types of herbicides:

- **Selective herbicides** are herbicides that are more toxic to some kinds of plants than to others. Selectivity depends on such things as plant age, rate of growth, and plant form.
- **Non-selective herbicides** are toxic to all plants. Some non-selective herbicides can be made selective to certain plants by varying the dosage, directing the spray to a specific site, or choosing spray additives such as wetting agents. Selective herbicides can be made non-selective by manipulating the same factors (for example, by increasing the dosage to kill more types of plants).
- **Translocated herbicides** can be absorbed by leaves, stems, or roots and moved throughout the plant. Root absorption and translocation take place in water-conducting tissues; leaf or stem absorption and translocation take place mainly in food-conducting tissues.
- **Contact herbicides** are toxic to living cells upon contact. They do not translocate in a plant. Contact herbicides destroy only the above-ground parts of plants and are only effective against annual weeds.
- **Soil sterilant herbicides** are non-selective herbicides that kill all plants and prevent weeds from becoming reestablished for a relatively long time.

Herbicides can also be classified according to when they are applied: before planting (pre-plant), before seedlings appear (pre-emergence), and after seedlings appear (post-emergence).

Factors affecting herbicides include:

Soil type

- **Organic matter** in soils limits herbicide activity. Soils with high organic matter content require higher rates of herbicides. Most

herbicide labels have charts showing the rates to be used on soils with varying levels of organic matter.

- **Soil texture** may also affect herbicide activity. Fine soils (silts and clays) have more surface area than coarse soils and thus need higher herbicide rates.
- **Soil acidity** can influence some herbicides. Chemicals such as atrazine and metribuzin (Sencor or Lexone) are more active in soils that have a higher pH.

Environmental conditions

- **Soil moisture** allows herbicides to work most effectively. If the soil is too dry, the herbicide may evaporate. If it is too wet, the herbicide may not make contact with soil particles. Warm, moist soil may increase microbial and chemical activity, causing herbicides to break down more rapidly. But dry soils may prevent chemical and microbial activity, reducing degradation and causing the herbicide to remain in the soil the following year.
- **Rainfall, irrigation and flooding** may cause soluble herbicides to leach downward through the soil. This may be desirable with relatively insoluble herbicides, but with more soluble herbicides, leaching may cause crop injury. Heavy rainfall may result in poor weed control or possible crop injury, depending on the solubility of the herbicide. With pre-emergence herbicides, water is needed to carry the chemical into the soil where the weed seeds are germinating. Rain and irrigation also provides moisture to help the weed seeds germinate so that they can absorb lethal amounts of herbicide. With post-emergence applications, rainfall may wash herbicides from leaf surfaces, resulting in poor weed control.
- **Humidity** affects post-emergence herbicide penetration and absorption. High relative humidity indicates favorable soil moisture conditions for rapid plant growth, a time when plants are very susceptible to herbicides.
- **Dew** on the weeds or crop when post-emergence herbicides are applied may increase or decrease the activity of some herbicides, depending on how quickly the chemical is absorbed by plants and how the chemical kills plants. The presence of dew can also increase crop injury with some post-emergence herbicides.
- **Temperature** affects the rate of plant growth and plant susceptibility to herbicides. Some herbicides evaporate quickly at high temperatures.
- **Sunlight** may destroy some herbicides if they are left on the soil surface for long periods.

Differences among weeds

- **Perennials** are controlled more effectively with translocated herbicides, because these chemicals move into all parts of the plants; contact herbicides kill only the above-ground parts.

- **Type of weed.** Some herbicides are strictly for use with broadleaf (dicotyledon) weeds. Some are strictly for grass (monocotyledon). A few herbicides can be used with both broadleaves and grasses.
- **Plant species** may respond to some herbicides differently. Moreover, within a single species there may be races of the weed that respond differently.
- **Growth rates.** The age of the plant and the rate of growth also affect how weeds respond to herbicides.
- **Plant and leaf structure** – waxy and hairy surfaces are problematic.

Preventing herbicide carryover

Some herbicides remain in the soil a long time, causing injury in the following year's crop. Herbicide carryover is more likely to occur with unusually low rainfall, because dry soils limit the chemical and microbial activity needed to degrade herbicides. To keep herbicide carryover in soil to a minimum, follow these guidelines:

- Apply the lowest rate practical.
- Apply uniformly.
- Avoid double coverage: shut off the applicator when turning.
- Select crop sequences that are tolerant to the herbicide used on the previous crop.
- Rotate herbicides, whether the same crop is grown continuously or different crops are grown in rotation.
- Spot treat when using high rates of herbicide.

More details on herbicides and other weed control methods can be found in the University of Minnesota Extension Service Bulletin AG-BU-3157 *Cultural and Chemical Weed Control in Field Crops.* This bulletin can help you plan an effective and economical weed-control program.

Managing Vertebrate Pests

All vertebrate animals have a jointed spinal column (vertebrae). These "higher" animals include fish, amphibians, reptiles, birds, and mammals.

What may be a pest under some circumstances may be highly desirable under others. Your first job in controlling vertebrate pests is to determine if they are actually causing damage.

- **Fish** of certain species may be considered pests by some because they are not useful for sport or for food or because they are harmful to more desirable species. Some fish may be a human health hazard because they serve as intermediate hosts for parasites of humans.

- **Reptiles and amphibians** include snakes, lizards, turtles, frogs, toads, and salamanders. These animals cause more of a psychological problem than an economic one. But snakes and turtles in fish hatcheries or waterfowl production areas can cause some economic problems. Poisonous snakes may be a problem, too, but there are only two poisonous species in Minnesota, both restricted to the southeast corner of the state.
- **Birds** can cause various kinds of damage: structural damage by woodpeckers; killing of fish, livestock, poultry, or game species; and destruction of fruit, nut, grain, timber, and vegetable crops. Birds can also be a health hazard to animals and humans because they may be hosts for disease organisms.
- **Mammals**, such as pocket gophers, moles, and rats, can also cause a variety of damage. Livestock may be killed by mammals. Mammals also do significant damage to fruit, vegetable, nut, grain, range, and tree crops. They may interfere with water-retaining structures, causing flooding. They damage such things as lawns, clothing, furniture, and buildings by gnawing and burrowing. They transmit many diseases to livestock and humans, including rabies, plague, typhus, food poisoning, leptospirosis, and tularemia.



Pigeon, USFW.
Photo: *National Pesticide Applicator Certification Core Manual*, NASDARF

As with other IPM programs, the first step in control is to detect and identify the problem.

Recognize damage patterns and the species of animal responsible. Look for the following evidence:

- **Birds:** peck marks, tracks, feathers, droppings, location of damage, evidence that items have been carried away.
- **Mammals:** tracks, droppings, tooth marks, diggings, burrows, hair, scent, type of damage.

Know the physical characteristics and life habits of most animal species that may be present in a given situation.

Choose control measures that are effective, selective, humane, and cause the least possible environmental damage, such as traps, sound, or barriers.

Know the local, state, and federal regulations that apply. It is especially important to know which animals are protected by the federal and state government. See Chapter 5: Protecting the Environment for more information on regulations protecting wildlife.

Summary

Integrated Pest Management (IPM) is a systematic plan which brings together different pest-control tactics into one program. It reduces the emphasis on pesticides by including cultural, biological, genetic, physical, regulatory, and mechanical controls. To carry out an IPM program, you need to scout and monitor your fields, recognize abnormal conditions and identify their causes, understand the different control methods available, and determine the economic costs and benefits. A good IPM program requires planning, monitoring and evaluation.

Managing Pocket Gophers



Photo: U.S. Fish and Wildlife Service

Pocket gopher numbers may be reduced by mechanical controls, such as traps, and natural controls, including natural enemies, starvation, and disease. In Minnesota, gophers are also controled by theuse of strychnine baits. Strychnine is toxic to all animals and must be handled and applied according to label instructions. All applications must be below-ground. Clean up all spilled bait.

Pocket gophers can move as much as 2¼ tons of soil to the surface in a year.

Except during breeding season, gophers live alone in a system of burrows. One adult may build as many as 100 mounds a year, moving as much as 2¼ tons of soil to the surface. Feeding burrows may be only six inches below the surface, while food storage and living chambers may be five-to-six feet deep.

On small acreage (10 acres or less), hand application of poison bait during the fall is usually effective. For added control, combine it with a fall trapping program. Trapping in the spring following a fall baiting program can also be effective. Special pocket gopher traps are available at most nurseries, farm supply outlets, and large hardware stores.

On areas larger than 20 acres, the most practical means of control is machine baiting with a burrow builder. Fall and spring applications give the greatest control. The soil must be moist enough to let the torpedo tube pass through easily and to hold a neat burrow shape when compressed. A depth of about 10 inches is desirable, but the burrow depth is less important than forming a neat tunnel. Completely enclose the field to be protected by parallel rows of artificial burrows spaced 25 to 40 feet apart—wider spacing in the spring, narrower in the fall. If bait is applied properly, you should attain 85 to 90 percent control within three weeks. Reapplication may be needed in two to four years. Some counties own burrow building machines which are available to pesticide applicators. Check with your county extension educator, Soil Conservation Service, or Soil and Water Conservation District.