UW | EXTENSION

Wyoming Agricultural Pest Control: All 901 Categories

For commercial applicators

Acknowledgments

Portions of this manual were adapted from Pesticide Applicator Training Manuals or information provided by University of Wyoming, The Wyoming Department of Agriculture, Purdue University, Colorado State University, and University of Nebraska.

The following individuals are gratefully acknowledged for reviewing this publication and for their valuable suggestions: Kent Drake, Chris Hilgert, Karen Panter, Scott Schell, and William Stump.

Wyoming Agricultural Pest Control: All 901 Categories

MP-127.901, August 2018

by Jeff Edwards

Lori Schafer, editor, Tanya Engel, editor and designer

Issued in furtherance of extension work, acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Glen Whipple, director, University of Wyoming Extension, University of Wyoming, Laramie, Wyoming 82071.

Preparation for Your Exam

If you are preparing to take any of the Wyoming Commercial Pesticide Applicator Exam(s) for categories 901 A–F, Agricultural Pest Control, review this manual several times. Please read and respond to the learning objectives that correspond to each of the manual sections for which you plan on taking exams.

Exam questions may come from any section of this manual — this includes the definitions and appendices; however, when focusing on a specific subcategory of 901, the questions in the exam will be weighted to cover mainly this material in the manual.

It is important that you take note of the following:

- You may bring a basic hand-held calculator with you to use during the exam (cell phones and other communication devices are prohibited — **you will be failed** if using your cell phone during the exam).
- Exams are closed book. You will not be allowed to refer to any notes, manuals, or other unauthorized training materials during the exam.
- You must pass each category with a 70% or better to be issued a license.
- Exams can be taken at any University of Wyoming County Extension office — please call your local Extension office to make an appointment.

Section 1: Integrated Pest Management

LEARNING OBJECTIVES

After studying this section, you should be able to:

A. Describe why crop rotation is an important IPM practice.

B. Identify a common tactic used in crop IPM programs.

C. List five observations revealed during a scouting trip.

D. Describe basic principles of crop monitoring.

E. Define economic threshold, damage threshold, and economic injury level.

F. Identify several of the seven strategies used to suppress weeds.

G. Describe three factors of plant disease management.

H. List three factors you should know in order to use a pesticide.

I. Identify growth stages of corn, dry beans, small grains, and sorghum.

INTRODUCTION AND FUNDAMENTAL CONCEPTS

Integrated pest management (IPM) combines appropriate pest control tactics into a single plan to reduce pests and pest damage to an acceptable level. Using many different tactics to control a pest problem tends to be least disruptive to living organisms and nonliving surroundings at the treatment site. Relying only on pesticides can cause pests to develop pesticide resistance, cause outbreaks of other pests, and can harm non-target organisms. Plus, using pesticides alone will not achieve adequate control with some pests.

IPM has been part of field crop production long before its more formal introduction by the Cooperative Extension Service (CES) during the early 1970s. Many producers have practiced sound pest management schemes for hundreds of years on this continent and for much longer in Europe. Strategies such as crop rotations, early harvesting, strip cropping, mechanical cultivation, trap cropping, and manipulating planting dates are not new pest management concepts.

The first organized and sponsored CES IPM efforts started in the 1970s with a pilot scouting program. A major emphasis was placed upon scouting and the use of thresholds for insects in corn. The procedures followed by entomologists involved in this early IPM program were: (1) contacting producers; (2) determining agronomic and cropping history of fields; (3) estimating plant stand; (4) determining the percentage of whorl feeding by European corn borers; (5) estimating corn rootworm and corn leaf aphid densities; and (6) recording the presence of beneficial insects.

During the last few decades, producers and the general public have become much more aware of the important and expanded role IPM programs continue to play in the efficient production of food and fiber, while protecting, and in some cases improving, the environment. Populations of organisms generally exist within a self-regulating system in natural settings such as forests, lakes, or undisturbed fields.

An **ecosystem** is a community of plants and animals that interact with each other and their surroundings. This balance of plant and animal life is more difficult to achieve within a field devoted to crop production. Agricultural ecosystems, popularly known as **agroecosystems**, contain far less diversity of animal and plant species than occurs in natural ecosystems. This lack of organism diversity also is due to frequent human-imposed disturbances placed upon agroecosystems, such as tillage, mowing, or pesticide use. Thus, certain populations of organisms may increase in numbers and threaten the profitability of a given crop. Pests are organisms whose population densities reach levels that compete with the desired production of food and fiber. In this manual, the term "pest" refers to any organism that can harm or is likely to cause damage to cultivated crops. Although the word "pest" is often used interchangeably with insects, field crop pests include insects, weeds, nematodes, plant pathogens, and rodents. Control measures for all pests should be integrated into a crop management system that is economically viable and uses environmental stewardship. IPM has been popularly defined as the intelligent selection and use of pest control practices that ensure favorable economic, ecological, and sociological consequences.

PESTICIDE USE ON FIELD CROPS

Pesticide use patterns are similar throughout midwestern region of the United States. The percentage of crop acres treated with pesticides remains very high. Herbicides and insecticides account for the largest share of pesticide applications made each season.[1]

A newer IPM strategy used in recent years is genetically modified organisms (GMOs). These include glyphosate-tolerant crops and Bt (*Bacillus thuringiensis*) enhanced crops. These crops are modified to resist herbicides, allowing for crop protection when controlling weeds. Such methods have decreased pesticide use in some agricultural crops.

For example, after Bt corn was introduced to the U.S. marketplace, use of the insecticide recommended for European corn borer control decreased from 6 million acre treatments to slightly over 4 million in 1999, a drop of about one-third, according to the Environmental Protection Agency.

Corn hybrids are now available with traits effective against European corn borer and corn rootworm. However, resistance to some Bt traits is appearing in parts of the Midwest. In some years, the market value of corn has discouraged crop rotation, leading to higher rootworm populations in some areas.

Some growers may use soil insecticides, at planting, or foliar insecticides targeting adult rootworms to reduce their populations.

Neonicotinoid seed treatments (such as Poncho or Cruiser) are widely used on corn and soybean to control or suppress early-season insects that may feed in the soil or above ground. Sometimes these

1 National Agricultural Statistics Service - Surveys - 2014 Agricultural Chemical Use Survey - Corn Highlights, USDA, May 2015, www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Chemical_Use/2014_Corn_Highlights/.

products have replaced the need for planting time or early post-emergence insecticide use.

Wyoming producers treat nearly all corn and sugarbeet acreage with herbicides. Although the acreage treated remains very high, total pounds of herbicide active ingredient applied in the state decreased significantly on corn and sugarbeets during the last 20 years. This reduction is largely due to use of newer herbicide products, which provide weed control at lower rates, not because of a fundamental shift in how producers manage weed populations. Genetically modified crops containing herbicide resistant traits have also contributed to the overall reduction of herbicide use.

Using the same pesticide or group of pesticides repeatedly may cause insect, disease, or weed populations to develop resistance. The pesticide selectively kills the most susceptible individuals in the population with each use. Some individuals naturally are able to withstand its effects in any population. These survivors may pass this trait onto their offspring. Continued use of the same pesticide may allow the resistant offspring to multiply, creating a population with pesticide resistance.

Herbicide-resistant weeds currently cause problems for producers throughout the nation and the world, especially in the last decade. Sound management strategies, including crop rotation and integrating nonchemical and chemical weed strategies, can help avoid herbicide resistant weeds. Also, avoid over-reliance and frequent use of a single, highly effective herbicide and overusing tank mixtures of herbicides with similar modes of action. A **mode of action** is the way the pesticide controls the pest. Switching among pesticide classes with different modes of action, or differing pesticide group numbers on the label, can help delay or mitigate pest resistance.

IPM also can help curtail pest resistance by using different methods of control. IPM is a planned strategy using appropriate economically and environmentally sound pest control combinations. It involves identifying pests, determining need or control methods, and choosing the appropriate combination of control methods for the situation.

IPM: MORE THAN JUST SCOUTING

IPM includes more than just scouting fields for pests, knowing the economic thresholds, and judiciously using pesticides. A well-designed IPM program should integrate several management strategies for insects, plant diseases, and weeds while maintaining agricultural profitability and environmental quality.

Effective pest management programs should anticipate potential pest problems and attempt to modify existing crop production practices if they continually lead to pest outbreaks, yield losses, and overuse of pesticides. This objective is most often accomplished by blending together pest control tactics. Pest management tools may include cultural, mechanical, biological, genetic, regulatory, and chemical methods. Using many of these strategies should optimize pest control.

IPM Methods

Cultural

Changing practices such as crop rotation, fertilization, and proper drainage. Using resistant varieties is a key cultural strategy to control certain insects and diseases in crops.

Sanitation

Modifying an environment to discourage pest survival and reproduction in order to help control the pest population.

Biological

Using natural enemies to control a pest. An example is a parasitic wasp that feeds on insect pests for control.

Mechanical

Mowing or tilling to remove weeds, or using physical barriers.

Chemical

Pesticides are part of an IPM program. Pest identification, monitoring, and thresholds are important steps needed to determine if pesticides are necessary to control the pests.

SCOUTING FIELD CROPS FOR PESTS

One key to a successful IPM program is regular monitoring of field crop conditions and pest infestations. **Field scouting** reveals which pests are present, what stage of growth each pest and the crop are in, whether the pests are parasitized or diseased, whether a pest infestation is increasing or decreasing, and the condition of the crop. This information can help determine whether a control measure is needed.

A scouting program requires accurate written records of the field location, current field conditions, a history of previous pest infestations and pesticide use, and a map of present pest infestations. These records allow the grower to keep track of each field and anticipate or diagnose unusual crop conditions.

Insect pests can be monitored in several ways. Methods of insect scouting include collecting insects with a sweep net, shaking the crop foliage and counting dislodged insects, counting insects on plants, and using traps. Usually, the insects are counted or the amount of crop damage is estimated. Counts of insects are commonly expressed as number per plant, number per row foot, number per sweep, or number per unit area (square foot or acre). Estimated crop damage is usually expressed as a percentage.

Also examine plants for symptoms of disease. If you find infected plants, then determine the severity of the disease. For example, note what percent of the leaf area shows signs of disease. Soil samples are required for estimating densities of nematodes; in some instances, plants may have to be analyzed at a diagnostic laboratory.

Conduct early-season weed scouting within two weeks after crop emergence to evaluate the performance of herbicides and determine whether rotary hoeing, cultivation, or post-emergence herbicides are needed. Make a weed map for each field to indicate the location of various weed species. Over time, these maps may reveal a shift in the composition of weed species within specific locations of a field.

Certain basic principles of crop monitoring apply to most scouting programs. Take samples from various areas of the field. The sampling sites should be evenly distributed over the field, with plants randomly sampled unless certain field characteristics suggest an uneven distribution of pests. Avoid border rows and field edges unless there are specific reasons for scouting these areas, such as being the place where a disease or insect pest outbreak is likely to occur. Scout at least once a week; some fields may require monitoring more frequently if insect densities begin to increase rapidly.

ECONOMIC THRESHOLDS AND INJURY LEVELS

The most familiar feature of field crop IPM programs is scouting fields for pests and basing treatment decisions on economic thresholds, often referred to as "action thresholds." The **economic threshold** (ET) is that pest density at which some control should be used to prevent a pest population from increasing further and causing economic loss. Examples of economic thresholds for some insect pests in various crops include:

(1) black cutworms in corn: "Apply a post-emergence rescue treatment when 3% or more of the plants are cut and larvae are still present," or

(2) potato leafhoppers in alfalfa: "Treatments are recommended when a certain number of potato leafhoppers are collected per sweep at a given plant height (e.g., 0.2 leafhoppers per sweep when plants are 0–3 inches tall)."

For plant diseases, damage thresholds help a producer make treatment decisions. Because pathogens are too small to be seen without a microscope, counting is not practical; therefore, an estimate is made of the amount of pathogen damage. The damage threshold is the maximum damage a crop can sustain without yield loss. Damage thresholds have been determined for many plant diseases. Examples for using these thresholds include counting diseased leaf petioles and stem blight; by estimating the percent infection of the flag leaf by rust pustules, or other fungal foliar blights in wheat; determining the density and kinds of nematode populations in a soil sample; and estimating the percentage of whole plant infection caused by fungal leaf blights in corn.

An economic threshold for weeds is the density when control is economically justified because of potential for yield reduction, quality loss, or harvesting difficulties. Densities of weeds that lower yields by more than 10% generally warrant treatment, as they are above the economic threshold.

Another level of pests frequently referred to in pest management programs is the **economic injury level** (EIL), or the lowest pest density at which economic damage occurs. The EIL is where the cost of the control measure equals the loss likely to be caused by the pest.

It is worthwhile to keep in mind that the ET and EIL are mathematically determined densities of pests and based on a detailed knowledge of pest ecology (the potential value of the harvested crop and the cost of pest control practices) as well as economics. Economic thresholds may vary with the field, crop variety, and stage of crop growth; they decrease as the value of the crop increases, but they increase as the cost of control increases.

Long-term population levels of organisms, referred to as the **general equilibrium position** (GEP), are generally unaffected by periodic pest control activities. Population densities of pests fluctuate around the GEP, and what triggers periodic outbreaks of many pests is poorly understood.

Reductions in pesticide use have been achieved because of improved pest-monitoring techniques and growing acceptance of the ET and EIL concepts. However, thresholds that incorporate environmental costs aren't being developed or used. Even though ETs and EILs have helped reduce pesticide overuse, they don't reflect the potential environmental hazards associated with a pesticide treatment. Environmental hazards associated with pesticide use are often referred to as unwanted externalities. These include reduced densities of beneficial insects such as predators and parasitoids; pesticide residues on food products; pesticide detections in surface and groundwater supplies; and wildlife kills. Before environmental thresholds can be used on a large-scale basis, monetary values of potential hazards to natural resources because of pesticide treatments will need to be determined.

For many pest control situations, it is difficult to assess the potential economic benefit and environmental hazards associated with a pesticide application. Treatment decisions aren't always clear for most pest management scenarios. To determine whether a pesticide application is warranted, many individuals, perhaps unknowingly, assess the costs as well as the benefits of treatment. This step is often referred to as determining the cost/benefit ratio. To estimate the cost/benefit ratio, consider a few points. First, pesticides rarely increase yield. Pesticide use may prevent a yield loss due to pest activity.

Second, the benefits of some pest control practices in agricultural situations are unknown. If you find this hard to believe, ask yourself how many producers leave check strips (no pesticide used) in their fields and measure yield from treated and untreated areas?

After determining the potential benefits of a pesticide application, one should also begin to identify some risks that may be linked to product use. An analysis of the benefits and risks of a pesticide treatment leads to the formulation of the benefit/risk ratio. What are the risks to the pesticide applicator's personal health and safety? What are the broader risks to society and the environment? These questions are often difficult, if not impossible, to answer satisfactorily. However, they must be raised continually and answers sought.

Insects

Nonpest insects are those that inhabit cultivated crops and rarely if ever reach densities sufficient to cause economic injury. Common examples of nonpest insects in field crops include pea aphids on alfalfa and yellow woolly bear caterpillars on corn.

Other field crop insects reach damaging densities only as the result of unusual environmental conditions or frequent use of nonselective insecticides. These insects are referred to as **occasional pests**. Most insect pests in field crops are occasional pests. Examples include two-spotted spider mites (not an insect), corn leaf aphids and black cutworms on corn, and grasshoppers and spittlebugs on alfalfa.

Some insects can cause frequent economic losses because their established economic injury level is just above the general equilibrium position for their population. These insects are called **perennial pests**. To limit economic losses, periodic control measures must be used when their density increases. Examples of perennial insect pests in field crops are uncommon; however, some entomologists consider corn rootworms to be a perennial pest in continuous corn.

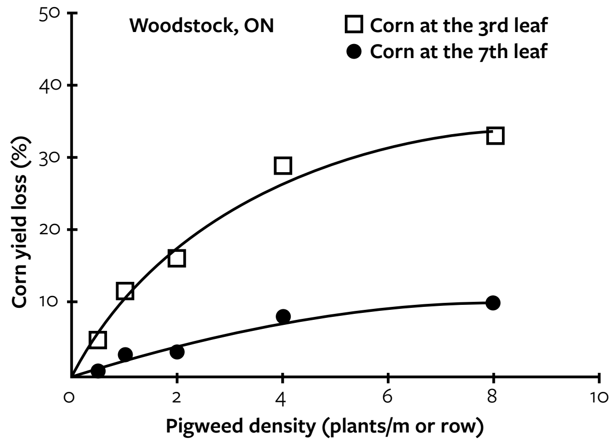
Some insects are referred to as **severe pests** and are characterized by causing economic injury levels below the general equilibrium position. A familiar example of this type of pest that continually plagues sweet corn producers is the corn earworm. To produce a marketable crop, sweet corn producers must monitor the corn earworm moth flight and be prepared to make timely and repeated insecticide applications.

Weeds

Weeds interfere with crop growth by competing for moisture, nutrients, light, and space. They may also affect crop quality, create harvesting difficulties, or serve as an alternate host for certain plant diseases. In most situations, some type of weed management is usually necessary for optimum crop yield.

Tillage, mowing, crop rotation, mulching, cover crops, biological controls, and herbicides have all been used to suppress weeds. A combination of weed management options (an integrated approach) is usually more effective than relying on a single practice.

The **economic threshold for weeds** is often defined as the density of a weed population at which control is economically justified. A certain population of weeds can grow with the crop throughout the season without a corresponding reduction in yield. Weeds vary in the amount of economic damage they may cause. Some weeds are very competitive with a particular crop, whereas others may not cause substantial yield loss. There also may be some variation from site to site and from year to year with differing environmental conditions. For an example of how pigweed density affects yield in corn and soybean crops, see Figure 1.1.



Figures 1.1. Effect of pigweed density on corn yield (Knezevic et al.)

In the past, economic thresholds haven't been widely used in planning a weed control program. Traditional weed control systems use preplant or preemergence herbicides, which are preventive in nature and applied before weeds germinate and emerge. Post-emergence herbicides may allow growers to treat only those areas or fields where weed populations exceed an economically damaging level.

Some limitations exist to the widespread use of economic thresholds for weeds. Landlord perception of the practice is often cited as a major concern. If landowners feel that tenants aren't satisfactorily controlling weeds, they may be unwilling to rent to them.

A second limitation is that most economic threshold programs don't address weed seed production. If a new weed problem is just beginning on a farm, it may be inappropriate to rely solely on economic threshold data. For example, if only a few shattercane plants are found in a field, they might not reach an economic threshold this year. However, it is important to remove these plants before the problem has a chance to spread. As more research is conducted on weed seed production and germination, economic thresholds may be adjusted to allow for seed production and weed seed banks (that is, weed seed and propagative vegetation in the soil from which more weeds will grow). Without some control measures, most fields will likely develop significant weed populations. Economic thresholds for weeds may be most useful after some form of primary weed control has been applied. Growers could then decide if the level of weed control in a given field is acceptable, or if additional weed management practices are economically justified.

The use of economic thresholds will continue to grow as farmers look for ways to improve efficiency and save money. The time spent scouting fields and assessing weed populations will allow for more site-specific weed management. With adoption of conservation tillage, practices of crop scouting and weed identification become more critical for successful weed management. With tillage reduced or eliminated, there has been emphasis on herbicides for weed control. Timely weed scouting becomes essential for making treatment decisions.

Plant Diseases

Managing plant disease problems in field crops relies on several factors. The first is a working knowledge of which diseases are common and which are unusual in a region. Second is properly identifying the disease based on signs, symptoms, and field distribution patterns, and then observing the severity of the disease. Finally, be familiar with the damage threshold for a given disease, to make management decisions before reaching the economic injury level.

Plant disease outbreaks result from three interacting conditions: (1) a susceptible host; (2) an environment favorable for disease development; and (3) a disease-causing agent. If any one of these conditions is not met, economic loss probably will not occur. Some diseases, **endemic diseases**, are present every year and generally don't cause significant damage. If all conditions favor the development of endemic diseases, however, economic losses may occur. A disease that becomes severe is an **epidemic disease** and control measures are usually necessary. Epidemic diseases vary from year to year depending upon the weather, crops grown, and crop varieties or hybrids.

Plant diseases can be divided into two broad categories: infectious and noninfectious.

Infectious

Infectious plant diseases are caused by a wide range of pathogens like fungi, bacteria, nematodes, and viruses, or by parasitic plants such as dodder.

These pathogens multiply within the host plant and can be transmitted from plant to plant. They may invade the entire plant (**systemic infection**) or only affect certain plant parts (**localized infection**).

Noninfectious

Noninfectious diseases are caused by **abiotic** (nonliving) agents. These agents cannot multiply within the host and cannot be transmitted from plant to plant. They generally result from adverse environmental or chemical conditions such as unfavorable temperatures, soil compaction, drought or flooding, nutrient imbalances, air pollution, or chemical excesses and misapplication.

Diagnosing Diseases

Most diseased plants have characteristic symptoms that greatly help diagnose the cause of the disease. Symptoms are the plant's expression of disease. Easily seen symptoms include wilts, lesions, yellowing, abnormal growth, mosaics, and root rots. Other symptoms, such as shriveled seed or reduced seed quality, may not be noticed until the crop is harvested.

Signs of infectious plant diseases are the evidence of the actual pathogen itself. Some signs of a pathogen are visible with an unaided eye; for example for fungi, you might see galls (smut). Others, such as spores, bacterial ooze, or virus particles require a hand lens or a microscope to be seen.

Plants affected by noninfectious diseases also produce characteristic symptoms. For instance, air pollution can cause leaf bronzing or scorching. However, no signs will be present because noninfectious disease isn't caused by plant pathogens. This often makes diagnosis somewhat more difficult.

Observing field distribution is also important to diagnose disease. The most common distribution for field crop disease is a random pattern. A disease distribution moving in from the edges of the field often indicates a disease spread (vectored) by insects. Another common pattern is disease associated with areas of high stress, such as low or compacted areas.

PESTICIDE SELECTION: MAKING CHOICES IF A PESTICIDE IS REQUIRED

The decision to use a pesticide should be based upon three factors: (1) information obtained from scouting; (2) knowledge of economic thresholds; and (3) an awareness of the potential benefits and risks associated with a treatment.

Used improperly, pesticides can harm the applicator, the crop, or the environment. Pesticides can provide effective control, but they should be used judiciously and combined with nonchemical methods that can be incorporated into the cropping system. Upon deciding to use a pesticide, carefully think through several questions.

1. Is the pest you want to control listed on the pesticide label?
2. Does the label state that the pesticide will control the pest, or does the word “suppression” appear on the label?
3. Are you familiar with university research and recommendations related to the pest or pesticide?
4. Is the recommended rate of application economical for your operation?
5. How toxic is the pesticide? Dermally? Orally?
6. Is the pesticide a restricted-use product (RUP)?
7. Does this pesticide have the potential to contaminate groundwater or surface water, even when label recommendations are followed?
8. Will using this pesticide expose humans to health or safety risks?
9. Will using this pesticide threaten wildlife populations?
10. Can you determine the pesticide’s mode of action group number from the label, and what that means?

Although pesticide use can reduce loss of food and fiber yields during pest outbreaks, their misuse may create adverse environmental effects. The general public will increasingly demand accountability from the agricultural community, which has the daunting challenge of providing an abundant, safe, and nutritious food supply while sustaining environmental quality. Clearly, the future emphasis lies in optimizing environmental quality while minimizing crop losses.

Remember, when you must use pesticides, help prevent pesticide resistance by using products with different modes of action. Repeatedly using the same pesticide, or one with the same mode of action, could result in survivors that then reproduce. Those offspring could increase the numbers of resistant pests in the next generation. Eventually that pesticide will be ineffective because a population has developed pesticide resistance. In time, the number of that resistant species will increase and spread.

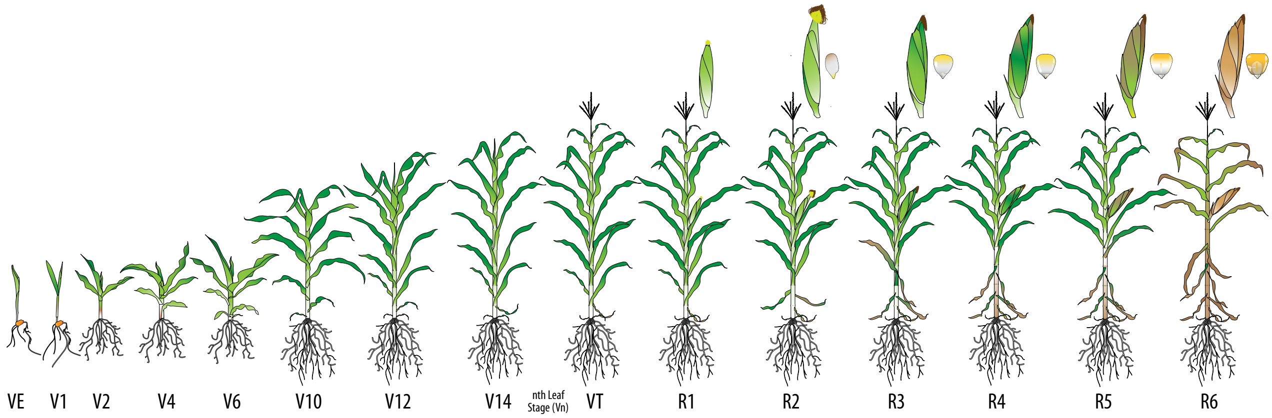


Figure 1.2. Growth stages of corn. (Ciampitti et al.)

GROWTH STAGES OF FIELD CROPS

Before applying certain pesticides, you should be able to recognize the stages of crop growth. Because some growth stages are more susceptible to pest injury than others, the economic threshold or damage threshold may not be the same at each stage. Become familiar with the growth stages and various plant parts of grasses, broadleaves, corn, dry bean, and small grains. The stages after are part of economic thresholds or timing of pesticide applications.

Corn

Vegetative (V) stages

The vegetative stages are defined according to the uppermost leaf on which the leaf collar is visible. The leaf collar is the region between the leaf blade and the leaf sheath. (Figure 1.2).

Stage VE: Emergence. The coleoptile, a protective sheath that surrounds the shoot, emerges. The first leaf emerges from within the coleoptile, and other leaves will emerge from within the sheath of the previously emerged leaf. The growing point of the plant is protected beneath the soil surface from hail, frost, and wind.

Stage V1: First-leaf stage. The collar of the first leaf is visible and other leaves are emerging.

Stage V6: Sixth-leaf stage. The collar of the sixth leaf is visible. The stalk is beginning to elongate and **the growing point is above the soil surface**.

Stage V12: Twelfth-leaf stage. Stalk is elongating rapidly. The size of the ears and the number of potential kernels on each ear are being determined.

Stage V18: Eighteenth-leaf stage. The tip of the tassel is visible. Brace roots are produced.

Stage VT: Tasseling. The last branch of the tassel is completely visible. This stage begins approximately 2–3 days before silking begins.

Reproductive (R) stages

Stage R1: Silking stage. Silks growing from the base of the ear are visible first and those growing from the ear tips emerge last. Pollination occurs and determines the number of kernels on each ear. Unpollinated ovules result in barren kernels.

Stage R2: Blister stage. Kernels are white, blister-shaped, and contain about 85% moisture. Kernel inner fluid is abundant and clear.

Stage R3: Milk stage. Kernels are yellow and contain approximately 80% moisture. Inner fluid is milky white because of accumulating starch. Silks are brown and dry.

1. Hypocotyl
2. Radicle
3. Cotyledon (simple leaf)
4. Cotyledonary node
5. Tap root
6. Lateral (branch) root
7. First true leaf (unifoliolate)
8. Trifoliolate leaflet
9. Terminal bud
10. Axillary buds
11. Hypocotyl arch
12. Nodes (point of leaf attachment)
13. Nodules
14. Root hairs

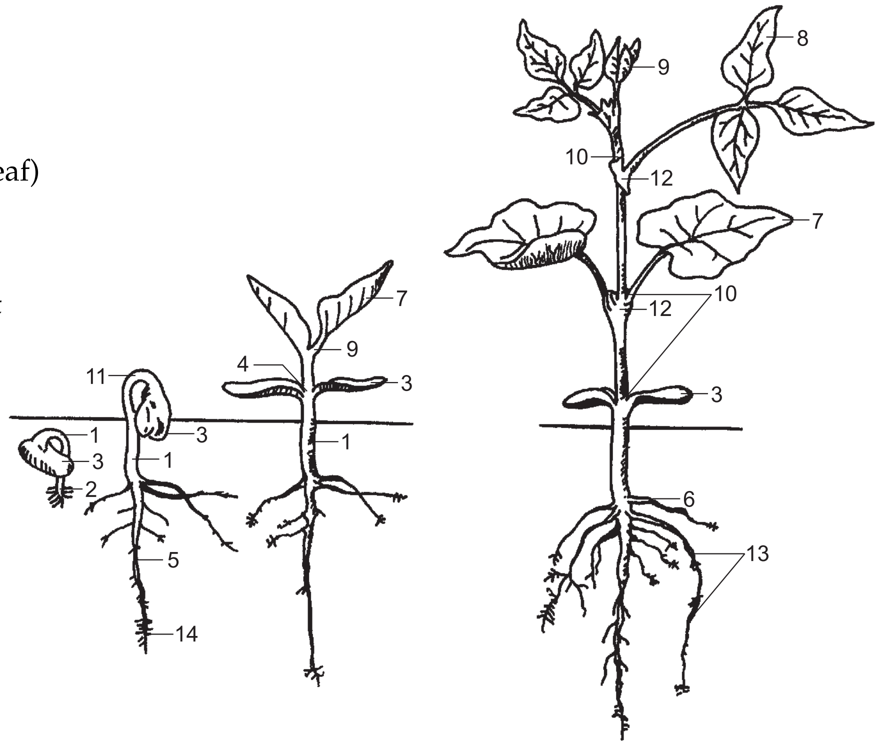


Figure 1.3. Dry bean plant description. (Osorno et al.)

Stage R4: Dough stage. Kernels contain approximately 70% moisture. Inner fluid thickens to a doughy consistency. Kernels begin to dent.

Stage R5: Dent stage. All kernels are dented or denting and contain about 55% moisture.

Stage R6: Maturity — **black layer formation**. All kernels have accumulated their maximum amount of dry matter. A black or brown layer forms on each kernel, beginning with those on the ear tip and progressing to the basal kernels. Kernel moisture is about 30% to 35%, although it varies with hybrids and environmental conditions.

For more detail on corn growth stages, see http://corn.agronomy.wisc.edu/Management/pdfs/Corn%20Growth%20and%20Development%20poster.pdf.

Dry Bean

Vegetative (V) stages

The vegetative stages are defined according to the uppermost fully developed leaf node — the one in which the leaves above it have unrolled leaflets (leaflet edges not touching). All of the vegetative stages of dry bean development are not described, but these are representative ones (Figure 1.3).

Stage VE: Emergence. The hypocotyl emerges (crook stage).

Stage VC: Cotyledon stage. Cotyledon (seed leaves) and unifoliate leaves visible.

Stage V1: First trifoliate stage. First fully developed trifoliate at the third node.

Stage V2: Second trifoliate stage. Count when leaf edges no longer touch.

Stage V3: Third trifoliate stage. Secondary branching begins to show in leaf axils.

Stage V(n): Nth trifoliate stage. Blossom clusters still not visibly open.

Stage V5: Bush (determinate plants). Plants may begin to exhibit blossom and become stage R1.

Stage V8: Vine (indeterminate plants). Plants may begin to exhibit blossom and become stage R1.

Reproductive (R) stages

Although some varieties (indeterminate) may continue vegetative growth, the plant enters the reproductive stages as soon as flowering begins.

Stage R1: Beginning bloom. One blossom opens at any node; indeterminate — tendrils show.

Stage R2: Pods ½-inch long at first blossom position, usually node 2 to 3; indeterminate—nodes 2 to 5.

Stage R3: Half bloom. Pod is 1-inch long at first blossom position.

Stage R5: Beginning seed. Pods more than 3 inches long, seeds discernible by feel.

Stage R7: Oldest pods have developed seeds.

Stage R8: Leaves yellowing over half of plant, very few small pods and these in axils of secondary branches; small pods may be drying (point of maximum production has been reached).

Stage R9: Full maturity. 80% of the pods have reached mature color. Only 30% to 40% of leaves remain green.

Small Grains and Sorghum

Stages of growth for small grains (Figure 1.4, page 13).

Seedling

Stage 1. The coleoptile, a protective sheath that surrounds the shoot, emerges. The first leaf emerges through the coleoptile, and other leaves follow in succession from within the sheath of the previously emerging leaf.

Tillering

Stages 2 to 3. Tillers (shoots) emerge on opposite sides of the plant from buds in the axils of the first and second leaves. The next tillers may arise from the first shoot at a point above the first and second tillers or from the tillers themselves. This process is repeated until a plant has several shoots.

Stages 4 to 5. Leaf sheaths lengthen, giving the appearance of a stem. The true stems in both the main shoot and in the tillers are short and concealed within the leaf sheaths.

Jointing

Stage 6. The stems and leaf sheaths begin to elongate rapidly, and the first node (joint) of the stem is visible at the base of the shoot.

Stage 7. Second node (joint) of stem is visible. Next to last leaf is emerging from within the sheath of the previous leaf but is barely visible.

Stage 8. Last leaf, the "flag leaf," is visible but still rolled.

Stage 9. Pre-boot stage. Ligule of flag leaf is visible. Head is beginning to enlarge within the sheath.

Stage 10. Boot stage. Sheath of flag leaf completely emerged and distended because of enlarging but head not yet visible.

Heading

Stages 10.1 to 10.5. Heads of the main stem usually emerge first, followed in turn by heads of tillers in order of their development. Sorghum brace roots produced. Heading continues until all heads are out of their sheaths. The uppermost internode continues to lengthen until the head is raised several inches above the uppermost leaf sheath.

Flowering

Stages 10.5.1 to 10.5.3. Flowering progresses in order of head emergence. Unpollinated flowers result in barren kernels.

Stage 10.5.4. Pre-milk stage. Flowering is complete. The inner fluid is abundant and clear in the developing kernels of the flowers pollinated first.

Ripening

Stage 11.1: Milk stage. Kernel fluid is milky white because of accumulating starch.

Stage 11.2: Dough stage. Kernel contents soft and dry (doughy) as starch accumulation continues. Plant leaves and stems are yellow.

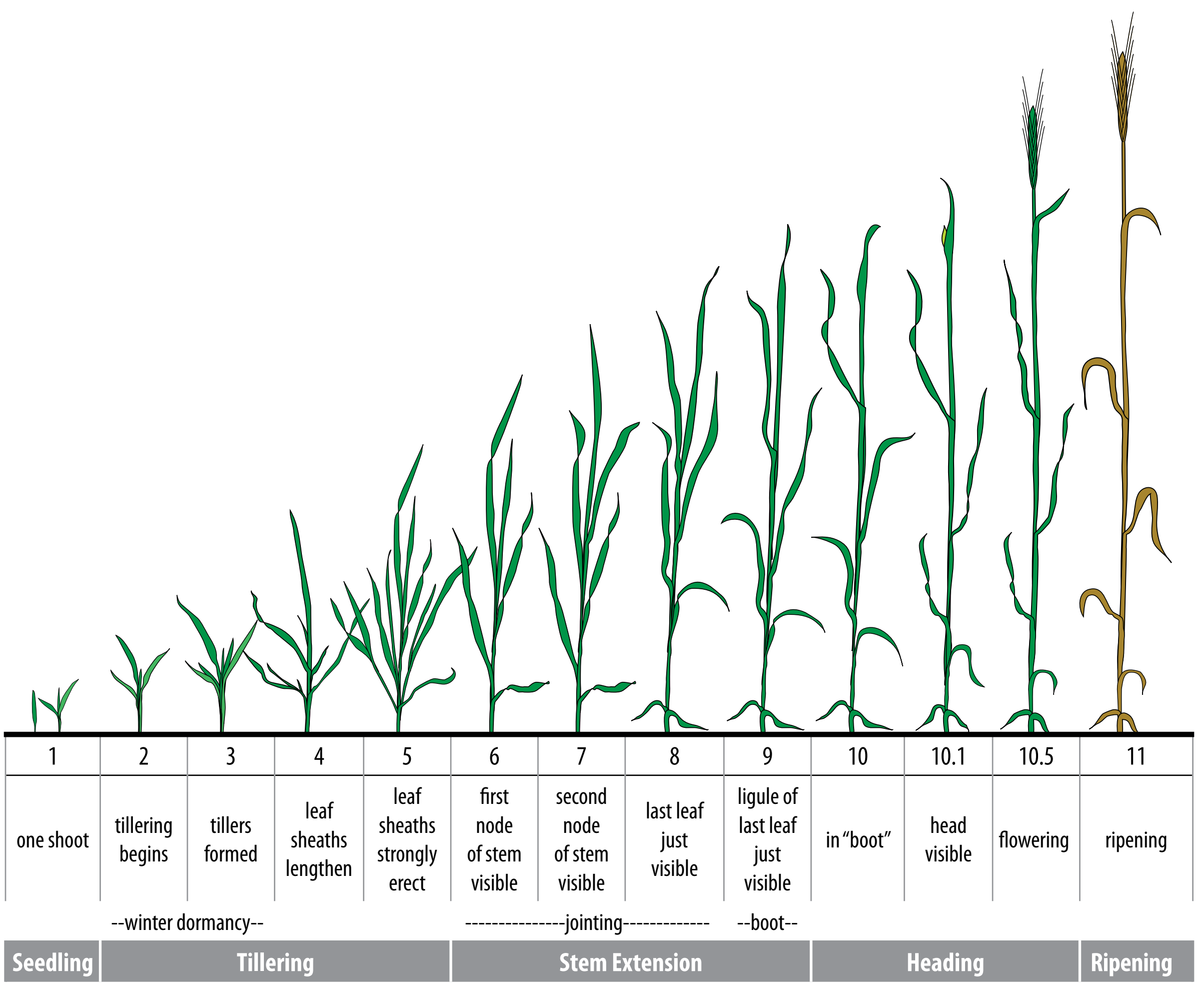


Figure 1.4. Growth stages of small grain growth (Feekes scale). (Jensen et al.)

Stage 11.3. Kernel hard (difficult to divide with the thumbnail).

Stage 11.4. Ripe for cutting. Kernel will fragment when crushed. Plant dry and brittle.

Section 2: Pesticide Application Equipment

LEARNING OBJECTIVES

After studying this section, you should be able to:

A. Identify the differences between flat-fan, flood, raindrop, cone, air-induction, twin fan, as well as broadcast and banding nozzles, and when each might be the preferred nozzle to use.

B. Describe particle drift and vapor drift, and the factors that influence each.

C. Identify four factors that affect spray droplet size.

D. Explain when nozzles should be replaced.

INTRODUCTION

Many components must come together for a pesticide application to be successful and safe. The process may be summarized as:

> *Putting the right product, on the right target, at the right time, under the right conditions, at the right rate, using the right equipment.*

This section focuses on the final three components — conditions, rate, and equipment.

Understanding operations of the spray equipment and its components is key to efficient application. For sprayers, pesticides are properly applied when the following six factors are adjusted and in balance with each other:

- agitation
- ground speed
- boom height
- nozzle type
- boom pressure
- sprayer design

Incorrect applications result in wasted chemical; marginal weed, insect, or disease control; excessive carryover; groundwater contamination; pesticide residues in plants; and/or crop damage.

If feasible, use different sprayers for herbicides that may cause injury to another crop or the same crop that does not have tolerance or resistance to an herbicide or herbicides. This also will help prevent accidental contamination and damage.

Many new technological developments assist in proper pesticide application. Along with these new developments is a trend toward decreasing spray volumes. This is because some herbicides perform better with reduced spray volumes, especially when using low-quality water. Also, many new row-crop sprayers have limited tank capacity, and hauling water is time-consuming and expensive. Decreased spray volumes may also allow the use of less expensive, smaller sprayers. Larger sprayers increase soil compaction, especially if the soil is wet.

Additives such as non-ionic surfactants and water conditioners are often tank-mixed as a percentage of carrier volume. Hence, as the number of **gallons per acre** (GPA) decreases, less additive is needed. Because of this, the trend toward lower spray volumes has provided a side benefit of reducing the amount of additive applied to crops and in the environment.

NOZZLES

Nozzle selection is a major factor in determining the amount of spray applied to an area, uniformity of application, coverage obtained on the target surface, and potential amount of drift. Nozzles may in fact be the most important part of the sprayer.

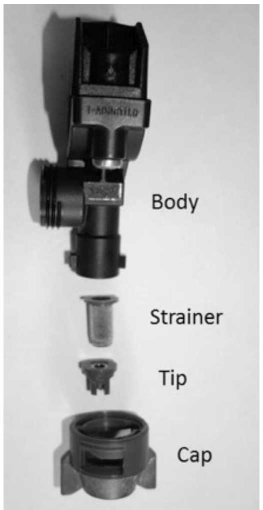


Figure 2.1. Four main parts of a nozzle.

Nozzles break the spray mix into droplets, form the spray pattern, propel the droplets in the proper direction, and determine uniformity of the application. Nozzles determine the amount of spray volume delivered at a given operating pressure, travel speed, and spacing. Drift can be minimized by selecting nozzles that produce the largest droplet size while providing adequate coverage at the intended application rate and pressure.

A nozzle has four major parts (Figure 2.1): nozzle body, strainer, tip, and cap. Many nozzles combine the tip and cap.

No one nozzle can cover every type of application. Nozzles vary according to capacity (gallons per minute or GPM), as well as spray angle and spray pattern. Even different strainers (screens) are available for high-rate (pre-emergent) vs. low-rate (typically systemic) products. While the strainer helps protect nozzles from abrasive particles, nozzles will still wear. Check nozzles regularly and replace when worn. This will be covered in detail later in this section.

Use identical nozzles for an application with your spray equipment. Do not mix nozzles of different materials, types, spray angles, or spray volumes. A mixture of nozzles produces uneven spray distribution.

Nozzle Material

Nozzles can be made from several materials. The most common are brass, polymer (nylon), stainless steel, and ceramic. Stainless steel and polymer nozzles last longer than brass and generally produce a more uniform pattern over an extended time. Polymer nozzles with stainless steel inserts are less expensive than solid stainless steel nozzles, and have a long life as well. Ceramic has superior wear life, is highly resistant to abrasive and erosive chemicals, and is usually the best buy for extended use (see Table 2.1).

Table 2.1. Nozzle material comparison abrasion resistance ratio.

Nozzle Material	Abrasion Resistance Ratio
Brass	1
Celcon Polymer	2 to 6
Stainless Steel	4 to 6
*UHMWPE	8 to 10
Ceramic	12 to 14

*Ultra High Molecular Weight Polyethylene Spraying systems AIXR nozzle

Types of Nozzles

Nozzle types commonly used in low-pressure agricultural sprayers include flat-fan, flood, raindrop, hollow cone, and full-cone, among others. Special features are available for some nozzle types. These include extended range, low-pressure, drift guard, turbos and air induction.

Flat-Fan

Flat-fan nozzles are one of the oldest nozzles, producing a fine droplet size and spray pattern with a tapered edge. Widely used for broadcast herbicide spraying, flat-fans are also available for band spray. Other types of flat-fan nozzles include the standard flat-fan, low-pressure flat-fan, extended-range flat-fan, drift guards, turbulence chambers (turbos), and special types such as off-center flat-fan and twin-orifice flat-fan. The relative droplet size for nozzles is shown in the patterns.

Standard flat-fan

The standard flat-fan (Figure 2.2) normally is operated between 30 and 60 pounds per square inch (psi), with an ideal range between 30 and 40 psi.

Even flat-fan

The even (E) flat-fan nozzle (nozzle number ends with E) (Figure 2.2) applies uniform coverage across the entire width of the spray pattern. These flat-fans are used for banding pesticide over the row, though not for broadcast applications. The band width can be controlled with the nozzle height, spray angle, and nozzle orientation.

Extended range flat-fan

The extended range (XR or LFR) flat-fan (Figure 2.2) is best operated between 20 and 30 psi. This nozzle is ideal for an applicator who likes the uniform distribution of flat-fan nozzle and wants a lower operating pressure to reduce spray drift. Since extended range nozzles have an excellent spray distribution over a wide range of pressures (15–60 psi), they can be used on sprayers equipped with flow controllers. Remember, spray drift increases with the higher pressures.

Flat-fan tips are available with the turbulence chamber (turbo) design. This incorporates a pre-orifice, which meters the liquid, with an internal turbulence chamber. This design produces larger droplets less prone to drift, along with a more uniform spray pattern. Of the turbulence chamber flat-fan nozzles, the Turbo TeeJet has one of the widest pressure range of the flat-fan nozzles — 15–90 psi. It produces larger droplets than the standard flat fan for less drift and is available only in 110-degree spray angles.

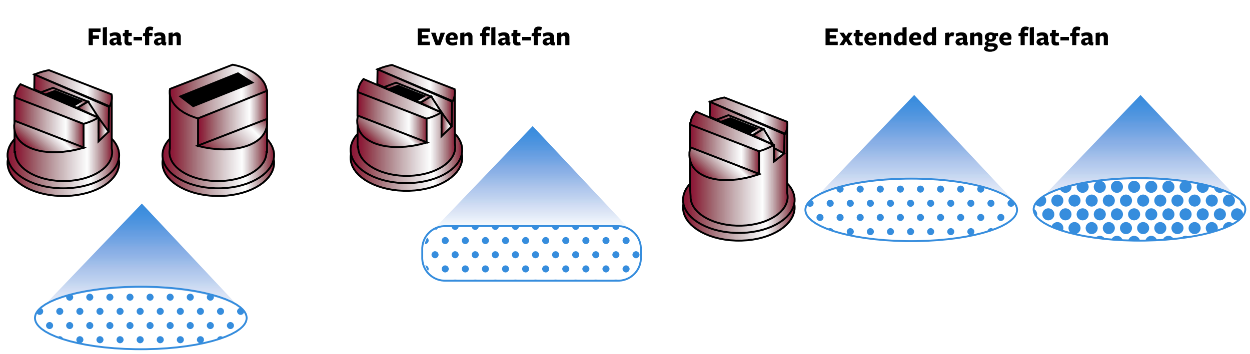


Figure 2.2. Standard flat-fan, even flat-fan, extended range flat-fan. (Grisso et al.)

The drift guard flat-fan has a pre-orifice that controls flow. The spray tip is approximately one nozzle size larger than the pre-orifice and therefore produces larger droplets and reduces the small droplets that are prone to drift.

Air induction

Air induction or venturi nozzles are flat-fan nozzles (Figure 2.3) where an internal venturi creates negative pressure inside the nozzle body. Air is drawn into the nozzle through one or two holes in the nozzle side, mixing with the spray liquid. The emitted spray contains large droplets filled with air bubbles (similar to a candy malt ball) and virtually no fine, drift-prone droplets. The droplets explode on impact with plant leaves and produce similar coverage to conventional, finer sprays. These include the Delavan Raindrop Ultra, Greenleaf TurboDrop, Lurmark Ultra Lo-Drift, Spraying Systems AI TeeJet, ABJ Agri Products Air Bubble Jet, Wilger's Combo-Jet, and others.

Figure 2.3. Air induction or venturi flat-fan nozzle. (Image courtsey TeeJet.)

Flat-fan nozzles also include the off-center (LX) flat-fan used for boom end nozzles for a wide swath projection; and the twin-orifice (TJ) flat-fan. The twin-orifice (TJ) (Figure 2.4) produces two spray patterns — one angled 30 degrees forward and the other directed 30 degrees backward. TJ droplets are small because the spray volume passes through two small orifices instead of one larger one. The two spray directions and smaller droplets improve coverage and penetration, a plus when applying post-emergence contact herbicides. To produce fine droplets, the twin-orifice usually operates between 30 and 60 psi.

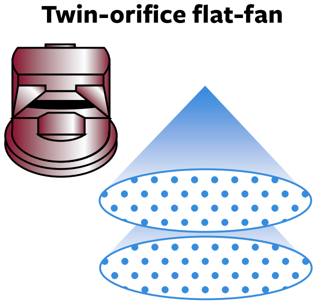


Figure 2.4. Twin-orifice flat-fan. (Grisso et al.)

Second generation venturi-type nozzles are commonly used because they combine the benefits of the turbos or extended range nozzles with those of the first-generation, venturi-type nozzles. Examples are the Air-Induction Extended Range (AIXR); and the TurboTee Induction (TTI). The label on the dicamba product approved for use on dicamba-resistant crops will state to use TTI11004 (Figure 2.5) or other approved nozzles. As requirements may change, always check the label with each product purchase to ensure correct nozzle and pressure usage is legally compliant.

Flat-fan nozzles are available in several spray angles. The most common spray angles are 65, 73, 80, and 110 degrees. Recommended nozzle heights for flat-fan nozzles during broadcast application are shown in Table 2.2, page 19.

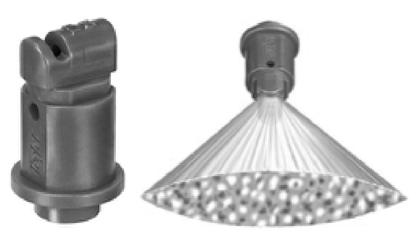


Figure 2.5. TeeJet TTI11004 is one example of an approved nozzle for use on herbicides for dicamba-resistant crops. (Image courtsey TeeJet.)

Table 2.2. Recommended nozzle height for flat-fan nozzles during broadcast application.

	Nozzle height (inches)			
Spray angle degrees	**20-inch spacing with overlap of**		**30-inch spacing with overlap of**	
	30%	**100%**	**30%**	**100%**
65	22	-NR-	-NR-	-NR-
73	20	-NR-	29	-NR-
80	17	26	26	38
110	10	15	14	25

-NR- Not recommended because of drift potential.

Flood

Flood nozzles with a pre-orifice, turbulence chamber, and reduced area to form the spray pattern are high volume. They are popular for applying suspension fertilizers where clogging is a potential problem. These nozzles produce large droplets at pressures of 10 to 25 psi. Nozzles should be spaced less than 40 inches apart; height and orientation should be set for 100% overlap. These nozzles are also good to use with soil incorporated herbicides, preemergence without contact herbicides, and with spray kits mounted on tillage implements.

Turbo flood

An example of a preferred flood nozzle is one by Spraying Systems called a turbo flood. It is designated as "TF" by Spraying Systems and "D" by Delavan. The value following the letters is the flow rate at the rated pressure of 10 psi. For example, TF-2 is a flood nozzle that applies 0.2 GPM at 10 psi. Many sprayer nozzle companies have similar nozzles.

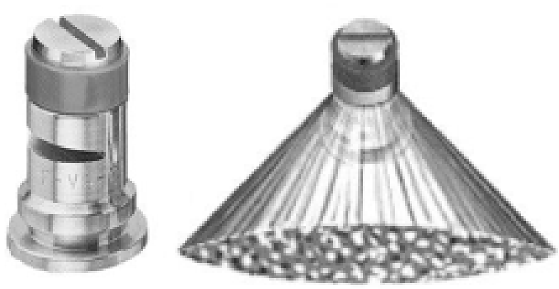


Figure 2.5. Turbo TeeJet Flood wide angle flat nozzle. (Image courtsey TeeJet.)

The pre-orifice controls the flow rate while the turbulence chamber absorbs energy, once again reducing the exit pressure from the nozzle. This not only creates larger droplets but also improves the uniformity of the spray pattern. The tip design more closely resembles a flat-fan nozzle (Figure 2.5). This greatly reduces the surface area, resulting in a much-improved pattern with tapered edges. Turbo flood nozzles are good if drift is a concern because their droplets are larger than standard flood nozzles. Also, with their wide angle, they can be used with lower boom heights. However, because of their large droplet size, do not use the turbo flood nozzle where good coverage is needed.

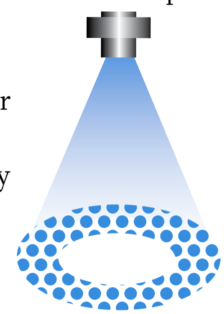


Figure 2.6. Raindrop hollow-cone nozzle. (Grisso et al.)

Raindrop

Raindrop nozzles (Figure 2.6) produce large drops in a hollow-cone pattern at pressures from 20 to 50 psi. The "RA" Raindrop nozzles are used for preplant incorporated herbicide and are usually mounted on tillage implements. When used for broadcast application, nozzles should be orientated 30 degrees from the horizontal. Spray patterns should overlap 100% to obtain uniform distribution. These nozzles are unsatisfactory for post-emergence or non-incorporated herbicides because the few number of large droplets produced would provide unsatisfactory coverage.

Cone

Hollow-cone nozzles generally are used to apply insecticides or fungicides to field crops for foliage penetration and complete coverage of leaf surface.

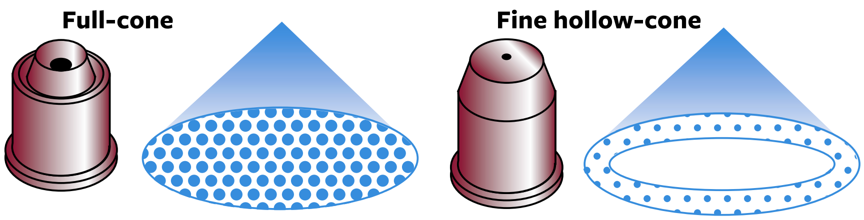


Figure 2.7. Full-cone and fine hollow-cone nozzles. (Grisso et al.)

These nozzles operate in a pressure range from 40 to 100 psi. Spray drift potential is higher from hollow-cone nozzles than from other nozzles due to the small droplets produced.

Full-cone

Full-cone nozzles (Figure 2.7) usually are recommended over flood nozzles for soil-incorporated herbicides. Full-cone nozzles operate between a pressure range of 15 to 40 psi. For optimum uniformity, angle nozzles 30 degrees from vertical and overlap spray coverage by 100%.

Fine hollow-cone

Fine hollow-cone nozzles (Figure 2.7) include the ConeJet (Spray Systems) and WRW-Whirl Rain (Delavan), both wide-angle (80 to 120 degrees), hollow-cone nozzles. These nozzles are used for post-emergence contact pesticides where a finely atomized spray gives complete coverage of plants or weeds best used under a hood. Drift potential is high for these nozzles.

Nozzle Size

Nozzle size is based on the size of the nozzle tip opening, called the orifice. Manufacturers use a numbering system that describes the nozzle discharge flow for a standard pressure.

Most nozzle manufacturers identify their flat-fan nozzles with a four- or five-digit number. The first numbers are the spray angle. The other numbers signify the discharge rate at rated pressure, usually 40 psi. For example, an 8005 has an 80-degree spray angle and will discharge 0.5 GPM at 40 psi. An 11002 nozzle has a 110-degree spray angle and will discharge 0.2 GPM at 40 psi. Additional designations are: "BR," brass material; and "SS," stainless steel; "VS," stainless steel with VisiFlo® color-coding; "VP," polymer with VisiFlo® color coding; and "VK, "ceramic with VisiFlo® color coding. See Table 2.3, page 21, for nozzle type and GPM discharge rates.

Delavan flat-fan nozzles are identified by "LF" or "LF-R" that reflect the standard and extended range flat-fan nozzles. The first numbers are the spray angle followed by a dash, then the discharge rate at rated pressure. For example, an LF80-5R is an extended range nozzle with an 80-degree spray angle, and will apply 0.5 GPM at 40 psi.

Nozzle Height

The correct nozzle height is measured from nozzles to target, which may be the top of the ground, growing canopy, or stubble. If nozzle or the spray angle from the nozzle is angled rearward, use this distance for boom height. Use 110-degree or wider angle nozzles when boom heights are less than 30 inches. Use 80-degree nozzles when booms are higher than 30 inches.

Although wide-angle nozzles produce smaller droplets that may be more prone to drift, reduced boom height reduces overall drift potential. The net reduction in drift potential more than offsets the effect of the smaller droplet size. The nozzle spacing and orientation should provide for 100% overlap at the target height. Nozzles should not be oriented more than 30 degrees from vertical.

Nozzle Selection and Pattern Considerations

It is important to select a nozzle that produces the desired spray pattern. The specific nozzle use, such as broadcast herbicide application or spraying insecticides on row-crops, determines the nozzle type needed. Examine current and future application requirements, and have several sets of nozzles for a variety of application needs. In general, do not select a nozzle with an orifice so small that it requires a nozzle screen finer than 50 mesh. **Nozzles requiring 80- and 100-mesh screens plug too easily. The larger the number, the finer the mesh**. A nozzle that produces 0.25 GPM at 40 psi or larger, reduces problems from plugging. Be aware that some nozzle types like the Air Induction may have two orifices in the bottom of the nozzle, which then requires a 0.5 GPM discharge at 40 psi to reduce plugging.

Since the flat-fan usually is the most widely used nozzle, flat-fan nozzle selection and spacing on sprayers are discussed here. The standard for nozzle spacing on broadcast sprayers has been 20 inches. Recently, there has been a trend to 15-inch nozzle spacing. This gives more options for application rates. For high application rates of 20 GPA or higher, use 15-inch nozzle spacing. For lower rates, shut or close off every other nozzle body so nozzle spacing is 30 inches. Also, many row crops are grown in 30-inch rows, so with 15-inch nozzle spacing you can spray over the rows and between the rows with drops.

Post-emergence contact herbicides require adequate and uniform coverage. Preplant incorporated herbicides require the least coverage, therefore large spray droplets could be used. Nozzles that produce large spray droplets, such as Spraying Systems' new turbo floods, could be used effectively for preplant soil incorporated herbicides

Table 2.3. Nozzles types and discharge rates at rated pressure.

Nozzle type	Discharge (GPM)	Rated pressure (PSI)	Min (PSI)	Max (PSI)
Regular flat-fan 8006	0.6	40	30	60
Regular flat-fan 11008	0.8	40	30	60
Low pressure flat-fan 8006LP	0.6	15	15	40
Low pressure flat-fan 11008LP	0.8	15	15	40
Extended range flat- fan 8006XR	0.6	40	15	60
Extended range flat-fan 11008XR	0.8	40	15	60
Turbo TeeJet TT11002VP	0.2	40	15	90
Turbo TeeJet TT11005VP	0.5	40	15	90
Drift Guard DG8002VS	0.2	40	40	60
Drift Guard DG11005VS	0.5	40	30	60
AI TeeJet AI11002-VS	0.2	40	30	100
AI TeeJet AI11005-VS	0.5	40	30	100
Flood TKSS 6	0.6	10	10	40
Flood TKSS 8	0.8	10	10	40
Turbo FloodJet TF-VS2	0.2	10	10	40
Turbo FloodJet TF-VS10	1.0	10	10	40
Raindrop RA-6	0.6	40	20	50

and would also reduce drift. University of Nebraska (NU) research has shown that at 10 GPA or less (Table 2.4, page 22), turbo flood nozzles did not give adequate control with a paraquat-atrazine tank mix for post-emergence applications.

Spray Deposition

NU research has demonstrated that spray pattern uniformity from 110-degree nozzles on 30-inch spacing was equal to 80-degree nozzles on 20-inch spacing. The 110-degree nozzles on 20-inch spacing had no advantage over 30-inch spacing if the carrier volume remained constant, such as 20 GPA for both nozzles.

SPRAY DRIFT

Drift can injure susceptible vegetation, contaminate water, or harm wildlife. While drift cannot be completely eliminated, using the proper equipment and application procedures should keep any drift deposits within acceptable limits.

The two kinds of drift are **particle drift** and **vapor drift**. Particle drift is off-target movement of spray particles at or near time of application. Vapor drift is the volatilization of pesticide molecules from liquids to gases and their movement off-target. Nozzles play an important role in drift management.

Droplet size is very important relative to spray drift. Spray particles smaller than 150 to 200 microns cause most spray drift. About the smallest the human eye can detect is a 100-micron droplet. A human hair is about 100 microns in diameter.

Major factors that affect spray droplet size are:

1. nozzle type
2. orifice size
3. nozzle spray angle
4. spray pressure

How nozzle type affects droplet size is explained earlier in this section. The orifice size, or opening, also affects droplet size: the larger the orifice, the larger the droplets, and less likely to drift; the smaller the orifice size, the more likely droplets are to drift. A given spray volume requires an increase in orifice size with an increase in nozzle spacing. Typically this means increasing the boom height to get the proper overlap. Since boom height is

Table 2.4. Control of green foxtail, triazine-resistant kochia, and volunteer wheat with paraquat plus atrazine at 0.31 plus 0.5 lb/A with a nonionic surfactant 0.25% v/v applied post-emergence.

Trt.	Nozzle	Volume GPA	Speed mph	Green foxtail 9 DAT	Green foxtail 35 DAT	TR-Kochia 9 DAT	Volunteer wheat 9 DAT	Volunteer wheat 35 DAT
				— % —				
1	XR11005	10.0	8.6	98 a*	98 a	97 a	97 a	95 a
2	DG11005	10.0	8.6	99 a	97 a	96 a	95 a	94 ab
3	TF-VS2.5	10.0	8.6	95 bc	81 cd	79 c	80 c	69 d
4	TF-VS2	7.5	9.2	94 c	78 d	70 d	71 d	65 d
5	XR11004	7.5	9.2	98 a	95 a	97 a	95 a	93 ab
6	DG11004	7.5	9.2	98 a	91 ab	96 a	89 b	86 abc
7	XR11003	5.0	10.3	98 a	96 a	95 a	94 a	85 bc
8	DG11003	5.0	10.3	96 abc	88 bc	89 b	90 b	83 c
9	Untreated check		—	0 d	0 e	0 e	0 e	0 e

*DAT = days after treatment. *Ratings followed by the same letter are not significantly different from each other using a t-test (LSD) at α = 0.05.*

the No. 2 factor in spray particle drift (wind speed is No. 1), this increase in boom height increases spray particle drift. As a general guideline, do not exceed a 30-inch nozzle spacing because of the potential for increased spray particle drift and spray pattern uniformity begins to degrade. The preferred configuration is nozzle spacing, height, and direction that gives 100% overlap.

Another factor relating to droplet size is nozzle spray angle. The wider the angle, the smaller the spray droplet. Table 2.5 lists the volume median diameter in microns of spray droplet for 80- and 110-degree XR nozzles for 20, 30, and 40 psi in 02 and 03 orifice size nozzles. Table 2.5 notes a nozzle delivering the same flow rate with a wider angle produces smaller spray droplets. But when comparing (Figure 2.8) a 50% larger nozzle (for example an XR8002 and XR11003) in an 80- versus 110-degree, the spray particle size is fairly close. Table 2.5 also shows the effect of pressure on spray droplet size. As spray pressure increases, droplet size decreases.

Table 2.5. Medium spray particle size in microns for XR8002, XR8003, XR11002, and XR11003 nozzles at 20, 30, and 40 psi.

	Pressure (psi)		
Nozzle	**20**	**30**	**40**
XR8002	321	287	267
XR8003	353	315	293
XR11002	269	241	224
XR11003	297	265	246

Reducing Drift

An estimated two-thirds of drift problems involve mistakes that could have been avoided. Drift is a concern because it takes the pesticide from the intended target, making it less effective, and deposits it where it is unneeded and unwanted. The pesticide then becomes an environmental pollutant in off-target areas. See Figure 2.8.

Dave Smith, a Mississippi State University agricultural engineer, analyzed data from more than 100 studies involving drift from ground sprayers. Of the 16 variables he considered, the three most important affecting spray particle drift are:

1. **Wind speed**. When wind speed doubled, drift increased 700%, when the readings were taken 90 feet downwind from the sprayer. Hence the recommendation (and requirement for many pesticide labels) is for spraying when winds are 10 mph or less.

2. **Boom height**. When boom height doubled from 18 to 36 inches, the amount of drift increased 350% at 90 feet downwind from the sprayer.

3. **Distance downwind**. If distance downwind is doubled, the amount of drift decreases five-fold. Therefore, if the distance downwind to a sensitive crop goes from 100 to 200 feet, you have only 20% as much drift at 200 feet as at 100 feet; if the distance goes to 400 feet, there is only 4% of the drift than was at 100 feet. Check wind direction and speed when starting to spray a field. You may want to start

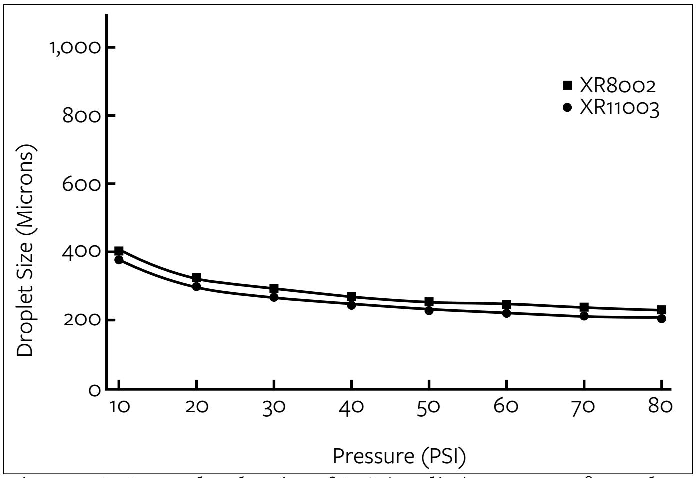


Figure 2.8. Spray droplet size of 80° (top line) versus 110° nozzles (bottom line.).

spraying one side of the field when the wind is lower. Also, it may be necessary to spray only part of a field because of wind speed, wind direction, and distance to susceptible vegetation. The rest of the field can be sprayed when conditions change.

New types of nozzle tips types also can reduce drift, as can spray pressure. Higher spray pressures produce smaller droplets that are more susceptible to drift. If using a rate controller, be careful of increased speed. Most rate controllers increase the pressure to maintain the same GPA. So when speed increases, try to maintain the speed within ±10%. For example, if applying 20 GPA at 8 mph at 40 psi and speed increases to 11 mph, the controller will boost the pressure to 75.5 psi. This will produce a lot of small particles prone to drift. Instead, when applying 20 GPA at 8 mph, try traveling no faster than 9 mph (8 mph × 10% = 8.8 mph) to keep pressure more constant. Also, when traveling faster than 10% over the desired speed, the pressure will be above the operating range of most tips. Drift reduction agents can be helpful.

A Nebraska Extension video describes "Reducing Risk of Herbicide Injury" at https://youtu.be/ztF5rgAkhgc.

OVERLAP AND BOOM HEIGHT

Most spray nozzle manufacturers recommend a spray pattern overlap of 30% to 50%; NU research recommends 100% overlap. Figures 2.9 and 2.10 illustrate 30% and 100% overlap. The advantage of 100% overlap is that each spot receives a spray from two directions. On uneven terrain, the end of the spray boom may not be as high above the target and hence reduce overlap.

Wider angle nozzles such as the 110° have a much greater tolerance on the overlap or spacing height ratio.

If overlap is 30% to 50%, it can easily be reduced to no overlap or even gaps where areas receive no pesticide. With 100% overlap, if a nozzle becomes partially plugged, the adjacent nozzles still will give at least 50% of the application rate. This provides some amount of control.

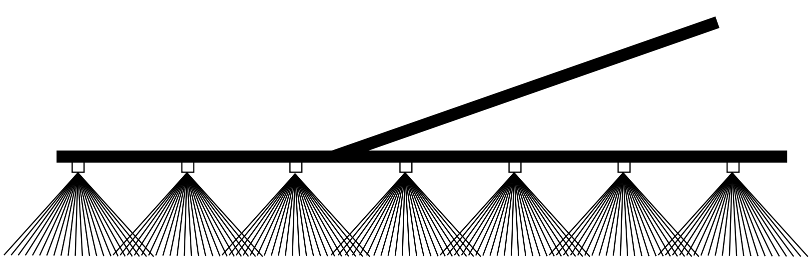


Figure 2.9. 80-degree nozzles, 20-inch spacing, 30% overlap.

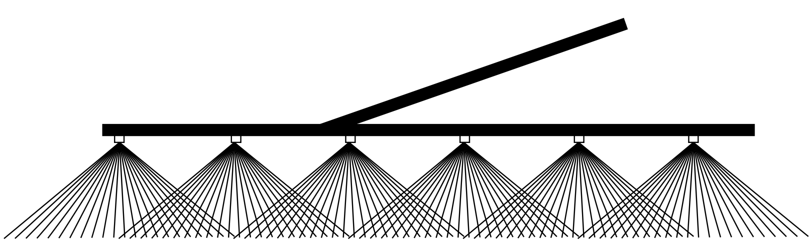


Figure 2.10. 110-degree nozzles, 30-inch spacing, 100% overlap.

Nozzle Spacing Considerations

The most popular row spacing now is 30 inches. With nozzles at 30 inches, one can easily use drop nozzles if needed. Some pesticides should not be sprayed directly in the whorl of the plant. With 20-inch spacing it is impossible to keep from spraying directly over some of the plants. With 30-inch spacing you can always have nozzles between the rows or, if needed, move them directly over rows for band spraying.

Spray Monitors and Controllers

Spray monitors and controllers are becoming more popular in achieving accurate application. However, they do not eliminate the need for sprayer inspection and calibration. Monitors measure the operating conditions such as travel speed, pressure, and/or flow rate. Spray controllers are monitors with the added capability of automatic rate control. The controller receives the actual application rate from the monitors and compares it with the desired rate. If an error exists, the pressure is regulated to adjust the spray volume. Nozzles can operate only within a limited range of pressure without either distorting the spray angle or creating off-target drift.

Table 2.6 shows a change made in speed and the resulting change required by the pressure regulator. Nozzles that can operate over a wider pressure range are best used with spray controllers. The controller will adjust the spray volume automatically by adjusting pressure. Since these adjustments are a direct response to various sensors, it is important that sensors be periodically checked and calibrated. Do not assume that monitors are fool-proof! Consult the manufacturer's operating manual to properly calibrate and adjust the sensors. Monitors that give travel speed, spray volume, etc. are usually adequate for most sprayer situations. Newer monitors keep track of which booms are being used and areas they cover, so that the calculated area sprayed is very accurate. Some controllers can even turn on and off each nozzle or boom section and keep one from spraying an area that has been sprayed.

Table 2.6. Pressure changes needed to adjust output because of speed changes with 8015 nozzles on 30-inch nozzle spacing at 10 mph at 40 psi applying 30 GPA.

Speed (mph)	% Change	Nozzle pressure (psi)	% Change	Spray Volume (GPA)
10	40	30		
5	- 50%	10*	- 75%	30
15	+ 50%	90*	+ 125%	30

**Outside recommended nozzle pressure*

Pulse-width modulation uses high-speed solenoid valves to regulate flow and varies application rate with duty cycle independently of pressure. The nozzle pulses 10 to 30 times per second. The alternating pulses combine with overlapping spray patterns and the natural dispersion of droplets traveling in air blend together to provide consistent coverage. Since pressure can be kept constant over a wide travel speed, the desired spray particle for both efficacy and spray drift management can be maintained.

WHEN TO REPLACE NOZZLES

Replace a nozzle when:

- nozzle flow rate is 10% greater than new nozzles (This indicates wear; if flow rate is lower, cleaning may solve the problem. Clean and recheck flow rate.)
- spray pattern is distorted
- nozzle shows irregular wear

Recalibrate after replacing nozzle tips.

Note: Each nozzle's flow rate on the spray boom should be within ±5% of the average flow rate of all nozzles. For example, if the average flow rate of the nozzles is 10.0 gallons per second (gps), each should be no less than 9.5 gps nor more than 10.5 gps (5% of 10 is 10 × 0.05 or 0.5, so subtract 0.5 from the average flow rate to see what the minimum should be; add 0.5 to the average flow rate to see what the maximum should be, to stay within the ±5% range).

SPRAYERS

Sprayer Types

Sprayer types include row crop, floaters, farm-type, spray booms on four wheelers, spray coupes, and others. Several have the ability to adjust wheel spacing either while in motion or standing still. Other developments include articulated sprayers, hydrostatic drive, windscreens, and spray shields. The advantage of windscreens or shields is that they permit spraying during windier conditions. Also, speed affects the spray pattern less, and shields greatly reduce drift compared to sprayers without this equipment. Disadvantages are that some shielded sprayers are completely enclosed and can be hard to service. Also, it is difficult to see whether nozzles are operating. Some controllers will inform the applicator of a problem. Some windscreens are open on top for easy nozzle access and to check the spray pattern. Their disadvantage is that they provide less protection from the wind compared to completely shielded sprayers. Some newer shielded sprayers, especially those used on plot sprayers, are made of Plexiglas. After a short time, Plexiglas becomes almost opaque unless properly cleaned and maintained.

Spray Booms

Stainless steel has become popular for spray booms. The advantage is that stainless steel is not damaged by some pesticides that can damage hoses. Also, there is very little restriction in the lines. End caps that snap on and off are available to help with cleaning and flushing. Diaphragm check valve nozzle bodies with one hole drilled into the stainless steel delivery pipe make for a quick-fitting attachment.

Self-Cleaning Line Strainer

A self-cleaning line strainer mounted on the pump's discharge side minimizes nozzle clogging. This strainer uses the excess flow to carry particles too large to pass through the filter back to the spray tank. To use the self-cleaning strainer you must have excess pump capacity for wash-down to occur. The amount depends on the strainer size. This is the amount required through the bypass line for the self-cleaning strainer. Minimum flow rate is 6 gpm extra for the 0.75- and 1.00-inch size self-cleaning line strainers and 8 gpm for the 1.25- and 1.50-inch size.

TANKS

Fresh Water Tanks

Very common on most sprayers is a fresh water tank for operator wash-up and in-field clean-up. These range from smaller tanks of 5 to 10 gallons on farm-type sprayers, to 100-gallon or larger tanks on floaters. Clean water is necessary for the first step in self-decontamination in the event of a spill.

Induction Tanks (Cones)

Induction tanks for adding chemical to the spray mix are a great safety device on sprayers. Induction tanks usually are mounted at a more convenient height for adding chemicals, so mixers and loaders do not have to climb up to add items to the main tank. Also, some can carry fresh water to rinse out the sprayer when the application is completed.

APPLICATION SYSTEMS

Direct Injection Systems

Direct injection systems have a number of benefits. Water carried in the spray tank eliminates the need to mix chemicals and eliminates the potential of leftover material. Compatibility problems are eliminated because each chemical is kept in its own container. These containers are part of a closed system, reducing operator exposure to chemicals, and are returnable. Direct injection systems can handle a number of chemicals. Each pesticide requires its own pump, injection system, and container. An operator can turn any of the systems on and off at the touch of a switch and can adjust the amount and type of chemical used. The chemical is injected directly into the spray lines carrying the water, fertilizer, or whatever carrier is used. The type of mixing that occurs depends on whether the injection is before or after the carrier pump in a system. Present systems are usually classified by the type of metering pump used. These include either the piston or diaphragm pump, which injects the chemical into the carrier. There it is combined in an inline mixer prior to spraying. Another type consists of a series of peristaltic pumps to meter a specific amount of chemical and inject it into the carrier on the inlet side of the carrier pump.

Impregnation and Onboard Application Systems

Dry material airflow applicators impregnate herbicide on fertilizer granular materials. These applicators give more uniform fertilizer application compared to spinner-type granular applicators. This impregnation and mixing can be done at the fertilizer plant or in the field. An advantage is that there is no potential for leftover material from over-mixing for the job. Also, mixing out in the field means odors and contamination around the plant are eliminated, and operator exposure is reduced.

Originally, problems with impregnation were numerous. Through experience and improved equipment, most problems have been eliminated. The infield on-the-go impregnation has succeeded with the availability of new granular herbicide formulations. It is designed to apply dry fertilizer and dry granular herbicide at the same time. This eliminated a lot of the problems of the original liquid impregnation process.

Variable Rate Technology

Fields have many soil types and different nutrient needs, so tailoring the exact amount of fertilizer and herbicide holds high interest. Several systems are being used. One uses a mapping system based on soil tests. Grid maps are developed for each field, based on specific soil information to help decide the level of input for fertilizer and herbicide. This information is placed into a computer file and entered into the applicator cab computer that directs time and placement of fertilizer and herbicide. Another system uses sensors mounted on the front of the applicator to analyze the crop on-the-go and feeds this information through a computer to regulate the amount of fertilizer and/or herbicide applied. Reference strips are needed with this system.

Section 3: Calibration and Pesticide Application

LEARNING OBJECTIVES

After studying this section, you should be able to:

A. Define calibration and explain why it is important.

B. Explain how to check nozzle flow rate (discharge).

C. Explain how wind direction, field speed, and driving too fast can affect treating a field.

D. Identify two factors to reduce drift injury.

E. Define temperature inversion and explain when it occurs and how it can affect pesticide movement.

CALIBRATION

A pesticide must be applied uniformly and at the correct rate for maximum effectiveness. The process of measuring the output of the application equipment over a given area is called calibration.

Calibration involves making a trial run where you know the size of the target area, in square feet or acres, and measuring the amount of pesticide applied to determine the rate at which the equipment delivers the pesticide product. In other words, calibration tells you the number of gallons, pounds, or ounces applied per acre or 1,000 square feet you will apply with a particular piece of equipment at a particular speed.

Why Calibrate?

Equipment is adjustable, and charts or tables assist the operator in adjusting the settings. Recommended settings, however, are only approximate and may not be appropriate for all situations. Also, wear and tear on equipment may affect its performance. Therefore, equipment must be periodically calibrated. How often depends on the type of equipment and frequency of use.

The application rate of a sprayer is affected by travel speed, nozzle spacing, nozzle size, sprayer pressure, and density of the spray solution. Even with the widespread use of electronics to monitor and control the pesticide application, a thorough sprayer calibration procedure is essential to avoid misapplication. Electronic or automatic controls can improve sprayer accuracy and performance. However, nothing substitutes for proper calibration.

Time invested in calibrating equipment is well-spent. Accurate calibration to determine the application volume under your operating conditions is important for cost, efficiency, and safety. Without proper calibration to deliver the correct application volume, you don't know if the equipment is applying the pesticide at the proper rate to control the pest.

Equipment can be calibrated by making a trial run on a pre-measured area and measuring the output. For example, when using a hand-held sprayer, spray a pre-measured test area with water using the same pressure and techniques (i.e., travel speed and equipment) as when applying the pesticide. After spraying the test area, determine how much water (volume) was used. Use this volume to calculate the amount of water and pesticide needed to cover the intended application area.

Nozzle Flow Rate

To calibrate and operate a sprayer properly, it is important to understand how each variable affects sprayer output. Nozzle flow rate, for example, varies according to the size of the orifice, nozzle pressure, and density of the spray liquid. To check the nozzle flow, one needs a measuring container, and stopwatch or other timing device. Also available are sprayer calibrators such as SpotOn™ that make the job easier since it gives gallons per minute as one of the results.

Two other factors affect the spray application rate. One is speed — **doubling the sprayer's ground speed reduces the gallons of spray applied per acre by one-half.** This assumes the pressure stays constant. The second is nozzle spacing — **doubling the effective width sprayed per nozzle (nozzle spacing) decreases the applied amount by one-half.**

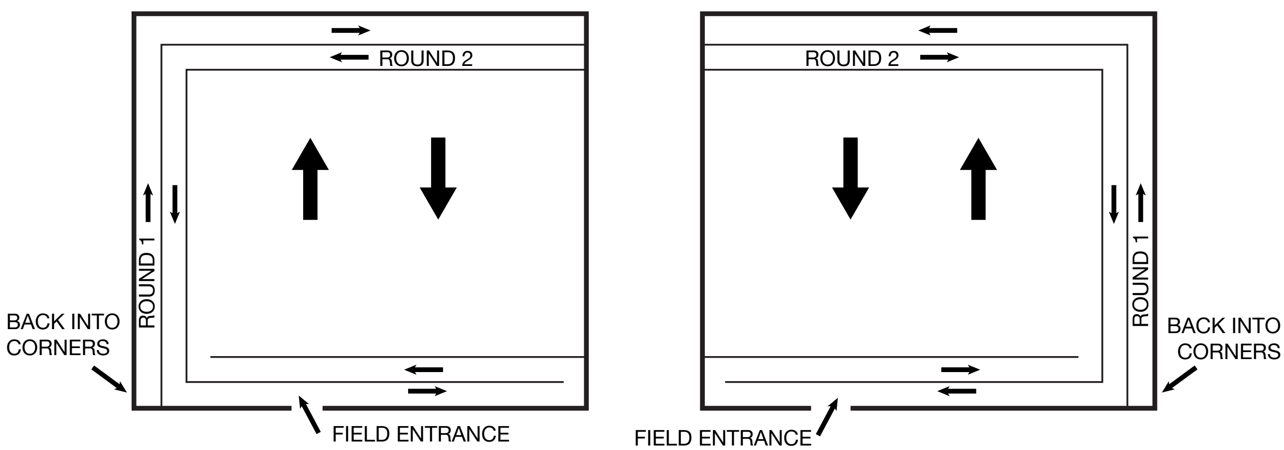
These short videos help demonstrate calibration:

- "How to Calibrate an ATV Sprayer," https://www.youtube.com/watch?v=twoHQF4URdE.
- "How to Calibrate a Backpack Sprayer," https://www.youtube.com/watch?v=waC51BtQX9A.

Calibration is so important that even though it is covered in the Pesticide Safety Education Program (PSEP) training materials, it also is included in Section 4, page 37.

HOW TO SPRAY A FIELD

Spraying a field improperly can injure adjacent crops, and potentially the crop being sprayed, as well as affect pest control. First, note areas that



Turn left if cab is on the left or in the center.   Turn right if cab is on the right.

Figure 3.1. How to start spraying a field — spraying three sides.

may be very susceptible to drift. To help prevent injury, start spraying a field on the side where the potential for drift damage is greatest when wind speeds are low or blowing away from the susceptible area. If wind speeds are not low, or if they blow toward the susceptible area, you may need to return to treat those areas when weather conditions permit pesticide application without causing injury. Consider wind speed and direction, as well as neighboring susceptible areas. They can make a difference in how you start or end spraying a field (Figure 3.1, page 29).

Spraying with GPS-RTK (Real Time Kinematic) is the application technology being used for most field spraying. It is much more accurate due to the use of a close range antenna that provides a known reference point. The computers use this antenna to calculate and correct any movement of spray boundaries due to the Earth's shifting. This means that once your boundaries are established they do not need to ever be mapped again. It also means that the spray boundaries are accurate to within one inch of where they were initially mapped. RTK systems do require an RTK antenna within about 30 miles, and likely a fee is required to access the antenna. When coupled with individual nozzle or boom section control, the savings on chemical and fertilizer can be substantial.

This control eliminates spraying an area twice or more, and also many of these systems reduce or increase the rate while turning.

The following discusses spraying techniques for spraying without GPS-RTK.

Spraying Fields with Rows

If rows are available, it usually is best to follow them. It works best if the sprayer and planter are set to the same row spacing. For example, with 30-inch rows, and 6, 12, 18, and 24 row planters, sprayers with boom lengths of 30, 45, 60, 75, 90, 105, and 120 feet work best. With 30-inch rows and 8, 16, and 24 row planters, sprayers with boom lengths of 40, 60, 80, 100, and 120 feet work best. Do watch for narrow and wide guess rows. In some situations with row widths less than 22 inches and wide tires on the sprayer, growers will spray perpendicular to rows because tire tracks do less crop damage. In most situations, two passes are needed on each end of the field in order to provide space for the sprayer to slow down, turn around, and then return to speed.

Spraying Fields Without Rows or Not Following the Rows

Start by spraying the two ends and one side of the field with two initial rounds. By spraying two rounds on three sides, turn room is provided when spraying the field. Spraying the ends first allows you to go around trees, power poles, guy wires, and other obstructions. You must back into the corners for complete coverage (Figure 3.1, page 29).

If the wind is blowing in the direction of susceptible crops, stop spraying far enough from the edge of the field so the spray does not carry past the field border. Then finish spraying when wind conditions permit.

Use previous wheel tracks across the end of the field as an approximate marker depending on sprayer length and if booms are positioned on the rear of the sprayer. In most situations, shut off the

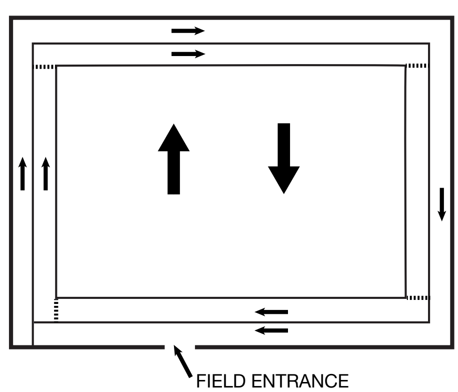


Figure 3.2. How to start spraying a field — spraying four sides.

booms as front wheels cross the wheel tracks at the end of the field.

Another method is to spray two rounds, covering all four sides, then spray the field interior (Figure 3.2, page 30). The disadvantage to this method is that a partial boom width overlap often occurs in the last pass; many times the foam mark or other mark has disappeared by the time you get back to that side of the field. Also, even with GPS, you may forget you have made two passes on the opposite side of the field.

Spraying Field Borders

Many factors increase the risk for problems along the field borders, including:

- weedy conditions next to a fence line with minimum tillage;
- weed and insect pressure from fence rows;
- higher potential for overlaps and skips;
- soil compaction from turning and frequent traffic;

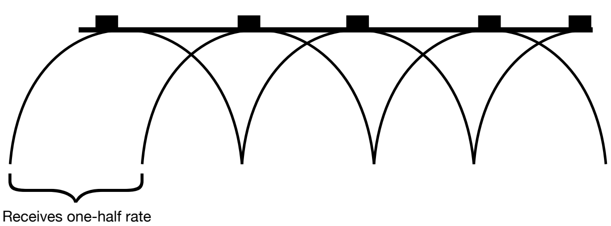


Figure 3.3. Shows one-half rate of pesticide from end nozzle.

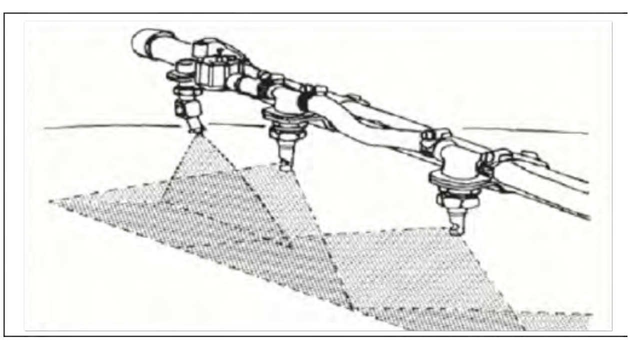


Figure 3.4. Additional nozzle on end to give full rate of pesticide — use only on ends and field borders. Must be turned off when swathing (spraying field).

- High soil pH from over-application of lime or dust from a nearby crushed limestone road (high pH increases crop injury from triazine and sulfonylurea herbicides).

The outermost sprayer nozzle along the field edge will not apply a full rate of the pesticide (Figure 3.3) since most nozzles are designed for some pattern overlap. Consider putting an extra nozzle at the end of the boom (Figure 3.4). This nozzle can be turned on for a full rate on field borders.

Use an off-center nozzle at the end of the boom to provide 100% overlap. For example, the Off-Center Air Induction tip, Air Induction Underleaf Banding Spray tip, (AIUB), or Underleaf Banding Spray tip (UB) could be used at the end of the boom to provide 100% overlap. Most spray nozzle companies have this type of nozzle tip. Ideally, these nozzles are one-half the size of the other nozzles. The nozzle tip to use depends on boom height, spray volume and speed.

Spraying While Turning

Spraying while making sharp turns (Figure 3.5) can result in 3 to 4 times the desired pesticide rate along the inner boom and as high as 40 to 50 times in the pivot position. The rate of pesticide near the outer end of the turn can be one-half to one-tenth the desired rate. To eliminate this as much as possible, spray in a straight line and do not turn while spraying. Be cautious to not compensate for turning while spraying if you

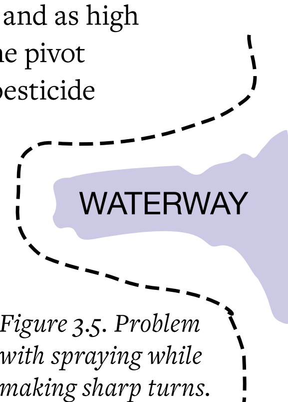


Figure 3.5. Problem with spraying while making sharp turns. Better to turn off sprayer and back into corner. Remember that different sprayers adjust output differently so it is important to know the equipment being used.

are using a sprayer with individual boom or nozzle controllers that adjust automatically (i.e. pulse-width modulation systems).

Spraying Irregular-Shaped Fields

Achieving pesticide coverage of point rows is difficult. Some guidelines to improve results include:

- Do you prefer overlap on irregular areas or should they be left untreated? In the case of weed control, these areas are also difficult to cultivate and many would rather risk crop injury from overlapping pesticides than have inadequate weed control. With point rows or uneven row lengths (Figure 3.6), don't always select the longest distance of travel. Consider the degree of angle into the point and minimize double-spraying. Place switches on each boom section or even on every two or three nozzles for controlled treatment of narrow swaths on terraces, point rows, and other irregular areas.
- Should you treat fencerows, waterways, terrace back slopes, and other areas?

Terraced Fields

Treating terraced fields can be very difficult. Farmable terraces often are sprayed as normal fields with the applicator traveling over the terraces. Other types of terraces, parallel and non-parallel, require one border along each terrace. Fill in the points between the terraces as necessary. Operate foam markers on both ends of the boom to help prevent excessive double spraying. In irregular-shaped fields where applications could overlap, avoid using pesticides that have the potential to cause carryover concerns or water quality problems.

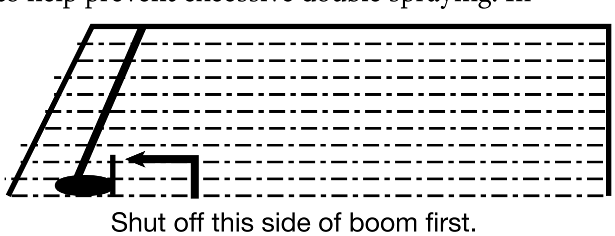


Figure 3.6. Spraying uneven row lengths.

Leaving Check Areas or Strips

Untreated areas (checks) are invaluable for later evaluation of a chemical or fertilizer application. Often, a planned check area provides the only means of evaluating results in terms of pest control, crop injury, or fertilizer effectiveness. Checks are especially essential when using new products or uncertainty about treatment value. The check area:

- Should be used only with the grower's consent.
- Is often placed in an area not readily visible to passersby.
- Need not be large — with spray booms, shut off a portion of the boom or shut off several nozzles. Mats can also be used with sprayer or spreader.
- Location should be noted on the field record sheet.

Proper Swath Overlap

Nozzle pattern overlap at the end of the boom should be the same as for the rest of the nozzles along the boom (Figure 3.7, page 33). For example, if the overlap is 100% along the boom, then the overlap at the edge of the swath should be 100%. The increased overlap of spray pattern and wide-nozzle spacing increases the distance with a double rate or no rate of pesticide.

Location of a foam marker can affect positioning of the boom end relative to the foam. In Figure 3.8A, page 33, the marker is placed at the end of the boom, even with the last nozzle. If the nozzle spacing is 30 inches you would move over 30 inches from the foam mark.

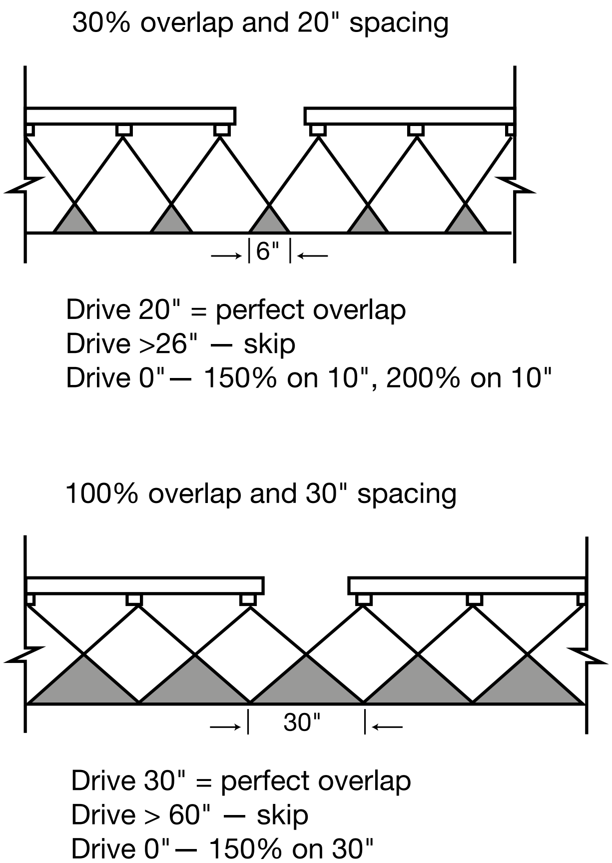


Figure 3.7. The advantage of more overlap with the spray pattern and wider nozzle spacing when swathing.

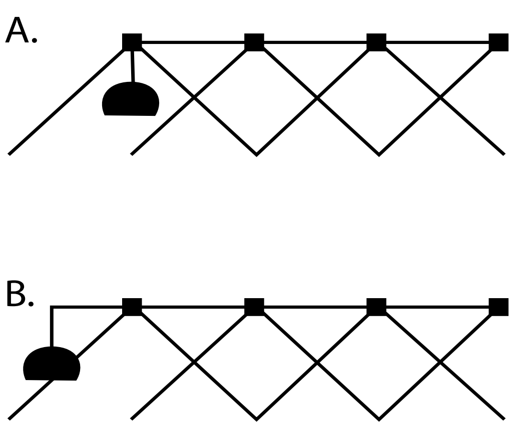


Figure 3.8A. Marker placed at end of boom, even with last nozzle. B. Marker placed on extension that is 50% of nozzle spacing.

Some sprayers have the foam marker placed on an extension that is 50% of the nozzle spacing (Figure 3.8B). In this situation, a person would have the foam marker directly above the foam on the return pass.

Field Spraying Effectiveness

Field speed greatly affects field treatment. Base your field speed on the slowest speed you would use during application during the most difficult part of the field. A slower speed helps maintain spray uniformity; faster and more widely variable speeds make uniform application difficult.

Driving too fast:

1. Increases boom bouncing and whipping.
2. Distorts the spray pattern; e.g., at 12 mph the pattern width is decreased 15% to 20% by wind for a nozzle placed at a height of 4 feet to 5 feet, as compared to the width of the pattern when the sprayer is stopped.
3. Creates a wind eddy behind the machine. This can be a serious problem behind large machines driven at high speeds.
4. Creates more dust that deactivates certain herbicides.

REDUCING DRIFT INJURY

Environmental Conditions

Note environmental conditions, such as wind direction and wind speed, and plan accordingly.

Wind direction

Be aware of nearby crops and drift potential of pesticides, fertilizers, etc. When possible, spray when winds are blowing away from sensitive or susceptible neighboring fields.

Wind speed

A doubled wind speed (from 7 mph to 14 mph) will increase the amount of drifted pesticide at 90 feet from the sprayer by 700%. Many pesticide labels give a range of wind speeds when pesticide applications are allowed. A field should not be sprayed on windy days. The recommendation is to avoid spraying when winds are over 10 mph.

Applications made under low- or no-wind conditions can sometimes produce more extensive drift than under high winds. Drift that occurs more than a mile is most often the result of applications made during a temperature inversion.

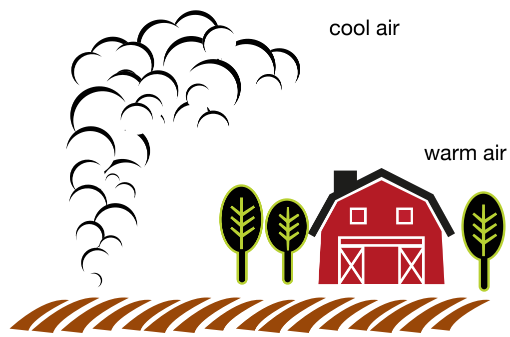
Temperature inversion

A temperature inversion can cause air to move sideways, taking spray droplets with it. An inversion exists when air at ground level is cooler than air above it. Under these conditions, the air is considered unstable because there is little or no vertical air movement. Almost all air moves sideways during an inversion. This causes a high concentration of small spray droplets to be suspended in the layer of cool air near the ground. Droplets can then be carried long distances, especially if wind speeds increase. When spray droplets settle out, they may still be concentrated enough to cause damage or harm.

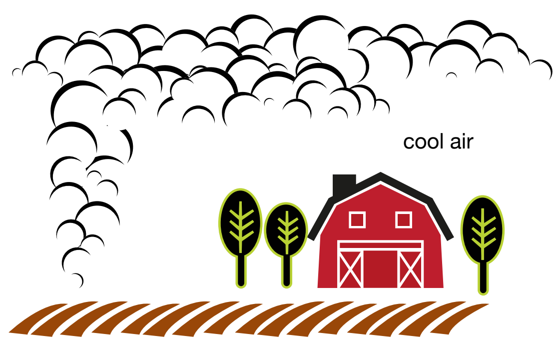
Inversions most often develop during early evening hours as ground temperature begins to cool and warm air has already risen.

Inversion conditions intensify during the night and may persist until midmorning, when the ground has warmed enough to start the vertical mixing of air (i.e., the wind starts to blow). This causes spray droplets to dilute and separate. Consequently, applications made during early evening, night, or morning hours under seemingly ideal conditions may result in highly damaging drift that can move long distances. This is especially true if the humidity is high. Such movement could occur up to one to three hours after the application.

You can recognize an inversion by watching how dust and smoke move. If dust or smoke rises little from its source and tends to hang in the air, an inversion may be present or developing (see Figure 3.10). Another way to detect inversions is to place one thermometer at ground level and



Normal conditions—smoke rises and disperses.



Inversion conditions—smoke concentrates.

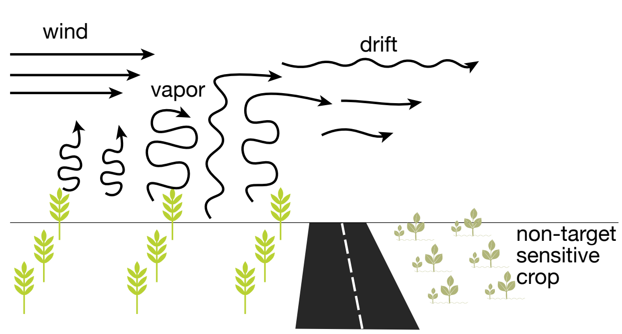


Figure 3.10. Vapor drift of pesticides is more likely as heat and wind increase and the relative humidity decreases.

a second thermometer high above the ground. Then compare the difference in temperature. If the temperature at ground level is below that found at the elevated thermometer, a temperature inversion exists. Do not apply pesticides under such conditions.

Equipment Settings and Cleaning

If your rate controller changes output by changing pressure, drift may be reduced by slowing down near susceptible vegetation. For example, if spraying 10 mph at 40 psi, then slowing to 7 mph, the pressure will drop to 20 psi. You need to stay above the minimum operating pressure for the nozzle tip being used (Table 3.1). This table also shows the effect on pressure as speed increases. For speeds other than 10 mph, use a percentage. For example, if you travel 7 mph, use 70%; if you travel 12 mph, use 120%.

The two most important factors to reduce drift are wind and boom height. Lowering boom height reduces drift, as does reducing pressure. However, boom height must be kept at a minimum so spray patterns have the correct overlap.

CLEANING THE SPRAYER

Pesticides enter the human body most frequently through the skin (dermally). When cleaning pesticide contaminated equipment, wear the same personal protective equipment (PPE) that the labeling requires for making applications, plus a chemical-resistant apron or other appropriate protective equipment. Also wear eye protection, even if not required by the label directions. Clean equipment

Table 3.1. How speed changes affect pressure on sprayers with rate controllers.

(Do not operate sprayer so that nozzle tips are outside their recommended pressure range. The example in each speed range is for 40 psi. Pressures are rounded to the nearest whole number.)

The 6.32 = √40

Speed	Pressure
Present-changed to:	Present-changed to:
10 mph to 9 mph	60 psi to 49 psi
	50 psi to 41 psi
(90% or .9 of original speed)	40 psi to 32 psi
	30 psi to 24 psi
$0.9 \times 6.32 = (5.69)^2 = 32.4$	20 psi to 16 psi
10 mph to 8 mph	60 psi to 38 psi
	50 psi to 32 psi
$0.8 \times 6.32 = (5.06)^2 = 25.6$	40 psi to 26 psi
	30 psi to 19 psi
	20 psi to 13 psi
10 mph to 7 mph	60 psi to 29 psi
	50 psi to 25 psi
$0.7 \times 6.32 = (4.42)^2 = 19.5$	40 psi to 20 psi
	30 psi to 15 psi
	20 psi to 10 psi
10 mph to 6 mph	60 psi to 22 psi
	50 psi to 18 psi
$0.6 \times 6.32 = (3.79)^2 = 14.4$	40 psi to 14 psi
	30 psi to 11 psi
	20 psi to 7 psi
10 mph to 11 mph	60 psi to 73 psi
	50 psi to 61 psi
$1.1 \times 6.32 = (6.95)^2 = 48.3$	40 psi to 48 psi
	30 psi to 36 psi
	20 psi to 24 psi
10 mph to 12 mph	60 psi to 86 psi
	50 psi to 72 psi
$1.2 \times 6.32 = (7.58)^2 = 57.5$	40 psi to 58 psi
	30 psi to 43 psi
	20 psi to 29 psi
10 mph to 13 mph	60 psi to 101 psi
	50 psi to 85 psi
$1.3 \times 6.32 = (8.22)^2 = 67.6$	40 psi to 68 psi
	30 psi to 51 psi
	20 psi to 34 psi
10 mph to 14 mph	60 psi to 118 psi
	50 psi to 98 psi
$1.4 \times 6.32 = (8.85)^2 = 78.3$	40 psi to 78 psi
	30 psi to 59 psi
	20 psi to 39 psi

where any spilled rinsate won't contaminate water supplies or other crops, or harm people or animals. If possible, rinse equipment at the application site and apply the rinsate to the labeled site.

Thoroughly rinse equipment with the recommended cleaning agent and carrier. Remove nozzles and screens, and flush the sprayer system twice with clean water. As much as 15 gallons of product can remain in the sprayer after the tank has been emptied, due to the volume in lines and filters. For large sprayers, 25 gallons of product may remain in the boom lines and filters. Collect rinsate from cleaned equipment and apply on a site labeled for the pesticide. Make sure the application will not exceed the amount allowed by the label.

Equipment rinsate may be used as a diluent for future mixtures of pesticides if:

- the pesticide in the rinsate is labeled for use on the target site where the new mixture is to be applied;
- the amount of pesticide in the rinsate plus the amount of pesticide product in the new mixture does not exceed the label rate for the target site;
- the rinsate is used to dilute a mixture containing the same or a compatible pesticide.

Rinsate cannot be added to a pesticide mixture if:

- the rinsate contains strong cleaning agents, such as bleach or ammonia, which might harm the plant, animal, or surface to which the pesticide will be applied;
- the rinsate would alter the pesticide mixture and make it unusable; for example, if the pesticides are physically or chemically incompatible.

If not reused, the rinsate must be disposed of as you would waste pesticides.

Store equipment properly. Basically, if you can store application equipment inside do so to prevent deterioration from sunlight. Also preventing application equipment from freezing will prevent repair issues in the spring.

Section 4: Calibrating Sprayers

LEARNING OBJECTIVES

After studying this section, you should be able to:

A. Understand which three factors affect the application equipment's output.

B. Understand spray equipment calibration.

C. Understand how to determine the output of a multiple-nozzle applicator.

D. Understand how to calibrate a single-nozzle applicator.

E. Understand there are multiple ways to calibrate spray equipment.

INTRODUCTION

Applying the correct rate of a product is an important part of obtaining good results with pesticide sprayers. In pesticide applications, too little product can mean poor control, while too much can mean crop injury, extra costs, possible residue on the crop, and/or carryover.

Many methods can be used to calibrate sprayers, including the ounce calibration and formula-based methods. With the ounce calibration method, 128th of an acre is sprayed and the spray is collected. When measured in ounces, the amount collected would be equal to the number of gallons applied per acre since there are 128 ounces in a gallon. Other methods involve using formulas which need to be remembered or recorded for easy use. These methods also may require converting some of the information you have.

The methods discussed here are simple relationships and do not require remembering formulas. However, you do need a general understanding of cross multiplication. The important thing is to be consistent: if you put an item on top of an equation on one side, the same item also goes on the top on the other side.

Three factors determine sprayer application rate:

1. speed,
2. nozzle spacing, and
3. nozzle output (determined by orifice size, pressure, and density of spray solution)

Definitions

- Speed = Length or distance covered divided by time
- Nozzle spacing = Width
- Nozzle output = The quantity applied/unit time

HOW TO DETERMINE SPEED IN MPH

To determine speed:

1 mile per hour (mph) is:

- 1 mile (5280 ft) in 1 hour (60 min)
- Or 1 mph = 5280 ft/60 min= 88 ft/min

Example 1

If we travel 440 feet (ft) in 30 seconds (sec) what is our speed?

The objective is to determine the distance traveled in 60 seconds (1 minute) and then divide by 88 (since 88 feet/minute is equal to 1 mph). D is the distance we are solving the equation for.

$$\frac{30\ \text{sec}}{440\ \text{ft}} = \frac{60\ \text{sec}}{D}$$

We cross-multiply to find the value of D

$$D = \frac{60 \times 440}{30 \times D}$$

$$D = \frac{26400}{30D}$$

$$D = 880\ \text{ft}/60\ \text{sec or}$$
$$D = 880\ \text{ft/min}$$

Since every 88 ft traveled in 1 min is equal to 1 mph, we divide 880 by 88 to get 10 mph.

$$D = \frac{880\ \text{ft/min}}{88} = 10\ \text{mph}$$

Example 2

If we travel 297 feet in 27 seconds, what is our speed?

$$\frac{27\ \text{sec}}{297\ \text{ft}} = \frac{60\ \text{sec}}{D}$$

$$D = \frac{297 \times 60}{27 \times D}$$

$$D = \frac{17820}{27}$$

$$D = 660\ \text{ft}/60\ \text{sec}$$

Divide by 88 since 1 mph = 88 ft/60 sec (1 min)

$$\frac{660}{88} = 7.5\ \text{mph}$$

Example 3

If we travel 660 feet in 1 minute and 15 seconds, what is our speed?

First convert 1 minute and 15 seconds to seconds:

60 + 15 = 75 seconds

$$D = 660\ \text{ft}$$

$$\frac{660 \times 60}{75 \times D}$$

$$D = \frac{660 \times 60}{75}$$

$$D = \frac{39600}{75}$$

$$D = 528$$

$$\frac{528}{88} = 6\ \text{mph}$$

HOW TO DETERMINE RATE PER ACRE

If the sprayer is moving at 6 mph, the distance covered in one minute is 528 feet
(6 mph × 88 ft/min = 528 feet).

To determine the area you cover with one nozzle in one minute if your sprayer has a 30-inch nozzle spacing:

- Distance traveled: 6 × 88 = 528 ft/min
- Nozzle Spacing: 30 in = 2.5 ft
- Area Sprayed: 1320 sq ft (2.5 ft × 528 ft/min)

Collect the output of several nozzles and determine the average output per nozzle. All nozzles should be within 10% of the manufacturer's rating for that nozzle. For example an XR11003 delivers 0.3 gpm at 40 psi. If it delivers more than 0.33 gpm or 42.24 (128 × 0.33) ounces/min at 40 psi, the nozzle should be replaced. Any nozzle delivering 5% above or below the average delivery rate for all the nozzles should be replaced.

In this next example, the average nozzle output is:

- 32 oz per minute or 32 (oz/min)
- one gallon = 128 oz or 128 (oz/gallon)
- Therefore the nozzle output is 0.25 gpm (gallons per minute) which is calculated by dividing the ounces/minute by number of ounces in a gallon

```
32 ÷ 128 = 0.25 gpm
```

What is the Rate per Acre?

One way to calculate application rate without remembering a formula is to use a relationship:
The amount applied and the area sprayed per minute are the same as the amount applied and the area sprayed per acre.

Rate (R) = gals/acre

Minute Box

0.25 gpm	=	R

We know ...

- Distance = 6 mph × 88 ft/min = 528 ft
- Nozzle spacing = 30 inches = 2.5 ft
- Area sprayed/minute = Distance × Nozzle spacing =
  - 528 ft × 2.5 ft =
  - 1,320 sq ft
- Sq ft per acre = 43,560 ft

$$\frac{\text{Avg. nozzle output gpm}}{\text{Area sprayed/Min}} = \frac{\text{Rate (R)}}{\text{Sq ft per acre}}$$

from minute box $\frac{0.25}{1{,}320} = \frac{R}{43{,}560}$ from acre box

Which is ...

$$\frac{0.25\ \text{gpm}}{1{,}320\ \text{sq ft/min}} = \frac{R}{43{,}560\ \text{sq ft/acre}}$$

Use cross-multiplication to rewrite the formula which leads us to ...

$$\frac{\text{Nozzle output gpm} \times 43{,}560}{\text{Area sprayed/min} \times \text{Rate (R)}}$$

$$R = \frac{0.25 \times 43{,}560}{1{,}320 \times R}$$

$$R = \frac{10{,}890}{1{,}320}$$

$$R = 8.25\ \text{gal/acre}$$

HOW TO DETERMINE THE ACRES SPRAYED PER MINUTE

- Travel distance in one minute = 616 ft
- Nozzle spacing = 30 inches (20 nozzles on sprayer)
- Nozzle output = 64 oz/min

What is travel speed?
(Remember 88 ft/min = 1 mph)

```
616 ÷ 88   =      7 mph
```

What is sprayer width?

```
20 nozzles × 2.5 feet (30-inch spacing) per nozzle = 50 ft
```

What is application rate (R)?

$$\frac{64 \text{ oz/min}}{128 \text{ oz/gal}} = 0.5 \text{ gpm}$$

Minute Box

0.5 gpm	=	R

We also know...

- Distance — 7 mph × 88 ft/min = 616 ft
- Nozzle Spacing — 30 in ÷ 12 = 2.5 ft
- Area sprayed/minute = Distance × Nozzle Spacing = 616 ft × 2.5 ft = 1,540 sq ft

$$\text{from minute box} \quad \frac{0.5}{1{,}540} = \frac{R}{43{,}560} \quad \text{from acre box}$$

This leads us to.....

$$\frac{\text{Nozzle output gpm} \times 43{,}560}{\text{Area sprayed/min} \times \text{Rate (R)}}$$

$$R = \frac{0.5 \times 43560}{1540 \times R}$$

$$R = \frac{21780}{1540}$$

$$R = 14.14 \text{ gal/acre}$$

To determine the area covered in one minute:

$$\frac{\text{Area sprayed/min} \times \text{number of nozzles}}{\text{Sq ft/acre}}$$

= 1,540 sq ft/nozzle/min × 20 nozzles
= (1,540 × 20) ÷ 43,560 sq ft/acre
= 0.71 acre/min

HOW TO DETERMINE NOZZLE SIZE NEEDED TO ACHIEVE THE OPERATIONAL GOAL

What nozzle size do I need to purchase with the following operational goals?

- Sprayer speed = 7 mph
- Nozzle spacing = 20 inches
- Application rate desired = 17 gpa
- Nozzle flow rate = F

Minute Box

F = gpm	=	17 gpa

We also know...

- Distance — 7 × 88 = 616 ft
- Nozzle spacing — 20 in ÷ 12 = 1.67 ft
- Area sprayed/minute = Distance × Nozzle spacing = 616 ft × 1.67 ft = 1029 sq ft

from minute box $$\frac{F}{1{,}029} = \frac{17}{43{,}560}$$ from acre box

$$\frac{\text{Area sprayed/Min} \times R}{43560 \times F}$$

This leads us to...

$$F = \frac{1029 \times 17}{43560 \times F}$$

$$F = \frac{17493}{43560}$$

$$F = 0.40 \text{ gpm}$$

This is the output from a 0.4 gpm nozzle, such as the XR8004, at 40 psi.

HOW TO ADJUST PRESSURE (PSI) TO MATCH NOZZLES

In the previous problem we needed 0.40 gpm by design; however, a 0.40 gpm nozzle may not always be available. **Nozzle output varies by the square root of the pressure**. For example, if you increase the pressure from 10 to 40 psi (a four-fold increase), you will only double the output.

$$\sqrt{10} \text{ psi} = 3.16 \text{ psi}$$

$$\sqrt{40} \text{ psi} = 6.32 \text{ psi}$$

$$\sqrt{4} = 2$$

If we need 0.4 gpm output and we only have 0.5 gpm nozzles, then we need to reduce the output by adjusting the pressure. Note: 0.4 gpm is 80% of 0.5 gpm nozzle output at 40 psi.

Now we take the square root of the original psi:

$$\sqrt{40} \text{ psi} = 6.32 \text{ psi}$$

and multiply by our 80% reduced output need.

$$6.32 \times 0.8 = 5.056$$

$$\sqrt{P} = 5.056$$

To solve for “P” you need to multiply the result by itself:

$$5.056 \times 5.056 = 25.6 \text{ psi}$$

So, a typical 0.5 gpm nozzle at 25.6 psi will give you 0.40 gpm.

HOW TO CALIBRATE A HAND SPRAYER—THE REFILL METHOD

First, fill sprayer with water to a known level, a mark you can later refill to accurately. (Best to spray test area over concrete so you can see evenness of application.)

Spray a test area which is

- 100 sq ft = 10 ft × 10 ft OR
- 250 sq ft = 10 ft × 25 ft OR
- 500 sq ft = 10 ft × 50 ft or 20 ft × 25 ft

Refill sprayer to same level as before. Measure the amount of water it takes to refill sprayer (to the mark from above.)

If the pesticide recommendation is 2 liquid ounces of product per 1,000 sq ft, the amount to include per 1,000 sq ft is 1/4 cup, 4 tablespoons, or 12 teaspoons.

If, during the test, 28 ounces of water were applied over 250 sq ft, how much water and pesticide should be added to a 3-gallon sprayer?

To find the volume of water applied to a 1,000 sq ft area, use the following formula:

$$V = \text{Output} \times 1000 \text{ sq ft}$$

$$\frac{\text{Amount of water applied per test area}}{\text{How much you will apply per 1000 sq ft}}$$

$$\frac{28 \text{ ounces} \times 1000 \text{ sq ft}}{250 \text{ sq ft} \times V}$$

$$\frac{28 \times 1000}{250 \times v}$$

$$V = 112 \text{ oz} \div 32 \text{ (oz/qt)} = 3.5 \text{ qt}$$

3.5 qt is the amount of water you would apply per 1000 sq ft.

Given the pesticide recommendation of 2 liquid ounces of product per 1,000 sq ft, the formula indicates that 2 oz of pesticide should be added for every 3.5 qt of sprayer capacity.

Ingredient	**Amount**	**Gallons**
28% Nitrogen	75 lb N	25.151
Balance Pro	2.0 oz	0.016
Fultime	2.25 qt	0.563
Gramoxone Extra	2 pt	0.250
Crop Oil Concentrate	1 qt	0.250
2,4-D 6 LVE	1/2 pt	0.063
Total		26.293 or 26.3 gal/acre

For example, if you were using a 3-gallon sprayer, you would add 6.9 oz (0.86 cup) of the pesticide to the sprayer.

```
3 gallons = 12 quarts (3 × 4 qt/gallon)

P (pesticide) = 2 oz per 3.5 qt
```

$$\frac{\text{12 qt in sprayer}}{\text{3.5 qt of capacity}} = 3.428$$

2 oz of P × 3.428 =
6.9 ounces (.86 cups)pesticide
for a 3 gallon sprayer

HOW TO CALIBRATE A SINGLE-NOZZLE HAND SPRAYER—THE 1/128TH METHOD

Sprayer calibration using the 1/128th method is relatively easy and can be completed quickly. The 1/128th method is also called the “ounce calibration” method. There is a direct ratio established when determining how much material is applied to 128th of an acre (128 equals the number of ounces in a gallon).

Because a gallon is equal to 128 ounces and the test area to be sprayed is 1/128 of an acre, ounces collected is equal to gallons per acre.

Measure out an area equal to 1/128 of an acre. Approximately 340 ft^2 or an area 18.5 feet by 18.5 feet.

Measure the time it takes to spray the measured area with water only. Repeat several times and take the average time.

Spray into a container for the same amount of time it took to spray the measured area. Measure the water collected in ounces. The amount collected in ounces equals gallons per acre.

Hand-Sprayer Example

- Measure area. 18.5 × 18.5 feet = 340 ft^2.
- Time to spray area = 51 seconds
- Amount collected = 40 ounces; therefore, 40 ounces = **40 gallons per acre**

Determining How Much Pesticide to Add to the Spray Mixture

The recommendation is to apply 1 quart of 2,4-D per acre.

The sprayer is applying 40 gallons per acre; therefore, you will need to add **1 quart of 2,4-D to each 40 gallons of water.**

Your sprayer only holds 1 gallon of spray mixture. So how much pesticide will you need to add to the gallon of water?

1 quart (32 ounces) divided by 40 gallons = 0.8 ounces.

1 fluid ounce = 2 tablespoons; therefore, you will need approximately 2 tablespoon of 2,4-D per gallon of water.

1 fluid ounce also = 29.57 milliliters (ml); therefore, if measuring in ml, you will need 0.8 ounces times 29.57 ml per ounce = **24 ml per gallon of water**.

How much area will 1 gallon spray? There is 43,560ft^2 per acre. If 40 gallons will spray one acre then one gallon will spray an area 1/40 that size or 43,560 ft^2 divided by 40 = **1,089ft^2**.

HOW TO DETERMINE THE DENSITY OF SPRAY SOLUTION

The rate a fluid flows through a spray orifice varies with its density. Since all the tabulations are based on spraying water, which weighs 8.34 lb per U.S. gallon, conversion factors must be used when spraying solutions which are heavier or lighter than water. To determine the proper size nozzle for the solution to be sprayed, first multiply the desired GPM or GPA of solution by the water rate conversion factor. The conversion factors are the square root of specific gravity.

Weight of Solution	Specific Gravity	Conversion Factors
Water: 8.34 lb per gallon	1.00	1.00
28% nitrogen: 10.65 lb per gallon	1.28	1.13
32% nitrogen: 11.06 lb per gallon	1.33	1.15

For example, the specific gravity of 28% nitrogen, which weighs 10.65 lb/gal, is:

$$\frac{10.65 \text{ (Wt of 28-0-0/gal)} = 1.28 \text{ specific gravity}}{8.34 \text{ (Wt of water/gal)}}$$

√ 1.28 is the conversion factor for 28-0-0 fertilizer or 28% nitrogen.

Example on Using Conversion Factor

Desired application rate is 20 GPA of 28% nitrogen:

$$\text{GPA (solution)} \times \text{Conversion factor} = \text{GPA (water)}$$
$$20 \text{ GPA (28\%)} \times 1.13 = 22.6 \text{ GPA (water)}$$

So, a nozzle size should be selected that will supply 22.6 GPA of water at the desired pressure, speed, and nozzle spacing.

Using another example, the following has been recommended for an ecofallow corn field:

75 lb of nitrogen from 28% UAN
Density of 28% N = 10.65 lb/gal
10.65 × 0.28 = 2.982 lb N/gal

$$\frac{75 \text{ lb N}}{2.982 \text{ lb N/gal}}$$

= 25.151 gal of 28% solution

To determine how this will spray out and how many gallons of water are needed to get 26.3 gal/Acre of this spray solution, three steps are required. If connected to a rate controller, it will change the pressure to adjust the output if you do not make any other adjustment such as speed.

1. To determine specific gravity, weigh an equal amount of this spray solution and an equal amount of water.

Spray solution = 13.08 lb
Water = 10.3 lb

Determine specific gravity weight of spray solution:

$$\frac{13.08 \text{ lb (wt of spray solution)}}{10.3 \text{ lb (wt of water)}}$$

= 1.27 specific gravity

2. Determine conversion factor $\sqrt{1.27} = 1.13$

3. Determine the quantity of water to calibrate sprayer:

Spray rate × Conversion factor = Water amount equivalent:

26.3 gal/A × 1.13 = 29.6 gal/A

Now you need to calibrate the equipment to apply 29.6 gal of water.

Remember, if you have a flow meter and it has been calibrated with water, it will read the same for a spray solution as with water.

Section 5: Pesticide Laws and Regulations, Environmental Safety

LEARNING OBJECTIVES

After studying this section, you should be able to:

A. List the three common ways pesticides enter the body.

B. State the minimum personal protective equipment for mixing, loading, or applying pesticides.

C. Define Restricted Entry Interval (REI).

D. Describe the importance of keeping detailed records on pesticide applications, and how long records must be kept.

E. Provide an example of when the Application Exclusion Zone must be implemented.

F. Describe two types of water pollution.

G. Identify three ways to reduce surface water runoff.

H. Identify properties of a pesticide that affect its ability to move off site.

I. Identify four field characteristics that can affect a site's potential for runoff or leaching.

INTRODUCTION

Pesticides (insecticides, herbicides, fungicides, desiccants, growth regulators, repellents, etc.) are regulated by law to help minimize injury to humans, nontarget animals and plants, and to protect water, soil, and air.

In the US, laws regulate pesticide manufacturing, labeling, sales, storage, transportation, use, and ultimately, disposal. The **Federal Insecticide, Fungicide and Rodenticide Act** (FIFRA) is the primary law regulating pesticides. Modeled after FIFRA, the **Wyoming Pesticide Control Act** regulates pesticide use in Wyoming. The act is overseen by the Wyoming Department of Agriculture (WDA).

Pesticide labels are legally enforceable. Every product label approved by EPA will have the following statement printed in the Directions for Use section: "It is a violation of Federal law to use this product in a manner inconsistent with its labeling" (Figure 5.1, page 52).In other words, "The label is the law."

In this section, you will learn about regulatory issues pertaining to pesticide applicators certified in Category 901, Agricultural Pest Control. The emphasis is on human safety and water protection. Category 901 applicators are responsible for pest management of agricultural sites such as field crops and pastures. As a Category 901 applicator, you will deal primarily with insects, diseases, weeds and mammals that can damage crop plants, reduce plant quality, and have the potential to economically impact food supplies grown in the US.

Directions for Use

It is a violation of federal law to use this product in a manner inconsistent with its labeling. DO NOT apply this product in a way that will contact workers or other persons, either directly or through drift. Only protected handlers may be in the area during application. For any requirements specific to your state or tribe, consult the agency responsible for pesticide regulation.

Unless otherwise directed in supplemental labeling, all applicable directions, restrictions, precautions and Conditions of Sale and Warranty are to be followed. This labeling must be in the user's possession during application.

Figure 5.1. Directions for use section.

AGRICULTURAL USE REQUIREMENTS

Use this product only in accordance with its labeling and with the Worker Protection Standard, 40 CFR part 170. This Standard contains requirements for the protection of agricultural workers on farms, forests, nurseries, and greenhouses, and handlers of agricultural pesticides. It contains requirements for training, decontamination, notification, and emergency assistance. It also contains specific instructions and exceptions pertaining to the statements on this label about personal protective equipment (PPE) and restricted-entry interval. These requirements only apply to uses of this product that are covered by the Worker Protection Standard.

Do not enter or allow worker entry into treated areas during the restricted entry interval (REI) of 24 hours.

Exception: if the product is soil-incorporated, the Worker Protection Standard, under certain circumstances, allows workers to enter the treated area if there will be no contact with anything that has been treated, such as plants, soil, or water is: Coveralls over short-sleeve shirt and short pants, chemical-resistant gloves made of waterproof material such as polyethylene or polyvinyl chloride, and chemical-resistant footwear plus socks.

Figure 5.2. WPS applies when Agricultural Use Requirements wording is on a pesticide label.

Category 901 also includes certification for chemigation for both commercial and private applicators.

Applying pesticides requires following vital steps to protect applicators, non-targets, and the environment. Always follow label instructions for proper **Personal Protective Equipment** (PPE) to protect yourself; and for proper use as well as application methods to protect children, wildlife, and endangered species from pesticide exposure. Agricultural pesticides also have the potential to contaminate water sources as seen later in this section. Category 901 applicators need to be particularly careful about this.

WORKER PROTECTION STANDARD (WPS)

The federal Worker Protection Standard (WPS) is intended to reduce the risk of illness or injury to pesticide handlers and agricultural workers. Under WPS, people hired to mix, load, service application equipment, apply, or dispose of a pesticide are called handlers. Workers are those hired to perform manual labor such as thinning, pruning, weeding, roguing, detasseling, hand harvesting, or irrigating.

Owners of agricultural establishments and members of their immediate families are exempt from many, but not all, WPS requirements. See EPA's "How to Comply with the Worker Protection Standard for Agricultural Pesticides" manual at https://www.epa.gov/pesticide-worker-safety/pesticide-worker-protection-standard-how-comply-manual.

WPS applies whenever a pesticide with an Agricultural Use Requirements box (Figure 5.2) on the label is used on an agricultural establishment such as a farm.

All WPS 2015 revisions became effective January 1, 2018. The following are revision highlights:

- Farm workers and handlers must receive EPA-approved pesticide safety training every year.
- Safety training covers how to prevent take-home exposure from work clothes, etc.
- PPE must be provided by employers.
- When a pesticide label requires the use of a respirator, the handler must have a medical evaluation, fit test, and training.
- Applicators must be at least 18 years old to apply pesticides.
- No-entry signs must be posted when certain hazardous pesticides are used, until the Restricted Entry Interval (REI) has passed.
- Pesticide application must be **suspended** if farm workers or others are nearby.
- Workers and handlers or their representatives can access information at a central location or through records, to be kept for two years.
- Farms must provide specific amounts of water for washing and decontamination.
- The employer must provide transportation to a nearby medical facility when there is a possibility that a handler or worker has been poisoned or injured by a pesticide.
- Examples of employers who may be required to follow WPS include:
  - Managers or owners of an agricultural establishment, such as a farm.
  - Labor contractors (crop advisors, detasseling companies, etc.).
  - Commercial pesticide-handling establishments, including self-employed applicators.

Employers are obligated under WPS to take steps to reduce pesticide-related illness and injury. One main area of employer responsibility is safety training. The safety training provides employees with a basic understanding of how they might encounter pesticides at work, and how to avoid unnecessary exposure.

What are the most common ways pesticides enter the body? By **ingesting, inhaling, and through skin and eyes**. The most common is dermally, through the skin. The groin and head are the most vulnerable areas for pesticides to enter the body. That's why PPE and safety training (Figure 5.3, page 54) are so important.

Employers must provide PPE and decontamination site/supplies to workers and handlers as required by the pesticide label, and provide notification of restrictions during application and to treated areas.

At a minimum, PPE includes long-sleeved shirt and long pants; chemical-resistant, waterproof gloves; socks plus chemical-resistant footwear. Protective eyewear and respirators must be used when required by the label. To use a respirator, a handler must first have a medical evaluation, fit test, and training that conforms to federal requirements. These must be supplied or paid for by the employer.

The decontamination site must include soap, water, hand towels, and, for handlers, a change of coveralls. The decontamination site for workers must include a minimum of **1 gallon of water per worker; the decontamination site for handlers and early-entry workers must provide a minimum of 3 gallons of water per person**. Employees are encouraged to wash their hands before eating, smoking, or using the restroom.

Emergency eye flushing supplies also must be provided at any site where handlers are mixing

Handler safety training must include:

- Format and meaning of information on pesticide labels, particularly the precautionary statements about human health hazards.
- Hazards resulting from pesticide exposure including acute effects, chronic effects, delayed effects, and sensitization.
- Routes through which pesticides can enter the body.
- Signs and symptoms of common types of pesticide poisoning.
- Emergency first aid.
- How to obtain emergency medical care.
- Routine and emergency decontamination procedures.
- Appropriate use of PPE.
- Prevention, recognition, and first-aid treatment of heat-related illness.
- Instructions on how to use application equipment.
- Safety requirements for handling, transporting, storing, and disposing of pesticides; and spill cleanup.
- Environmental concerns such as drift, runoff, and non-target effects.

Figure 5.3. Handler safety training is intended to protect people from pesticide injuries.

or loading a pesticide that requires protective eyewear, or the mixing and loading of any pesticide using a closed system operating under pressure. **Additionally, 1 pint of water in a portable container must immediately be available to each handler**.

WPS requires that specific information must be displayed at a central location on the agricultural establishment.

The displayed information must include:

- pesticide safety information, such as found on a federally approved safety poster as provided by EPA as of Jan. 1, 2018;
- name, address, and phone number of a nearby emergency medical facility;
- access to safety data sheets (SDS) for any pesticides applied to work sites within the past 30 days.

If a worker or handler is suspected of being poisoned or injured by a pesticide, the employer is responsible under WPS to transport the victim to a nearby medical facility and provide the medical personnel with information on pesticide(s) that might be involved. This includes copies of the SDS, product name, EPA registration number, active ingredients, a description of how the pesticide was used, and information about employee exposure.

Commercial applicators who apply pesticides to privately owned land must provide the producer with information to display at a central location for employees (product name, EPA registration number, active ingredient(s), treatment site location, date, start and estimated end time of application, and the REI).

APPLICATION EXCLUSION ZONE, RESTRICTED ENTRY INTERVAL

The revised WPS includes the Application Exclusion Zone (AEZ) and Restricted Entry Interval (REI).

Application Exclusion Zone (AEZ)

The AEZ (Figure 5.4) is designed to protect people from coming into contact with pesticides. Agricultural employees must keep workers and others out of the treated area and AEZ that are on the owner's property. **The AEZ is measured from the application equipment, and moves like a halo with the equipment**. The AEZ extends 100 feet from equipment for spray applications using extremely fine, very fine, or fine droplet sizes. If persons come within 100 feet of the application equipment, the applicator must suspend (temporarily stop) the application until the applicator can ensure the pesticide will not contact anyone in the AEZ (based on wind direction, for example). This is for areas that extend beyond the boundary of the establishment, such as a roadway. An applicator cannot resume application while workers or others on the establishment are within the AEZ.

Restricted Entry Interval (REI)

The REI is the amount of time that must pass after a pesticide application before anyone other than a trained and equipped handler involved with the application, and wearing proper PPE, may enter the treated area. Listed on the pesticide label under the Agricultural Use Requirements, the REI is based on the toxicity of the active ingredient and tasks involved. In most cases, REIs range from 4 to 72 hours. Keeping people informed should eliminate potential harm from REI incidents.

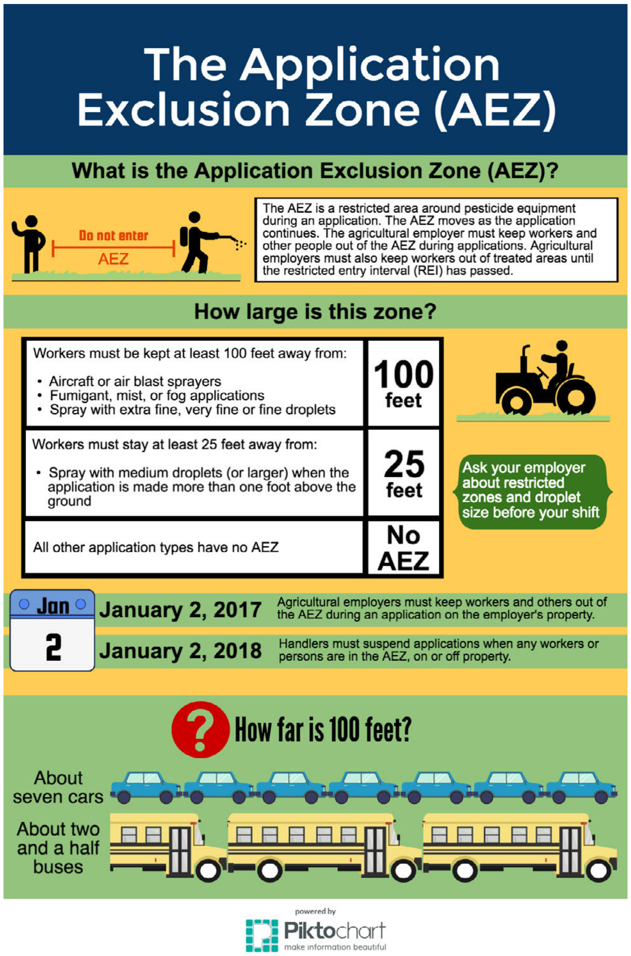


Figure 5.4. The AEZ is the area around the application equipment, which moves as the equipment moves. The size of the AEZ varies with application factors, and can be as much as 100 feet from the application equipment (Image courtsey: *http://pesticideresources.org/wps/guide/aez/infographic.png*.)

LEGAL USES OF A PESTICIDE

While Wyoming has no law limiting pesticide application when the wind is above a certain speed, many product labels address this issue. Some labels may state a specific wind speed above which application is not allowed. Most labels advise the applicator to avoid application under conditions that favor drift. Some will mention specific sensitive sites that must be avoided or sensitive species around which special care should be taken when applying pesticides. If the label does not mention wind speeds, most recommendations are to stop spraying if wind speeds are less than 3 mph or exceed 10 mph.

In the end, a person must read and become familiar with the product label because the label establishes the legal conditions for use. It is also a violation of the Wyoming pesticide control act and inconsistent with its labeling. Remember — **the label is the law**!

A few exceptions to these general statements include:

1. use of the product at dosages, concentrations, or frequencies less than those specified on the label (unless the label specifically prohibits lower rates);
2. application against a pest not listed on the label, as long as the site is specified on the label (unless the label specifically prohibits the use against a particular pest);
3. application by an alternate method (unless prohibited by the label), except that chemigation must be listed as one of the application methods allowed;
4. use of mixtures of pesticides or pesticides with fertilizers, if they are not prohibited by label directions.

The following are examples of common mandatory label statements:
Applicators and other handlers must wear: long-sleeved shirt, long pants, shoes plus socks, and protective eyewear. Do not add surfactants.

The following are examples of common optional label language:
User should wash hands before eating, drinking, chewing gum, using tobacco, or using the toilet. Ammonium sulfate, drift control additives, or dyes may be added.

Figure 5.5. Handler safety training is intended to protect people from pesticide injuries.

Every pesticide label contains several sections intended to guide the applicator toward personal and environmental safety, and protection of non-target species. Some of this guidance is specific and mandatory. Other guidance statements appear as recommendations rather than requirements. **Mandatory statements** give specific instructions, often using words like *do not* or *must*. Mandatory statements represent portions of the label that have significant legal weight. In contrast, **optional statements** may include words such as *should*, *may*, or *it is recommended*, and can be considered good advice rather than legal requirements (Figure 5.5).

Understand that years of research are behind the language that appears on a product label approved by EPA. The approval process is based upon the ability to guarantee with a reasonable amount of certainty that, when the product is used according to label directions, the applicator, other species, and the environment will not be harmed. When a pesticide product label is approved, both the manufacturer and EPA consider the applicator to bear full responsibility for proper application.

STORAGE AND DISPOSAL

The secure storage of pesticides, especially RUPs, has received increased attention. Although only a few pesticides have labels that require they be stored under lock and key, this is worth considering for all pesticides.

Allowing a pesticide to freeze may affect its viability. If emulsified crystals are present after thawing, the pesticide should not be used as it will be ineffective. Rather, properly dispose of it according to label directions.

COMMERCIAL AND NONCOMMERCIAL RECORDKEEPING REQUIREMENTS

Recordkeeping is a very important part of pesticide application for personal safety and liability reasons. It is better to over-document than under-document. For example, if a form requires the **start time and environmental conditions of the application, it's a good idea to include the end time and environmental conditions even if not asked for on the form**, as conditions may change during the course of application. By law, the following information must be recorded, within 48 hours of application. Records must be kept for at least two years and should be kept at the principal place of business.

- WDA pesticide license number
- name & address of person for whom the application was made, and if applicable, who purchased the pesticide(s)
- location of the pesticide application
- commodity/site treated
- pest controlled
- pesticide applied, including:
    - brand name of product
    - EPA registration number
    - total amount of pesticide used
    - rate of application
    - method of application
- date and time of application
- weather conditions: (at time of application)
    - temperature
    - wind direction and velocity
- such records shall be open for inspection at any time during business hours, by a WDA designated employee.
- documentation of the Restricted Entry Interval (REI).

ENVIRONMENTAL SAFETY

Wyoming Weed and Pest Control Act of 1973

Wyoming has a state law that requires landowners to effectively control weed species listed as noxious weeds. Wyoming noxious weed list can be found at: https://www.wyoweed.org/weeds/state-designated-weeds.

Landowners and commercial applicators should be familiar with these weeds and appropriate methods for their control.

Protecting Water Resources

Pesticides don't always stay where they are applied — many have properties that allow them to move easily through the soil beyond the root zone, or to move off the field in runoff solution or attached to sediments. Some products have human or ecological health hazards, and are of concern if found in concentrations that affect drinking water supplies or aquatic life. The Wyoming Pesticide Act's intent is to regulate "the labeling, distribution, storage, transportation, use, application, and disposal of pesticides for the protection of human health and the environment." To this end, the statute allows the Wyoming Department of Agriculture to further regulate specific pesticides if it is determined that:

- harm to humans or the environment would result without further regulatory restrictions;
- the state's water quality standards are exceeded; or,
- additional restrictions are needed to meet the Pesticide Act, FIFRA, or any plan adopted under the Pesticide Act or FIFRA.

These statements clearly show that in order to keep the wide variety of pesticides needed to protect Wyoming's agriculture, **it is up to the pesticide**

applicator and the landowner to ensure that off-site movement is kept to a minimum.

Types of pollution and the label

There are two types, or sources, of water pollution: point sources and nonpoint sources. **Point sources** can generally be thought of as "end of pipe" events, such as when a wastewater treatment plant discharges to a stream — there is a definite, identifiable source of the pollutant.

Because pesticides are rarely applied in this manner, point source events involving pesticides are usually accidental, such as a spill caused by a disconnected hose or a vehicle accident. Regardless of the cause, these types of events must be reported to the proper authorities. For spills involving roads or rights-of-way, contact the Wyoming Highway Patrol at 1-800-525-5555.

Most labels contain specific language to prevent or reduce the potential for point source contamination should a pesticide spill occur. An example would be "Do not mix, load, or apply within 50 feet of a well." The EPA and manufacturer have placed such language on the labels of certain products to ensure their safe use.

Nonpoint sources of pollution are less localized and can originate from a larger area. An example would be the presence of excessive sediments or pesticides in a rural stream. The source in this scenario is likely agricultural runoff, but it would be hard to pinpoint exactly which fields were contributing to the problem. An example would be products containing the active ingredient atrazine, often used in agricultural settings. Due to its **tendency to leach and contaminate** groundwater and run off into streams and reservoirs, products containing atrazine have very specific language concerning setbacks from wells and streams, precautions about use in areas with shallow water tables, and requirements for use around tile outlets. The label directions specifically prohibit its use under conditions that might pollute groundwater and surface water. The continued availability of atrazine products lies with applicators using these products according to their label directions.

Pesticide labels often have specific language to reduce the potential for nonpoint source contamination. An example might include a label for products containing atrazine, which says, "Product must not be applied within 66 feet of the points where field surface runoff enters perennial or intermittent streams and rivers or within 200 feet of natural or impounded lakes and reservoirs. If this product is applied to highly erodible land, the 66-foot buffer or setback from runoff points must be planted to crop or seeded with grass or suitable crop."

Prevent off-site movement of pesticides

Many steps can be taken to help prevent pesticides from leaving the application site. An applicator should use common sense and knowledge gained from previous experience as one important step toward this goal. The applicator and landowner are likely to be most familiar with, and therefore the most responsible for, site specific conditions that may lead to off-site pesticide movement.

Integrated Pest Management, or IPM, is an important concept covered extensively in Section 1 of this manual. By employing field scouting and comparing the results to published economic thresholds, pesticide applications can be limited to situations where significant economic threats exist from pests. IPM will likely reduce the number of pesticide applications made, and therefore, the potential for water contamination. Other management tools that should be considered by the applicator are reduced rates and split applications (if allowed by the label), tank mixes of two or more pesticides with differing modes of action, and alternating the use of a particular pesticide from year to year. **These three options** likely will reduce the amount of pesticide product applied at any one time, thus reducing the amount available to leach or runoff.

Other pesticide management options to protect waters include conservation practices such as filter strips, grassed waterways, crop rotations, crop residue management, irrigation water scheduling and management, and terraces.

A pesticide's ability to move in the environment is through its solubility, persistence, and ability to adsorb to soil and organic matter. Knowing these three properties and being able to compare them to one another allows the applicator to incorporate this information in the pesticide selection process. Much of this information can be found in computer programs such as USDA's Win-PST software (http://go.usa.gov/Kok). Such tools can help in looking up information and applying it to real situations.

Conditions at the application site also affect whether a pesticide will stay or move off-site. Field characteristics such as soil texture, percent slope, percent organic matter, and the presence of cracks, channels, or other large openings in the soil profile combine to give each site a relative potential for runoff and leaching. This ranking can then be used with the pesticide's properties to get an overall relative risk for any pesticide-site combination.

PROTECT NONTARGET PLANTS AND ANIMALS

Non-targets are plants and animals for which you don't intend to apply pesticides. They can be exposed through direct spray, drift, or contact with runoff water that contains pesticides. Besides people, pets, and wildlife, non-targets of special concern include pollinators such as bees and butterflies, found in both rural and urban settings.

Most pesticides are at least somewhat toxic to honey bees and other pollinators; however, the degree of toxicity varies considerably from product to product. Insecticides generally are the cause of a bee kill; herbicides, fungicides, and defoliants present relatively minor danger to bees if used according to label directions.

Pollinators

Pollinators are very important to the food supply and the economy. Nationwide, insect pollinators help produce foods amounting to $20 billion annually. An estimated 70% of the world's crop plants ranging from coffee to melons depend on pollination.

Pesticide toxicity to bees and other beneficial pollinators is a growing concern. Because pollinators may fly great distances when foraging for pollen, they can be exposed to pesticides even when an applicator has taken precautions to limit exposure. Try to avoid using pesticides known to be toxic to pollinators. **Also try to apply pesticides in early morning, late evening, or at night, when bees and pollinators are least likely to be foraging**. Pollinators are attracted to plants in bloom even in roadsides and weed patches. If possible, control pests before bloom or after bloom is complete. If you need to apply pesticides to flowering plants and it is allowed by the label, apply in evenings using an insecticide with a short residual.

In an effort to protect bees and pollinators, the U.S. Environmental Protection Agency (EPA) announced that the use of some pesticide products would be prohibited when bees are present. Insecticide products that contain the active ingredients imidacloprid, clothianidin, and thiamethoxam (in the neonicotinoid group of insecticides) have bee advisories on their labels. EPA developed a pollinator advisory box for these labels (Figure 5.6, page 60) to alert applicators of specific use restrictions and instructions to protect bees and other insect pollinators. The advisory box includes reminders that bees and other insect pollinators forage on plants that are flowering, shedding pollen, or producing nectar. The label also encourages applicators to minimize exposure of bees and other insect pollinators to the product when they are foraging on plants around the application site. Recommendations include minimizing drift to attractive habitat around the application site and being cautious of drift toward beehives.

Make every effort possible to notify beekeepers no less than 48 hours prior to the time of the planned application so that the bees can be removed, covered, or otherwise protected before you use a pesticide.

SUMMARY

Safety is the main concern when dealing with insect, weed, and disease pesticides to help protect Wyoming crops. Always follow label directions and avoid exposing yourself, other people, animals, and non-target plants to pesticides. Protect yourself by wearing proper PPE. Keep detailed records to show you are a responsible, certified applicator, and to protect yourself from liability.

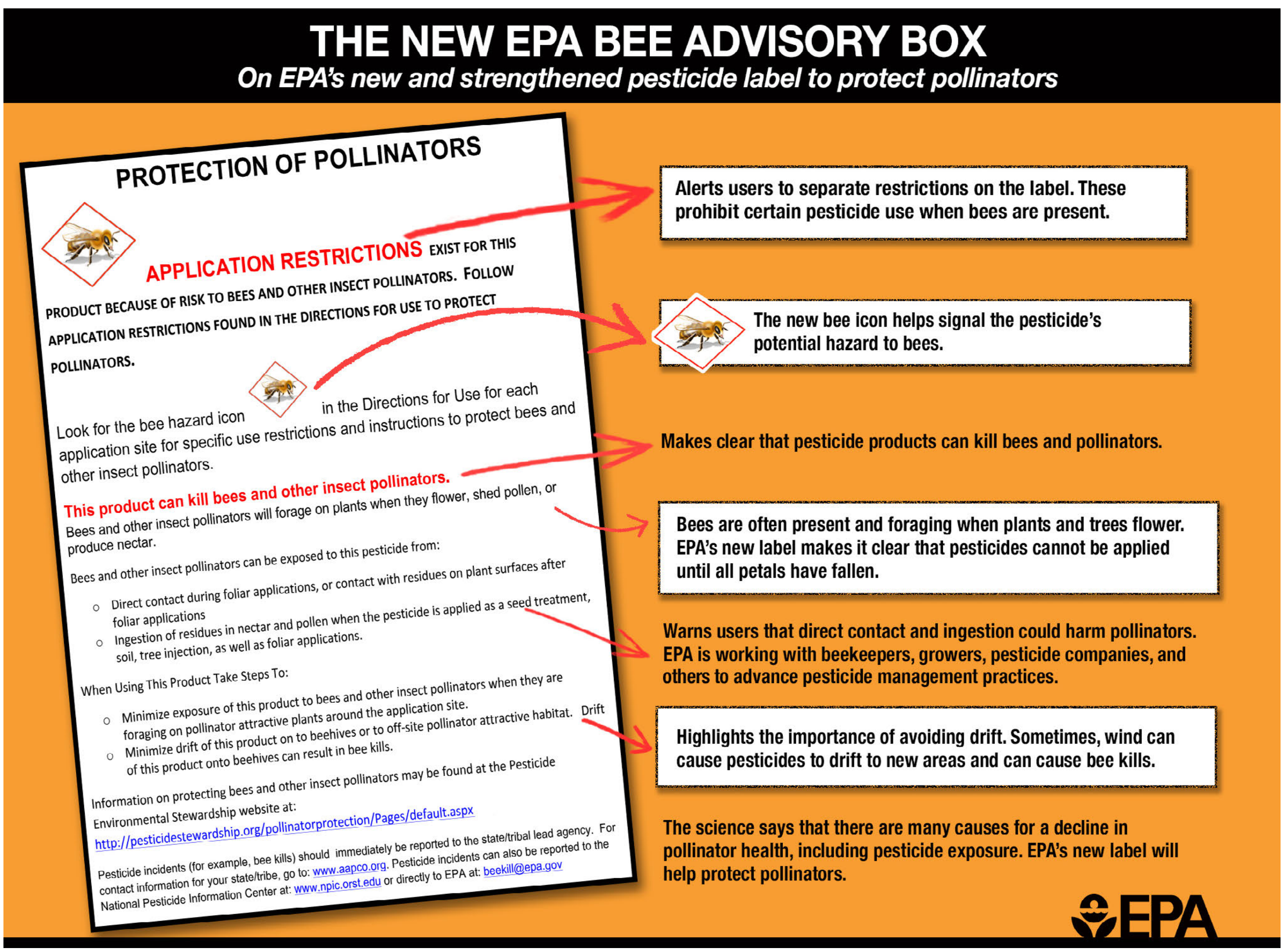


Figure 5.6. Bee advisory box. Some labels have information on how to protect pollinators when using the product. Visit https://www.epa.gov/pollinator-protection/new-labeling-neonicotinoid-pesticides.

Know the insects, weeds, diseases, or mammals with which you are dealing. Determine if pest control is even needed, and if so, the best method or methods. If pesticides are needed, follow the label and correctly calibrate the equipment, using the right applicator, nozzles, rate, and under correct conditions. Be aware of how to protect one of Wyoming's most precious resources — water, both groundwater and surface water. Understand how pesticides can move in water or air, to prevent them from running off or drifting.

Develop a mindset that your desire and goal is to follow the best research-based knowledge that science has to offer to enhance crop production, while protecting yourself and the environment. Then you are doing your job and all will benefit.

Section 6: Category 901A — Weed Control

LEARNING OBJECTIVES

After studying this section, you should be able to:

A. Describe the differences among annual, biennial, and perennial weeds.

B. Describe the differences between herbaceous and woody perennial plants, and grass and broadleaf weeds.

C. Describe the factors that affect soil-applied herbicide rates.

D. Explain how to minimize herbicide carryover.

E. Describe the factors that determine herbicide placement.

F. Explain when post-emergence foliar-applied herbicides are applied and how they control weeds.

G. Describe what affects the uptake of foliar herbicides in the plant.

H. Describe how to conduct a pesticide compatibility (jar) test.

I. Explain why spray adjuvants are tank-mixed with herbicides.

J. Describe herbicide translocation and when it is most effective in a plant.

K. Describe ways to minimize the development of herbicide-resistant weed populations.

INTRODUCTION

Uncontrolled early-emerging weeds are estimated to cause yield losses of 10% to 30% in corn, 10% to 20% in sorghum, and 5% to 10% in small grains. With herbicide-resistant weeds on the rise, corn and other crops can receive more than one herbicide application. About 30% to 40% of these applications are custom-applied, with many farmers depending on commercial applicators to help them plan weed control programs.

This section deals with weed problems that occur in field crops, though also may apply to rangeland, alfalfa, and hay. Principles of cultural, mechanical, and chemical weed control in conventional and conservation tillage systems are also discussed. Detailed information about herbicides and their use in field crop production has been provided to help select and properly apply herbicides, to help avoid the development of herbicide-resistant weed populations, and prevent carryover and drift.

TYPES OF WEEDS

Weeds are classified according to their life cycle. These include annuals, biennials, and perennials. To complete their life cycle, annual weeds require one year, biennial weeds require two years, and perennial weeds live for more than two years. Seeds are the primary way that weeds spread from one location to another, although many perennials propagate vegetatively once they are established.

Each year, a single weed plant may produce thousands of seeds that re-infest the area. Control measures must be carried out well ahead of seed formation to prevent yield loss, harvesting difficulties, or of weed seed in soil (seed bank) buildup for coming years. It is recommended to treat weeds within the first 10 days after emergence as seedlings or before they reach 4–6 inches tall, as the effectiveness of most post-emergence herbicides decreases as weeds get bigger. See examples of many weed types found in row crops, small grains, hay fields, and pastures in Table 6.1, page 64.

Annual Weeds

Annual weeds usually thrive under cropping conditions where the soil is disturbed and the crop stand is spotty or poor in quality. They are most prevalent where they can complete their lifecycle easily. Summer annual (warm-season) weeds such as velvetleaf or pigweed emerge early to late spring. They commonly occur in row crops and in small grain fields and pastures where stands are thin. These weeds quickly become established and compete effectively with the crop for nutrients, water, and sunlight.

Winter Annuals

Winter annuals such as downy brome or pennycress emerge in the fall. They occur in wheat, forages, and pastures, as well as no-till corn, soybean, and sorghum fields. Annual weeds are most easily controlled in the seedling stage and become progressively more difficult to control as they mature. The most effective treatment time for winter annual weeds is in the fall after emergence.

Biennial Weeds

Biennial weeds such as musk thistle or poison hemlock are commonly found in no-till fields or in pastures and fencerows. They are not a problem in annually tilled areas because they need two growing seasons to complete their life cycle. Biennials are most susceptible to chemical control as seedlings, or while in the rosette stage during the fall of their first year or spring of their second year.

Perennial Weeds

Perennial weeds are classified as either woody or herbaceous, depending on whether the aboveground parts overwinter.

Woody Perennials

Woody perennials have aboveground parts year round, herbaceous perennials do not. The aboveground parts of these latter plants last for a growing season and dieback before winter.

Herbaceous Perennials

Herbaceous perennials such as field bindweed or Canada thistle can be found in cropping systems, pastures, and roadsides; woody perennials such as poison ivy are usually restricted to fencerows, pastures, and roadsides that are not mowed or tilled frequently. However, fields under no-till production for several consecutive years may become invaded by herbaceous, and then by woody, perennials.

Herbaceous perennials have overwintering, underground vegetative parts known as propagules. These propagules include rhizomes, tubers, budding roots, and bulbs. They contain stored food for new shoots developing from buds on the propagules. Like annual and perennial seedlings, perennial weeds are quite susceptible to herbicide applications in the seedling stage. However, perennial species begin to produce vegetative propagules four to six weeks after seed germination. Soon after, the plants can survive the destruction of aboveground parts by producing new shoots from buds on the propagules. Therefore, these shoots should be destroyed by mowing or with herbicide applications before the plants can develop sufficient foliage to replenish stored food (carbohydrates) in their underground parts. This process may need to be repeated several times to kill perennial plants.

Table 6.1. Field Crop Weeds

COMMON WEEDS IN ROW CROPS	
GRASS WEEDS—ANNUAL	
Foxtail species	*Setaria species*
Fall panicum	*Panicum dichotomiflorum*
Field Sandbur	*Cenchrus Longispinus*
Crabgrass species	*Digitaria species*
Shattercane	*Sorghum bicolor*
Barnyardgrass	*Echinochloa crus-galli*
Volunteer corn	*Zea maize*
Wild proso millet	*Panicum miliaceum*
GRASS AND GRASSLIKE WEEDS—PERENNIAL	
Johnsongrass	*Sorghum halepense*
Yellow nutsedge	*Cyperus esculentus*
BROADLEAF WEEDS—HERBACEOUS PERENNIAL	
Common milkweed	*Asclepias syriaca*
Field bindweed	*Convolvulus arvensis*
Hedge bindweed	*Calystegia sepium*
Canada thistle	*Cirsium arvense*
Honeyvine milkweed	*Ampelamus albidus*
Horsenettle	*Solanum carolinense*
Hemp dogbane	*Apocynum cannabinum*
Jerusalem artichoke	*Helianthus tuberosus*
Swamp smartweed	*Polygonum coccineum*
BROADLEAF WEEDS—ANNUAL	
Common cocklebur	*Xanthium strumarium**
Velvetleaf	*Abutilon theophrasti*
Smartweed species	*Polygonum species*
Pigweed species	*Amaranthus species*
Jimsonweed	*Datura stramonium**
Morningglory species	*Ipomoea species*
Common lambsquarters	*Chenopodium album*
Ragweed species	*Ambrosia species*
Eastern black nightshade	*Solanum ptycanthum**

COMMON WEEDS IN SMALL GRAINS	
GRASS WEEDS—WINTER ANNUAL	
Cheat	*Bromus secalinus*
Downy brome	*Bromus tectorum*
Jointed goatgrass	*Aegilops cylindrica*
BROADLEAF WEEDS—SUMMER ANNUAL	
Common ragweed	*Ambrosia artemisiifolia*
Giant ragweed	*Ambrosia trifida*
Kochia	*Kochia scoparia*
Lambsquarters species	*Chenopodium species*
Smartweed species	*Polygonum species*
Wild buckwheat	*Polygonum convolvulus*
BROADLEAF WEEDS—WINTER ANNUAL	
Common chickweed	*Stellaria media*
Henbit	*Lamium amplexicaule*
Pepperweed species	*Lepidium species*
Field pennycress	*Thlaspi arvense*
Tansy Mustard	*Descurainia pinnata*
Wild mustard	*Brassica kaber*
BROADLEAF WEEDS—HERBACEOUS PERENNIAL	
Curly dock	*Rumex crispus*
Canada thistle	*Cirsium arvense*
Field bindweed	*Convolvulus arvensis*

COMMON WEEDS IN HAY FIELD AND PASTURES	
GRASS WEEDS—WINTER ANNUAL	
Downy brome	*Bromus tectorum*
Cheat	*Bromus secalinus*
GRASS AND GRASSLIKE WEEDS—PERENNIAL	
Johnsongrass	*Sorghum halepense*
Quackgrass	*Elytrigia repens*
Broomsedge	*Andropogon virginicus*
GRASS WEEDS—SUMMER ANNUAL	
Foxtail species	*Setaria species*
Crabgrass species	*Digitaria species*
BROADLEAF WEEDS—HERBACEOUS PERENNIAL	
Common dandelion	*Taraxacum officinale*
Plantain species	*Plantago species*
Curly dock	*Rumex crispus*
Common milkweed	*Asclepias syriaca*
Horsenettle	*Solanum carolinense*
Canada thistle	*Cirsium arvense*
Ironweed species	*Vernonia species*
Aster species	*Aster species*
White snakeroot	*Eupatorium rugosum**
Spotted waterhemlock	*Cicuta maculata**
Goldenrod species	*Solidago species*
Perennial sowthistle	*Sonchus arvensis*
Leafy spurge	*Euphorbia esula*
BROADLEAF WEEDS—WINTER ANNUAL	
Mustard species	many
Rough fleabane	*Erigeron strigosus*
Common chickweed	*Stellaria media*
Henbit	*Lamium amplexicaule*
BROADLEAF WEEDS—SUMMER ANNUAL	
Horseweed or marestail	*Conyza canadensis*
Giant ragweed	*Ambrosia trifida*
Pennsylvania smartweed	*Polygonum pensylvanicum*
Common lambsquarters	*Chenopodium album*
Common cocklebur	*Xanthium strumarium**
Eastern black nightshade	*Solanum ptycanthum**
Sowthistle species	*Sonchus species*
Dodder species	*Cuscuta species*
Sunflower species	*Helianthus species*

COMMON WEEDS IN HAY FIELD AND PASTURES, CONT.	
BROADLEAF WEEDS—WOODY PERENNIAL	
Multiflora rose	*Rosa multiflora*
Honeysuckle species	*Lonicera species*
BROADLEAF WEEDS—BIENNIAL	
White campion	*Silene alba*
Bull thistle	*Cirsium vulgare*
Musk thistle	*Carduus nutans*
Plumeless thistle	*Carduus acanthoides*
Poison hemlock	*Conium maculatum**
*Poisonous to livestock	

Some herbicides translocate (move) within the plant and interfere with normal plant development. Herbaceous perennial weeds are usually most susceptible to translocated herbicides when they are in the bud-to bloom stage or in late summer regrowth, depending on the herbicide used. Fall applications before a killing frost can also be effective. Herbaceous herbicides are translocated more easily when the plant is not stressed due to drought or adverse environmental conditions. However, multiple applications may be required to control deep-rooted perennials. Moreover, some perennials with shallow root systems can be controlled with tillage by cutting the roots or rhizomes into small pieces and incorporating the herbicide into the tilled area. Tillage cuts up the propagules and brings them to the surface so pieces can freeze or dry out. With some weeds, however, cutting up the roots or rhizomes can spread the infestation. Identifying the weed is crucial before developing any weed control program. More on translocation is at the end of this section.

Annuals and perennials are the most troublesome weeds in row crops. Weeds that emerge before the crop canopy develops are very competitive for water, nutrients, and sunlight. Weeds may also cause harvesting problems or grain contamination, resulting in dockage or spoilage.

Weed problems aren't usually severe in small grains unless the crop stand is thin due to poor emergence or winter kill. Contaminated seed or weed seed infested soils can result in winter annual weeds germinating with the crop. Summer annual weeds that become established in small grain fields can create harvesting problems. Occasionally other perennial weeds can be troublesome in small grains.

Various weed species grow in hay fields and pastures in Wyoming. Overgrazing or thin stands of forage crops can permit annual weeds to invade. The severity of the problem is directly related to the species of weeds and their number in proportion to the crop vegetation available for forage. Many weed species are palatable to livestock, although their nutritional quality may not be as high as that of forage species. It is important to control weeds if they reduce nutritional quality or the stand of the desirable species, or if they are poisonous to livestock.

Although livestock poisoning sometimes occurs in rotational pastures, it is primarily a problem in permanent pastures. Poisonous weeds usually become prevalent in permanent pastures due to low fertility; poor management; wet, poorly drained soils; or excessive shade from trees or shrubs.

WEED IDENTIFICATION

Identifying weeds is crucial for a successful weed management program. Identifying seedling weeds for early post-emergence treatment requires close examination of the plants, sometimes even with a hand lens. For publications describing mature weed identification characteristics, along with information about how to obtain these publications, consult a local Wyoming Extension Educator. Another good reference for identifying weeds is Weeds of the West, available from University of Wyoming publications.

Grass Seedlings

Grass seedlings are distinguished from one another by differences in their blades, sheaths, ligules, and auricles (Figure 6.1, page 67). The sheath encloses the bud shoot and is connected to the leaf blade at the collar. The sheath of most grass plants is split and overlapping. The ligule is located on the inner side of the leaf blade and appears as an extension of the sheath at its intersection with the blade. The auricles are finger-like projections of the blade that extend around the shoot at the collar. Blades and sheaths vary among species in hairiness, texture, and color. Ligules are hair-like or membranous and vary in length and shape. Most grass plants have a ligule; a common exception is barnyardgrass. Auricles, which may or may not be present, also vary in length. Long auricles may cross one another and clasp the stem, as in quackgrass.

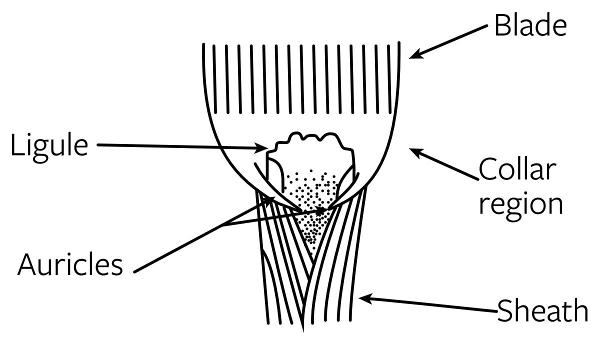


Figure 6.1. Parts of a grass seedling. Adapted from University of Illinois image.

Broadleaf Seedlings

Broadleaf weed seedlings vary in the shape, color, texture, and arrangement of the main plant parts: hypocotyl, cotyledons, true leaves, and petioles (Figure 6.2).

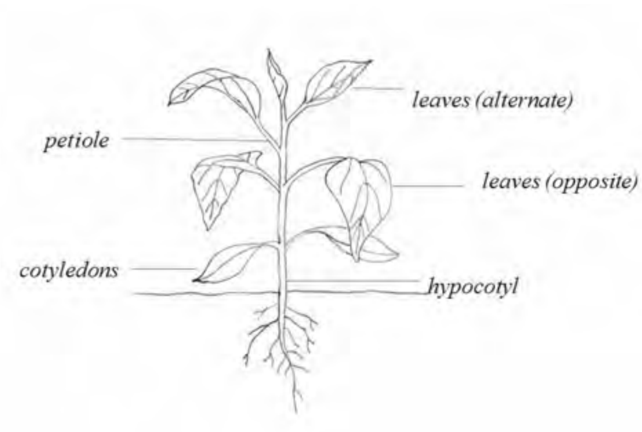


Figure 6.2. Parts of a broadleaf seedling. Adapted from University of Illinois image.

The cotyledons are the first pair of "leaves" on the broadleaf seedlings. They are not true leaves, and they always appear as a pair opposite to each other. True leaves occur after the cotyledons, higher on the stem. The portion of the stem below the cotyledons is the hypocotyl. The hypocotyl and cotyledons are absent on perennials when (as commonly occurs) the plant emerges from rootstock (propagules) rather than from seed. The petiole is the leafstalk. For descriptions and photos of weeds, see *Weeds of the West*, from University of Wyoming Extension, at http://bit.ly/weeds-west.

WEED BIOLOGY

Seed Banks

Seed banks are reservoirs of weed seeds that may, under favorable conditions, germinate and emerge to compete with crops. Most agricultural soils contain large reservoirs of weed seeds, ranging from 370–12,500 seeds/ft^2. The number and composition of weed seeds in soils vary greatly but are closely associated with climatic factors, soil characteristics, cropping, cultivation, and weed management practices. Seed banks are comprised of numerous weed species, although several species may constitute 70% to 90% of the total seed bank. This large group may be followed by a second smaller group of species that may comprise 10% to 20% of the seed reserve. A final group, accounting for only a small percentage of the total seed bank, consists of species that are remnants of past crops.

The depth of seed burial and the amount and intensity of soil cultivation are important factors determining seed longevity in the soil seed bank. Weed seed longevity will be less in cultivated soils than in noncultivated soils. Only a portion of weed seed in the seed bank emerges each year, and many annual weeds have well-defined periods of emergence. For example, summer annuals such as common lambsquarters and redroot pigweed have major peaks of emergence from mid-spring until early summer, whereas winter annuals such as downy brome emergence peaks from late summer through fall.

In cultivated soils, most seeds are found in the upper six inches, although they may be found as deep as the soil is cultivated. As the intensity of tillage declines, the seed bank moves closer to the soil surface. Seeds are then in a better position to germinate and interfere with crop production; conversely, under good weed management, the seed bank could be more easily reduced. Design of planting and weed control systems in crops that capitalize on the shallow seed bank can improve the effectiveness of the cropping system. It is important to design weed management programs that limit the renewal of seed banks. Programs incorporating the most suitable crop rotations, herbicides, and cultivation practices play an important role in limiting the number and diversity of weed seeds in the seed bank.

Weed species that infest cropped fields vary greatly in their potential seed production capacity. Some examples of the potential seed production capacity per plant for several annual weeds are 250 for wild oat, 117,400 for redroot pigweed, 72,450 for common lambsquarters, and 7,160 for barnyardgrass. The actual production per plant varies greatly from year to year and depends upon factors such as plant competition, environmental conditions, the suppressive effect of weed control techniques, and time of emergence.

Longevity of the seed bank depends on the percentage of weed seeds that germinate and the number of seeds produced by those weeds. Clearly, increasing the rate of weed seed germination, coupled with preventing seed production, can shorten the time needed to reduce weed populations to noncompeting levels.

INTEGRATED WEED MANAGEMENT

Integrated weed management (IWM) has been defined in many ways. Some describe it as a combination of mutually supportive technologies to control weeds. Others call it a multidisciplinary approach to weed control by applying numerous alternative control measures.

IWM advocates the use of all available weed control options such as plant breeding, fertilization, crop rotation, planting pattern, cover crops, and mechanical, biological, and chemical control. It does not mean abandoning chemical weed control, rather relying on it less. A single weed control measure isn't feasible due to the number of weed species, and their highly variable life cycles and survival strategies. In addition, if only one or two control methods are used, weed populations can adapt to those practices. Applying the IWM principles can help minimize the overall economic impact of weeds, reduce herbicide use, and provide optimum economic returns to producers.

In essence, developing an integrated weed management program is based on a few general rules for any farm:

1. use agronomic practices that limit the introduction and spread of weeds, preventing weed problems before they start,
2. help the crop compete with weeds, and
3. use practices that keep weeds off balance and don't allow weed populations to adapt.

Combining agronomic practices based on these rules will allow you to design an IWM program for your farm. The goal is to manage — not eradicate — weeds. There is no single recipe for all conditions and years, so adjust your plan based on your farming operation and season.

Prevent Weed Problems Before They Start

The best method of weed control is to keep weeds out of the field. **Field sanitation** involves practices that prevent weeds from entering or spreading across your field. Planting weed-free crop seed is a good starting point to reduce weed infestations. Plant weed-free, **certified seeds** to produce vigorous seedlings, good crop emergence and establishments, which are important for providing a competitive crop advantage over weeds and higher yields.

Controlling volunteer weeds along field edges, fence lines, and ditches helps prevent weed spread. **Clean equipment**, especially combines, before moving from field to field, to further reduce the spread of weeds. **Tarp grain trucks** to prevent the introduction of weeds on road sides, which in turn can invade neighboring fields. **Manure** can cause problems by increasing weed numbers and introducing new weed species to a field, especially if the animals or livestock feed were imported from a different region. Age or compost manure for at least a year before spreading on the field to reduce viability of weed seed. Control patches of new **invading weeds** or **herbicide-resistant weeds** before they spread to the rest of the farm. In general, preventive weed control techniques are usually the least expensive, though routinely the most overlooked.

Help the Crop Compete Against Weeds

You can help give the crop an advantage over weeds. For example, fertilizer placement affects the crop's ability to compete with weeds. Studies indicate that banding nitrogen fertilizer reduced competitiveness and population density of many weed species. Adjusting row spacing also allows the crop to be more competitive. Indications are that soybean planted at 7- or 15-inch row spacing is more competitive against weeds than soybean planted at 30 or 38 inches. Certain crop varieties can be more competitive than others. For example, taller wheat and soybean varieties close their canopy more completely than shorter types, and this helps shade out weeds. Herbicides might still need to be sprayed, but weed control will be better due to added crop competition.

Keep Weeds Off Balance — Don't Give Them a Chance to Adapt

Crop rotation

Crop rotation is the first step to keeping weeds off balance. Diversified crop rotation will allow weeds to be managed in different ways and at different times over the growing season. For example, using forage crops (perennial or annual) allows weeds to be cut before they set seeds, is an important form of weed removal. Crops also differ in their competitive ability. For example, winter cereals are generally better competitors against summer annual weeds than spring cereals. Rotating crops with different life cycles will prevent weeds with specific life cycles from adapting and establishing. Annual weeds are more common in annual crops while biennial and perennial weeds are mostly found in perennial crops. For example, winter annual weeds adapt well in the fields of winter annual crops (e.g., downy brome in winter wheat), and perennial weeds are more common in perennial crops (e.g., dandelion in alfalfa).

Crop rotation also allows rotation of different modes of action herbicides. This will help delay weed adaptation and reduce the chance of resistance developing. Selecting herbicides for a particular application window (e.g., preplant incorporated, preemergence, post-emergence) will also help keep weeds off balance. For example, widespread use of post-emergence herbicides may shift weed populations toward late emerging weeds (e.g., fall panicum, crabgrass, morning glory). Rotating herbicide-tolerant crops would also help diversify herbicide options for weed control. Even though herbicide-tolerant crops aren't "silver bullets," they should be viewed as another tool for weed management.

Planting date

Crops also can be selected to vary the planting date, to help manage a particular weed species. Early planting may give a competitive advantage to a crop against late-emerging weeds such as waterhemp, morning glory, and fall panicum. Planting late may allow the use of a burndown herbicide or a tillage operation to control early-emerging weeds such as field pennycress, shepherds purse, mustards, henbit, velvetleaf, lambsquarters, and green foxtail. Changing the planting date from year to year helps prevent a specific weed to adapt to a field.

Cover crops

Using cover crops and their residues can also keep weeds off balance. Cover crops help manage weeds through competition, physical suppression, and allelopathic (biochemical produced by a plant that suppresses the growth factor) effects. Biological weed control also has the potential for weed management through the use of grazing animals and natural enemies (insects, pathogens). It is a more suitable method of weed control in perennial crops (e.g., pastures) than in annual crops. Annual crops require more rapid weed control and the site disturbance often prevents long-term establishment of a biocontrol agent. In general, keeping weeds off balance and preventing them from adapting to your cropping practices involves a variety of tools.

Making a Spray Control Decision

One of the most common questions producers ask about herbicide use is when to spray. Before deciding whether to spray, consider the following general guidelines: scout your field. Assess the type and number of weeds to determine if a spray operation is necessary. Walk the entire field in an inverted "W" pattern and assess weed density. Some weeds aren't distributed uniformly, and can be found in patches or in low spots of the field. These areas should be sprayed separately, as spraying the entire field may be unnecessary. Mapping weed patches also will help assess the effectiveness of the control program over time. More on scouting is found on page 72.

Weed emergence

Consider timing of weed emergence relative to the crop growth stage. Studies of crop-weed competition show that yield loss is very sensitive to small differences in the period between crop and weed emergence. Use the concepts of critical period of weed control, discussed in the next sections, and economic thresholds.

Critical period of weed control

Critical period of weed control (CPWC) is a period in the crop growth cycle when weeds must be controlled to prevent yield losses. Weeds that emerge before or after this period may not threaten crop yields. This information is essential to determine the need for and timing of weed control and in achieving efficient herbicide use.

Research has shown that each crop has a critical period of weed control, the length of which is influenced by cropping practices (e.g., nitrogen level in corn and row spacing in soybean). Reducing the N-fertilizer level in corn resulted in a longer critical period of weed control, thus making corn a less competitive crop. The critical period of weed control ranged from the 1st to 10th, 3rd to 9th, 4th to 9th, and 6th to 9th leaf stages of corn for N levels of 0 lb/A, 55 lb/A, 110 lb/A, and 210 lb/A, respectively. Reducing the row spacing in soybean delayed the timing of weed control, thus increasing the crop tolerance to weed presence early in the season. In wide-row (30-inch) soybean, the beginning of the critical period of weed control was at the first trifoliate stage, suggesting that in wide-row soybean, control measures should start early in the season (at the first trifoliate stage). With 15-inch rows, the beginning of the critical period of weed control was delayed and corresponded approximately to the second trifoliate stage. With 7.5-inch row soybean, the critical control period was at the third trifoliate stage.

Cost of delaying weed control

Delaying weed removal beyond the start of the identified period for weed control will cost a producer an average of 2% in yield loss per every leaf stage of delay in both corn and soybean. From a practical standpoint, an arbitrary level of, for example, 2%, 5%, or 10% yield loss can be used to signify the beginning of the critical period (time of weed removal). This range will allow a producer to make adjustments depending on the level of risk he or she is willing to take. To illustrate the point, an arbitrary level of 5% yield loss was used to determine the beginning of the critical period of weed control for corn and soybean (Figures 6.3 and 6.4).

To determine the cost of delaying weed control, use the curve above the arbitrarily selected point (the beginning of the critical period of weed control). For example, if an arbitrarily selected point is 5%, the 5% corn yield loss will occur if the weeds are removed at first and second leaf stage in 0-N-level (Figure 6.3). Delaying weed control to the third leaf stage will cause about 7% yield loss, in essence costing the producer a 2% yield loss. A similar trend is observed for the later leaf stages at each of the four curves (Figure 6.3).

Delaying weed control in soybean resulted in similar yield losses as in corn and was significantly influenced by crop row spacing. For example, 5% yield loss in drilled soybean (7.5-inch rows) occurred at the third trifoliate stage compared to a 7% yield loss at the fourth trifoliate (Figure 6.4). This indicates a 2% yield loss. Similar costs in delaying weed control in soybean were observed for the later leaf stages at each of the three curves (Figure 6.4).

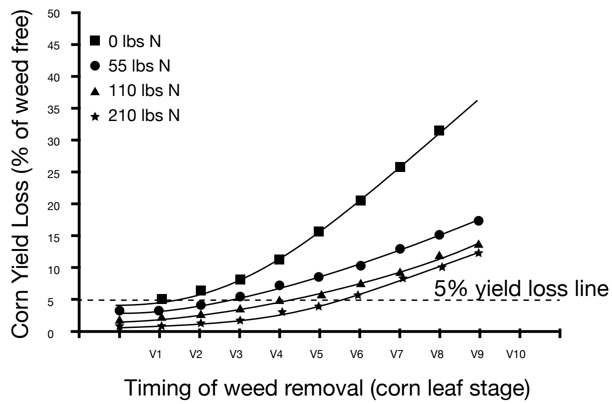


Figure 6.3. Corn yield loss and beginning of the critical period of weed control as influenced by the timing of weed removal and nitrogen rate. (Knezevic et al. 2000)

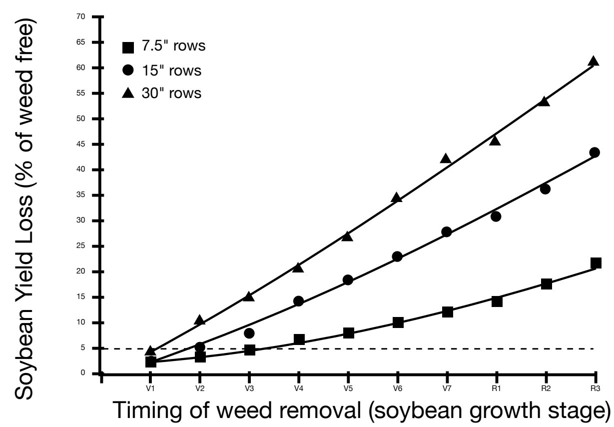


Figure 6.4. Soybean yield loss and beginning of the critical period of weed control as influenced by the timing of weed removal and row spacing. (Knezevic et al. 2000)

To determine the actual economics of delaying control, the producer can convert the percentage yield loss of the actual target yield on his farm. For example, if a target yield for corn is 100 bushels per acre, delaying weed control for every leaf stage of crop will cost producers about 2 bushels per acre of yield (thus 2% of 100 bushels per acre). In terms of actual economic loss, it will be about $4 per acre for every crop leaf stage of delay, assuming a price of $2 per bushel for corn. The loss in soybean will be about one bushel (2% of a 40 bu/A target yield). If soybean is $5 per bushel, the economic loss would be about $5 per acre for every leaf stage of delay.

Economic threshold is the level of weed infestation at which the cost of weed control equals the increased return on crop yield in the current year. Threshold values will vary with time of weed emergence, competitiveness of weed species, and commodity prices. **The bottom line is: Spray only when it pays.** Spraying for annual weeds that are below threshold level is unnecessary from both biological and economical perspectives.

Field Scouting to Determine Weed Density

Crop producers are well aware of the effect of high weed densities on crop yields; however, it is at low weed densities that they must make weed management decisions, comparing the economic benefits of controlling weeds with the costs. As mentioned earlier, field scouting is an important part of deciding whether to spray. Accurately determining the types of weeds, their density, and relative times of emergence in the field will help determine if a spray operation is necessary.

One major constraint to using weed thresholds at the farm level is a lack of practical sampling methods for estimating weed density over larger field scale. Wyoming Extension suggests that the entire field first be walked to get a feel for the "weed pressure" and then sampled. While several sampling methods are available, Extension recommends using an inverted "W" pattern, as illustrated in Figure 6.5.

The scout should walk for about 100 paces along the edge of the field, turn at a right angle, and walk 100 paces into the field. Sampling begins at this point. Use a wooden or wire "quadrant" enclosing a 2-foot-by-2-foot area to determine weed density at every sampling spot along the inverted "W" pattern.

At each sampling spot, count the number of weeds in the quadrant on the ground. Sample a minimum of 20 units, each at least 20 paces apart across the field. Calculate the average weed density.

Weeds are not uniformly distributed and may be more heavily concentrated in patches, low spots, and along field edges. These areas should be considered separately from the rest of the field.

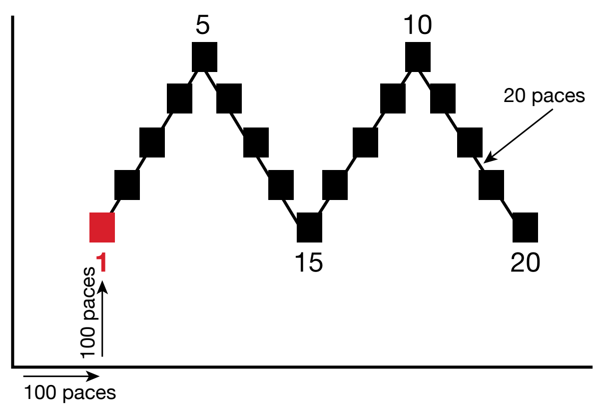


Figure 6.5. Field scouting pattern for determining weed thresholds.

Documentation and Recordkeeping

Documentation and recordkeeping are essential to an IWM program. Field histories and information on cropping practices will help evaluate your weed control program over time. Pesticide application records can be handwritten or recorded electronically. Pesticide application records are required to list information such as target pest, site location, and other information. Recordkeeping requirements are covered in Section 5, page 51. Additional information could be helpful in evaluating effectiveness or in case of an application dispute. This includes wind direction and velocity, air temperature, follow-up evaluations, etc.

Integrated Weed Management—Making It Work

Since there are many kinds of weeds with very different life cycles, no single weed management practice is best under all circumstances. IWM is effective because it is flexible, using practices that fit a particular weed situation. The use of advanced technology that incorporates sensors, computers, and robotics for real-time weed identification and targeted control will make it possible to use all of the described techniques in a truly integrated approach. These systems, some still in the research phase, will significantly advance weed control more than any other new development. In the meantime, use the best available combination of techniques for your needs.

There are many ways to start developing an IWM program. The easiest way is to try one or two techniques, adding more each year. After a few years, you will have developed an IWM program that works well for your operation. Using a variety of weed control tools reduces the reliance on any single tool, which means that those tools will still be effective in the years to come. Using various methods keeps weeds off balance and prevents them from adapting to your management strategy. Remember, there is no such a thing as a "silver bullet" for weed control.

NONCHEMICAL WEED CONTROL

Nonchemical weed control can be used exclusively or integrated with chemical control. In either case, nonchemical methods can play a major role in weed management. The major nonchemical weed control techniques include biological, cultural, and mechanical approaches.

Successful nonchemical control is best achieved through an integrated approach based on the biology of the weeds and the crop. The following discussion highlights some major elements of nonchemical weed control.

Biological

Biological weed control is the control of weeds by insects and mites, plant pathogens, and birds or other animals. Biological control reduces weed density but doesn't eliminate the target weed, as the biocontrol agent often needs the weed as a host or food source. In some instances, biological control can be permanent as the biocontrol agent may be self-perpetuating and not require additional management. The target organism may then be controlled indefinitely without further human effort. This is an advantage, especially in settings with limited access. Biocontrol agents have no harmful environmental effects since candidate organisms are rigorously evaluated prior to approval and release. In addition, the effect of biocontrol agents is limited to the target weed and perhaps a few close relatives. The economics of successful biocontrol can be favorable because following release, the organism perpetuates itself indefinitely and often disperses on its own.

The response to a biocontrol program is often slow since the population of the organism must increase from the level of the initial release. As a result, most biocontrol agents are best suited to a stable long-term environment, i.e. grazing land or natural areas rather than an annual cropping system. Biocontrol agents, by virtue of their specificity, control only a single species and aren't well suited to address the complex of weeds normally found in cropland. Since most biocontrol agents by themselves don't reduce weed populations to an acceptable level, they must be used in conjunction with other approaches in an integrated weed management program.

An often-cited example of biological control success is the use of the imported cactus moth and several secondary insects to control prickly pear in Australia. In the US, a large-scale biocontrol program used the Klamath beetle and other species to control the Klamath weed in Oregon. Varying degrees of success have been realized in Wyoming, with biocontrol efforts targeting Canada thistle, diffuse knapweed, leafy spurge, musk thistle, and purple loosestrife. Research continues at the national and state levels to develop biocontrol agents.

Cultural

A variety of cultural practices can be used to improve crop competitiveness. Crop rotation and crop selection are two of the easiest and most effective practices.

Crop rotation

Crop rotation permits diversified weed management, which allows less opportunity for an individual weed to become dominant. For example, the use of forage crops (perennial or annual) provides an opportunity to cut weeds before they set seeds, which is an important form of weed removal. Most crops do differ in their competitive ability. For example, winter cereals are generally better competitors than spring cereals against summer annual weeds. Rotating crops with different life cycles will help prevent a single weed, or small group of weeds, from dominating and having an economic impact on crop production. For example, winter annual weeds do well in fields of winter annual crops (e.g., downy brome in winter wheat), and perennial weeds are more common in perennial crops (e.g., dandelion in alfalfa).

Crop selection

Crop and cultivar selection provide a variety of planting date options to aid in managing a particular weed species. Planting early gives the crop an edge against late-emerging weeds such as waterhemp, morning glory, and fall panicum. Planting late may allow the use of a pre-planting tillage operation to help manage early emerging weeds, such as winter annuals (field pennycress, shepherds purse, mustards, henbit); and annuals (velvetleaf, lambsquarters, green foxtail). Changing the planting date from year to year can reduce buildup of specific weeds.

Population density and row spacing

Adjusting crop population density and row spacing influences plant competition for water and nutrients, canopy closure, and crop shading effects on weeds. To a point higher crop population densities generally are more competitive with weeds than lower population densities. The time to canopy closure can be altered by changing row spacing. As mentioned earlier, narrow-row spacing usually results in earlier canopy closure than wider-row spacing. Canopy shading is a major means by which crop plants suppress weeds, but the crop must develop rapidly to stay ahead of the weeds. Nebraska research showed that soybean is more competitive when planted in narrow rows than in wide rows. Crop selection, population density, and row spacing should be considered in any cropping system. These cultural practices are especially important for crops with shorter stature.

Cover crops

Cover crops and their residues also may help keep weeds in check. Cover crops are generally planted in closely spaced rows to provide good ground cover, thus the name cover crops. They help manage weeds through competition, physical suppression, and allelopathic effects.

Mechanical

Mechanical weed control is one of the most common nonchemical methods of weed control: tillage, mowing, cutting, and, for small areas, hoeing, hand removal, and physical barriers. A variety of implements can be used, depending on the crop and the system.

Tillage

Tillage destroys emerged weeds but also plants seeds that are on the soil surface. Depending on the depth of weed seed burial, tillage often tends to encourage large-seeded broadleaf weeds and discourage small-seeded broadleaves and grasses.

Primary tillage includes moldboard plowing, chiseling, heavy disking, rototilling, and similar operations. Tillage will destroy annual and biennial weeds and disrupt the root systems and other vegetative reproductive structures of perennials. Primary tillage also buries crop residue, leaving soil subject to erosion.

Secondary tillage is performed after primary tillage and is intended to prepare a weed-free seedbed for crop planting. Commonly used implements are disks, field cultivators, and harrows.

Tertiary tillage is performed after crop planting and is intended to prevent weeds from becoming established in the growing crop. Commonly used implements include harrows, rotary hoes, and various row cultivators. Many specialized implements have been designed for mechanical in-crop weed control.

Ridge planting is a system that incorporates mechanical weed control in that the crop is planted on an existing ridge. A sweep on the planter removes any growing weeds from the row area ahead of the planter unit and also moves weed seeds to the middle of the rows. Subsequent cultivation and ridging controls weeds between the rows and buries small weeds growing in the crop row.

Successful weed control with secondary and tertiary tillage depends on timing, weather, and soil moisture before and after the operation. Soil moisture must permit tillage while weeds are in the small vulnerable stage; drying conditions must exist for several hours after the operation to dry out or desiccate the small weeds. Delaying planting provides the opportunity to kill weeds prior to planting and allows the soil to warm up, resulting in rapid crop growth. Rapid crop growth is important in reaching a size differential between a larger crop plant and the weed. This size differential is required for success with many crop harrow, rotary hoe, and cultivation operations.

Mowing

Mowing tends to be more effective on broadleaf weeds than grasses since most grasses rapidly regrow from the crown. Mowing must be carefully timed to maximize damage to the weed and minimize damage to the crop.

Properly timed mowing or cutting will suppress weeds, but with few exceptions, not kill them. Cutting cedar trees (or other plants without basal buds) below the lowest branch will kill them.

Physical barriers

Physical barriers include placing black plastic sheeting (mulch) either on the soil surface or beneath a surface covering of gravel or stone. This method is used in certain high-value horticultural crops. The crop or plant to be grown is planted through a hole cut in the plastic. Black plastic is important because it prevents sunlight from reaching weed seeds or small plants.

Flame weeding

Flame weeding is an acceptable weed control option in organic production, although this nonchemical control method has received renewed interest for conventional production. It can be used as part of IPM to control insects as well as weeds.

Flame weeding controls weeds by heating, but not burning, plant tissue. Propane burners can generate combustion temperatures of 2,000°F, boiling water molecules inside the cells and rupturing them. This

Table 6.2. Amount of dry and liquid herbicide to add to 1 pint of carrier.

Spray Volume Rate/Acre (liquid gallons)	**Dry Herbicides** (tsp/lb*)	**Liquid Herbicides** (tsp/pint**)
5	7½	2½
10	3¾	1¼
15	2½	1
20	2	¾
25	1½	½
30	1¼	½
35	1¼	⅓
40	1	⅓

tsp = teaspoon

*For dry herbicide rates of ¼ lb use ¼ the amount listed and for ½ lb use ½ the amount needed.

**For liquid herbicides of ¼ pint use 4 pints of carrier, and for ½ pint use 2 pints of carrier and the appropriate amount of compatibility agent. Then use the amount of liquid herbicide listed in this table. If other herbicides are used in the mix at pound or pint rates, it is necessary to increase their rates by the rate the carrier was increased.

Table 6.3. Amount of dry and liquid herbicide to add to 2 gallons of carrier.

NOTE: Add 4 teaspoons (tsp) or 20 ml of compatibility agent to one jar marked "with" and stir. See Steps 2, 3, and 4, but add according to the table.

Spray Volume Rate/Acre (liquid gallons)	**Dry Herbicides** (tsp/oz)	**Liquid Herbicides** (tsp/oz)
5	7½	2½
10	3¾	1¼
15	2½	1
20	2	¾
25	1½	½
30	1¼	½
35	1¼	⅓
40	1	⅓

dehydrates the plant, resulting in plant death, or makes it weak and non-competitive.

Flame weeding may have almost the same weed control capacity as a mechanical cultivator, but is usually slower than chemical weed control. Moreover, crops must be flamed at certain growth stages or else they could be injured. For example in wheat, flaming is recommended only before the crop emerges.

Summary

Few nonchemical methods of weed control are effective enough that they alone can provide acceptable weed control. Using IWM and incorporating multiple approaches is important for success with nonchemical long-term weed management.

CHEMICAL WEED CONTROL

Cultural and mechanical practices alone often do not give adequate weed control. For this reason, they are used along with chemical weed control practices in IWM. Most of the row-crop acreage in Wyoming receives at least one herbicide treatment during the growing season. It is important that the applicator understand the principles of weed control when using herbicides.

Herbicide Combinations

Different herbicides often are applied in combinations to control more weed species, reduce carryover, minimize crop injury, or minimize development of weed resistance. Some combinations are sold as a premix; others are tank-mixed by the applicator. Tank-mixing allows you to adjust the herbicide ratio in the spray tank for local weed and soil conditions.

Producers can legally apply two or more herbicides, provided that none of the labels prohibit the combination. The applicator must assume responsibility and liability for tank mixes not listed on the label, and cannot advertise such mixtures. All herbicides used in combination must be registered for the crop treated, and restrictions on all products must be followed. Applying two herbicides at different times is called a sequential treatment. Examples of sequential treatments are a preplant application followed by a preemergence application, a soil-applied herbicide followed by a post-emergence treatment, or a broadcast application followed by a banded or directed one.

Problems sometimes occur when mixing two or more pesticides of different formulations or certain formulations in a carrier of liquid fertilizer or hard water. Sludge, clumps of solids, or an oily layer that will not mix, may form immediately or upon setting if the products are improperly mixed or agitated. When using liquid fertilizer or pesticide combinations that you believe might not disperse evenly, check their compatibility using the Compatibility Jar Test before application.

Compatibility Jar Test

A Compatibility Jar Test should always be done before mixing large quantities of pesticides and/or fertilizers. You will need containers and measuring spoons to do the test. This example is based on an application rate of 25 gallons per acre. See Table 6.2, pages 76, for other rates.

1. Use two quart jars. Larger containers will be needed for rates lower than 1/4 pound dry or 1/4 pint liquid (see herbicide rates and use, Table 6.3, page 76). If the carrier is water, put 1 pint of water in each of the two jars. If the carrier is fertilizer, add 1 pint of fertilizer to both jars. If it is a mixture of fertilizer and water, add them in the same ratio they will be used in tank. For example, with a 2:1 fertilizer to water ratio use 2/3 pint fertilizer to 1/3 pint water. Use water and fertilizer from the same source and at the same temperature as when you mix to spray.

2. To one jar marked "with," add 1/4 teaspoon (1.2 ml, 1 teaspoon = about 5 ml liquid) of a compatibility agent (adjuvant, described in next section) and stir. For comparison, no compatibility agent is added to the other jar.

3. To both jars, add the appropriate amount of herbicide(s). Add dry herbicides first, flowables second, and emulsifiable concentrates last. Stir for 5 to 10 seconds after adding each material.

   Dry herbicide: For each pound per acre to be applied, add 1½ level teaspoons. For wettable powders and flowables, pre-slurry each product with water in the ratio of 2 parts product to 1 part water prior to adding to the two jars.

   Liquid herbicide: For each pint per acre to be applied, add ½ teaspoon or 2.5 ml. Also add crop oils, crop oil concentrate (COC), etc.

4. 5 to 10 minutes after the final addition and mixing, observe both jars for the formation of large flakes, sludge, gels, or other precipitates.

If incompatibility occurs in the jar without the compatibility agent, adding a compatibility agent is recommended.

If incompatibility in any of these forms occurs in the jar with the compatibility agent added, the carrier and the herbicide **SHOULD NOT BE TANK MIXED**.

Let jars stand and observe them for 30 minutes.

If the mixture is found to be **compatible**, start filling the tank. Strong agitation with a rolling effect on the carrier surface is recommended. Remember to pre-slurry the wettable powders and flowables. Allow time for good dispersal and empty the tank as much as possible before mixing a new batch.

Compatibility Agents and Mixing Order

Compatibility agents are adjuvants added to the spray tank to improve mixing, especially with a liquid fertilizer spray carrier. Compatibility agents are usually phosphatic esters of alkyl aryl polyoxy ethanol or ethylene glycol plus an alcohol solubilizer. Extra phosphatic acid may be added for buffering (acidifying) effects. Herbicide labels often specify a compatibility test to determine the need for a compatibility agent when mixing with liquid fertilizer. The rate is usually 1 to 4 pints per 100 gallons of spray mix.

Consult pesticide labels for specific mixing recommendations. When no specific directions are given, use the following order:

- When compatibility agents are necessary, add them to the carrier before adding any pesticides.
- Add wettable powders (WP), water-dispersible granules (WDG), and dry flowables (DF) to the tank before flowables (F).
- Add emulsifiable concentrates (EC).
- Add water-soluble concentrates (SC) and surfactants last.

Pre-slurry WPs, WDGs, or DFs by mixing them with water before adding them to the tank. For thorough mixing, agitate the tank while adding each product individually and while filling the tank with carrier. Agitate continuously during operation and while moving from field to field until the spray tank is empty. Empty and clean spray tanks often to prevent accumulation of material on the interior surfaces.

Soil-applied Herbicides

Herbicide rates

Recommended **rates for soil-applied herbicides** differ with the adsorptive capacity of different soils. Adsorptivity (the ability of soil to bind pesticide molecules) is determined by the soil texture (percentage of sand, silt, and clay) and the amount of organic matter in the soil. Therefore, a range of rate recommendations is given on the label of many soil-applied herbicides, depending on soil type. For example, soils that are light colored because of low organic matter content require lower rates of most herbicides than dark-colored soils. Medium-textured soils (those with a moderate clay content) require lower rates of herbicides than fine-textured soils, which have a higher clay content. Sandy soils have little adsorptive capacity and may not be able to hold the herbicide in the upper soil surface. Therefore, if rainfall leaches the herbicide into the zone where the crop seed is planted and below where most weed germination occurs, weed control could be poor and crop injury could result, especially if crop tolerance is marginal. For sandy soils, the herbicide label may specify “do not use,” or “use at a reduced rate.” Regardless of soil type and organic matter content, follow label instructions. Applying too much herbicide may result in carryover or direct crop injury; applying too little may result in poor weed control.

Reduced tillage systems may require higher application rates of soil-applied herbicides than are required in conventional systems, depending upon the amount of crop residue. Vegetation remaining on the soil surface can absorb some of the herbicide and might prevent uniform herbicide distribution. Higher herbicide rates may be needed if excessive crop residue remains on the soil surface. Consult the herbicide label.

Herbicide carryover

Carryover can be a problem with herbicides that don't break down during the season of application and persist in the soil in sufficient quantities to injure succeeding crops. Herbicides such as atrazine, Pursuit, or some of the sulfonylureas (Classic) are prone to carryover. They give long-season weed control; however, if the weather during the growing season is cool and dry, or an excessive rate was applied, breakdown in the soil may be incomplete, resulting in possible injury.

Carryover potential can be minimized by early, uniform application of the herbicide. Avoid creating "hot spots" of high herbicide concentration due to dripping nozzles or improper overlap of the spray pattern. When spraying on a rough surface, incorporate thoroughly to give uniform distribution of the herbicide, thereby minimizing areas of high concentration. Tilling at season's end will facilitate the breakdown process. Reduce the rate of the persistent herbicide and apply it in combination with another less persistent herbicide to lessen carryover potential, without compromising effective weed control.

If the weather during the application season is cool or dry, take precautions during the following season to protect the crop from serious injury. Consider tilling the soil, if possible, to dilute any residual herbicide. Don't use an herbicide that would add to the carryover effect of the previous herbicide. For example, when atrazine carryover is likely, carefully consider both the risks and benefits of following with another triazine herbicide such as Sencor.

One way to determine whether carryover is a problem is to conduct a bioassay, growing susceptible plants in samples of the soil. If injury occurs on these test plants, injury in the field also might occur. The closer to planting time the soil samples are taken, the better indication of the possibility of crop injury.

The bioassay must be done correctly if the information obtained from it is to be valuable. For techniques on performing this test, see *G1891 A Quick Test for Herbicide Carryover in the Soil*, available online at http://extensionpubs.unl.edu/publication/9000016366062/a-quick-test-for-herbicide-carryover-in-the-soil/.

Another cause of herbicide carryover is a pesticide spill. If a pesticide spills, the area may be unfit for crop production unless the pesticide is removed or deactivated. Activated charcoal is one method that may be used to deactivate herbicides. The inside front cover of this manual lists emergency telephone numbers to call in case of a spill.

Herbicide placement

Herbicides are incorporated into the soil to increase their effectiveness. Some herbicides require incorporation to prevent their loss by volatilization (escape to the air as a gas) or photodecomposition (breakdown due to sunlight). Herbicides not subject to loss by these processes do not need to be mixed mechanically into the soil; however, thorough incorporation distributes the herbicide in the "weed zone" of the soil, providing more consistent weed control year after year than surface applied herbicides that rely on rainfall to move them into the soil.

Optimum **herbicide placement** in the soil depends upon the type of weeds to be controlled. Many annual weed seeds germinate in the top one to two inches of soil, so most herbicides should be placed in that area for best results. Some herbicides are incorporated deeper in the soil (three to five inches) to control large-seeded weeds or weeds emerging from vegetative propagules. These weeds contain more stored food and can emerge from deeper soil depths than small-seeded weeds.

The depth and thoroughness of incorporation depend upon the type of equipment used, the depth and speed of operation, soil texture, and soil moisture. It is important to obtain uniform distribution, both horizontal and vertical, to prevent areas of high and low herbicide concentration that may result in crop injury, poor control, or residual hot spots. Tandem disk harrows and field cultivators are the most commonly used tools for incorporation; power-driven tillers, ground-driven seedbed conditioners, and combination tillage tools also can be used.

Thoroughly distribute the herbicide by disking twice, disking and field cultivating, or power tilling. One disking or the use of a field or rolling cultivator or bed conditioner alone often provides only fair distribution. Avoid using rotary hoes and drag and spring-tooth harrows as incorporation tools because they don't adequately distribute the herbicide.

Preemergence herbicides are applied after the crop is planted but before the crop or weeds emerge. These herbicides require rainfall within a few days after application to move them into the soil for absorption by the germinating and emerging weeds. The amount of rainfall required varies from one-half to one inch, depending on the herbicide.

Preemergence application is recommended for highly water-soluble herbicides that could move too deeply into the soil if incorporated, thereby resulting in poor weed control. Although preemergence applications aren't as dependable as incorporated treatments, they may reduce the amount of tillage required. If rainfall does not occur in time to activate the herbicide, either irrigate or rotary hoe to kill emerging weeds.

Foliar-applied Herbicides

Foliar herbicides are applied after weeds emerge. Post-emergence herbicides can solve a variety of weed control problems, and shouldn't be considered simply as rescue treatments for preemergence herbicides that did not activate in the soil due to lack of moisture.

Post-emergence herbicides can be used in sequence with pre-plant-incorporated or preemergence herbicides to broaden the spectrum of weed control. Post-emergence treatments are often best for controlling perennial weeds, volunteer corn, late-season weed species, and certain annual weeds such as annual morning glories that are fairly tolerant to soil-applied herbicides in soybean. In established forage crops and pastures, post-emergence herbicides can be important to control herbaceous as well as woody species such as multiflora rose. The trend toward reduced tillage, and use of genetically modified crops such as Roundup Ready® corn and sugarbeets, has put greater emphasis on post-emergence treatments. Preemergence treatments may give less reliable control with reduced tillage than when used in conventional tillage systems.

If the crop is herbicide-tolerant, a spray broadcast application can cover both weed and crop foliage. If the crop has a low tolerance, the herbicide can be applied with directed application equipment to reduce contact with the crop foliage. For a directed application, there must be a height difference between the crop and the weeds. If the weeds are shorter than the crop, the herbicide can be basally directed with the use of drop nozzles aimed to spray beneath most of the crop foliage and onto the weeds. If the weeds are taller than the crop, the herbicide can be applied above the crop onto the weeds with minimum contact to crop foliage. Wiper applicators can be used for this over-the-top directed application.

Page 75 describes how soil type and tillage practices are important in determining the application rates for soil-applied herbicides. For post-emergence treatments, rate varies instead with weed species and size, climatic conditions, and sometimes with the use of adjuvants.

Foliar herbicide uptake

Uptake of foliar herbicides is affected by leaf shape and orientation, and by the nature of the leaf surface, that is, a presence or absence of hair and cuticle thickness. Weed species differ in how they intercept and retain herbicide droplets. Broadleaf plants with large leaves parallel to the ground intercept and retain more spray droplets than grass plants, most of which have narrow upright leaves more prone to droplet runoff. The presence of leaf hair, called pubescence, also prevents effective herbicide contact with the surface because the hairs hold spray droplets away from the leaf surface. This reduces potential for herbicide penetration. Adding a surfactant to the spray will improve foliar coverage in pubescent plants such as velvetleaf. Velvetleaf has a dense hairy upper leaf surface; without a surfactant, herbicide penetration and therefore control may be poor.

Plant leaves have an outer wax-like layer called a **cuticle**. The cuticle protects the plant from excessive water loss. The cuticle also is a barrier to absorption of foliar applied herbicides. The herbicide must penetrate the plant cuticle before it can reach the site of action in the plant. The cuticle thickens and is less permeable as the leaf ages, during periods of drought, low humidity, or high temperatures. Aqueous (water-based) spray droplets "bead up" on the waxy cuticle rather than spreading across the leaf surface.

Relative humidity, temperature, and adjuvants play a major role in herbicide spray penetration. Penetration is greater under high temperatures and high relative humidity. Plants growing under drought or drought-like conditions have thicker cuticles (harder to penetrate) than those growing under moist conditions. Non-polar herbicides such as acid esters penetrate the cuticle faster than polar herbicides such as amine salts. Spray adjuvants can sometimes be used to increase foliar coverage of spray droplets and penetration into the cuticle.

Weeds growing under drought or drought-like conditions or during prolonged cool weather often require a higher herbicide rate than do actively growing weeds. Under hot, moist conditions, weeds are more susceptible to herbicides although crop injury may also occur. Under cool and dry conditions, plants are generally less susceptible to herbicides, so a higher rate and the use of any adjuvant may be needed to achieve greater control. Weeds should generally be treated in the spring when they are young and the growing conditions are not extreme. However, applying translocated herbicides to established perennial weeds, such as Canada thistle, is recommended when the weeds are in the bud-to-bloom stage or in the early fall before frost, depending on the herbicide and the weed species.

The ideal temperatures for applying most post-emergence herbicides are between 65°and 85°F. Control is slow when the air temperature is below 60°F. Above 85°F, the risk of volatile drift is much greater from dicamba (Banvel or Clarity) and ester formulations of 2,4-D and MCPA.

Rainfall occurring shortly after application may reduce weed control. Herbicides vary in the time required for effective absorption. For example, Blazer and Cobra may require four to six hours after application for adequate absorption. The ester formulations of 2,4-D are absorbed in one to two hours, while the amine formulations require six to eight hours. Glyphosate is mostly absorbed within two hours. Gramoxone SL is absorbed within 30 to 60 minutes.

Spray Additives

Additives are commonly used with post-emergence herbicides because they increase herbicide penetration of the treated plant surface and improve herbicide performance. Effectiveness of the additive varies with the herbicide, weed species, and environmental conditions. Therefore, it is important that additives not be indiscriminately added to the spray mixture.

Modifier additives alter the application characteristics of the spray solution and include anti-foaming agents, compatibility agents, and drift control agents. For a comprehensive list of additives, see the *Compendium of Herbicide Adjuvants*, http://www.herbicide-adjuvants.com/.

Post-emergence herbicide activity is strongly influenced by the additives included in the spray mixture. The most commonly used spray additives (adjuvants) include oils, surfactants (surface active agents), and fertilizers. A crop oil concentrate (COC) increases herbicide penetration and reduces surface tension. The degree of weed control and the potential for crop injury are both influenced by additives. However, additives that increase weed control may also increase crop injury; there may be a fine line between increased weed control and increased crop injury.

Oil concentrates can be made of oils from petroleum or from seeds and usually are composed of at least 17% emulsifiers and 83% oil. Combining an emulsifier with the oil results in a unit, one portion of which is highly oil soluble, the other portion water soluble. Without the emulsifier, the oil would not mix with water. Methylation improves the effectiveness of seed oils as spray additives. Oil concentrates are generally used at 1% volume of oil concentrate per volume of spray solution or 1 to 2 pt/A, depending upon the herbicide, oil, and spray volume.

Surfactants

Surfactants enhance penetration of foliar-applied herbicides. The spray mixture is primarily water; plant surfaces have tension and are waxy, so water beads up on them. Surfactants reduce surface tension of spray droplets, causing them to spread out and wet the sprayed surface. This improved wetting and retention generally results in increased herbicide uptake by the plant.

Compounds that function in this way generally consist of two components. One portion of the molecule is hydrophilic (water soluble) and the other portion is lipophilic (oil soluble). Surfactants concentrate at the interface of two surfaces, binding them together.

Surfactants are classified by the hydrophilic portion of the molecule. Three important classes of surfactants are: (1) **anionic**, (2) **cationic**, and (3) **nonionic**. Anionic surfactants ionize in water to form a negative ion. Cationic surfactants ionize in water to form a positively charged ion. Nonionic surfactants contain no ionizable groups and therefore carry no charge. They are by far the most commonly used surfactants.

Organosilicone surfactants are a class of nonionic surfactants that are especially effective in reducing surface tension of water mixtures. This results in efficient wetting of very waxy surfaces. Most other nonionic surfactants interfere with the function of organosilicones and should not be used with them. Organosilicones are most stable and most effective in solutions of pH 6 to 8. In more alkaline or acidic solutions, these compounds hydrolyze with a loss in activity.

Ammonium-containing fertilizers

Ammonium-containing fertilizers with 28-0-0 and 32-0-0 UAN (urea ammonium nitrate) ratio are effective spray additives, and 21-0-0 spray grade ammonium sulfate (AMS) are the most commonly used in herbicide solutions. The ammonium in these fertilizers enhances the uptake of certain herbicides, especially weak acids, by a mechanism not well understood. While oils and surfactants function primarily at the waxy leaf surface, the ammonium ion functions inside the cell wall. This enhanced activity due to the ammonium ion is pronounced with several post-emergence (POST) herbicides. Fertilizers are not surfactants and do not replace the need for surfactants in the spray mixture.

AMS is the fertilizer additive that should be used with glyphosate. Calcium, magnesium, and iron in spray water antagonizes glyphosate activity by reacting with glyphosate, forming salts with reduced activity. AMS added to the spray water reacts with calcium, magnesium, and iron in the water, forming insoluble sulfates that will not react with glyphosate, effectively preventing antagonism. Other nitrogen containing fertilizers, including UAN, will not prevent the antagonism caused by calcium, magnesium, and iron and therefore should not be used as an additive with glyphosate. AMS added at 2% by weight (17 lb/100 gallons spray) will overcome spray water antagonism of glyphosate. Liquid forms of AMS are equally effective if used at equivalent rates. Some common liquid AMS products contain approximately 3.75 pounds AMS per gallon.

Herbicide Drift

Drift can occur as vapor (volatile) drift or as spray particle drift. Vapor drift varies with temperature and formulation.

The most serious vapor drift problems occur with herbicides that volatilize as the temperature exceeds 85°F (for example, 2,4-D ester). Amine 2,4-D formulations volatilize at higher temperatures than esters and are usually recommended to minimize 2,4-D vapor drift. Command volatilizes when it is left on the surface of moist soil. Therefore, except for very early preplant applications, it should be incorporated soon after application.

Particle drift varies with droplet size, height of fall, and wind speed. Droplet size is determined by nozzle type and size, spray pressure, and spray volume. Nozzles that deliver adequate spray coverage at lower spray pressures have less drift potential than nozzles that require high pressure to maintain a proper spray pattern. Extended range flat-fan, drift reduction flat-fan, turbo and flood flat-fan nozzles can be operated at lower pressures. These produce larger drop sizes than regular flat-fan, hollow cone disk and core, and whirl chamber nozzles. Several nozzles, including drift reduction flat-fan, turbo flood-jet, and air-induction nozzles are specifically designed to reduce particle drift. More on nozzles is in Section 2, page 16.

Before spraying, evaluate weather conditions carefully. The wind velocity should be between 3 mph and 10 mph; some product labels specify a suitable range for spraying. Wind direction should be away from susceptible crops. The wind is generally least turbulent in the early morning and late evening, and most turbulent during mid-afternoon. Air temperature may also affect particle drift by reducing droplet size through evaporation.

Although conditions with no wind may seem perfect for pesticide application, they actually can cause spray drift. Temperature inversions are addressed in Section 3, page 34.

Herbicide Mode of Action

Herbicide mode of action is the chain of events or the action that causes plant injury or death. The herbicide is applied to that part of the plant where it can be absorbed for **translocation** to the site of action. The site of action is where the herbicide works.

Plants have two types of tissue to transport materials. Xylem carries water from the roots to the shoots and branches; phloem carries sugars, produced through photosynthesis in leaves, throughout the plant. The meristem is tissue with rapid cell division, where growth occurs. Meristematic tissue is in the growing tips of roots and shoots, along with other places in the plant.

Herbicides that translocate in the xylem are usually applied to the soil either before planting or before the crop emerges. They include the photosynthetic inhibitors and some of the meristematic inhibitors.

Some herbicides translocate in the phloem, which runs from the photosynthesizing leaves to the meristematic (growing) tissue that need food for energy. Herbicides that move primarily in the phloem usually are applied post-emergence to the foliage. They include the growth hormone herbicides, the post-emergence grass herbicides, and glyphosate (Roundup).

Some herbicides translocate in both the xylem and phloem. They may be applied either to the soil or the foliage. Examples of herbicides that move in both streams are dicamba and imazethapyr.

Contact herbicides do not translocate but interfere with the plant system in the tissue where they are absorbed. Dinitroanilines are applied to the soil and inhibit the root development of seedlings growing through the herbicide layer. Contact foliar herbicides are applied to plant foliage and damage all membranes. Because they require thorough coverage of plant foliage for effective control, they are usually applied with a surfactant or crop oil concentrate if crop tolerance allows.

Note that herbicides within the same chemical families may have different sites of absorption. Don't assume that since a particular herbicide is in a family that it will have the same site of absorption as other members of the family.

Common herbicides classified according to their mode of action are listed in Table 6.5, page 87.

Weed Resistance to Herbicides

Producers in many states face the dilemma of populations of weed species becoming resistant to herbicides.

Herbicide-resistant weeds can develop as a result of repeatedly using the same herbicide or herbicides with the same mode of action. Herbicide-resistant plants are naturally present in extremely low numbers. Repeatedly using the same herbicide allows the resistant weeds to multiply while the susceptible weeds are controlled. Therefore, continuous use of the same pesticide may lead to a resistant population. Over time the weed population shifts to primarily herbicide-resistant weeds so weed control fails. Resistant weeds cannot be controlled by increasing the herbicide rate.

One way to slow the development of resistant weeds is to use herbicides with different modes of action; that is, herbicides that kill weeds through different processes. If you must make multiple applications, use pesticides with different modes of action to help reduce resistance from developing in target pest populations. International committees classify pesticides based on their modes of action on the label. For example, an herbicide label may have the following:

GROUP	**1**	**HERBICIDE**

If the applicator uses this herbicide, and must use an herbicide again, he or she should consider using one with a group number other than 1, as it would have a different mode of action. The label also may contain information under the heading "Resistance Management Recommendations."

For example, a weed resistant to Pursuit also develops resistance to Classic, another amino acid synthesis inhibitor (Group 2). Multiple resistance is resistance to more than one class of herbicides with different modes of action (where more than one mechanism for resistance is involved). Once a weed population develops resistance, cross-resistance, or multiple resistance to some modes of action herbicides, control with the same class of herbicides can be very difficult. If multiple resistance occurs, choices may be severely limited.

Furthermore, some weeds are developing resistance to glyphosate (Group 9), including common ragweed, marestail, giant ragweed, kochia, common waterhemp, and Palmer amaranth. Glyphosate resistant kochia has been identified in northern Wyoming.

The following suggestions can help minimize the evolution of herbicide-resistant weeds:

1. Rotate crops to keep any one weed species from dominating. Rotations including row crops, small grains, and perennial forage crops are the most effective.
2. Include tillage as a component of the weed management program. Crop rotation permits a variation in tillage timing.
3. Use cultural practices that enhance crop growth to outcompete weeds. Planting sorghum and beans in narrow rows improves their competitiveness with weeds.
4. Apply herbicides with different modes of action in successive years and, where possible, within a year. This approach will slow the increase of a weed resistant to one mode of action.
5. Use short-residual rather than persistent herbicides. Most cases of resistant weeds involve persistent herbicides. When using long residual herbicides, also use other control measures such as tillage.
6. Scout fields regularly to identify changes in weed response to effective herbicides used previously.

If you suspect the possibility of resistance developing, check the following criteria to aid your diagnosis. If all or most of the following statements are true, contact a Wyoming Extension office or the Wyoming Department Agriculture.

1. All other causes of herbicide failure have been eliminated.
2. Other weeds listed on the herbicide label are effectively controlled.
3. The field has a history of continuous use of the same herbicide or of herbicides with the same mode of action.
4. The weed species was controlled effectively in the past, and control was based on herbicides rather than mechanical control.

Weed Management in Herbicide-Resistant Crops

Herbicide-resistant crops coupled with the appropriate herbicide have generally resulted in better weed control with less risk of crop injury than with conventional management systems. As with most things in life, there are pros and cons using herbicide-resistant crops.

Pros

The pros include weed management that usually will be improved because herbicide rates and timings are not dictated by crop tolerance. Also, the total cost of weed management is lower, even when the increased seed cost is included.

Crops that are less competitive with weeds (for example, sugarbeets is less competitive than corn) and cropping systems that reduce crop competition (for example, skip-row corn or low population rain-fed corn) benefit the most from herbicide-resistant crops each year due to plant variety protection restrictions.

Cons

The cons are the increased cost of seed for most varieties and hybrids and that the producer must buy new seed. Also, GMO crops may have a limited market and can contaminate adjoining crops. Another con is that there is an increased potential for weeds to develop resistance to herbicides.

The first case of glyphosate resistance in a weed occurred where soybean was planted continuously with no-till and only glyphosate was used before and after planting.

Total post-emergence (POST) weed management programs have become popular with herbicide-resistant crops. Let's compare the advantages and disadvantages of total POST programs with preemergence (PRE) plus POST programs.

As Table 6.4 shows, a PRE + POST program is usually the best and most flexible weed management program for many producers.

Table 6.4. Weed Management Strategies

Weed Control	Advantages	Disadvantages	Risk of evolving herbicide resistance
PRE followed by POST	Excellent weed control POST timing less critical Tolerant/resistant weeds checked	Two operations Higher costs unless reduced amount of PRE is used	Low
POST one time	Single operation Low cost	Narrow application window Early ad late competition Incomplete control	High
POST two times	Excellent weed control	Two operations Two post treatments (wind) Select tolerant/resistant weeds	Moderate

Table 6.5. Herbicide Groups, Modes of Action, Chemical Families, Active Ingredients, Trade Names, and Locations of Uptake

Herbicides can be classified into families based on their chemical similarity or grouped by how they kill plants (mode of action and site of action). In some cases, herbicides from different chemical families have a similar site of action. Combinations of herbicides having the same site of action can lead to problems. For example, repeated use of acetolactate synthase (ALS) inhibitors can result in the selection for ALS-resistant weeds. Using sulfonylurea and imidazolinone herbicides (Classic, Pursuit, etc.) in the same growing season can result in increased carryover problems or possible crop injury. These problems can be lessened by rotating or combining herbicides with different sites of action. This table lists herbicides by specific site of action (column 1), broad mode of action (column 2), and chemical family (column 3). Those herbicides with a common site of action site are the highest risk of an additive effect, which can lead to resistant weed development, additional carryover, or more crop injury. Refer to the journal, Weed Technology, 11:384-393 (1997) for additional information on herbicide classification.

Group, based on site of action	Mode of Action (Herbicide Type)	Chemical Family	Active Ingredient	Trade Name	Location of uptake*
GROUP 1					
ACCase Inhibitors (acetyle CoA carboxylase)	Lipid Synthesis Inhibitors	Aryloxyphenoxypropionates	clodinafop propargyl	Disovery	F
			diclofop	Hoelon	F
			fenoxaprop	Acclaim Extra	F
			fluazifop	Fusilade DX	F
			quizalofop	Assure II	F
		Cyclohexanedione	clethodim	Select	F
			sethoxydim	Poast Plus	F
			tralkoxydim	Achieve	F
GROUP 2					
ALS Inhibitors (acetolactate synthase)	Amino Acid Synthesis Inhibitors (Groups 2, 9)	Sulfonylurea	bensulfuron	Londax	F/R
			chlorimuron	Classic	F/R
			chlorsulfuron	Glean	F/R
			ethametsulfuron	Muster	F
			foramsulfuron	Option	F
			halosulfuron	Permit/ Battalion	F/R
			iodosulfuron	Autumn/Equip	F
			metsulfuron	Ally/Escort	F/R
			nicosulfuron	Accent	F
			primisulfuron	Beacon	F/R
			prosulfuron	Peak	F/R
			rimsulfuron	Matrix	F/R
			sulfometuron	Oust	F/R
			sulfosulfuron	Maverick	F/R
			thifensulfuron	Harmony/ Pinnacle	F/R

Section 6

Group, based on site of action	Mode of Action (Herbicide Type)	Chemical Family	Active Ingredient	Trade Name	Location of uptake*
			triasulfuron	Amber	F/R
			tribenuron	Express	F/R
			triflusulfuron	Upbeet	F
Imidazolinone			imazamethabenz	Assert	R/F
			imazamox	Raptor	F/R
			imazapic	Plateau	R/F
			imazaquin	Scepter	R/F
			imazapyr	Arsenal	R/F
			imazethapyr	Pursuit	R/F
Triazolopyrimidine			chloransulam	FirstRate	F/R
			flucarbazone	Everest	F/R
			flumetsulam	Python	R/F
GROUP 3					
Microtubule Inhibitors	Seedling Root Growth Inhibitors (cell division)	Dinitroaniline	benfluralin	Balan	S/R
			ethalfluralin	Curbit/Sonalan	S
			oryzalin	Surflan	S
			pendimethalin	Prowl	S
			prodiamine	Barricade	S
			trifluralin	Treflan	S
Pyridines			dithiopyr	Dimension	R/F
Benzamides			pronamide	Kerb	S/R
Benzoic acids			DCPA	Dacthal	R
GROUP 4					
Specific site not known	Growth Regulators (Synthetic Auxins) (Groups 4, 19)	Phenoxyacetic acids	2,4-D	Many	F/R
			2,4-DB	Butyrac	F
			dichlorprop	Many	F
			MCPA	Many	F/R
			mecoprop	Many	F
		Benzoic acids	dicamba	Banvel/Clarity	F/R/S
		Carboxylic acids	aminopyralid	Milestone	F/R
			clopyralid	Stinger	F/R
			fluroxypyr	Starane	F
			picloram	Tordon	F/R
			triclopyr	Garlon	F/R
		Quinoline carboxylic acid	quinclorac	Paramount	F/S

Group, based on site of action	Mode of Action (Herbicide Type)	Chemical Family	Active Ingredient	Trade Name	Location of uptake*
GROUP 5					
Photosystem Inhibitors	Photosynthesis Inhibitors (Groups 5, 6, 7)	Triazines	ametryn	Evik/F	R/F
			atrazine	AAtrex	R/F
			cyanazine	Bladex	R/F
			prometon	Pramitol	R/F
			simazine	Princep	R
		Triazinones	hexazinone	Velpar	R/F
			metribuzin	Sencor	R/F
		Phenylcarbamates	desmedipham	Betanex	F
			phenmedipham	Betanal	F
		Uracils	bromacil	Hyvar	R
			terbacil	Sinbar	R
		Pyridazinones	pyrazon	Pyramin	R/F
GROUP 6					
Photosystem Inhibitors	Photosynthesis Inhibitors (Groups 5, 6, 7)	Nitrile	bromoxynil	Buctril	F
		Benzothiadiazinones	bentazon	Basagran	F
		Phenylpyridazine	pyridate	Tough	F
GROUP 7					
Photosystem Inhibitors	Photosynthesis Inhibitors (Groups 5, 6, 7)	Phenylureas	diuron linuron	Karmex	R
			siduron	Lorox/F	R/F
			tebuthiuron	Tupersan	R
				Spike	R
GROUP 8					
Non-ACCase Lipid Synthesis Inhibitor	Seedling Shoot Growth Inhibitors (Groups 8, 15)	Phosphorodithionates	bensulide	Betasan	R
		Thiocarbamates	butylate	Sutan +	S/R
			cycloate	Ro-Neet	S/R
			EPTC	Eptam/ Eradicane	S/R
			triallate	Far-Go	S/R

Group, based on site of action	Mode of Action (Herbicide Type)	Chemical Family	Active Ingredient	Trade Name	Location of uptake*
GROUP 9					
EPSP Synthesis Inhibitors	Amino Acid Synthesis Inhibitors (Groups 2, 9)	None accepted	glyphosate	Roundup/ Touchdown	F
GROUP 10					
Nitrogen Metabolism Inhibitors	Glutamine Synthetase Inhibitors	None accepted	glufosinate	Liberty	F
GROUP 12					
Phytolene desaturase inhibitor	Pigment Inhibitors	None accepted	fluridone	Avast	S/R
		Pyridazinone	norflurazon	Zorial	S
GROUP 13					
Diterpene synthesis inhibitor	Carotenoid Pigment Inhibitors (Groups 13, 27)	Isoxazolidinone	clomazone	Command	R/S
GROUP 14					
PPO Inhibitors	Cell Membrane Disruptors (Groups 14, 22)	Diphenylethers	acifluorfen	Blazer	F
			fomesafen	Reflex/Flexstar	R/F
			lactofen	Phoenix/Cobra	F
			oxyflurofen	Goal	R/S
		N-phenylphthalimides	flumiclorac	Resource	F
			flumioxazin	Valor	S/F
			sulfentrazone	Authority/ Cover/Spartan	R
			carfentrazone ethyl	Aim/Affinity	F
		Aryl triazinones (Triazolinones)	fluthiacet methyl	Action	F
		Pyrimidinedione	saflufenacil	Kixor	R/F/S

Group, based on site of action	Mode of Action (Herbicide Type)	Chemical Family	Active Ingredient	Trade Name	Location of uptake*
GROUP 15					
Long-chain fatty acid inhibitors	Seedling Shoot Growth Inhibitors (Groups 8, 15)	Chloroacetamides	acetochlor	Harness/ Surpass NXT	S/R
			alachlor	Lasso/Intrro	S/R
			dimethenamid	Frontier/ Outlook	S/R
			metolachlor	Dual	S/R
			propachlor	Ramrod	S/R
		Oxyacetamides	flufenacet	Define	S/R
		Acetamides	napropamide	Devrinol	R/S
GROUP 16					
Lipid synthesis inhibitors	Seedling Growth Inhibitors	Benzofuranes	ethofumesate	Nortron SC	S/R
GROUP 19					
Auxin Transport inhibitors	Seedling Growth Inhibitors (Groups 4, 19)	Phthalamates	naptalam	Alanap	R/F
		Semicarbazone	diflufenzopyr	Distinct	F
GROUP 20	Cell Wall Synthesis Inhibitors (Groups 20,21)	Nitriles	dichlobenil	Casoron	R/F
GROUP 21	Cell Wall Synthesis Inhibitors (Groups 20,21)	Benzamides	isoxaben	Gallery	R/S
GROUP 22					
Photosystem I electron diverter	Cell Membrane Disruptors (Groups 14, 22)	Bipyridyliums	diquat paraquat	Reward	F
				Gramoxone Max	F

Section 6

Group, based on site of action	Mode of Action (Herbicide Type)	Chemical Family	Active Ingredient	Trade Name	Location of uptake*
GROUP 27					
HPPD Inhibitors	Carotenoid Pigment Inhibitors (Groups 13, 27)	Callistemones (Triketone)	mesotrione	Callisto	F/R
			tembotrione	Laudis	F/R
		Isoxazoles	isoxaflutole	Balance Pro	R/F
		Pyrazolones	pyrasulfotole	Huskie	F/R
			topramezone	Armezon/ Impact	F/R
Unclassified or Unknown					
		Organoarsenical	DSMA	Many	F
			MSMA	Many	F
		Other	endothall	Aquathol	R/F
			difenzoquat fosamine	Avenge	F
				Krenite	F

*Site of herbicide uptake:
R=Root uptake
S=Shoot uptake
F=Foliage uptake

Section 7: Category 901B - Insect Control

LEARNING OBJECTIVES

After studying this section, you will be able to:

A. Identify common insect pests for corn, wheat, and alfalfa.

B. Describe the biology and life cycle of crop pests.

C. Describe two nonchemical control measures for controlling pests in crops.

D. Describe how soil insecticides are applied.

E. Describe how foliar insecticides are applied.

F. Identify factors that might decrease insecticide performance.

INTRODUCTION

Insects and mites are major competitors for available food, each year causing millions of dollars in damage to field crops in the United States. In addition, millions are spent to prevent and control these pests. In 2014, in the major corn-producing states, insecticides were applied to 13% of corn acres, according to the National Agricultural Statistics Service.[2]

More than 80 species of insects and mites may feed on corn, soybean, forage legumes, small grains, sorghum, sugarbeets, dry beans and pastures (Tables 7.1, 7.2, 7.3, 7.4, page 94). Most rarely build up to economically important numbers, so only the more common damaging pests will be discussed in detail in this section.

The first part of this section provides descriptions of and information about life cycles and habits of common insect pests of field crops. The discussion of each insect also includes scouting tips, economic thresholds, and recommended pest management practices. Be aware that thresholds and guidelines may change over time. Specific insecticides aren't reviewed in detail because registrations and recommendations change annually. For more information, the *Guide to Weed Management* is available at https://marketplace.unl.edu/extension/extpubs/ec130.html.

The second part of this section addresses insect pest management tactics for field crops, including cultural, biological, and chemical control methods. It also includes the increasingly important topic of

2 National Agricultural Statistics Service - Surveys - 2014 Agricultural Chemical Use Survey - Corn Highlights, USDA, May 2015, www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Chemical_Use/2014_Corn_Highlights/.

TABLE 7.1. INSECT PESTS OF CORN

Insects that feed on underground portions of the plant	corn root aphid, corn rootworm larvae, garden symphylan, grape colaspis larvae, seedcorn beetles, seedcorn maggot, white grubs wireworms
Insects that feed at or just above or below the soil surface	billbugs, cutworms, southern corn leaf beetle, webworms
Insects that feed on leaves	armyworm, corn earworm larvae, European corn borer, fall armyworm, flea beetles, grasshoppers, yellowstriped armyworm
Insects that tunnel inside plants	European corn borer, stalk borer
Insects that feed on silks and ears	corn earworm, western bean cutworm, corn rootworm beetles, European corn borer, fall armyworm, woolly bear caterpillars
Insects that suck plant juices	corn leaf aphid, spider mites, thrips

TABLE 7.3. INSECT PESTS OF SMALL GRAINS

Insects that feed on leaves	army cutworm, armyworm, grasshoppers, pale western cutworm
Insects that suck plant juices	bird cherry-oat aphid, chinch bug, corn leaf aphid, English grain aphid, greenbug, Hessian fly, Russian wheat aphid, wheat curl mite (also transmits wheat streak mosaic)
Insects that bore inside stems	stalk borer, wheat jointworm, wheat stem maggot, wheat stem sawfly, wheat strawworm

TABLE 7.2. INSECT PESTS OF FORAGE LEGUMES

Insects that feed on leaves	alfalfa caterpillar, alfalfa weevil, bean leaf beetle, blister beetles, clover leaf weevil, clover root curculio adults, fall armyworm, grasshoppers, green cloverworm, lesser clover leaf weevil, variegated cutworm, webworms
Insects that feed below the soil surface	clover root borer, clover root curculio, cutworms
Insects that suck plant juices	alfalfa plant bug, blue alfalfa aphid, cowpea aphid, meadow spittlebug, pea aphid, potato leafhopper, spotted alfalfa aphid, tarnished plant bug

TABLE 7.4. INSECT PESTS OF SUGARBEETS AND DRY BEANS

Insects that feed on leaves	Western bean cutworm
Insects that feed on underground portions of the plant	sugarbeet root maggot, wireworms, sugarbeet root aphid
Insects that feed at or just above or below the soil surface	cutworms
Insects that feed on leaves	Mexican bean beetle

protecting bees and other pollinators that enhance the economy and the food supply.

INSECT PESTS OF CORN

Insects that attack corn generally are separated into two categories: those that attack the plant belowground and those that attack the plant aboveground.

Belowground

A common belowground insect pest is corn rootworm. Populations of belowground insects are often difficult to predict; consequently, many corn producers prevent damaging infestations with crop rotation, Bt corn hybrids, or insecticide use at planting.

Aboveground

Common aboveground insect pests include the European corn borer and grasshoppers. Aboveground insects are more easily monitored, and if they exceed economic thresholds, can be treated with foliar insecticides. Bt corn hybrids may be an option for several aboveground and belowground pests. Overviews of corn rootworm and European corn borer follow. Refer to https://cropwatch.unl.edu and use the search tool for additional information.

Corn Rootworm

Corn rootworms are the most economically important corn pests. The corn rootworm complex includes three species: western, northern, and southern corn rootworms. Southern corn rootworms don't overwinter in the Midwest; therefore, the western and northern species are the most economically important species in Wyoming.

The background color for both male and female western corn rootworms is yellow-tan, but the two sexes differ somewhat in their markings. On males, usually the entire front half of each wing cover is black; only the tips of the wing covers are yellow-tan. Females are slightly larger and usually have three distinct black stripes on the wing covers, one near each outer edge and one in the middle (Figure 7.1). Northern corn rootworms have no distinct markings. Newly emerged northern corn rootworms are cream or tan in color, but they become green as they age. Both species are about 1/4-inch long. The larvae of both species are creamy white with a brown head and tail plate (Figure 7.2).

Figure 7.1. *Side-by-side comparison of adult specimens of the southern corn rootworm* (Diabrotica undecimpunctata howardi)*, northern corn rootworm* (D. barberi) *and western corn rootworm* (D. virgifera virgifera)*. Photo: R.L. Croissant, Bugwood.org.*

Figure 7.2. *Western corn rootworm larvae (about one-quarter inch long). Photo: Scott Bauer, USDA Agricultural Research Service, Bugwood.org.*

Damage

Rootworm beetles will feed on corn leaves and weed blossoms, but prefer corn silks and pollen.

They clip fresh, green silks off at the ear tip. This injury may interfere with pollination, so some kernels never form. An average of five or more beetles per plant may be sufficient to cause economic damage if they are clipping silks to within one-half inch of the ear tip. Beetles mate in July and August; females lay eggs almost exclusively in cornfields. Western and northern corn rootworms complete one generation each year.

Life cycle

Western and northern corn rootworms overwinter as eggs in the soil. Eggs begin hatching in late May to early June. Rootworm larvae survive only on the roots of corn and a few grasses. They cannot survive on the roots of soybean and other broadleaf plants.

Larvae chew on and tunnel inside or along the roots. As they feed, the larvae may prune roots all the way back to the stalk. Extensive feeding weakens the root systems. Injured plants cannot take up water and nutrients efficiently and are susceptible to lodging. Yield losses result from both root pruning and lodging.

When the larvae finish feeding, they pupate within small earthen cells. The pupa transforms into the beetle stage in about one week, and beetles begin emerging in late June or early July.

Control

A corn-corn-dry bean-wheat rotation usually provides excellent control of rootworm larvae because (1) the larvae survive only on corn roots; (2) rootworm beetles don't lay many eggs in dry beans or wheat; and (3) rootworms complete only one generation each year. A corn-dry bean rotation may fail to control rootworms when volunteer corn plants or grassy weeds in a dry bean field attract egg laying beetles or when northern corn rootworms exhibit prolonged diapause. Diapause is a biological phenomenon that allows some rootworm eggs to remain dormant in the soil for more than one winter. However, the occurrence of this trait is infrequent in Wyoming and rarely contributes to economic damage in a corn-dry bean rotation.

Corn planted after corn is susceptible to injury by corn rootworm larvae, depending upon the size of the rootworm population. Producers now have a variety of options to control damage by rootworm larvae, including granular and liquid insecticides applied at planting, seed treatment using neonicotinoid insecticides, and transgenic corn hybrids active against rootworms (e.g. Bt). By counting western and northern corn rootworm beetles from mid-July into September, growers can determine the potential for rootworm larval injury the following year. The economic threshold is 0.75 beetles per plant. This indicates a potential for root damage the next summer. Suppose you find an average of 0.75 or more beetles per plant and the plant population is 24,000 plants per acre, for any sampling date. Then plan to rotate to a non-host crop or use a rootworm control measure if corn will be planted the following year. If the average is fewer than 0.75 beetles per plant, the probability of economic damage the next year is low, and rootworm control measures are unnecessary.

Another corn rootworm management tactic is to control the beetles in July and/or August to prevent them from laying eggs. However, this is a complicated process. You must identify both species (western and northern), distinguish between the sexes, and determine whether the females are ready to lay eggs. Frequent and precise scouting is required.

European Corn Borer

Damage

Historically, the European corn borer has been one of the most destructive corn pests in the U.S. The larvae tunnel inside the corn plants and disrupt the flow of water and nutrients to the developing ear. Extensive tunneling may cause stalks to break or lodge. Tunneling in the ear shank may result in ear drop. Corn borer feeding also provides an avenue into the plant for infection by stalk rot organisms. Since the introduction of Bt corns active against European corn borer, stalk rots have become much less common. Corn borers still may damage popcorn, seed corn, and non-Bt field corn.

Life cycle

Two generations of European corn borers occur every year. European corn borers overwinter as mature larvae, usually inside the stalk (Figure 7.3). The larvae begin pupating in May, spend about two weeks in the pupal stage, and emerge as moths in late May and June.

Figure 7.3. *European corn borer* (Ostrinia nubilalis). *Photo: Mariusz Sobieski, Bugwood.org.*

Figure 7.4. *European corn borers are in flight July through mid-August, also the time to scout for egg masses. Photo: Mark Dreiling, Bugwood.org.*

Figure 7.5. *European corn borer egg mass. Photo: Frank Peairs, Colorado State University, Bugwood.org.*

Moths laying eggs for the first generation seek the tallest (earliest planted) corn.

Moths laying eggs for the second generation seek later maturing fields with fresh pollen and silks.

Control

Scout for first-generation corn borers and injury during June. The percentage of plants with whorl feeding and the average number of larvae per infested plant are needed to make management decisions.

Scout for second-generation corn borers by counting egg masses. Start checking when moth flight is underway, usually from July through mid-August (Figure 7.4). Entomologists have developed management worksheets for both first- and second-generation European corn borers to aid in making control decisions.

The most effective corn borer control is to apply treatments soon after egg hatch to kill the young larvae before they bore into the plant. The larvae begin tunneling into stalks about 10 days after hatching.

Grasshoppers

See discussion under *General Insect Pests*, page 106.

INSECT PESTS OF ALFALFA

Because of its lush growth, alfalfa provides an excellent habitat for a great variety of insects: species destructive to alfalfa and other crops, species that inhabit alfalfa but have little or no effect on the crop, pollinating insects, incidental visitors, and predators and parasitoids of other insects. Because of its perennial growth, many species overwinter in alfalfa.

More than 100 species of insects and mites are capable of reducing alfalfa yield, impairing forage quality, or reducing the vitality and longevity of the crop. However, only three insect species are regular pests in Wyoming: alfalfa weevil, for the seed industry, lygus bugs, and the alfalfa seed chalcid. See *Alfalfa Insects I* and *Alfalfa Insects 2* at http://extensionpubs.unl.edu/publication/9000016366812/alfalfa-insects-i/ and http://extensionpubs.unl.edu/publication/9000016366819/alfalfa-insect-ii/.

Alfalfa Weevil

The mature alfalfa weevil larva is about 3/8-inch long and has a black head. The larva's curved body is green with a white stripe along the center of the back (Figure 7.6). The adult alfalfa weevil is about 1/4-inch long with a distinct snout. It is light brown with a darker brown stripe along the center of the back (Figure 7.7).

Figure 7.6. *Alfalfa weevil* (Hypera postica) *larva. Photo: Clemson University - USDA Cooperative Extension Slide Series, Bugwood.org.*

Figure 7.7. *Adult alfalfa weevil* (Hypera postica). *Photo: Joseph Berger, Bugwood.org.*

Damage

The larvae and adult weevils are responsible for damage to alfalfa. Larvae mainly injure the first crop but may also injure the second crop. Young larvae feed on the stems for a while, then move to the leaf buds at the tops of the plants. They chew cavities in the young buds and later feed on the leaves. Their feeding skeletonizes the leaves, so that an infested alfalfa field appears frosted, grayish or whitish. The injury to buds stunts plant growth, reduces yield, reduces the quality of the hay, and make the field unfit for seed production. After the first cutting, newly emerged adults may remain in the stubble and cause considerable damage by feeding on regrowth buds.

Life cycle

In Wyoming, adults overwinter in leaf litter or in the field and deposit eggs in the spring. By the time larvae emerge, alfalfa is 6 to 10 inches tall and can tolerate some weevil feeding.

Newly hatched larvae feed in the growing tips. An early sign of injury is pinholes in newly opened leaves. As larvae grow larger, they shred and skeletonize the leaves. Heavily infested fields appear frosted because of green leaf tissue loss. Anything that slows spring alfalfa growth increases the impact of weevil damage.

When weevil larvae finish feeding, they spin net-like cocoons on the plants or in soil debris and pupate. After several days, adults emerge and feed on alfalfa for a few weeks. Although adults usually cause only minor damage to alfalfa, signs of their feeding are obvious. They cause leaves to appear “feathered,” and they scar the stems of the alfalfa plants. Both surviving larvae and newly emerged adults may severely damage regrowth after the first cutting. They remove early shoot growth, deplete food reserves in the roots, and reduce the stand.

Adults eventually leave alfalfa fields to enter summer dormancy in sheltered sites. In the fall, most adults return to alfalfa, where they feed for a while before “hibernating.” Alfalfa weevils complete one generation each year.

Control

The key to effective alfalfa weevil management is timely monitoring. Growers should inspect their fields closely for the first signs of larval feeding in the tips of alfalfa stems during April and May. All growers should examine the stubble after the first cutting of alfalfa has been removed.

Don’t treat for alfalfa weevil unless weevil damage approaches the level that will reduce net profit by at least the cost of an insecticide application.

Parasitic wasps and a fungal disease may regulate alfalfa weevil populations in the spring. When scouting for alfalfa weevils, look for signs of parasitism and for diseased weevils (discolored, moving slowly, or not at all). When natural enemies suppress weevil numbers, insecticide treatments may be unnecessary.

Lygus Bugs

Lygus bugs have been called the most devastating insect pest of the alfalfa seed crop. Plant growth, buds, flowers, and seed development are all seriously affected by lygus feeding. All life stages have piercing-sucking mouthparts and feed on plant sap. Adults are about 1/4-inch with four wings that lie flat over their back and have a distinct V on the back just in front of the wings. Lygus may be greenish or various shades of brown or almost black. (Figure 7.8.) Nymphs are usually green and can be confused with aphids, however, they run about rapidly in contrast to the slow-moving aphids. Lygus appear to feed both day and night. Eggs are inserted into the alfalfa stem tissue.

Figure 7.8. Lygus *sp. Photo: Frank Peairs, Colorado State University, Bugwood.org.*

Damage

When lygus feed on flower buds of alfalfa, the buds turn white and die in two to five days. Blooming may be completely aborted if lygus are present in significant numbers. Immature seeds, if fed upon, will shrivel, become discolored, and fail to germinate when planted. Lygus feeding may also affect the hay forage quality. After lygus are removed and the plants clipped, the new growth is usually normal.

Life cycle

Lygus have three life stages: egg, nymph, and adult. Adults overwinter and become active early spring. They mate soon after and the females begin to lay eggs immediately. Egg laying continues through July. Egg incubation is approximately 15 days then the nymphs pass through five nymphal instars which take approximately 21 days before reaching the adult stage. There can be up to five generations per year.

Control

Several natural factors help control this pest. Wet winters with little or no snow cover with alternating mild and low temperatures result in poor survivability of hibernating adult lygus. Oviposition, incubation of eggs, and nymphal development are retarded by wet cold spring weather (often fatal to large numbers of nymphs). Nymphs are also sensitive to heat and unable to survive short walks in the hot soil between plants on hot summer days. Lygus also have natural enemies including damsel bugs, bigeyed bugs, and ants.

Nymphs will be easier to control than adults. When deciding to treat a field sample the alfalfa with a 15-inch diameter sweep net, taking a 180-degree sweep. Insecticide should be considered if you find two lygus per sweep in pre-bloom, five per sweep in full bloom, or eight per sweep post bloom. Best results will be achieved if you can eliminate the lygus before bloom and before pollinators are active in the field. If you must apply insecticide during bloom, make applications when pollinators are not present such as evening, at night or early morning.

Alfalfa Seed Chalcid

Seed losses from this pest are commonly estimated between 10% and 15%. This pest is a small (2 mm) black wasp with clear membranous wings (Figure 7.9).

Figure 7.9. *Seed chalcid* (Euperilampus *sp.*). *Photo: Johnny N. Dell,* Bugwood.org.

Damage

The female inserts eggs into the newly developing seeds by means of a short ovipositor. Seeds are destroyed when larvae feed on the internal contents.

Life cycle

In the Intermountain West, chalcids overwinter as larvae inside the alfalfa seed. As temperatures increase in the spring, the larvae inside the seed pupates and develops into adults. When development is complete, the adult escapes the seed by chewing a hole through the seed coat. Males seem to emerge before females. Once mated females seek out newly developing seed and deposit 2 to 3 eggs per seed.

Control

There has been little success in the use of insecticides to control the alfalfa seed chalcid — including systemic insecticides.

Only cultural practices are recommended for managing populations of the alfalfa seed chalcid.

INSECT PESTS OF WHEAT

In Wyoming, relatively few insects attack wheat. However, when outbreaks of insects coincide with the head-filling stage of wheat growth, yield losses can be serious. Most of the potential pests are defoliators, such as armyworms and grasshoppers, which may cause extensive injury to the flag leaves. For more details, refer to http://entomology.unl.edu/extension/crops/wheat.shtml.

Aphids

Several species of aphids can injure wheat. Greenbugs (Figure 7.10) and Russian wheat aphids (Figure 7.11) are the most likely to cause economic injury, although other aphids also can be found in wheat fields.

The greenbug is lime green with a dark-green stripe along the center of its back. The Russian wheat aphid has an olive-green spindle-shaped body and short antennae. Their “double-tailed” appearance and reduced cornicles help distinguish them from greenbugs and other aphids found in wheat.

Figure 7.10*. Greenbug* (Schizaphis graminum). *Photo: Frank Peairs, Colorado State University, Bugwood.org.*

Figure 7.11*. Russian wheat aphid* (Diuraphis noxia). *Photo: Frank Peairs, Colorado State University, Bugwood.org.*

Life cycle and damage

Spring winds carry greenbugs and Russian wheat aphids into Wyoming. Their numbers can increase rapidly into large colonies unless predators and parasitoids hold the aphids in check. Both species suck plant juices from leaves and stems. Damaged plants turn yellow, then brown. Aphid injury is most likely when grain heads begin to fill. These aphids may also feed on developing kernels. Both greenbugs and Russian wheat aphids can transmit a virus that causes barley yellow dwarf disease.

Corn leaf aphids and bird cherry-oat aphids rarely cause damage to wheat in Wyoming. However, their presence may create a diagnostic problem. Correctly identifying the aphid species present in wheat is essential for effective management.

Wheat Curl Mite

Wheat curl mites are small (1/100-inch long), white, and have a cigar-shaped body with two pairs of legs (Figure 7.12). On wheat, they are found within the whorl of the newly emerging leaves and infest the wheat head when it emerges.

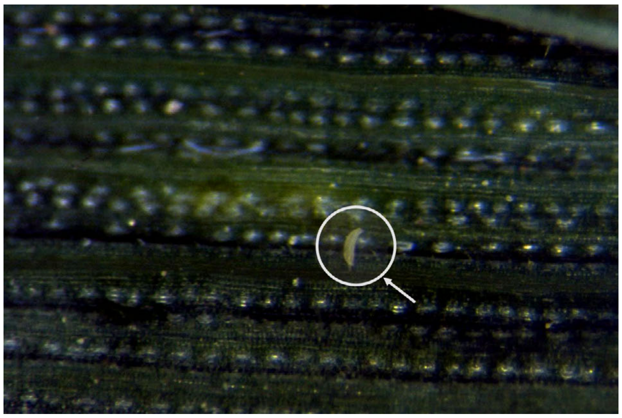


Figure 7.12*. The wheat curl mite* (Eriophyes tulipae)*, inside a rolled wheat leaf. Photo: Frank Peairs, Colorado State University, Bugwood.org.*

Damage

The wheat curl mite is the only known vector of three viruses in wheat: wheat streak mosaic, high plains (also called wheat) mosaic, and Triticum mosaic virus. This complex of viruses causes the greatest disease loss in winter wheat production in the western Great Plains. Widespread outbreaks of this complex are often linked to pre-harvest volunteer wheat resulting from hail.

Wheat plants heavily infested with mites often have curled leaf margins. Wheat curl mites have a broad range of hosts including wheat, corn, and numerous other cultivated and wild grasses.

Life cycle

The complete life cycle of the wheat curl mite requires 7 to 10 days, with egg, larva, nymph, and adult stages. It has a continuous life cycle, with mites overwintering on the plants in all stages of development. Wheat curl mites have a very high reproduction rate. The offspring from a single female potentially could reach 3 million mites in 60 days. Mite population density will spread between or within fields.

Control

Economic thresholds for wheat curl mites haven't been established. Wheat fields affected by pre-harvest hail should be controlled using tillage or herbicide application of glyphosate or paraquat at least 14 days prior to fall planting. Hail shatters wheat heads and kernels fall to the ground, where they germinate and produce volunteer wheat. The wheat curl mite infests the volunteer wheat and transmits viruses into it. When volunteer wheat cannot be controlled, a resistant variety, such as "Mace" or "Snowmass" should be planted, preferably near the end of the recommended planting window for wheat. Controlling perennial or native grasses isn't recommended, as they are unlikely to allow mite populations to build up into high enough numbers to cause widespread damage.

Wheat Stem Sawfly

The wheat stem sawfly is a native grass feeding insect that has long been a threat to spring wheat production in the northern plains. In the early 1980s, however, it emerged as a significant pest of winter wheat. Since then, sawfly infestations in winter wheat have spread from North Dakota and Montana into southeastern Wyoming, the Nebraska Panhandle, and, most recently, northeastern Colorado.

Figure 7.13*. Wheat stem sawfly* (Cephus cinctus). *Photo: Pest and Diseases Image Library, Bugwood.org.*

Damage

The wheat stem sawfly has traditionally infested spring wheat, but over the last few decades the damage is becoming increasingly common in winter wheat. It also feeds in several hollow-stemmed non-cultivated grasses, including quackgrass, smooth brome and various wheatgrasses. It does not attack corn or broad leaf crops. Although the sawfly may lay eggs in other cereals, including barley, oat, and rye, larvae rarely mature in barley and rye and do not survive in oat.

Darkened areas on the stem, just beneath the node, indicate larval infestation. To verify the presence of the sawfly in a suspected plant, split the stem from top to bottom. A stem filled with a sawdust-like substance indicates feeding activity. The larva will most likely be located in a chamber within the stem, just above the crown.

The most visible wheat stem sawfly damage is stem breakage or lodging just prior to harvest. The stem is greatly weakened by the groove the larva cuts around the base of the plant. Lodging becomes more obvious as harvest approaches and results in yield loss of 5% to 10% due to unrecoverable wheat heads because the combine cannot pick up the lodged stems. In addition, physiological damage caused by feeding activity results in yield losses of 10% to 20% in infested heads that are harvested.

Life cycle

The wheat stem sawfly produces one generation per year. Adults emerge in late May or early June and are generally active when winds are calm and field temperatures are above 50° F. The adult wheat stem sawfly is about 3/4-inch long with smoky-brown wings. It is wasp like in appearance, with a shiny black body with three yellow bands around the abdomen. When not in flight they often are found on wheat stems, positioned with the head pointed downward.

Females lay eggs immediately upon emergence and typically live about one week. The adult emergence and flight period continues for 3 to 6 weeks. They are not strong fliers and usually only fly until they find the nearest wheat field or other suitable host grasses. In wheat, this often results in more serious problems occurring at the field margins closest to the adult emergence site, which is the previous year's wheat field. They preferentially select the largest wheat stems available and insert eggs into the first available internode or when a stem is fully developed, below the uppermost node. If sawflies are abundant, eggs may be laid in smaller stems, and multiple eggs may be laid in a single stem. However, only one larva will survive in each stem due to cannibalism. Females lay an average of 30 to 50 eggs, depending on the size of available host stems. Eggs are difficult to detect because they occur inside the stem.

Sawfly larvae are always found within the stem and will assume an S-shaped position when taken out of the stem. They move slowly down the stem as they feed, for approximately 30 days. Sawfly larvae are cream colored, have a broad head, and are 1/2- to 3/4-inch in length when fully grown. When they are mature they move down towards soil level and cut a V-shaped notch around the interior of the stem. They then seal the interior of the stem just below the notch with frass and move down near the crown. The upper stem often breaks at this weakened notch just prior to harvest, and the remaining stem containing the overwintering chamber is referred to as the 'stub'. The larvae overwinter in the stubs, slightly below soil level, before pupating in early spring. They produce a clear protective covering that protects them from excess moisture and moisture loss.

Cultural controls

Tillage reduces wheat stem sawfly survival. Tillage has variable impact on overall sawfly abundance and damage to the next wheat crop. Shallow tillage after harvest lifts the crowns and loosens the soil around them. This maximizes the larvae's exposure to the late summer dryness and winter cold, increasing mortality. Intense tillage that buries stubble also reduces sawfly survival, but to a lesser degree. Intense tillage may interfere with important biological control agents and will increase the risk of soil erosion. No-till has been linked to many of the recent wheat stem sawfly problems in the region. However, the advantages of controlling the sawfly with tillage must be weighed against the considerable benefits of no-till.

Planting attractive varieties of trap crops such as barley, oat or rye along the edge of wheat fields may be effective in decreasing damage and reducing the number of sawflies the following year. The sawflies will oviposit in the trap crop, but the larvae will be unable to complete development. This method is especially effective when sawfly abundance is low to moderate and significant infestations are limited to the field margins. However, when sawflies are abundant, females may move past the trap crop and into the wheat to oviposit, resulting in significant damage.

Planting wheat in larger blocks as opposed to narrow strips is another cultural practice that may reduce sawfly damage potential. This minimizes the amount of field border adjacent to stubble where sawfly adults will be emerging, and thus, the part of the field most vulnerable to infestation. Sawflies are not strong fliers and tend to fly only until they reach a stem that is suitable for egg-laying, which is the basis for this practice. Though the soil erosion benefits of planting in narrow strips may be reduced, larger fields are still a viable option if erosion is addressed by no-till practices. Use crop diversification to minimize the amount of wheat in the cropping system. Also, arrange rotations to avoid planting wheat in fields adjacent to fields that contained wheat in the previous year.

Resistant wheat varieties

Solid-stem varieties of wheat have been shown to be effective in reducing damage caused by the wheat stem sawfly. The availability of several adapted solid-stemmed wheat cultivars provides a viable management option for parts of the northern High Plains. In areas where the sawfly is a recent arrival, wheat breeding programs are beginning to focus on incorporation of the solid-stem characteristic into adapted varieties, using both conventional selection and linked DNA markers. A program at Colorado State University also is initiating long-term research into novel methods for making the wheat plant less attractive to the sawfly.

Biological control

Several parasitic wasps attack wheat stem sawfly on the northern plains, and these are thought to be important mortality factors. The presence and effectiveness of natural enemies in Wyoming has not been determined.

Chemical control

Currently available insecticides are ineffective and cost-prohibitive. The most promising strategy seems to be control of adults to prevent egg-laying. However, the prolonged flight period likely would require repeated treatments and there is no evidence for the effectiveness of this approach. Using solid-stemmed cultivars and cultural controls are currently the most effective alternatives.

INSECT PESTS OF SUGARBEETS AND DRY BEANS

Insect problems on sugarbeets are sporadic. The most common insect pests are sugarbeet root maggot, cutworms, wireworms, and sugarbeet root aphid. The major insect pests of dry beans are the western bean cutworm, discussed here, and the Mexican bean beetle. General treatment recommendations for these and other insect pests can be found in at http://entomology.unl.edu/extension/crops/sugarbeet.

Sugarbeet Root Maggot

In Wyoming, root maggot flies begin to emerge from the soil in early May. Peak emergence and fly activity occurs in late May or early June. During and shortly after this peak fly activity, egg laying occurs in sugarbeet fields. Larvae feed on sugarbeet roots, causing damage and possibly stand loss.

Figure 7.14. *Adults of the sugarbeet root maggot* (Tetanops myopaeformis). *Whitney Cranshaw, Colorado State University, Bugwood.org.*

In areas where root maggot is continuously serious, growers can have control problems even with insecticides applied at planting. The orange sticky stake fly-trapping method can determine both need and proper timing for a supplemental lay-by treatment to improve control. Using a 2x2-inch stake, mount a garden stake with a 1x10-inch orange stripe on the side, and paint or spray an adhesive (Tangle trap) on the stripe. The base of the orange garden stake should be one foot above the ground. Sugarbeet root maggots are attracted to the orange, and will become stuck on the adhesive. The orange sticky-stake trap should be in place by May 1 to catch the first fly activity of the season.

Western Bean Cutworm

Western bean cutworm moths begin to emerge in early July. The peak moth flight is usually in the latter half of July. This moth flight can be monitored by using pheromone traps to attract male moths. Pheromone traps will indicate the time, and to some extent, the size of the population.

Young larvae feed on buds and young leaves (Figure 7.15). Maturing larvae feed on dry bean pods and seeds, and under heavy infestations, will reduce bean yield. Damaged or "worm-chewed" beans are significant quality factors for both processed and bagged dry beans.

Figure 7.15. *Western bean cutworm* (Striacosta albicosta). *Photo: Adam Sisson, Iowa State University, Bugwood.org.*

Figure 7.16*. Adult western bean cutworm* (Striacosta albicosta). *Photo: Adam Sisson, Iowa State University, Bugwood.org.*

Larvae feed at night and spend the days in the soil; consequently they are very difficult to locate in bean fields.

Use pheromone traps to determine the potential for cutworm damage. If trap catches accumulated from the beginning of the moth flight exceed 500 to 700 moths per trap at peak catch, the potential exists for damaging populations. At this point, further sampling of adjacent corn fields to determine the extent of cutworm infestations, and examining pods to detect the onset of pod feeding, can further establish the likelihood of a problem. If severe cutworm damage is expected based on pheromone or other sampling, the best time to treat is 2 to 3 weeks after the peak moth catch with pheromone traps. For more information, consult *G2013 Western Bean Cutworm in Corn and Dry Beans* at http://extensionpubs.unl.edu/publication/9000016367337/western-bean-cutworm-in-corn-and-dry-beans/.

GENERAL INSECT PESTS

Armyworm

Newly hatched larvae are pale green with longitudinal stripes and a yellow-brown head. Fully grown larvae are about 1-1/2 inches long and green-brown with two orange stripes on each side (Figure 7.17). Several lengthwise stripes mark the remainder of the body. Each proleg (the false, peg-like legs on the caterpillar abdomen) has a dark band. The moth is tan or gray-brown and has a 1-1/2inch wingspan. A small white dot in the center of each forewing is a distinguishing mark.

Figure 7.17*. Fall armyworm* (Spodoptera frugiperda) *larva. Photo: Frank Peairs, Colorado State University, Bugwood.org.*

Damage

The armyworm feeds on several field and forage crops. Armyworms prefer grasses and grain crops such as corn and wheat but occasionally can be found in forage legume crops.

Armyworm moths may lay numerous eggs in wheat fields, and larvae feed until the grain matures or the wheat is harvested. Larvae feed on leaves, working their way up from the bottom of the plants. Injury to lower leaves causes no economic loss, but injury to upper leaves — especially the flag leaf — can reduce yields. After armyworms devour flag leaves, they often chew into the tender stem just below the head, causing the head to fall off.

Armyworms cause two distinct problems in corn. If corn is planted in reduced or no-till fields where grasses are abundant, moths will lay eggs before the corn is planted. The same situation can occur with corn planted into fields with grass cover crops. When the grasses are killed with herbicides, seedling corn plants are the only remaining hosts. Damage to seedling plants can be severe. The larvae bite chunks from the leaf edges. If infestations are intense, seedlings may be chewed to the ground.

The second problem occurs in cornfields that border small grain fields. After the grain matures or is harvested, larvae in the small-grain field will migrate into the adjacent cornfield. Large numbers of larvae can destroy corn plants within a day or two.

Life cycle

Few armyworms overwinter in Wyoming, but some partly grown larvae probably survive the winter under debris. Pupation occurs in April; moths emerge and begin laying eggs in May. Moths that migrate from southern states into Wyoming add to the resident population.

Moths prefer to lay eggs on grasses or grain crops. Eggs hatch in about a week, and larvae begin to feed on foliage. Young larvae scrape the leaf tissues; older larvae feed from the leaf edges and consume all of the tissue. Larvae feed only at night or on cloudy days. After feeding, the larvae pupate under debris or in the soil, and moths emerge to begin another cycle. There are two or three generations each year in Wyoming.

Control

Early detection of armyworm infestation is essential for effective management. Examine dense wheat stands for larvae. If the number exceeds six non-parasitized worms (3/4- to 1-1/4-inches long) per foot of row, an insecticide may be justified.

Monitor fields of no-till corn early in the season. If 25% or more of the plants are being defoliated and some seedlings are being killed, treatment may be warranted. Cornfields that border wheat fields should be monitored closely as the wheat matures.

Weather and natural enemies cause major reductions in armyworm numbers. Hot, dry weather promotes the development of parasitoids and diseases, reducing armyworm populations. Cool, wet weather is most favorable for an outbreak.

Grasshoppers

Grasshoppers are among the most destructive insect pests of field and forage crops, and rangeland in the US. They readily feed on corn, alfalfa, soybean, small grains, sorghum, and many other cultivated crops.

Although several species of grasshoppers occur in Wyoming, differential and redlegged grasshoppers are the most prevalent in agronomic crops. The differential grasshopper (Figure 7.18) is large (1-1/2 inches long), and olive-green and yellow. Dark chevrons or “sergeant’s stripes” on the hind legs are distinguishing marks. The redlegged grasshopper (Figure 7.19, page 108), is smaller than the differential grasshopper and is reddish-brown above, yellow beneath, and has red-tinged hind legs. For detailed descriptions of grasshopper species see *EC1569 Grasshopper Identification Guide for Cropland Grasshoppers*, available at http://extensionpubs.unl.edu/publication/9000016363512/grasshopper-identification-guide-for-cropland-grasshoppers-summer-feeding-species/.

Figure 7.18. *Differential grasshopper* (Melanoplus differentialis). *Photo: David Riley, University of Georgia, Bugwood.org.*

Figure 7.19. *Redlegged grasshopper* (Melanoplus femurrubrum). *Photo: Whitney Cranshaw, Colorado State University, Bugwood.org.*

Adults deposit batches of eggs in the soil during late summer and fall. Eggs overwinter and hatch the following spring. Tillage operations to cropland have very little effect on species like the differential grasshopper that deposit egg masses in uncultivated areas such as roadsides, fencerows, and field edges. The redlegged grasshopper tends to lay eggs in field margins, roadsides, pastures, meadows, and forage crops.

After eggs hatch in the spring, nymphs feed in non-crop areas for roughly 40 to 60 days. This is a window of opportunity for management because grasshoppers may be managed more easily when they are nymphs. Nymphs are less mobile than adult grasshoppers because they lack functional wings. As vegetation in uncultivated areas bordering crops is mowed or dries out, nymphs begin to move into adjacent rows of corn, soybean, or other field crops. If populations of nymphs average 15 to 20 per square yard in non-crop areas bordering a crop field, consider using an insecticide labeled for use in these sites.

Another management strategy is to wait until grasshopper numbers and levels of injury exceed established thresholds within the crop field. In soybean, control might be warranted when defoliation reaches 30% before bloom or 20% to 30% between bloom and pod fill. In corn, seven or more grasshoppers per square yard represents a potentially damaging population; in alfalfa, 15 to 20 per square yard might cause economic damage. Nymphs often succumb to fungal and bacterial diseases during periods of warm, humid weather. This wait-and-see strategy allows time for diseases to suppress grasshopper populations before deciding to treat.

INTEGRATED PEST MANAGEMENT (IPM) TACTICS

Successful pest management combines appropriate pest control tactics. IPM has been defined as selecting management practices that promote favorable economic, ecological, and sociological outcomes. In this context, insecticides should be used only after all other effective insect control alternatives have been explored, and only when an insect population has reached or exceeded an economic threshold. Insecticides should supplement a completely integrated insect management program that also includes cultural, mechanical, and biological control tactics.

NONCHEMICAL INSECT CONTROL

A truly integrated insect management program should include nonchemical as well as chemical control measures. Nonchemical control measures are usually relatively inexpensive and do not cause undesirable side effects in the environment. Practical nonchemical control measures that have proven effective are strongly encouraged.

Cultural Control

Cultural control reduces pest populations through changes in farming practices or by avoiding situations that favor increased pest numbers. This alone often is effective without using other control techniques.

Cultural control measures are usually applied to the most vulnerable stage or weakest link of a pest's life cycle. The environment is changed by altering farming practices at the correct time to kill pests or slow their reproduction. Cultural control measures are usually preventive rather than curative.

Three types of cultural control are:

1. **Crop rotation**, which means planting different crops in a field in successive years instead of planting the same crop every year. This disrupts the life cycles of some major insect pests. Annually rotating corn and soybean usually prevents corn rootworm infestations. Since rootworm beetles don't lay many eggs in soybean and rootworm larvae cannot survive on soybean roots, a corn-soybean rotation provides excellent rootworm control without the need for preventive insecticide applications.

2. **Planting resistant varieties** is often considered a cultural control tactic to reduce pest populations. Resistant varieties provide cumulative control over time, create no hazard to people or the environment, and are usually inexpensive.

   Excellent examples are wheat varieties resistant to Hessian flies and sorghum varieties resistant to greenbugs.

   Tolerant varieties are better able to withstand an insect pest attack or can repair damaged tissues or recover from an attack. Some corn hybrids can tolerate feeding by European corn borers; others compensate for injury from rootworm larvae by growing new roots. Some varieties of alfalfa tolerate feeding by alfalfa weevils or potato leafhoppers better than other varieties.

3. **Tillage and timing of planting and harvesting activities** are also cultural control tactics. Help manage Hessian fly populations by destroying volunteer wheat during the summer and sowing wheat after fall's fly-free date. Both techniques reduce the opportunities for Hessian fly females to lay eggs. One method of managing alfalfa weevils is to harvest alfalfa somewhat early to avoid using an insecticide that may be harmful to predators and parasitoids.

   Cutting alfalfa greatly reduces survival of alfalfa weevil larvae by exposing them to the environment and by removing a food source.

Biological Control

Biological control reduces pest populations by means of living organisms. Many predators, parasitoids, and diseases occur naturally and often regulate insect pest populations. This process of natural control suppresses pest populations. For example, European corn borer populations are often reduced by *Beauveria bassiana*, a fungus, or by *Nosema pyrausta*, a protozoan. These diseases are part of the natural ecosystem and work without human intervention.

Through a process more appropriately called applied biological control, predators, parasitoids, or disease pathogens are introduced artificially into an agricultural ecosystem. Applied biological control programs are commonly initiated for insect pests that have been introduced from foreign countries. Foreign insects transported into the U.S. usually arrive without the parasitoids and predators that attack them in their native land. An introduced insect pest's natural enemies are searched for, studied, and, if deemed feasible, reared and released to establish themselves on their host. A program to control alfalfa weevils with several species of parasitic wasps has successfully established these natural enemies in many parts of the US, including Wyoming.

Microbial insecticides also offer potential within an IPM program. Microbial insecticides are made of microscopic living organisms (viruses, bacteria, fungi, protozoa, or nematodes) or the toxins they produce. These insecticides can be formulated to be applied as sprays, dusts, or granules. Microbial insecticides' chief advantage is their extremely low toxicity to nontarget animals and humans. The spores and the crystalline endotoxin of the bacterium *Bacillus thuringiensis* var. kurstaki (Bt) have been formulated into microbial insecticides that kill the caterpillar stages of moths, including important pests like European corn borers.

Predators

Insect predators kill insect pests by direct attack. They usually prey on a large number of individuals to obtain sufficient food. Many predators are common in field and forage crops. Don't mistake predators for insect pests. The presence of a large number of predators in a field indicates that natural control is in effect and an insecticide treatment may not be necessary. The predators described below commonly occur in Wyoming field and forage crops.

Assassin bugs

Assassin bugs use their strong, curved beaks to feed on many types of insects. They are usually brown or black, somewhat oval and elongated, and from 1/2- to 1-1/2-inches long, depending upon the species. Their front legs are adapted for grasping. The head is narrow, and the area behind the eyes resembles a neck. Both adults and nymphs are predaceous, meaning they eat other insects.

Figure 7.20: Assassin bug (Sinea spinipes) *nymph. Photo: Louis Tedders, USDA Agricultural Research Service, Bugwood.org.*

Bigeyed bugs

Bigeyed bugs are small, and their front legs are modified for grasping prey. As their name implies, bigeyed bugs have large, protruding eyes. Both adults and nymphs use their piercing, sucking mouthparts to prey on small insects, insect eggs, and mites. Adults overwinter in debris on the ground in alfalfa and small-grain fields. Females lay eggs in the spring, and the nymphs pass through five instars. A generation is complete in about a month, so there are several generations in a season.

Figure 7.21: Bigeyed bug (Geocoris punctipes) *adult. Photo: Russ Ottens, University of Georgia, Bugwood.org.*

Damsel bugs

Damsel bugs, or nabids, are slender insects about 1/4- to 3/8-inch long. They are gray or tan and sometimes finely lined or spotted. Their front legs are modified for grasping, and they use their long "beak" to pierce their prey and suck out body contents. Both adults and nymphs are predaceous, feeding on aphids, small caterpillars, and other small insects. Adults overwinter in alfalfa and small-grain fields or under protective debris. Females lay eggs in the spring in soft plant tissues. Nymphs go through five instars before they transform into adults. There is usually only one generation a year.

Figure 7.22: Damsel bug (Nabis *sp.*) *adult. Photo: Whitney Cranshaw, Colorado State University, Bugwood.org.*

Green lacewings

Adult green lacewings have delicate, light-green bodies about 3/4-inch long, large, clear wings, and bright golden or copper-colored eyes. They emerge in the spring and fly slowly and erratically. Females lay eggs borne at the ends of threadlike stalks. The eggs hatch in 3 to 5 days, and the elongated, mottled-brown-and-white larvae begin searching for prey.

Figure 7.23: Green lacewings (Chrysoperla *sp.*) *adult. Photo: Frank Peairs, Colorado State University, Bugwood.org.*

Figure 7.24: Green lacewings (Chrysoperla *sp.*) *egg. Photo: Whitney Cranshaw, Colorado State University, Bugwood.org.*

The voracious larvae, called aphid lions, use their sickle-shaped mandibles to grasp and puncture prey so they can suck out juices. They prefer to feed on aphids but also prey on other small, soft-bodied insects and insect eggs. Since the life cycle from egg through three larval instars to adult requires about a month, some stages of lacewings are present throughout the season.

Figure 7.25. Green lacewings (Chrysoperla *sp.*) *larva. Photo: David Cappaert, Bugwood.org.*

Ground beetles and rove beetles

Adult and larval ground beetles and rove beetles prey on a wide range of insects. They are especially important as predators of caterpillars and other soft-bodied insects in field crops. Together these two beetle families include nearly 5,000 species widely distributed throughout North America. Most are predaceous in both the larval and adult stages, although some adults feed on plant material.

Adult ground beetles are fairly large (3/4 to 1-1/2 inches), have flattened bodies, and are usually dark and shiny, occasionally metallic. They can run rapidly on their long legs. The larvae are long and thick-skinned, and have sharp, forward-projecting mandibles. They can also run rapidly. Both larvae and adults are aggressive hunters at night when they search for larvae and pupae. They are rather inactive during the day. Most species have one generation a year.

Figure 7.26. Ground beetle. Photo: Joseph Berger, Bugwood.org.

Adult rove beetles are long and slender with very short wing covers that don't completely cover the abdomen. They are active insects that run or fly rapidly. Their mandibles are very long, slender, sharp, and usually cross in front of the head. Most are black or brown and vary considerably in size.

Figure 7.27. Rove beetle. Photo: Joseph Berger, Bugwood.org.

Lady beetles

More than 400 species of lady beetles are in North America. The adults are round or oval, ranging in color from the familiar orange with black spots to various shades of red and yellow, to jet black. Larvae are flattened, elongated, and tapered toward the posterior end, resembling miniature alligators. They are brown, blue, or black and are spotted or banded with bright orange, red, or tan. The body is covered with tubercles and spines.

Figure 7.28: Spotted lady beetle (Coleomegilla maculata). *Photo: Whitney Cranshaw, Colorado State University, Bugwood.org.*

Figure 7.29. Sevenspotted lady beetle (Coccinella septempunctata). *Photo: Whitney Cranshaw, Colorado State University, Bugwood.org.*

Figure 7.30. Two-spotted lady beetle (Adalia bipunctata). *Photo: Whitney Cranshaw, Colorado State University, Bugwood.org.*

Figure 7.31. Convergent lady beetle (Hippodamia convergens). *Photo: Ward Upham, Kansas State University, Bugwood.org.*

Figure 7.32. Twice-stabbed lady beetle (Chilocorus kuwanae). *Tom Murray, Bugwood.org.*

Adults overwinter in protected areas, usually in large masses. When the weather warms in spring, beetles mate and females lay orange, spindle-shaped eggs in clusters. Larvae hatch, search for, and feed on other insects; they are fully grown in about three weeks. They pupate after gluing the tip of the abdomen to a surface. Because a generation, from egg to adult, is complete in about 30 days, there may be several generations a year.

Lady beetle adults and larvae are voracious predators of aphids and other soft-bodied insects. Lady beetles can build up in enormous numbers in fields where aphids are numerous.

Minute pirate bugs

These predaceous bugs are 1/6- to 1/8-inch long. Adults have black and white markings, somewhat similar to chinch bugs. Nymphs are orange, tan, or brown. Both adults and nymphs have piercing, sucking mouthparts and prey on small insects, spider mites, and insect eggs. They are important controls of soybean aphids. Adults overwinter in wheat, alfalfa, grasses, and some weeds. Females lay eggs in the spring, and nymphs feed for about two weeks. There may be two to three generations a year, but the bugs are most common in August.

Figure 7.33. Minute pirate bugs (Orius *sp.*). *Photo: Whitney Cranshaw, Colorado State University, Bugwood.org.*

Predaceous stink bugs

Several species of stink bugs prey on the larval stages of moths and beetles. Adults are broad, flat, and shield-shaped; nymphs are rounded and strikingly colored. One common species, the spined soldier bug, has prominent spines on its shoulders. Stink bugs overwinter as adults and begin laying barrel-shaped eggs in masses in the spring. Nymphs pass through five instars. There may be one to three generations a year, depending upon the species.

Figure 7.34. Predatory stink bug (Euthyrhynchus floridanus). *Photo: Johnny N. Dell, Bugwood.org.*

Soldier beetles

Soldier beetles are elongated, soft-bodied beetles that resemble lightning bugs. Adults have yellow wing covers marked with two black spots. Both larvae and adults are predaceous.

Figure 7.35. Spined soldier bug (Podisus maculiventris) *nymph. Phil Sloderbeck, Kansas State University, Bugwood.org.*

Figure 7.36. Spined soldier bug (Podisus maculiventris) *adult. Phil Sloderbeck, Kansas State University, Bugwood.org.*

Spiders

These distant relatives of insects are common in many field and forage crops. All spiders are predaceous and have four pairs of legs. They kill their prey by injecting a poison that causes paralysis, then suck out body fluids. Spiders are most numerous in August.

Syrphid fly larvae

Adults are called “flower flies” because they hover near flowers and feed on nectar and pollen. They resemble bees except they have only one pair of wings and lack a stinger. The predaceous larvae are green, yellow, or gray, with body contents are visible through the skin. They are slug-like in appearance, with no legs, and a body that tapers toward the head. The larvae prey on spider mites and other soft-bodied insects such as aphids.

Figure 7.37. Syrphid larva feeding on oleander aphid. David Cappaert, Bugwood.org.

Figure 7.38. Adult syrphid fly. Whitney Cranshaw, Colorado State University, Bugwood.org.

Parasitoids

Parasitic insects or parasitoids develop as larvae in or on a host insect from eggs laid on, in, or near the host. They usually kill the host by consuming all or most of the host's body. The adults are normally free-living but seek host insects on which they lay eggs. They commonly attack only one stage of the host. Because the life cycle of most parasitic insects is short (usually only 10 to 14 days), there may be several generations each year. The parasitoids described below commonly occur in Wyoming field and forage crops.

Parasitic wasps

There are three major groups of parasitic wasps: family *Braconidae*, family *Ichneumonidae*, and superfamily *Chalcidoidea*. All are relatively small (1/32- to 1-inch long), brown or black, with two pairs of transparent wings. The female has an ovipositor or stinger that she uses to penetrate the host's body and deposit eggs. Each species of wasp attacks only one host species or a group of closely related species.

When the wasp's eggs hatch, the larvae feed on the host body tissues and fluids. The host usually remains alive until the wasp larvae mature. Parasitic wasp larvae may pupate either inside or outside the host's body.

Parasitic flies

Members of the fly family *Tachinidae* are parasitoids of many different insects. Adults are gray, robust, flattened, and are about twice the size of a house fly. The base of the abdomen is covered with long bristles. Females deposit cream-colored eggs on the skin of many insect larvae. They usually lay the eggs just behind the host's head so that the host cannot scrape them off. Maggots hatch and cut through the skin into the host. They feed on tissues and fluids and complete their larval development in the host.

Insect Pathogens

Insect pathogens are occasionally responsible for suppressing outbreaks of pest insects. These disease organisms can spread through insect populations quite rapidly if weather conditions favor infection. Insect pathogens include fungi, bacteria, protozoa, and viruses. Except for the fungi, organisms gain entry and infect the hosts through the mouth and digestive tract. Fungi gain entrance through the insect's "skin" (integument).

Fungi are the most important group of pathogens that infect pest insects. Fungal diseases spread through an insect population more rapidly during wet seasons. *Nomuraea rileyi* is a fungus that infects green cloverworms. Diseased larvae are covered with white-to-green spores. Other common genera are *Beauveria*, which infects European corn borers, corn rootworm beetles, and bean leaf beetles; and *Zoophthora*, which infects alfalfa weevils and potato leafhoppers.

A common protozoan, *Nosema* species, infects European corn borer larvae and grasshoppers. Diseased insects become soft, limp, and filled with fluid. Bacteria and viruses occur less frequently in pest insect populations.

Another group of microscopic organisms, insect-attacking nematodes, also play a role in controlling some insects. These nematodes enter insects through the digestive system, or in some species, through the integument. They carry a symbiotic bacterium with them. The nematode and bacterium depend on each other to survive. Inside the insect, the bacteria are released, multiply, and kill the insect. Nematodes reproduce inside the insect, feeding on the bacteria and insect remains. Then they leave the host and search out new insects.

CHEMICAL INSECT CONTROL

Insecticides and miticides are frequently the only tools available to manage outbreaks of insects or mites. When insecticides are used properly, they provide effective and reliable control of most pest species. Although insecticides should be used only when necessary, chemical control is an important part of an insect management program.

Deciding to use an insecticide should be based upon information obtained from scouting and from thorough knowledge of economic thresholds. Misuse or overuse of insecticides is economically unsound and is environmentally hazardous. Complete eradication of an insect pest is neither necessary nor desirable. A timely application of a selective insecticide at the lowest effective rate will reduce the target pest population and leave a reservoir of pests. Natural control agents can then maintain the pest population below an economic level.

Most insecticides are contact poisons. The target insect is killed either when it is treated directly or comes into contact with treated soil or foliage.

These insecticides can also act as a stomach poison when the insect ingests the chemical. A few insecticides are systemic; they are absorbed by the treated plant and move from the site of absorption to other tissues. An insect is killed when it feeds on treated plants and consumes the insecticide.

Chemical insecticides most commonly used in Wyoming fall into several chemical classes. Many crop insecticides are organophosphates, synthetic organic compounds that contain phosphorous. For example: chlorpyrifos (Lorsban), malathion, and terbufos (Counter). Carbamates are also synthetic organic insecticides but are derived from carbamic acid. Example carbaryl (Sevin). Pyrethroids are synthetically produced chemicals closely related in activity to the naturally occurring pyrethrum, a botanical insecticide and include esfenvalerate (Asana), bifenthrin (Capture), and tefluthrin (Force). Neonicotinoids, chemically similar to nicotine, have become registered for use as seed treatments on field crops, including imidacloprid (Gaucho, Prescribe), clothianidin (Poncho), and thiamethoxam (Cruiser).

Responsible pesticide use includes resistance management. Pesticides have a classification number based on their mode of action. Rotate products with a different number (found on the label) for successive applications against the same pest.

GROUP	3	INSECTICIDE

Follow resistance management instructions on the label.

Soil-applied Insecticides

Soil insecticides are applied primarily to prevent damage by soil-borne insects in cornfields. Soil insecticides are rarely applied to other field and forage crops.

Soil insecticides are applied in one of several ways: in a 7-inch band over the row at planting time, in the seed furrow at planting time, or broadcast post-emergence. The method of application depends on the insecticide and its formulation as well as on the target insect.

Although most soil insecticides are applied in a band over the row, some can also be placed in the furrow with the seed. This method of application sometimes provides better control of certain soil insects, such as wireworms. However, phorate (Thimet) should never be applied in the furrow in direct contact with the seed. This insecticide can cause crop injury if it contacts the seed.

Another option at planting time is the use of insecticide-treated seed. Historically, active ingredients such as lindane or permethrin were applied by growers as dust applications to seed in the planter box and mixed manually. These have now mostly been replaced by seed treated by the seed supplier with a neonicotinoid insecticide (thiamethoxam, clothianidin, imidacloprid). These insecticides have both contact and systemic activity, and can control belowground and aboveground pests early in the season. Advantages to this approach are the uniformity of insecticide application on the seed and reduced grower exposure to insecticides. However, research is being conducted as to whether neonicotinoid seed treatment adversely affects beneficial pollinators, due to dust in the planting equipment.

Liquid insecticides may be applied at planting or post-emergence. They can be applied alone, but some can be tank mixed with certain herbicides and fertilizers unless the label states otherwise. The insecticide must be compatible with the herbicide and fertilizer to be effective and keep equipment from clogging. Liquid insecticides applied post-emergence also are sometimes mixed with herbicides. Custom applicators are often called upon to apply liquid insecticides as post-emergence sprays.

Soil insecticides are usually applied as a preventive treatment to protect the underground portions of corn plants from several soil insects. The need for a soil insecticide on corn usually depends upon the cropping sequence. Rootworms are a potential problem in corn after corn, but few soil insects cause problems in corn after soybean. A sporadic problem is extended diapause, when eggs laid in a cornfield that is planted to soybean the next spring do not hatch. They remain in diapause for another year and emerge the next year when it is rotated back to corn. This can significantly reduce the efficacy of rotation to a non-host crop when controlling for corn rootworm. Extended diapause is only found in Northern corn rootworms. The previous year's crop greatly influences whether a soil insect problem will occur and what kind it will be.

Foliar-applied Insecticides

Foliar insecticides are usually applied to control insects feeding on aboveground plant parts of corn, soybean, forage legumes, small grains, sorghum, and grass pastures. Foliar-applied insecticides are usually less persistent than soil-applied insecticides. A few foliar-applied insecticides remain effective for more than a week, but most break down and lose effectiveness in a matter of days.

Foliar insecticides are commonly applied by aerial applicators, although they can also be applied with ground equipment or injected into overhead irrigation systems (chemigation). Some granular formulations are applied to control insects like European corn borers feeding in corn whorls. Most foliar insecticides, however, are applied as liquid sprays broadcast over the field. A few are applied as a spray directed at the plant base or over the row.

Deciding to use a foliar-applied insecticide should be based upon thorough knowledge of economic thresholds. Foliar insecticides are usually applied in response to an economic infestation of insects. They are rarely applied as preventive treatments.

Insecticide Performance

No insecticide provides 100% control, and the presence of a few insects that survive the treatment does not constitute a failure. Some apparent failures can be attributed to the fact that the insecticide was applied to control an insect not on the insecticide's label. Not all insecticides are broad spectrum, and insecticides simply will not kill all insects. The label lists the insects for which the insecticide is registered.

Application mistakes

Application mistakes are frequently responsible for insecticide failures. With some exceptions, most insecticides should not be applied at a rate that is less than the rate suggested for the target insect. This could lead to development of a population resistant to the pesticide. Placement of a soil insecticide is also important.

Temperature

Temperature may alter insecticide effectiveness. High temperatures usually increase not only the rate at which an insect absorbs the insecticide, but also the rate of insecticide degradation, either in soil or on foliage. Conversely, some insecticides are not effective in low temperature.

Moisture

Moisture may also affect performance. Soil insecticides require some moisture to move them into the soil. A long, dry spell after applying a soil insecticide often reduces its effectiveness. Too much moisture and warm soil temperatures may cause the insecticide to degrade more rapidly. Heavy rainfall after applying a foliar insecticide may wash the insecticide from the plants.

Wind

Wind may move both soil and foliar insecticides off target. In addition, strong winds, low humidities, and high temperatures increase the volatility of many insecticides applied to foliage so the insecticide doesn't remain on the treated surface very long. Exposure to sunlight increases the rate of photodegradation of some insecticides.

Soil and water pH

The pH of the soil or the pH of the water in which the insecticide is applied can alter its effectiveness. A very low or very high pH may render an insecticide completely ineffective. Warnings about this interaction are sometimes included on the label.

Insect development and plant growth

The stage of insect development and the amount of plant growth may influence insecticide performance. In general, larvae and nymphs are easier to kill than eggs, pupae, and adults. Insecticides applied during the wrong stage of insect development may not provide effective control. Heavy foliage on some crop plants may prevent adequate coverage. Insects feeding near the base of plants with heavy foliage may never come into contact with the insecticide.

Microbial degradation

Resistance and enhanced microbial degradation are two biological phenomena that can cause an insecticide to fail. In Nebraska in 2015, western corn rootworm was found resistant to Bt in some corn hybrids. Western corn rootworm also is resistant to carbaryl and previously labeled methyl parathion in areas of central Nebraska where adult control programs were commonly used. Greenbugs also are resistant to chlorpyrifos in other states.

Enhanced microbial degradation occurs when soil microbes use the applied insecticide as a food or energy source. After repeated applications of the same insecticide in the same field, the insecticide biodegrades so quickly that it isn't effective. This phenomenon has been documented for failing to control corn rootworms for at least one soil insecticide, the formerly registered carbofuran (Furadan). Because of the potential for resistance and enhanced microbial degradation, growers are encouraged to alternate among soil insecticides.

Diagnosing inscecticde failure

When diagnosing an alleged insecticide failure, first determine whether the insecticide has actually failed. If it didn't control the target insect, consider all potential causes. Usually you can identify one principal cause; occasionally, however, there may be more than one reason for a failure. For example, strong winds during application or a heavy rainfall after application may move a soil insecticide completely off-target. If you are unable to explain an insecticide failure, contact the insecticide manufacturing company, which may be able to determine the reason for poor performance.

NEIGHBORING FIELDS

You and/or your employer are responsible for pesticide damage to properties next to the application site. Follow label directions regarding wind, temperature, and weather conditions for legal and safe pesticide applications. Keep records of weather, including wind direction and speed, temperature, and relative humidity. These are important if complaints ever arise.

Fieldwatch is a voluntary web-based communication tool for crop producers, beekeepers, and pesticide applicators. Applicators registered with Fieldwatch receive notification of specialty crops and apiaries in areas in which they are interested. Access *Fieldwatch, BeeCheck, and Driftwatch* through http://driftwatch.org.

All Wyoming bee keepers are required by law to register the location of their hives. This information can be found online at http://wyagric.state.wy.us/divisions/ts/sections-a-programs/plant-industry.

Section 8 Category 901C — Disease Control

LEARNING OBJECTIVES

After studying this section, you should be able to:

A. Distinguish biotic from abiotic plant disease, and disease from plant injury.

B. Identify the three fundamental factors that are necessary for biotic disease to occur.

C. List four types of common plant pathogens.

D. Identify five different methods to control plant disease.

E. List examples of cultural control methods for plant disease.

PLANT DISEASES

A plant disease is a continuous irritation that interferes with the proper function of plant cells and tissues. Unlike plant injury, which occurs instantly, plant disease development usually consists of a series of harmful processes. These may be obvious and subtle, eventually resulting in plant damage or death in parts or all of the plant.

Plant diseases can be divided into two broad categories: **infectious or biotic** and **noninfectious or abiotic**.

Infectious (Biotic)

Infectious plant diseases are caused by organisms that belong to the same biological groups as those causing diseases in animals and humans. Most described plant pathogens, however, infect only plants. Only a very few, such as *Colletotrichum*, have been associated with human or animal infections. Infectious plant diseases are caused by a range of microscopic organisms including fungi, fungus-like organisms, bacteria, nematodes, and viruses, or by parasitic plants such as dodder. Pathogens grow and multiply in or on their host plants and can be dispersed both from diseased to healthy plant organs of the same plant and from diseased to healthy plants within a field or across a larger area. Plant pathogens can cause disease on one or several plants, one or several plant parts, and on different tissues of the plant. Some pathogens invade the vascular tissue, xylem and phloem, causing a systemic infection. Other pathogens invade nonvascular tissues only, causing a localized or nonsystemic infection.

For biotic or infectious plant diseases to occur, three main factors must interact:

1) a susceptible host,

2) a virulent pathogen such as bacteria, fungi, nematodes, or viruses, and

3) a favorable environment for disease development.

Noninfectious (Abiotic)

Noninfectious diseases, also known as abiotic disorders, are caused by abiotic (non-living) factors. These cannot multiply in the plant nor can they be transmitted from one plant to another. Abiotic disorders generally result from adverse environmental or chemical conditions such as air pollution, unfavorable temperatures, soil compaction, drought, flooding, nutrient imbalances, or toxicity caused by pesticide or fertilizer misapplications.

Symptoms

Most plant pathogens cause characteristic symptoms in their hosts that greatly aid in diagnosing the cause of a disease. Some pathogens, however, may not bring on visible symptoms, at least during the initial stages of disease development. In such situations, disease damage may only be evident at later stages of plant development or at harvest, and would typically be reflected by a significant yield reduction.

Primary disease symptoms brought on by plant pathogens are:

- dead plant parts or necrosis (leaf spots, leaf and shoot blights, wilts, root rots, fruit rots);
- underdevelopment or overdevelopment of tissues and organs (poorly developed roots, stunted plants, malformations of leaves and stems, profuse growth of organs); and
- alterations of morphology and normal color of plant parts (yellowing, abnormal growth, and mosaics).

Signs

Signs of infectious plant diseases are structures or other evidence of the pathogen itself that are visible to the unaided eye. Examples are external fungal mats (mycelium), large sclerotia, large fruiting bodies, fungal pustules, and bacterial ooze. Other forms or parts of a pathogen are too small to see without a hand lens or microscope. These include individual spores, fungal and bacterial cells, or virus particles.

Plants affected by noninfectious disease may also display characteristic symptoms. For example, air pollution can cause leaf bronzing or scorching. No signs will be present, however, since plant pathogens are not involved in noninfectious diseases. This often makes diagnosis more difficult.

A reference for photos and information about numerous crop diseases is the *Disease and Pests* series, available from the American Phytopathological Society at http://my.apsnet.org/APSStore/Category?Category=Compendium.

TYPES OF PLANT PATHOGENS

Bacteria

Bacteria are microscopic, one-celled organisms. They vary in size from 1 to 2 micrometers (much less than 1/1000 of an inch) and may be rod-like, spherical, spiral, or relatively irregular in shape. Bacteria reproduce by fission (one cell dividing into two), with division occurring very rapidly with a suitable host and favorable weather or ambient conditions. These microbes can live and survive in virtually any type of habitat, including soil, water, organic matter, or within plants, fungi, humans, insects, or other animals. Most bacteria are beneficial to the environment by degrading organic and inorganic matter and chemical compounds, thus contributing to nutrient recycling. However, some bacteria can also cause infectious diseases in plants, humans, and animals. Bacterial diseases in humans, such as tuberculosis, cholera, and anthrax, can be fatal.

Many types of bacteria may be found on the surface of plant roots, leaves, stems, and fruits. Some are beneficial and live only on the surface or may reproduce inside plant tissues. An outstanding example of a beneficial bacterial-plant association is that between nitrogen fixing bacteria (genus *Rhizobium*) and soybean roots. On the other hand, plant pathogenic bacteria enter plants through natural plant openings or wounds, or are deposited by some insect mouthparts. Most plant pathogenic bacteria grow on plant surfaces, although some develop inside the plant. Bacteria species that develop within the plant typically are released back into the soil as infected plant parts decay. A few kinds of bacteria are confined to the plant vascular system, hence are able to migrate throughout the plant. Bacterial diseases of plants can be severe and occur wherever a plant host is available. Typical symptoms caused by bacterial plant pathogens are wilts, leaf spots, blights, abnormal growths or galls, soft rots of roots, fruits, and tubers, and cankers (Figure 8.1). Bacteria can be spread by rain and irrigation water, in wind-blown infested soil, and by humans, insects, and other animals. Humans contribute to the spread of bacteria by using infected hand tools or machinery, wearing soiled clothing, or by transferring infected plant material to bacteria-free locations.

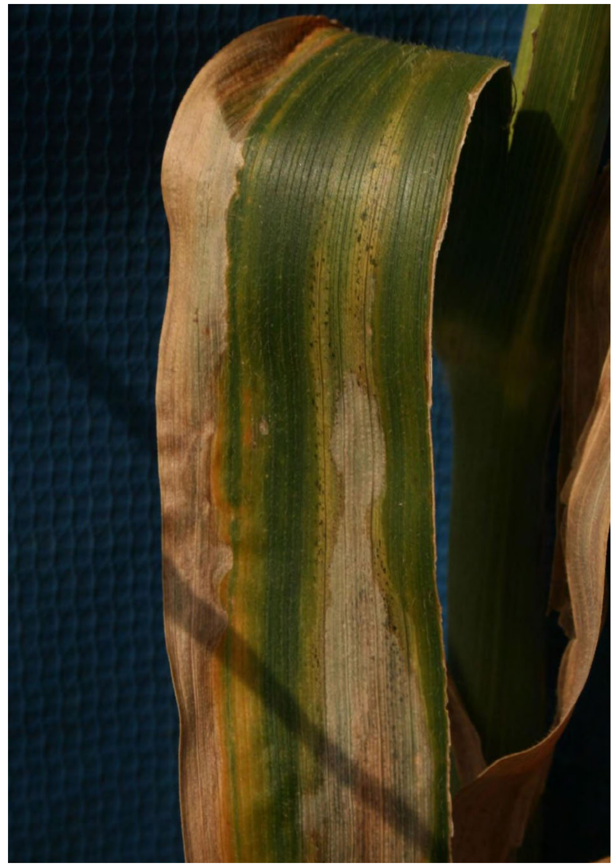


Figure 8.1. Goss' bacterial wilt (Clavibacter michiganensis *ssp.* nebraskensis). *Photo: Larry Osborne, Bugwood.org.*

Fungi and Fungus-like Organisms

Fungi are generally microscopic organisms that reproduce by sexual and/or asexual spores. More than 100,000 species of fungi have been described to date; the majority of them feed on decaying organic matter such as dead roots, leaves, and stems. Thus, like bacteria, fungi also contribute to decomposition of organic matter converting it into minerals and other nutrients available to plant roots. Relatively few fungal species cause disease in humans and animals, though more than 10,000 species attack living plants. Fungi constitute the group of plant pathogens that cause most of the economically important crop diseases worldwide.

Plant parasitic fungi vary in how they invade their hosts. Some grow only on the plant epidermis (outer "skin"), some penetrate between the cuticle and the epidermis, some between cells, and even both between and through the cells. Many species reproduce rapidly in the vascular tissue or in the spaces between cells in different plant parts.

Plant pathogenic fungi penetrate into leaves, stems, and roots through wounds and natural openings, or by forcing their way directly through the plant's protective epidermis. After growing for several days, weeks, or even years, most disease-causing fungi give rise to spores or spore-producing bodies. Spores have many different shapes, colors, and sizes, and are borne sexually and asexually. The spore-bearing structures of fungi can appear as moldy growth on surfaces of buds, leaves, and shoots (as in the case of powdery mildews, sooty molds, blights, and many rusts); or as speck-sized, fungal fruiting bodies partially or totally embedded in the leaf tissue or in stems (Figure 8.2). Certain fungi may form decay-resistant overwintering structures (e.g., sclerotia and chlamydosphores) that allow them to survive in the soil from season to season.

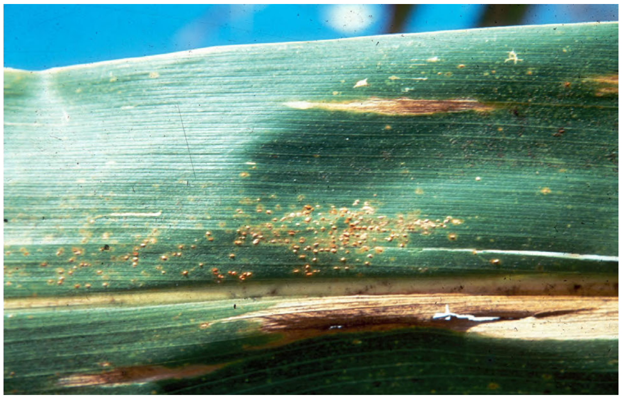


Figure 8.2. Southern corn rust (Puccinia polysora). *Photo: Department of Plant Pathology , North Carolina State University, Bugwood.org.*

Microscopic fungal spores travel easily to other plants by wind currents, splashing water drops during rain events or irrigation, insects, mites, birds, plant parts, and worker hands, clothing, and equipment. Most fungi are killed by extreme temperatures or moisture levels. However, production of thick-walled resting spores, fruiting bodies, and sclerotia allows certain fungi to withstand extreme heat or cold, droughts, and floods. Fungal survival structures may lie dormant for several months or years before germinating and resuming activity.

Common fungal diseases include root rots, damping-off, cankers, scabs, rusts, smuts, wilts, galls, fruit rots, and blights on leaves, branches, and flowers. Except for powdery mildews, which thrive best in humid but not wet conditions, fungi are more damaging to plants in damp humid areas or during wet weather than under dry conditions. Moisture is essential to rapid reproduction and spread of practically all fungi.

Until recently oomycetes were considered fungi. This group of organisms produce spores with appendages that enable them to swim in water. Oomycetes are commonly known as water molds and cause root rots, damping-off, leaf blights, and downy mildews. Oomycetes cause some of the most destructive plant diseases. The best-known are Pythium and Phytophthora.

Viruses

Viruses are much smaller than bacteria. They can exist and multiply only inside living cells. Viruses are spread by vectors such as nematodes, mites, and sucking insects such as aphids and leafhoppers. These vectors may feed on an infected plant and transmit the pathogen to other plants. Contaminated equipment can spread viruses from one plant to another, as well. Mosaic (a mixture of dark and light green areas), flecking, and ringspots are common foliar symptoms typical of viruses.

Stunting and other growth disorders also can be caused by viruses.

Plant viruses can cause chlorotic yellow and necrotic (brown or dead) local lesions, mosaics, mottles, leaf rolling, and ringspots. These symptoms can be frequently confused with nutritional deficiencies, pesticide or fertilizer injury, insect or mite damage, hormone damage, genetic abnormalities, and other types of plant malfunctions.

Viruses may remain from season to season in perennial weeds, insects, nematodes, and seeds. Once a plant is infected with a virus, no practical treatment will completely remove it. Often, the entire plant must be removed to prevent the virus from spreading to healthy plants.

A virus infection usually interferes with cell division, causing abnormal growth. On their own, plant viruses are unable to penetrate plant surfaces or be transferred from an infected plant to a healthy plant.

Viruses can survive in live plants, in insect bodies, and in plant debris. Most plant viruses can infect a number of different plant species. A few can cause diseases of economic importance, like the wheat streak mosaic virus.

Nematodes

Nematodes are microscopic, unsegmented, worm-like animals that inhabit diverse types of ecosystems and geographic regions. Nematodes are found in areas ranging from deserts to rain forests, and polar to tropical regions. Although nematodes are mostly found in soil, they also can live in water, as they are essentially aquatic animals. At several thousand species, nematodes are the most numerous multicellular animals now known on Earth. Most nematodes are free-living, because they feed on decaying plant and animal organic matter or on soil microorganisms. These include fungi, bacteria, and protozoa (single-celled organisms). Only a small fraction of described nematode species are plant feeders.

Herbivores or plant parasitic nematodes can be distinguished from free-living and animal parasitic nematodes by a specialized needle-like structure, called a stylet or spear, in the head region. Nematodes use this stylet to puncture plant cell walls, inject compounds that cause abnormal cell growth, and withdraw plant nutrients. Although plant parasitic nematodes feed mostly on roots and other below-ground plant organs, they can also feed on stems, leaves, flowers, seeds, and fruits. Nematodes feeding on plant roots may distort root structure and reduce root mass. This impairs the plant's ability to absorb water and nutrients, especially with heavy infestations. As a result, foliage becomes chlorotic or may show symptoms similar to those caused by drought, excessive soil moisture, nutrient imbalance, root girdling, and other damage. Nematode damage to roots also opens the door to root-rotting and wilt-inducing fungi and bacteria. Nematode-infested plants don't respond to fertilization as well as healthy plants. Stressed plants are also more susceptible to winter injury, serious insect damage, or other diseases.

Worm-like plant parasitic nematodes vary in size from 250 micrometer to 12 mm (approximately 1/1000- to 1/2-inch). Females of some species may swell at maturity and acquire a round, bulbous, or lemon shape. Nematodes may complete their entire life cycle, or a part of it, inside or outside plant tissue and remain in one part of the plant or migrate to other organs. The life cycle of plant parasitic nematodes is usually 2 to 6 weeks. All plant parasitic nematodes require a living host to survive. Some species have evolved survival mechanisms and structures allowing them to withstand unfavorable environmental conditions, thus they remain a threat to field crops for longer periods of time.

To determine whether nematodes are causing disease, infected plant tissue and/or soil must be collected and prepared for observation under the microscope. For root nematodes, both soil and roots should be collected since nematodes tend to concentrate in the root zone. When scouting for nematodes in a crop field, it is best to dig up plants and examine the roots for potential nematode damage, rather than rely solely on aboveground symptoms. Root symptoms may consist of galls or swellings, lesions, dark spots, stunting, or stubby roots. Other pathogens also may cause these symptoms, so don't rely on them to confirm the presence of nematodes.

Fall is usually the best time for scouting nematodes in the field. Nematode presence and identity can be determined by a competent nematologist. Most land-grant universities provide a nematode assay service and will make suggestions for control. Ask a local Extension office for further information, www.uwyo.edu/uwe.

DISEASE COMPLEXES

Plants under heat or drought stress are often susceptible to more than one biotic disease. This results in a disease complex and makes diagnosis and control more difficult. The effect of infection by more than one pathogen on the host may be additive, synergistic (in which the damage is greater than the sum of the damage expected from each of the individual pathogens), or antagonistic (in which the damage is less than the sum of the damage expected from the individual pathogens).

Disease Control

Integrated pest management also applies to plant diseases. Disease control, therefore, applies one or several methods to minimize or regulate disease level in a crop, landscape, or other plant setting. Deciding to treat for plant diseases depends upon the damage thresholds discussed in Section 1. The damage threshold is the maximum damage a crop can sustain without yield loss.

The two primary goals typically are:

1. prevent the disease from developing, and
2. suppress the disease after it has occurred.

Most pathogens can be seen only with a microscope, so counting them generally is unpractical. It is more practical to estimate the amount or level of diseases. This is done, for example, by:

- counting diseased leaf petioles in the case of soybean pod and stem blight;
- estimating the percentage of infection of the flag leaf covered by rust pustules or other fungal foliar blights in wheat;
- determining the density and kinds of nematode populations in a soil sample;
- or estimating the percentage of whole plants with fungal leaf blights in corn.

Disease levels are affected by weather elements such as temperature, relative humidity, rain, and wind, as well as by antagonistic pathogens that naturally regulate disease levels. Control practices normally are implemented after disease is detected but has not progressed to damaging levels, and favorable environmental conditions are prevailing or forecast. In general, **five different types of measures are recognized to control plant diseases**.

Biological control

Biological control reduces or destroys a pathogen population through another organism, either naturally or by human introduction. Pathogen-antagonistic microorganisms occur aboveground or in naturally suppressive soils, and prevent or reduce development of pathogen populations. Typically, antagonistic organisms exert their effect by colonizing the plant surface or tissue before a pathogen can do so.

Cultural control

Cultural control reduces the reproduction, dispersal, and survival of a plant pathogen. Cultural practices often are part of normal farming operations that the grower normally implements. These include tillage (see below), drainage, sanitation, mulching, burning, rotating crops, using resistant varieties, modifying irrigation, removing secondary and alternate hosts, altering planting and harvesting dates, and using agronomic practices that promote plant health and vigor.

Tillage. Tillage systems are classified based on the amount of crop residue left after harvest and before planting and harvest of the next crop. When greater than 30% of crop residue is left, the system is categorized as “conservation tillage.” This can be no-till, ridge-till, strip-till, or mulch-till. If between 15% and 30% residue remains, the system is classified as “reduced” or “minimum” tillage; if less than 15% residue remains, the system is classified as “conventional tillage.” A major drawback to conventional tillage is the possibility of serious soil erosion on sloping lands.

Tillage operations can control disease. However, its effectiveness depends greatly on a good understanding of the disease biology and ecology. For instance, many foliar pathogens can survive on crop residues and provide a disease reservoir for the next cropping season. Moldboard plowing can destroy or deeply bury infested crop residue, speed up decomposition, and prevent or minimize disease. Timing of tillage also influences the effectiveness of disease control. For example, early tillage (either after harvest or after rotation with corn or soybean), may significantly reduce nematode and fungal populations since tillage alters soil aeration, temperature, and moisture levels. The key for success in using tillage for disease control lies in knowing the crop diseases and how tillage could affect and help reduce disease levels.

Additional examples of cultural control are:

Drainage operations. Drainage operations, including tiling and ditching, can help reduce levels of certain root-rot pathogens favored by wet conditions. Both Pythium and Phytophthora are oomycetes that cause more severe crop losses in excessively wet soils. Lowering soil water levels through drainage operations can reduce yield losses caused by these pathogens.

Sanitation. Sanitation involves cultural control measures that remove crop residues, diseased plants or plant parts, as well as cleaning all machinery when moving from one field to another. Many pathogens, including soybean cyst nematode, can be moved within and among fields in plant parts or soil that may adhere to machinery or tools.

Removing hosts. Removing alternative and alternate hosts is effective in disrupting the overwintering and survival of plant pathogens. Many weeds serve as alternative hosts for plant pathogens. Without removal, these weeds can contribute to higher disease in the cropping season. They also function as overwintering niches, allowing pathogen spread into crop plants.

Some types of rust fungi require two different host species to complete their life cycle. The crop plant is usually the primary host; a weed, tree, or some other noncultivated plant is the alternate or secondary host. If the alternate host is destroyed, the pathogen cannot complete its life cycle and will be unable to infect a primary host.

Crop rotation. Crop rotation is another way to decrease plant pathogens. Most pathogens don't survive from season to season if a host plant is unavailable. Many plant disease problems can be reduced simply by planting one or more non-host crops. Some soil-borne pathogens such as those causing root rots, however, may not be effectively controlled with crop rotation. These organisms are a natural part of the soil and can survive many years even when host plants are absent. Certain other organisms may form resting or survival structures that enable them to survive for several seasons, even if hosts are absent. For this reason, use several control methods to attain better results.

Resistant and tolerant varieties. Resistant and tolerant varieties limit development of plant diseases through biochemical, physiological, or physical means. Certain plant pathogens can develop new races or strains that attack commonly used resistant varieties. Therefore, it's important to also use crop rotation or other methods to reduce losses rather than continually plant the same resistant variety.

Modifying dates. Modifying planting or harvesting dates may also help reduce crop losses from plant diseases. For example, planting wheat after the Hessian fly-free date will reduce chances of infection with certain wheat viruses. Another example is harvesting corn early to reduce losses from stalk rots.

Mechanical and physical control

Mechanical and physical control methods may be used to manage populations of some plant pathogens in field crops and greenhouse crop productions. Manipulating air and soil temperature, air movement, light period or intensity, and radiation levels can be effective to reduce disease impacts. Examples of mechanical methods of disease control include burying infested crop residue with tillage, sterilizing soil with heat or solarization, controlling light for greenhouse crops, using radiation, hot-water or hot-air treatment of fruits and propagative organs, and refrigeration.

Chemical control

Chemical control uses pesticides to control disease. Fungicides, bactericides, and nematicides are three main categories of pesticides used to control different types of pathogens. Fungicides by far are the most commonly applied, mostly in foliar and seed treatments. To be effective, most fungicides must be applied before the disease occurs, or when symptoms are first seen.

Legal control

Legal control measures consist of regulatory actions taken under federal, state, or local laws to avoid the introduction of high-risk pathogens to pathogen-free areas, and to slow or stop disease spread in affected regions to avoid devastating epidemics. Legal control methods usually involve inspections and quarantines, and to a lesser extent, voluntary or compulsory crop destruction or eradication. National quarantines and inspections are used by countries to prevent the introduction of an exotic pathogen, race, or strain from infested regions. In such situations, specific laws dealing with plants and sanitation are enforced by trained inspectors stationed at borders, seaports, and airports.

Locally, a grower could put into practice unofficial regulatory control measures on his own land by knowing which diseases are present, and how severe they are on his own land, as well as in neighboring fields and counties. This may help in planning tillage operations and prioritizing planting, harvesting, and agrochemical applications, thus minimizing introduction or spread of diseases. On a regional scale, growers should avoid importing plant materials or soil from areas known to be infested with a particular pathogen, and refrain from shipping diseased or questionable materials to areas where the pathogen in question has not been reported. When returning from visits to farms or agricultural fields in other countries, it is important to thoroughly clean shoes, wash clothes, and avoid bringing plant parts that may be pathogen-infested. When returning to the US, international travelers are usually asked if they have any plant materials or have visited farms. Footwear may be inspected and sprayed to prevent the introduction of pathogens or insects. Note, even when plant parts do not show any symptoms, they still may harbor pathogens.

SUMMARY

All control methods described above can be implemented either as preventative or suppressive measures. Successfully managing plant diseases depends upon a balanced, integrated program that includes the judicious use of both preventative and suppressive control methods.

Management strategies for many common plant diseases found in Wyoming field crops are listed in Tables 8.1 through 8.5, "Table 8.1. Management Strategies for Alfalfa Diseases" on page 129. For more information, contact a Wyoming Extension office, www.uwyo.edu/uwe.

TABLE 8.1. Management Strategies for Alfalfa Diseases

Disease common name or pathogen B=Bacterium F=Fungus N=Nematode O=Oomycete V= Virus	**Highly effective**	**Moderately effective**	**Slightly effective**
Bacterial wilt (B)	Plant winter-hardy, resistant varieties	Well-drained soil (pH 6.5–7.0)	Crop rotation; balanced fertility; cut in mid-to-late bud stage; maintain weed and insect control
Dry root and crown rots (F, O)		Well-drained soil (pH 6.5–7.0); crop rotation; balanced fertility; avoid late planting and cutting; maintain weed and insect control	Winter hardy, resistant varieties; high-quality seed; avoid rank growth and high stubble
Phytophthora root rot (O)	Plant winter hardy, resistant varieties	Well-drained soil (pH 6.5–7.0); avoid late planting and cutting; metalaxyl seed treatment fungicide.	Crop rotation; balanced fertility
Fusarium wilt (F)	Winter hardy, resistant varieties	Avoid late planting and cutting	Crop rotation; well-drained soil (pH 6.5–7.0); balanced fertility; avoid rank growth and high stubble; maintain weed and insect control
Anthracnose (F)	Winter hardy, resistant varieties; crop rotation	Balanced fertility; avoid rank growth and high stubble	Well-drained soil (pH 6.5–7.0); maintain weed and insect control
Spring black stem (F)	Winter hardy, scout fields regularly in May to detect disease buildup early	High-quality seed; cut in mid-to-late bud stage; avoid rank growth and high stubble	Well-drained soil (pH 6.5–7.0); balanced fertility; maintain weed and insect control
Summer black stem (F)		High-quality seed; cut in mid-to-late bud stage; avoid rank growth and high stubble	Well-drained soil (pH 6.5–7.0); balanced fertility; maintain weed and insect control
Common leaf spot (F) (*Pseudopeziza* leaf spot)	Winter hardy, resistant varieties	Crop rotation; balanced fertility; cut in mid-to-late bud stage; avoid rank growth and high stubble	Well-drained soil (pH 6.5–7.0); maintain weed and insect control
Stemphylium leaf spot (F) (Zonate leaf spot)	Winter hardy, resistant varieties; crop rotation	Cut in mid-to-late bud stage; avoid rank growth and high stubble	Well-drained soil (pH 6.5–7.0); balanced fertility; maintain weed and insect control

TABLE 8.1. Management Strategies for Alfalfa Diseases

Disease common name or pathogen B=Bacterium F=Fungus N=Nematode O=Oomycete V= Virus	**Highly effective**	**Moderately effective**	**Slightly effective**
Pepper leaf spot (F) (*Leptosphaerulina* leaf spot)	Winter hardy, resistant varieties	Crop rotation; cut in mid to late bud stage; avoid rank growth and high stubble	Well-drained soil (pH 6.5–7.0); balanced fertility; maintain weed and insect control
Yellow leaf blotch (F)		High quality seed; crop rotation; balanced fertility; cut in mid-to-late bud stage; avoid rank growth and high stubble	Well-drained soil (pH 6.5–7.0); balanced fertility; maintain weed and insect control
Stagnospora leaf and stem spot (F)		Crop rotation; cut in mid-to-late bud stage; avoid rank growth and high stubble	Well-drained soil (pH 6.5–7.0); balanced fertility; maintain weed and insect control
Rhizoctonia stem blight (F)		High-quality seed; well-drained soil (pH 6.5–7.0); balanced fertility, cut in mid-to-late bud stage; avoiding rank growth and high stubble	Maintain weed and insect control
Seed rots, seedling blights, damping-off (F, O)	High-quality seed	Well-drained soil (pH 6.5–7.0); seed treatment fungicides; balanced fertility	Crop rotation; maintaining weed and insect control
Sclerotinia crown and root rot (F)		Well-drained soil (pH 6.57.0); avoiding late planting and cutting; avoid rank growth and high stubble; maintain weed and insect control	High-quality seed; crop rotation; balanced fertility; cut in mid-to-late bud stage
Mosaics (V)		Maintain weed and insect control	High-quality seed
Verticillium wilt (F)	Seed treatment fungicides; resistant varieties	Maintain stand no longer than 3 years; crop rotation	Well-drained soil; balanced fertility (pH 6.5–7.0); maintain weed and insect control

Table 8.2. Management Strategies for Corn Diseases

Disease common name or pathogen B=Bacterium F=Fungus N=Nematode O=Oomycete V= Virus	**Highly effective**	**Moderately effective**	**Slightly effective**	**Comments and activities**
Stalk rots (B, F)		Tolerant hybrids; crop rotation; balanced fertility	Tillage	Plant full-season, well-adapted hybrids; control insects and corn leaf diseases; overall stress reduction will reduce stalk rot diseases
Ear and kernel rots (F)		Resistant hybrids	Clean plowing; balanced fertility	Control stalk rots and leaf blights; ear and kernel rots are increased by bird and insect damage
Storage molds (F)				Store undamaged corn for short periods at 15%–15.5% moisture; dry damaged corn to 13%–13.5% moisture; inspect weekly for heating, crusting, or other signs of mold
Maize dwarf mosaic (V)	Resistant hybrids			Control Johnsongrass and perennial grasses in and around fields
Maize chlorotic mottle (V)(this virus in combination with maize dwart mosaic causes corn lethal necrosis)	Resistant hybrids	Crop rotation		The virus is vectored by some beetles, including corn rootworm
Nematodes (N)		Crop rotation, nematicides	Balanced fertility and other stress reduction can enable plants to compensate for some damage	More than 12 species are possible and vary significantly by their host crops; select rotation crops carefully according to number and types of nematodes present
Stewarts disease (B)	Resistant hybrids			Early control of corn flea beetle may be helpful on susceptible hybrids
Seed rots and seedling blights (F, O)	Seed treatment fungicides		Balanced fertility	Plant high-quality seed into warm (50°–55°F) seedbed

Table 8.2. Management Strategies for Corn Diseases

Disease common name or pathogen B=Bacterium F=Fungus N=Nematode O=Oomycete V= Virus	**Highly effective**	**Moderately effective**	**Slightly effective**	**Comments and activities**
Helminthosporium leaf blights and spots (northern corn leaf blight, northern corn leaf spot, and southern corn leaf blight) (F)	Resistant hybrids	Crop rotation; tillage; foliar fungicides		Fungicide applications in susceptible hybrids timed according to the label
Physoderma brown spot (F)		Tillage		Management is usually unnecessary as disease will stop spreading once wet conditions are over
Eyespot (F)	Resistant hybrids; tillage	Crop rotation		Management is usually unnecessary as disease will stop spreading once temperatures increase above 90°F
Anthracnose (F)	Resistant hybrids; tillage	Crop rotation		Anthracnose may develop as a leaf blight, stalk rot, or top die back disease
Crazy top and sorghum downy mildew (F)	Resistant hybrids		Crop rotation; tillage	Avoid planting in low, wet areas, or improve drainage; avoid sorghum in rotations; control of shattercane (alternate host) is important
Common smut (F)				Management is usually unnecessary or not possible; avoid mechanical injury to plants; control insects
Head smut (F)		Seed treatment fungicides		
Common and southern rust (F)			Fungicides	
Goss' bacterial wilt and blight (B)	Resistant hybrids; tillage	Crop rotation	Bactericides	Timing of bactericide use is important and products may not have residual or curative activity

Table 8.3. Management Strategies for Wheat Diseases

Disease common name or pathogen B=Bacterium F=Fungus N=Nematode O=Oomycete V= Virus	**Highly effective**	**Moderately effective**	**Slightly effective**	**Comments and activities**
Stem rust (F)	Resistant varieties foliar fungicides			
Leaf rust (F)	Resistant varieties; foliar fungicides			
Loose smut (F)	Resistant varieties; pathogen-free seed; seed treatment fungicides			
Bunt (F)	Resistant varieties; pathogen-free seed; seed treatment fungicides			
Septoria leaf blotch (F)	Resistant varieties; foliar fungicides	Crop rotation; clean tillage	Seed treatment fungicides	
Glume blotch (F)	Resistant varieties	Foliar fungicides	Crop rotation; clean tillage; seed treatment fungicides	
Soil-borne mosaic (V)	Resistant varieties			
Wheat streak mosaic (V)	Post-harvest control of volunteer wheat and grassy weeds; resistant varieties			
Barley yellow dwarf (V)	Resistant varieties	Post-harvest control of volunteer wheat and grassy weeds; control of aphid vectors		
Scab (F)	Crop rotation	Seed treatment for seedling blight only; resistant varieties		Avoid planting in fields with corn or sorghum stubble, or following corn or wheat
Take-all (F)	Crop rotation	Control of grassy weeds; balanced fertility	Clean tillage	Use ammonium nitrogen
Cephalosporium stripe (F)	2-year crop rotation	Resistant varieties		
Powdery mildew (F)	Resistant varieties	Foliar fungicides		
Seedling blights and crown and root rots (F, O)	Plant into firm, mellow seedbed	Seed treatment fungicides	Crop rotation; clean tillage; balanced fertility	

TABLE 8.4. Management Strategies for Sugarbeet Diseases

Disease common name or pathogen B=Bacterium F=Fungus N=Nematode O=Oomycete V= Virus	**Highly effective**	**Moderately effective**	**Slightly effective**	**Comments and activities**
Rhizomania (V)		Tolerant or resistant varieties; surveys to locate infested fields	Plant when soil temperature is cooler; management of soil moisture; deep tillage to improve drainage	Most effort to control spread is placed on containment or limiting movement of infested soil into uninfested areas.
Sugar beet nematode (N)	Combination of non-host crop rotations; good weed control and trap crops; nematicides	Rotation with non-host crops; sanitation; early planting		
Cercospora leaf spot (F)	Resistant varieties; foliar fungicides	Cultivation and crop rotation		
Powdery mildew (F)	Foliar fungicides			
Rhizoctonia root and crown rot (F)	Resistant varieties	Seed treatment with fungicides	Early planting; 3-year crop rotation; good weed control; sanitation	Tillage and fertilization practices that promote good crop growth will reduce disease outbreaks
Root knot nematode (N)	Fumigants	Insecticide-nematicide treatments with organophosphates and carbamates	Crop rotation if species is known and crop susceptibility is known	

Table 8.5. Management Strategies for Dry Bean Diseases

Disease common name or pathogen B=Bacterium F=Fungus N=Nematode O=Oomycete V= Virus	**Highly effective**	**Moderately effective**	**Slightly effective**
Bacterial brown spot (B)	Plant certified seed; treat seed with streptomycin	Incorporate debris into soil; rotate to non-host crops for 2 years	Avoid reuse of irrigation water from infested fields; stay out of wet fields; use bactericides
Bacterial wilt (B)	Plant certified seed; treat seed with streptomycin	Incorporate debris into soil; rotate to non-host crops for 2 years	Minimize cultivation damage to roots; avoid reuse of water from infested fields
Fusarium dry rot (F)	Plant certified seed; treat seed or furrow with fungicides	Rotate to non-host crops	
Rhizoctonia root rot (F)	Treat seed with fungicides; rotate crops	Plant in warm, moist soil; incorporate crop residue into soil	
Pythium damping-off (O)	Treat seed with fungicides; rotate crops	Plant in warm, moist soil; minimize root damage during cultivation	Manage irrigation tail water to prevent spread of fungus
Rust (F)	Plant certified seed varieties when late planting	Avoid susceptible varieties; incorporate crop residue into soil	Fungicides to prevent or reduce infection
White mold (F)	Plant certified seed; rotate to non-host crops for 3 years	Use recommended plant populations and row widths; apply recommended fertilizer amounts; irrigate only when needed	Fungicides during blossoming
Common bean mosaic (V)	Certified seed	Avoid rubbing and injury of plants during cultivation	
Curly top (V)	Plant certified seed		

Section 9 Category 901 D — Animal (Pest Control)

LEARNING OBJECTIVES

After studying this section, you should be able to:

A. Identify the primary arthropod pests of livestock.

B. Identify biological features which may aid in control of arthropods affecting livestock.

C. Identify the proper control tactics for arthropods affecting livestock.

INTRODUCTION

Control or management of insects is important to the progressive livestock producer. Insect control may be accomplished through the use of practices that will avoid or reduce insect problems and it may involve the use of an insecticide that will alleviate or prevent a pest problem. Insecticides available to the livestock industry in the United States today must be used while considering the maximum benefit to society and minimum risk to human health and the environment.

The objective of this section is to provide information that the potential insecticide applicator can utilize in order to safely and effectively control insect and related pests of livestock. The applicator should learn three things: (1) recognition of insect problems; (2) biological features of the insect that may be utilized in successful control; and (3) proper control techniques. Specific insecticides will not be discussed because of the frequent changes in insecticide registrations.

INSECTICIDE APPLICATION

Methods of Insecticide Application

There are a number of techniques commonly utilized in the control of several different livestock insect pests and the application of animal systemic insecticides. These insecticides are either injected or are absorbed through the skin and carried by the blood system to kill blood-sucking insects as well as those that live internally in the host.

High-Pressure Spray

High-pressure spray is used to apply dilute insecticides to livestock. Spray is applied by means of a high-pressure livestock sprayer at 300 to 350 psi. The high pressure penetrates dense wool or a thick hair coat and wets the skin of the treated animal. Wetting of the skin, not just the hair, is necessary in the use of systemic-type insecticides. Several animals can be sprayed at a time by working them back and forth in a small pen.

To calibrate the sprayer determine the delivery in gallons per minute for the particular spraying disc in the spray gun, usually a number 4, 5 or 6, and the pressure. The amount of spray per head will vary with size of the animals, and thickness of hair coat or fleece. Experience in Wyoming indicates that for thorough coverage of cattle 1-1/2 to 3 gallons of spray per cow and 1 to 2 gallons per calf are required. Depending on wool length, from 1 to 2 gallons of spray per animal will be required to completely soak sheep.

Low-Pressure Spray

Tractor-mounted and other low-pressure sprayers are satisfactory equipment for applying dilute sprays at low pressure, i.e., 50-70 psi. Apply 1 to 2 quarts of spray per animal. This spray will not soak an animal but is sufficient to wet the hair or fleece.

Compressed Air Spray

One of the easiest methods of spraying a small number of animals for fly or louse control is with a hand-held, compressed-air sprayer. The sprayer is especially useful for treatment of horses because it makes little noise and does not frighten them.

Sponge Method

The sponge method is an effective method if treating one or two animals. Wet a sponge, cloth or special glove made for this purpose, and rub onto the animal's body. When not using the special gloves, be sure to wear other protective gloves. This method is especially useful for applying insecticides to horses that react to sprayer noises.

Dip

Dipping of cattle or sheep is a method for obtaining thorough coverage. Large numbers of animals may be treated fairly rapidly. The dip vat method requires a large initial expenditure for construction and materials as well as chemicals.

Pour-on

The pour-on method is a quick and simple method of applying animal systemic as well as certain non-systemic insecticides to cattle and sheep. The pour-on liquid, either an oil or an emulsion, is applied from a calibrated dipper or other device at the correct rate, evenly, along the animal's back or in a single spot so that none of the liquid drips off.

Injection

Several systemic insecticides are administered with standard automatic or single dose syringes. The recommended route of administration is by subcutaneous injection.

Residual Premise Spray

For fly control in and around buildings make application at low pressure, e.g. 80 psi, to produce a coarse spray. Apply to walls and ceilings of buildings but avoid spraying feed and water. One application may give protection for an entire season.

Space Spray or Aerosol

This is an effective method for quickly clearing indoor spaces of flies. A machine is used that produces a very fine mist that remains suspended in the air for several hours. Usually the application must be repeated daily.

Dusting

If only a small number of animals need to be treated for parasites such as lice, flies, ticks or keds, hand dusting is both inexpensive and effective.

Feed-through

There are several products available for feed lot animals that control filth flies.

BIOLOGY AND CONTROL OF INSECTS AND RELATED PESTS OF LIVESTOCK

General Pests

Biting flies and nuisance flies

Flies are familiar to everyone. The biting flies particularly bothersome to livestock in Wyoming are stable flies, horn flies, horse flies, deer flies, mosquitoes, and black flies. The face and house flies are examples of nuisance flies. They are very bothersome even though they don't bite and draw blood.

Both biting and nuisance flies affect the production and performance of livestock. Flies hinder grazing and resting and even force animals to run about in order to be momentarily freed from annoyance. Additionally, many flies are important in transmission of disease-causing organisms.

Horse and deer flies

Horse and deer flies belong to the same insect family and have quite similar biologies. Deer flies are usually the size of house flies and have patterns on their wings. Horse flies are larger and generally darker in color than deer flies.

Most adult flies lay their eggs near the damp or wet soil of streams, marshes, lakes, or ponds. After a short incubation period of approximately one week, larvae hatch, then develop in the soil. Later in the season, or the following year, the full grown larvae migrate to drier soil. Each forms a pupal case, from which an adult fly emerges in a few weeks. The adult flies of different species appear in peak numbers at certain times during the season.

Only the female horse fly and deer fly attack animals. The bite is extremely painful and causes the flow of blood, much of which is not even ingested by the fly. Frequently clusters of house flies or face flies, which cannot draw blood themselves, are seen around pools of blood formed by the feeding of horse flies.

Figure 9.1. Horse fly (Tabanus *spp.*). *Photo: Herbert A. 'Joe' Pase III, Texas A&M Forest Service, Bugwood.org.*

Figure 9.2. Deer fly (Chrysops *sp.*). *Photo: Clemson University - USDA Cooperative Extension Slide Series, Bugwood.org.*

Mosquitoes

Adult mosquitoes are small (body length about 1/4-inch), delicate organisms with a conspicuously long proboscis. Mosquitoes have four life stages: egg, larva, pupa, and adult. The eggs are laid on or near water. When in contact with water the eggs hatch and produce the aquatic immature stages. The larvae or "wigglers," named after the manner of swimming, must have standing water with relatively little movement or wave action. Water in puddles and roadside ditches as well as water along the edges of vegetation-choked channels is ideal. It is in the larval stage that the mosquito attains most of its growth by feeding on microorganisms and organic matter in the water. After four wiggler stages of increasing size which usually occupy 10 or more days, mosquito larvae reach a length in excess of 1/2-inch. They then molt to the pupal or "tumbler" stage. Unlike most insect pupae, the tumbler as its name implies, is active. The tumbler appears to consist of large a "head" with a "tail", and moves about in the water by a tumbling action when disturbed. No further growth is accomplished in the tumbler stage because it does not feed. After a period of more than four days, the pupa rises to the surface of the water, and the adult mosquito emerges from a slit in the "back" of the pupa.

Usually adult male mosquitoes emerge first and remain near the breeding site in order to fertilize females. Newly emerged males may form tall columns of mosquitoes into which females fly for mating. Most fertilized female mosquitoes then require a blood meal before egg-laying. Although the males do not fly great distances, the females of some species have been reported to fly 10 or 20 miles.

Mosquitoes that bother livestock in Wyoming may be divided into two groups: those belonging to the genus *Aedes*; and those belonging to *Culex* and *Culiseta*.

Aedes (e.g. flood water mosquitoes) — These mosquitoes annoy livestock to the greatest extent in Wyoming. They are produced in large numbers in inundated areas, such as marshes, flood plains of rivers, and irrigated fields. The eggs are laid singly on moist surfaces subject to flooding and in areas where the female mosquitoes are protected from the wind. The eggs, if unflooded, can survive several years. Aedes mosquitoes overwinter in the egg stage, then hatch the following spring after flooding due to runoff of melted snow and irrigation. Depending on the species of *Aedes*, additional flooding may produce additional broods of mosquitoes.

Figure 9.3. Aedes. *Photo: Ary Farajollahi, Bugwood.org.*

Culex* and *Culiseta — Many species of these mosquitoes will feed on livestock and are either known to be, or suspected to be, important as vectors of arboviruses that cause the encephalitides. The eggs of these genera are laid in groups called "rafts" on the surface of water and they hatch shortly thereafter. These mosquitoes, therefore, may not require flooding for egg hatching. *Culex* and *Culiseta* overwinter in sheltered areas as adults.

Figure 9.4. Culex. *Photo: Ary Farajollahi, Bugwood.org.*

Black Fly

Black flies are among the smallest of the biting flies attacking livestock. They are frequently called buffalo gnats because of their "humped back" appearance. Black fly may be a misnomer because these insects are frequently light brown or yellow in color.

Larval and pupal black flies spend their lives in rivers or streams where running water provides sufficient aeration. These aquatic stages are attached to objects such as submerged or trailing vegetation, stones, and logs. Adult flies are capable of moving great distances from the streams of their origin. Females are blood suckers and may occur in large swarms. Several hundred eggs may be deposited on or in the water.

Black flies feed on exposed areas of skin or deep within the hair coat where they must bury themselves in order to obtain a blood meal. Black flies bite in the daytime or dusk but not after dark. The reaction to bites may be quite severe. Some species appear to ignore man completely in favor of animals such as horses and cattle.

Figure 9.5. Black fly (Austrosimulium *sp.*). *Photo: Whitney Cranshaw, Colorado State University, Bugwood.org.*

Stable Fly

The stable fly looks much like a house fly except that it has a slightly more robust body and a prominent beak or proboscis.

Eggs of the stable fly are deposited in wet and decaying organic matter. Piles of grass clippings, hay contaminated with manure and urine, and wet feed are particularly good media for development of stable fly larvae or maggots. In areas where bodies of water occur, stable flies may be abundant because piles of decaying "seaweed" are good media. Within five days after egg hatching, the larvae or maggots pass through three larval stages. After the larval stage a pupal stage is formed. In a period of 1-1/2 to 2 weeks, an adult fly emerges from the pupal case. Stable files can produce several generations per season.

Both male and female stable flies have a stout proboscis with which they pierce the skin and suck blood. The bite is painful. Stable flies are found indoors as well as out-of-doors.

Figure 9.6. Stable fly (Stomoxys calcitrans). *Photo: Whitney Cranshaw, Colorado State University, Bugwood.org.*

Horn Fly

The adult horn fly looks like a small stable fly. Both sexes have beaks which they utilize to obtain blood meals. Horn flies may reach very large populations, i.e., thousands of flies per animal, on the preferred host, which is cattle. Horn flies in many areas of the country are considered the most serious pest of range cattle. Horn flies have been reported as pests of sheep and horses as well as cattle.

Unlike other flies that come to livestock only to feed, horn flies remain with the cattle at all times, leaving only to visit fresh dung and lay eggs. Horn fly larvae develop within the dung over a period of about a week. Following the pupal stage of about another week, newly emerged adults seek out cattle.

The flies on a bovine host do not feed constantly, but usually at certain times during the day.

Figure 9.7: Horn fly (Haematobia irritans). *Photo: Craig Sheppard, University of Georgia, Bugwood.org.*

Face and house flies

The primary non-biting, nuisance-type flies affecting Wyoming livestock are the face and house flies. The two species are similar in appearance and are difficult to distinguish from one another in all but the pupal stage, which is reddish-brown in the case of the house fly and white in the case of the face fly.

The life stages of the face fly, *Musca autumnalis*, and house fly are egg, larva, pupa, and adult. The adult female face fly lays its eggs in fresh cow dung. The eggs hatch within a day or two, and the larvae or maggots grow rapidly within the manure. After a period of 4 to 5 days, including three molts to permit body growth, the maggots seek a drier location at the edge of the dung pat and form a pupal case. After a week or more the adult fly emerges from the pupal case. The face fly is a strong flier and can travel several miles. Individual face flies do not remain with cattle and horses at all times and do not generally enter darkened buildings. Due to the short life cycle, many face fly generations can be produced in one season. The adult face fly passes the winter in the adult stage within shelters such as attics of homes and is frequently a household pest in the spring when the flies emerge from their indoor hibernation quarters.

The face fly, has the annoying habit of landing on the face and probing the eyes and nostrils of the host. It is involved in the transmission of the disease known as pink eye. Although it is primarily a pest of cattle, it is also very annoying to horses.

Figure 9.8. Face fly. Photo: Rogert Meerts, shutterstock.com.

The house fly is a pest closely associated with man's activities. It is able to utilize all sorts of excrement and fermenting organic material. It is primarily a pest in and around buildings, and can be very annoying to animals and humans when present in great numbers. It has been implicated in the transmission of several parasites and diseases of public health importance.

Figure 9.9. House fly (Musca domestica). *Photo: Jim Baker, North Carolina State University, Bugwood.org.*

Control of Flies

Although control of flies may be difficult, horn flies, because of their constant association with cattle, are easily controlled by a variety of methods, including spray, dip, backrubber, dust bag, insecticide ear tag, feed through and sustained release bolus. These techniques will also provide relief from the annoyance of some other biting and nuisance flies.

Oil solutions of insecticides can be applied by means of a commercially produced oiler or a homemade backrubber. The backrubber is a far less expensive method but must be recharged more frequently.

The backrubber consists of a length of cable, chain, or wire around which burlap is wrapped. The completed backrubber is then attached to two posts approximately 15 to 20 feet apart and should sag to about 18 to 24 inches from the ground at the center. The backrubber should be recharged frequently to keep it moist and effective. Backrubbers are placed in an area where cattle loaf, e.g., near water or a salt lick.

The dust bag is a simple method developed primarily for horn fly control. Dust bags are heavy burlap sacks filled with an insecticide dust and suspended below backline height in outdoor areas where cattle are likely to pass. When an animal bumps against the bag a small quantity of dust sifts through the fabric and is deposited on the animal. Ready-made dust bags can be purchased. These generally consist of a grommeted burlap sack and a plastic hood to protect the bag from rain. A less expensive way is to purchase a heavy burlap sack and insecticide dust and make your own dust bags.

Water tanks or salt blocks may be fenced, and dust bags installed in a gate so that cattle are forced to use the bags. Frequently, cattle will use the bags after a short period of adjustment if they are located in a favorite loafing place.

Insecticide ear tags are easy to use and in the past have provided excellent, season-long horn fly control. These ear tags perform by dispensing insecticide continuously over a period of several months. The insecticide diffuses to the tag surface and is brushed onto the animal's body through normal body movement. Most of the original fly tags contained pyrethroid insecticides. The pyrethroid family of compounds is effective against flies at very low dosages and provides quick knock-down. Unfortunately, strains of horn flies resistant to pyrethroids have resulted from the continuous exposure to the ear tags. Where this has occurred producers should consider switching to an alternative method of control or to a different ear tag. If the decision is to switch to a different ear tag, the producer has the choice of selecting either a more potent pyrethroid tag or one with a different family of insecticide, e.g., an organophosphate.

Several products are on the market for control of the larval stage of dung-breeding flies. These products may be administered in a number of ways. Sustained release boluses, which are administered by means of a balling gun, continuously release a compound that prevents fly development in cattle dung. Several feed-through type materials, both insecticides and insect growth regulators, are incorporated into salt blocks, mineral mixes, feed supplements, etc. Certain other compounds, i.e., some of the animal systemics applied as a pour-on or injection, are known to appear in feces at levels that are larvicidal for a period of time.

Protection of livestock through frequent applications of fast acting insecticides or insecticide-repellent combinations is often the only method of protection from adult flies other than horn flies. This method is practical only for animals that must be handled frequently, e.g., dairy cows, or companion animals.

Relief from stable fly and house fly may be achieved through sanitation in and around livestock buildings and/or the application of residual wall sprays. Use of fly screens on windows may be helpful. Most flying insects can be controlled temporarily in confined spaces through the use of space sprays or aerosols. Out-of-doors, mist sprays and fogs will produce only very temporary relief.

Mosquito annoyance may be reduced through elimination of standing water which provides a suitable habitat for mosquito larvae. Mosquito larvae can also be controlled through the removal of protective emergent vegetation from irrigation ditches and the edges of ponds and lagoons. Large-scale larval and adult control programs utilizing larvicides and/or adulticides may be conducted by communities against mosquitoes as well as black flies.

Lice

Lice are serious wintertime pests of livestock. Livestock producers' losses to lice have been estimated between 5 and 6 million dollars per year. Two types of lice infest livestock in the United States, the biting or chewing lice and the sucking lice. Chewing lice have mandibles for chewing on skin surface. They also crawl over the skin between the hairs or feathers. The skin becomes irritated and the animals rub themselves trying to relieve the itching. Sucking lice derive nutrition from the host animal by sucking blood. Sucking lice are irritating because they pierce the skin. Extremely heavy infestations may produce anemia.

Lice are extremely injurious to livestock. They help create open sores which may provide entrance for infectious agents. Animals may become nervous and edgy and may go off feed and fail to gain at their normal rate. Lack of stamina may make them susceptible to respiratory infections.

Lice are a problem on all kinds of livestock in Wyoming. Each livestock species has its own host-specific species of lice. They are transferred between animals by contact.

Cattle lice

Cattle lice infestations are easy to recognize. Bluish or gray colored patches appear on heads, necks, dewlaps and shoulders of cattle. Lice may climb about on the host's facial hairs. Cattle scratch and rub against objects and remove hair in an attempt to relieve itching due to lice. All of these signs mean that the lice have reached serious levels and will cause a substantial monetary loss unless controlled.

Losses to cattle lice are many. In addition to the more obvious death losses and lost weight, impaired feed conversion, carcass and hide blemishes, and damaged fences must also be considered.

Studies showing the effect of cattle lice on weight gains of cattle are available from many parts of the world. The benefit derived from controlling lice is from 0.1–1.2 lb. per animal per day depending upon the severity of the infestation and the condition of the cattle. The most severely affected animals are those under stress, that is, under extremely severe winter conditions and receiving poor feed.

Four different species of lice are important parasites of cattle in North America. Only one of the four species is a chewing louse. The cattle biting louse is a little, red-colored louse about 1.5 mm in length. These lice in great numbers produce skin lesions and cause hair to fall out in clumps.

Three sucking lice species are also abundant in Wyoming. The short-nosed cattle louse is about 4mm long, the long-nosed cattle louse is about 2 mm long, and the little blue cattle louse is about 1.5 mm in length.

Figure 9.10. Long-nose cattle louse. Photo: Kansas Department of Agriculture, Bugwood.com.

All four cattle lice species have similar life cycles. The adult female produces eggs which hatch to immature stages known as nymphs. All stages are found exclusively on the host animal.

The eggs are glued to hairs, and in severe infestations, are very noticeable. The duration of the egg stage varies, but usually they hatch after 1 to 2 weeks. Nymphal lice look very much like the adults except that they are smaller. There are three nymphal instars which last between 2 to 3 weeks. Adults may live approximately 2 weeks, producing one to two eggs per day.

Although lice can be found on cattle at any time of the year, the most severe infestations occur during the winter and early spring months. Populations tend to build up in the fall and decline with warm weather in the spring.

Although lice are considered by many the most serious insect pests of livestock on the North American continent, they are among the easiest to control. Treatment with any of the approved insecticides will reduce a population to an insignificant level. If practical, cattle should be treated in the fall before louse populations have had a chance to build up. Usually louse damage has already started before warning signs are visible. Early treatment, perhaps combined with cattle grub control, will eliminate this loss. Research has shown that if treatment is delayed until cattle are obviously lousy, gains will be less than those of similar animals treated earlier.

Insecticides may be applied in a number of different ways. Dips and sprays give excellent control because of thorough coverage of the animal and some effect against eggs or against nymphs that hatch shortly after treatment. Injectable formulations of animal systemic insecticides as well as pour-on formulations of some of the non-systemics have become popular for control of cattle lice. These methods of application are less laborious and much less stressful to the animals. The injectables, however, are not recommended for control of the cattle biting louse.

Sheep Lice

Although lice are not often seen on sheep in Wyoming, two species, the **sheep biting louse** and the **sheep foot louse**, may infest sheep at times.

The sheep biting louse is a small species up to 1.8 mm in length with a pale abdomen, darker thorax, and reddish head. The preferred location on the host is along the back and the upper sides, but in heavy infestations may be found anywhere on the body.

Sheep biting lice cause intense irritation which sheep relieve by biting and pulling the wool and by rubbing against posts and other objects. The fleece of heavily infested sheep becomes ragged and torn.

Female sheep biting lice attach eggs to the wool fibers. The egg stage lasts about 10 days, the nymphal stages about 20 days, and the adult stage around 25 days. It has been estimated that a female will live for 20 to 30 days and will lay one egg every 1 to 2 days.

Populations of sheep biting lice are heaviest during winter and early spring. They are transmitted by direct contact. Lambs easily become infested from their mothers.

The sheep foot louse feeds on blood. The adult is 2 mm long, and the abdomen is covered with long bristles. It is widely distributed in North America. This louse is not considered very injurious since feeding occurs on the hairier parts of the sheep's body and the animal exhibits little discomfort. In severe infestations, however, it may cause some lameness.

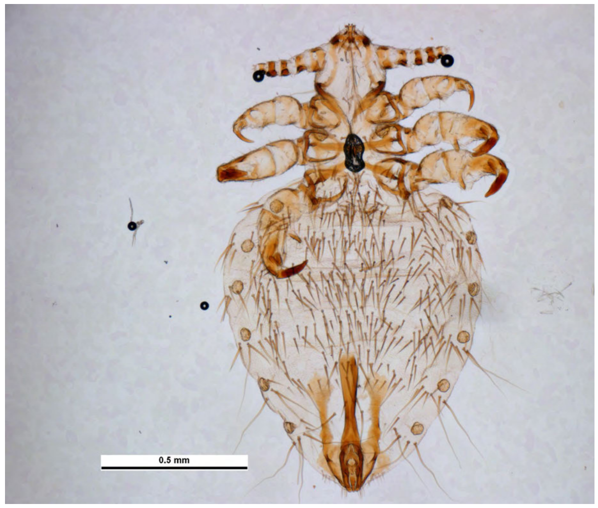


Figure 9.11. Sheep foot louse. Photo: Pest and Diseases Image Library, Bugwood.org.

Light infestations of the sheep foot louse occur as small colonies of lice between and around the accessory digits. In heavy infestations not only the legs support heavy numbers of lice but also the scrotum of rams. The egg stage lasts 17 days, and each of the three nymphal stages re quires 7 days.

The sheep foot louse has a pronounced seasonal fluctuation in populations, numbers being greatest in winter and early spring and lowest in summer. Lambs may become infested from their mothers within a few hours after birth. Younger sheep are most susceptible. Older sheep carry only light infestations. Infestations may be acquired either by direct contact with infested sheep, or from an infested pasture.

Sheep lice are usually controlled by means of dip, high pressure spray, pour-on, or dust.

Horse lice

Horses are occasionally infested with the horse sucking louse which is about 3 mm in length, and the horse biting louse which is about 1.5 mm in length. Horse lice are usually discovered after the infestation has become sufficiently severe to cause annoyance.

Louse populations are most numerous and severe in the winter. This is also the time of year when the animals are under additional stress due to cold weather and possibly poor nutrition. The combination can produce an unhealthy, anemic, and unthrifty horse. The sucking louse of horses is said to be more irritating and more important than the biting louse because it feeds by sucking blood from the host.

The lengths of various life stages of horse lice vary: 1 to 2 weeks for eggs, 2 to 3 weeks for nymphs, and 2 weeks or longer for adults.

Horse lice are pests of closely related hosts such as horses, mules, and asses. Horse lice spend their entire lives on their host animals and spread from one animal to another when the hosts are in close contact.

Horse lice are easy to control with a variety of spray materials. Remember that a new horse or one that has not been treated with the others may re-infest a herd. The use of an application mitt or a small hand-held sprayer to treat a horse is usually less stressful to the horse and to the applicator.

Ticks

Livestock in Wyoming frequently become infested with ticks. Ticks are not insects and do not resemble them. Ticks have four developmental stages: egg, larva, nymph, and adult. The larvae, nymphs, and adults can be differentiated according to size. Larval or "seed ticks" are very tiny and they possess six legs, whereas adults and nymphs are larger and have eight legs.

Male and female ticks are obligatory parasites and require blood meals in order to develop. The tick feeds by driving its mouthparts into the skin of the host and feeding for extended periods of time. The feeding of ticks produces wounds, removes large quantities of blood, causes considerable irritation and worry to the host, and may transmit disease organisms or causes paralysis.

Winter tick

The winter tick is a frequent and widespread pest of horses in Wyoming. Sometimes it occurs on cattle. Preferred hosts are horses, moose, and elk. Young animals are especially vulnerable to attack and may be killed by heavy infestations. This tick is a pest in the fall, winter, and early spring of the year. The larval or seed ticks spend the summer in clusters on the ground. When the cool weather of fall approaches, the larval ticks become active and seek a host. The tick remains on and feeds on the blood of the same host throughout its life. For this reason the winter tick is called a one-host tick. The mated, fully blood-engorged female tick drops off the host in early spring. Egg laying takes place on the ground later in the spring.

Figure 9.12. Winter tick. Photo: Mat Pound, USDA Agricultural Research Service, Bugwood.org

Rocky Mountain wood tick

The Rocky Mountain wood tick attacks most domesticated animals in Wyoming. In addition to being very pestiferous, toxins secreted by the female tick can paralyze many animals including man, sheep, and horses.

Figure 9.13. Rocky Mountain wood tick. Photo: Mat Pound, USDA Agricultural Research Service, Bugwood.org

Rocky Mountain wood ticks may cause tick paralysis in animals by the feeding of females and their injection of a toxin into the blood stream of the host. First symptoms are weakness and staggers. In a few hours they are incapable of standing, and finally death ensues. There is no struggling in the later stages and temperature remains normal. Animals can be saved by removing the offending ticks. Recovery may be rapid (within an hour) or it may take up to 2 days. When recovery does not occur within this time, it is an indication that some ticks have been overlooked in the removal.

The Rocky Mountain wood tick transmits the pathogen of tularemia to sheep and may cause epidemics of the disease in bands of sheep of the Western states. It is also a biological vector of anaplasmosis of cattle.

The Rocky Mountain wood tick is troublesome in the spring of the year when adults come out of hibernation. They climb upon vegetation and wait to attach to a suitable large mammal host. Mating and feeding occur on the host, with the female dropping off the host in about 1 to 3 weeks. Egg-laying takes place on the ground in a sheltered location. Over 6,000 eggs can be produced by one female. The larval or seed ticks hatch in a month. These, if fortunate, attach to a small wild mammal host where they feed for a period of 2 to 8 days, then drop off. Nymphs appear 3 weeks after the larvae drop. At this time they may either hibernate that winter as nymphs or find another small mammal host. If another host is found, the tick feeds, drops off, and molts; then spends the winter as an unfed adult. Overwintering nymphs seek small mammal hosts the following summer, feed for about a week, drop off the host, molt, and overwinter as unfed adults.

Spinose ear tick

The spinose ear tick is a pest of many species of domesticated and wild animals in Wyoming. It is considered primarily a pest of warmer climates, but has become firmly established in Wyoming. The larvae and nymphs of this species invade the ears of horses, cattle, sheep, dogs, cats, deer, rabbits, and numerous other domesticated and wild animals. They may be quite abundant during the summer months.

Figure 9.14. Spinose ear tick. Photo: Mat Pound, USDA Agricultural Research Service, Bugwood.org

The spinose ear tick causes injury by puncturing the tender skin within the ear and sucking blood. Wounds may become infected with bacteria, giving rise to a condition known as “ear canker”. Plugs formed by accumulation of ticks, their excretions, and ear wax may close the ear passage completely. An infested animal with this condition shakes its head and repeatedly turns it from side to side. A tendency for the animal to rub and scratch affected ears may result in extensive lacerations.

Larval ticks hatch from eggs that have been laid on the ground. The larvae climb onto weeds, vegetation, feed troughs, etc. to contact the host animals. After attaching to the host, the larval tick moves to the ear where it attaches to the delicate lining of the ear and engorges. It molts in 1 to 2 weeks to the nymphal stage, which may remain in the ear up to 6 months. The nymphs then drop to the ground, molt to the adult stage, mate, and lay eggs.

Mange mites

Several different mite species produce a disease of animals known as mange. The type of mange is named after the mite causing it, e.g. sarcoptic mange and psoroptic mange, which are caused by sarcoptes and psoroptes mites, respectively.

Both mite species mentioned are related to and have developmental stages similar to those of ticks, i.e. eggs, six-legged larvae, nymphs, and adults. Mites are nearly microscopic in size and barely visible to the naked eye.

The symptoms of mange are quite obvious and consist of blisters and small bumps in the skin, swelling and inflammation of the skin, and scabs which consist of serum and scurf. In advanced cases, a dry, leathery skin condition may follow.

Positive diagnosis of mange is made by microscopic examination of skin scrapings for mites.

Sarcoptic mange

Adult sarcoptic mites burrow within the skin of the host and cause severe irritation. Eggs are laid within the burrows. Development of the mite from egg to reproductive adult takes approximately 2 weeks. Lesions usually first appear on the head, neck, and shoulders, then spread to other parts of the body.

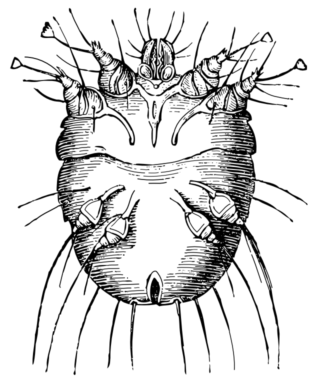


Figure 9.13. Sarcoptes scabiei. *Illustration: Hein Nouwens, shutterstock.com.*

As the host scratches to relieve irritation, blisters and small bumps develop. Further scratching causes the blisters to break, forming scabs. In advanced cases the mites become inactive and the affected skin becomes dry, wrinkled, and hairless, and remains so for some time.

Sarcoptic mange of horses can be transmitted to humans where it causes transitory itch.

Psoroptic mange

Psoroptic mange mite life cycles take about 2 weeks. Psoroptic mites do not burrow in the skin of the host. Instead, by pricking the skin to feed, they cause serum to ooze from the wounds. Accumulation of serum causes the formation of scabs which start on the hairier parts of the body. Psoroptes infestations eventually may involve large areas of skin all over the body.

Psoroptes mange is often called “scab” or “scabies,” a highly contagious mange of sheep and cattle, respectively.

Mange mites are transmitted by contact with infected animals. Populations are generally greatest in the winter when host hair coats are long and animals are frequently crowded together.

Dipping, thoroughly spraying or injectable treatment with certain animal systemic insecticides are the only treatments for mange control. Current state and federal regulations concerning treatment of Psoroptes infested livestock must be followed.

PESTS OF CATTLE

Grubs

Two species of cattle grub occur in Wyoming, the **common cattle grub**, the predominant species, and the **northern cattle grub**, *Hypoderma bovis*. Losses due to these insects have been estimated as high as $10 per head.

Figure 9.14. Common cattle grub. Photo: Pest and Diseases Image Library, Bugwood.org.

The grub-like larvae which appear in the backs of cattle in the spring are familiar to everyone who handles cattle. The adult fly, which somewhat resembles a bee, is less familiar. Frequently one observes the reaction of cattle to egg-laying attacks of the adult fly. This reaction, which involves running with tails in the air, is termed "gadding," hence the term "gad fly".

In the spring both fly species lay eggs on the lower parts of the body of cattle. The eggs hatch in 3 or 4 days into tiny larvae. The grubs burrow into the skin of the animal then wander through the body until they reach the gullet sometime between October and December in the case of the common cattle grub, or the spinal canal in the case of the northern cattle grub. The grubs stay at these locations for a couple of months then migrate to the back. Shortly after they reach the back they cut breathing holes in the hide and in 1 to 2 months grow to full size. After reaching full growth, the larva drops from the back and forms an inactive pupa on the ground. Adult flies emerge from the pupae when weather is sufficiently warm. These flies mate, then seek cattle for egg-laying and the beginning of a new, one-year cycle.

Control of cattle grubs in beef cattle and non-lactating dairy cattle is quite simple with the animal systemic insecticides. These chemicals may be applied as a high pressure spray, a dip, a pour-on or injection.

The animal systemic insecticides applied for cattle grub control also provide either suppression or control of cattle lice depending upon the insecticide and the formulation.

Animal systemics should not be used for grub control during the winter months of November through February, unless cattle were treated with a systemic earlier in the fall. Wyoming cattle treated during the winter months may demonstrate a reaction due to the death of grubs in the area of the esophagus or spinal cord. Prior to November 1 grubs are not usually found in these critical areas of cattle that have summered in Wyoming.

PESTS OF SHEEP

Sheep Ked

The sheep ked, sometimes called sheep "tick", is a common pest of sheep in Wyoming. Sheep keds have a negative effect on wool production and carcass weights.

Figure 9.15. Sheep ked. Photo: By Acarologiste, Wikimedia Commons.

Sheep grazed through the year on range may acquire heavy infestations during the winter and early spring months. Damage, most evident at these times, may result from loss of blood and from irritation caused by the bites. Many ranchers attribute "back loss" to heavy infestations of this parasite. Also, injury may occur after transfer of large number of keds from ewes to newborn lambs. Ked bites are the cause of a defect in sheepskin called "cockle." The latter are raised, pimple-like blemishes that cannot be flattened out or covered with dyes. In the United States it is estimated that this defect is responsible for annual losses of about $4 million. If sheep are freed of the parasite, they spontaneously recover from this effect of ked bites.

The sheep ked is actually a wingless fly which has adapted to a parasitic existence. For an insect it has a remarkable way of reproducing. An egg hatches within the uterus of the female ked, and the young larva develops to maturity on food material secreted by nutritive glands of the mother. Only a single larva develops at a time, the full-grown larva being born after 8 days of feeding and growing in the uterus.

The larva is cemented to the sheep's wool and forms the red barrel-shaped puparium sometimes confused with eggs or nits. The pupal period averages 22 days, after which the young adult keds emerge.

Females live about 100 days and produce 15 or more larvae during a lifetime. Males live about 80 days.

The entire life of a ked is spent in the fleece of the host. Ked populations increase during the fall and winter, reach peak numbers in January and February, and then decline until June to low numbers that are carried over the summer.

Sheep producers have a choice of applying approved insecticides as pour-ons, low volume sprays (1/3 oz. per animal), high or low pressure sprays, dips, sprinkles (from sprinkler can) or dusts. The most convenient time to treat is in spring after shearing, when wool is short. Sheep are subject to stress and risk of exposure if dipped or sprayed during the periods of low temperatures. Therefore, sheep should not be sprayed or dipped when daytime temperatures are below 40°F. When animals are sprayed or dipped, enough time should be allowed for their wool to dry before evening. When wool is long, spray penetration is more satisfactory at high pressures, i.e., 300–350 psi.

Sheep Bot Fly

In Wyoming more than 90% of the sheep are infested with sheep bot fly. Goats are equally subject to infestation. This pest, known commonly as the sheep bot fly, is found in nearly all parts of the world where sheep are raised.

Figure 9.16. Sheep bot fly. Photo: Cosmin Manci, shutterstock.com.

Sheep bot fly larvae generally do not cause death loss but are detrimental to health, and the persistency of the adult flies in depositing larvae in the nostrils interferes with the grazing of the animals. Presence of a fly excites the sheep. They shake their heads, keep their noses against each other or next to the ground, and in other ways indicate they are attempting to escape something trying to enter their nostrils.

The larvae irritate membranes lining the nasal cavities, and predispose the sheep to bacterial infection. This causes a mucopurulent discharge referred to as "snotty nose." The discharge becomes viscous, making it difficult for the animal to breath freely.

Small, first-stage larvae are deposited in the nostrils by female flies, each of which produces up to 500 larvae. These larvae remain in the nasal passages for a time, then migrate to the frontal sinuses for further development. After reaching full growth in the sinuses, larvae, now over 1 inch long, work their way out of the nostrils and drop to the ground, where they bury themselves and pupate within a few hours. The pupal period lasts about one month.

In Wyoming, larvae overwinter in the sheep as larvae and the larval period lasts from 8 to 10 months. In warm climates, where at least two generations are produced each year, the developmental cycle may be completed in as short a time as 2 to 3 months.

Control of sheep bot fly larvae may be achieved by an oral drench of an approved systemic insecticide, preferably in the fall after cessation of adult fly activity.

Wool Maggots

In spring and early summer, sheep are sometimes infested with masses of maggots, larvae of certain species of blowflies. Infestations begin most often in the crutch area or where neglected wounds exude offensive discharges. Literally thousands of maggots may be found on a single sheep. After hatching from eggs, maggots spread extensively over the body and feed on the skin surface, causing severe irritation.

Infested animals show characteristic symptoms. Sheep become restless, stamp their feet, constantly wag their tails, and bite at the site of the trouble. As the condition worsens, sheep may leave the flock to hide in secluded places. Badly infested sheep, if untreated, become weak and may die.

Life cycles of the several species of wool maggots are similar. The usual breeding places are in carrion, but under certain conditions they find a favorable environment for development on living sheep. Attracted by foul odors emanating from soiled, wet wool, or running wounds, female blow flies deposit hundreds of eggs on an animal.

Eggs hatch in a few hours and maggots develop rapidly, completing growth in 3 to 4 days. They then drop from the host and enter the ground, where they transform to the pupal stage. After 7 to 10 days, adult flies emerge from pupal cases. Several generations develop each year. Depending on the species, blow flies overwinter as larvae, pupae, or adults.

Much can be done to avoid maggot infestation of animals through flock management. Sheep should be kept as clean as possible. If the breech area becomes saturated with urine and feces during the blow fly season, the animals should be "crutched" by clipping wool from the crutch and from the area above the tail down the back of the hind legs to the hocks.

Wounds should be prevented by handling sheep gently and by providing safe chutes and corrals. Protruding nails and sharp splintered boards should be removed.

Shearing early in spring before the blow fly season is a good practice. It removes soiled or fermenting wool, making sheep less attractive to blow flies. It also permits shear cuts to heal before the blow fly season.

Lambing early is advisable for protection of both ewes and lambs, since wool of ewes soiled from afterbirth and exposed umbilical cords of lambs may attract flies. When lambing occurs early, docking and castrating often can be performed before blow flies become abundant.

Insecticides are useful not only to control maggot infestations but also to prevent them. When sheep have accidental wounds or when necessary operations are performed during the blow fly season, timely applications will do much to prevent blow fly injury.

If sheep are unshorn in late spring, or if they scour during warm months, preventive application of insecticidal sprays or dips may be advisable. Spraying or dipping with a recommended insecticide effectively prevents blow fly injury.

PESTS OF HORSES

Horse bot flies

Three species of bot flies infest horses in Wyoming. Two of them, the **nose bot fly** and the **throat bot fly** have received names based on the egg-laying habits of the female flies. The third species is simply called the **horse bot fly**. Adult bot flies are large flies which frequently are seen laying eggs on horses. The larval or bot stage is attached to the lining of the stomach or intestines.

Horse bots cause injury in several ways. Since the mouthparts of the adult flies are non-functional, they cannot bite. However, the egg laying habits of flies annoy or terrorize horses and cause them to mill or run, thus interfering with work and grazing. First-stage larvae or bots penetrate and irritate submucosal tissues of the inner lip, mouth, and tongue; and induce horses to rub their mouths on objects, causing additional sores. Second- and third-stage larvae attach to the lining of the stomach and intestines removing nutrients and causing ulceration and inflammation. Heavy infestations hinder passage of food through the alimentary canal and impair digestion of food.

Horse bot fly

Female horse bot flies may lay up to 1,000 eggs. The eggs are usually attached to the hairs of the forelegs or in other places the horse can reach with its mouth. After a 5-day incubation period, heat caused by licking of the horse stimulates the eggs to hatch. Young larvae are taken into the mouth, where they burrow into the surface of the tongue. After 3 to 4 weeks in the subepithelial layer of the mucous membrane of the tongue, the larvae pass to the stomach where they attach to the lining and pass their lives as second and third larval stages. The larvae remain in the stomach for 10 months (until the following spring) when they pass out with the feces. Pupation takes place in soil or ground litter. The pupal period lasts from 3 to 5 weeks. Individual adult flies may live for about 3 weeks but because larvae continue to drop from the host over a long period of time, flies can be found annoying horses in Wyoming from June through September.

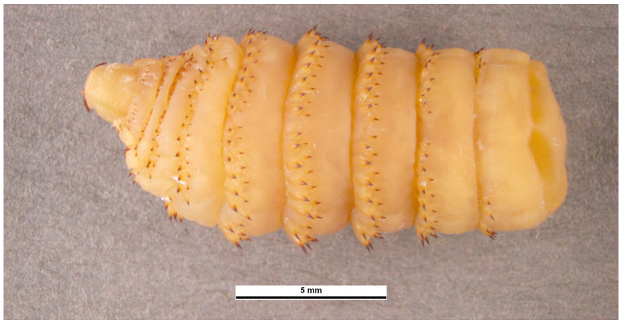


Figure 9.17. Horse bot fly. Pest and Diseases Image Library, Bugwood.org.

Throat Bot Fly

Eggs of the throat bot fly, which are attached to hairs of the lower jaw of the horse, apparently require no stimulus to hatch. One female can lay from 300 to 500 eggs. Within 6 days after egg-laying, newly hatched larvae migrate to the lips, then to the inside of the mouth, and burrow into the tissue lining the mouth. After 3 to 4 weeks they move back to the pyloric portion of the stomach and the anterior portion of the duodenum. The rest of the life cycle is similar to that of the horse bot fly.

Nose bot fly

The eggs of the nose bot fly, which are laid mainly on the hairs of the upper lip, require an incubation period of approximately 2 days. Moisture provided by licking may be necessary for hatching. The larvae penetrate the lips and migrate into and invade tissue of the mouth. This species attaches to the stomach and duodenum in the second and early third larval stage. Unlike the other species, however, it then detaches and reattaches in large numbers in the rectum, very close to the anus, before dropping out with the feces. The rest of the life of the nose bot fly is similar to that of the other two species.

Chemical control of bot flies is directed against the larvae. A number of chemicals that are available for control of bots will also control parasitic worms. The simplest control technique is the use of an oral paste or gel or feeding of an approved insecticide formulation.

Section 10 - Category 901E - Small Animal Damage Management

LEARNING OBJECTIVES

After completing the following section, you should be able to:

A. Be able to explain why it is important in some situations to manage rodents and other vertebrates.

B. Explain the four points of assessing vertebrate damage.

C. Understand and describe the diseases that are vectored by vertebrates.

D. Identify and understand the control tactics for a variety of vertebrate pests.

E. Describe what causes bait shyness.

F. Understand the Federal requirements for baiting rodents and how it impacts the record keeping and program documentation.

PREFACE

Small mammalian pests in normal situations are considered a minor nuisance; however, populations of these pests are often cyclical, and many hungry mouths can have significant impact on well-managed turf and kill ornamental trees and shrubs. Small mammalian activities can also negatively affect irrigation, interrupt electrical supply, and crop production. They also have the potential to transmit diseases to livestock and humans.

Small animal control tactics have experienced few recent improvements. The majority of the information presented below has been taken from university publications available through a variety of means. Most of the material was published originally in the mid 1990s with revisions made in the 2010s. One of the compilations for small animal control, *The Handbook: Prevention and Control of Wildlife Damage*, is available electronically at http://digitalcommons.unl.edu/icwdmhandbook/?utm_source=digitalcommons.unl.edu%2Ficwdmhandbook%2F22&utm_medium=PDF&utm_campaign=PDFCoverPages.

The information presented below has been designed for two purposes:

1. To provide necessary information to persons interested in becoming a certified private or commercial applicator of pesticides used in wildlife damage control.

2. To serve as a resource manual in providing information in the control of wildlife commonly found in Wyoming.

The material in this section can be used as a comprehensive reference of North American vertebrate species that can cause economic damage to resources or become a nuisance at various times and places. The information is intended for use by extension agents and specialists, wildlife biologists, animal control officers, public health personnel, pest control operators, teachers and students of wildlife biology, and others who deal with wildlife damage problems.

Wildlife damage management is an essential part of contemporary wildlife management. This material is a condensation of current, research-based information on wildlife that cause problems and the control of damage that they cause. While the material emphasizes prevention of damage as being desirable when possible, it does not neglect the necessity of population reduction in cases where animals must be removed to solve problems. This publication stresses an integrated approach to damage management and includes treatment of materials and techniques such as exclusion, habitat modification, repellents, frightening stimuli, toxicants, fumigants, trapping, shooting, and others. All of the major vertebrate pesticides currently federally registered are included.

The Wyoming Department of Agriculture recognizes many products other than those listed may be commonly used, legally registered, and distributed by firms not mentioned. In addition, the applicator must keep in mind that many products may be canceled, their uses restricted, or new products developed at any time. Users of these products are encouraged to check with the appropriate federal, state, or county authorities for updated information.

The mention of specific pesticide product manufacturers and distributors listed herein is supplied with the understanding that no discrimination is intended and no endorsement of any product is implied by the Wyoming Department of Agriculture or the University of Wyoming.

Compiled by Kent Drake,
Predator Management Coordinator
Wyoming Department of Agriculture
2219 Carey Avenue
Cheyenne, Wyoming 82002-0100
Phone: 307-777-6781
Fax: 307-777-1943

INTRODUCTION

Wildlife management is often thought of in terms of protecting, enhancing, and nurturing wildlife populations and the habitat needed for their well-being. However, many species at one time or another require management actions to reduce conflicts with people or with other wildlife species. Examples include an airport manager modifying habitats to reduce gull activity near runways, a forester poisoning pocket gophers to increase tree seedling survival in a reforestation project, or a biologist trapping an abundant predator or competing species to enhance survival of an endangered species.

Wildlife damage control is an increasingly important part of the wildlife management profession because of expanding human populations and intensified land-use practices. Concurrent with this is the growing need to reduce wildlife-people conflicts, public attitudes, and environmental regulations restricting use of some of the traditional tools of control such as toxicants and traps. Agencies and individuals carrying out control programs are being more carefully scrutinized to ensure their actions are justified, environmentally safe, and in the public interest. Wildlife damage control activities must be based on sound economic, ecological, and sociological principles and carried out as a positive, necessary component of overall wildlife management programs.

Wildlife damage control programs can be thought of as having four parts:

1. Problem identification; refers to determining the species and numbers of animals causing the problem, the amount of loss or nature of the conflict, and other biological and social factors related to the problem.

2. Ecology of the problem species; refers to understanding the life history of the species, especially in relation to the conflict.

3. Control methods application; refers to taking the information gained from parts 1 and 2 to develop an appropriate management program to alleviate or reduce the conflict.

4. Evaluation of control. Allows an assessment of the reduction in damage in relation to cost and impact of the control on target and non-target populations and the environment.

Increasingly, emphasis is being placed on integrated pest management whereby several control methods are combined and coordinated with other management practices in use at that time.

ASSESSING DAMAGE

The objective of any responsible rodent or predator control program is not to eliminate the target species, but to reduce the population to below injurious levels. Reducing the population may be necessary in some situations to alleviate wildlife damage, while at other times, removal of the problem animal may be the correct solution.

Control personnel should be aware of values placed on wild animals by persons not affected with wildlife damage. Non-affected persons often object to any type of control activities. A concept promoted by some organizations and individuals is to preserve all wildlife in the interest of conservation. However, at times this concept may actually work against the desired results. Control personnel must remember this concept when considering control activities, as the wildlife values of the non-affected party are generally different than those of the affected party.

The animal species covered in this section are **vertebrates**. Vertebrates, simply stated, have a jointed spinal column (vertebrate) and include fish, amphibians, reptiles, birds, and mammals. A vertebrate pest is any native or introduced, wild or feral, non-human vertebrate animal that is currently troublesome to one or more persons in a particular situation or over a large area, either by being a health hazard, a general nuisance, by destroying food, fiber, natural resources, or damaging monetary or aesthetic items of value to man.

Any animal that may currently be a pest to one or more persons may at the same time be desirable or of neutral interest to someone else. Examples can include birds, tree squirrels and deer.

Judgment as to the propriety of controlling vertebrate pests is a relative matter. A homeowner usually will not tolerate the presence of a single rodent, snake or other animal that he may consider a pest; whereas a farmer or rancher usually does not object to most of these same species unless they become so numerous as to cause him economic loss. Damage to habitat and economic loss will occur if necessary pest control measures are not carried out. A good management system will employ integrated control, which is a system that uses all suitable techniques and methods in a compatible manner to maintain pest animals at levels below those causing economic or habitat.

The Assessment

Before implementing a control program an assessment or evaluation should be made for each situation. This assessment is necessary to be successful in reducing damage without endangering non-target animals, for which several factors should be considered.

1. **Problem identification and verification of the pest causing damage**. The first thing to do in any pest control program is to accurately define the problem including the amount of loss or nature of the conflict, the species doing the actual damage and the number of animals causing the damage. Proper identification of the pest is imperative in conducting successful control. Wrong identification will lead to wasted money and time as many species have similar damage-causing characteristics. When physical evidence is present, the experienced person usually does not have any difficulty in identifying the animal or animals responsible for the damage. Situations will arise where evidence may be difficult to find, and when found may be inconclusive to the observer. When this occurs, it may be advisable to consult other people who are more knowledgeable in properly identifying the pest.

2. **Ecology of the pest species**. To properly control any pest, the control personnel must have knowledge and understanding of the life cycle of the target animal(s), especially in relation to the damage being caused. By knowing the life cycle, the control personnel may be able to select the proper control measure and time its application to be the most successful in controlling the pest.

3. **Selection of control methods and application**. After the control personnel have made the proper identification of the pest and understand its ecology, the correct control method and its application may be made to reduce or alleviate the damage. Proper timing of control is often necessary in controlling the target pest. Preventive and protective control is often overlooked by those being affected, causing added expense and the need for extended control measures. In some situations, the habitat can be altered making it undesirable for the pest species; in others, the food supply may be removed or reduced. There are many situations when these non-lethal control measures will not be applicable, but they should be considered.

4. **Evaluation of control**. The evaluation of control is an assessment of the reduction in damage in relation to the cost and impact of control. By taking this final step and evaluating the results, the control personnel may take the appropriate measures in the future to alleviate or reduce the damage prior to implementing control methods that may be more costly and time consuming. In addition, the control personnel in assessing their methods, can make the necessary changes to be more successful in the future.

WILDLIFE DISEASES AND HUMANS

Diseases of wildlife can cause significant illness and death to individual animals and can significantly affect wildlife populations. Wildlife species can also serve as natural hosts for certain diseases that affect humans (zoonosis). The disease agents or parasites that cause these zoonotic diseases can be contracted from wildlife directly by bites or contamination, or indirectly through the bite or arthropod vectors such as mosquitoes, ticks, fleas, and mites that have previously fed on an infected animal. These zoonotic diseases are primarily diseases acquired within a specific locality, and secondarily, diseases of occupation and a vocation. Biologists, field assistants, hunters, and other individuals who work directly with wildlife have an increased risk of acquiring these diseases directly from animal hosts or their ectoparasites. Plague, tularemia, and leptospirosis have been acquired in the handling and skinning of rodents, rabbits, and carnivores. Humans have usually acquired diseases like Colorado tick fever, Rocky Mountain spotted fever, and Lyme disease because they have spent time in optimal habitats of disease vectors and hosts. Some general precautions should be taken to reduce risks of exposure and prevent infection.

General Precautions

Use extreme caution when approaching or handling a wild animal that looks sick or abnormal to guard against those diseases contracted directly from wildlife. Procedures for basic personal hygiene and cleanliness of equipment are important for any activity but become a matter of major health concern when handling animals or their products that could be infected with disease agents. Some of the important precautions are:

1. Wear protective clothing, particularly disposable rubber or plastic gloves, when dissecting or skinning wild animals.

2. Scrub the work area, knives, other tools, and reusable gloves with soap or detergent followed by disinfection with diluted household bleach.

3. Avoid eating and drinking while handling or skinning animals and wash hands thoroughly when finished.

4. Safely dispose of carcasses and tissues as well as any contaminated disposable items like plastic gloves.

5. Cook meat from wild game thoroughly before eating.

6. Contact a physician if you become sick following exposure to a wild animal or its ectoparasites. Inform the physician of your possible exposure to a zoonotic disease.

Precautions against acquiring fungal diseases, especially histoplasmosis, should be taken when working in high-risk sites that contain contaminated soil or accumulations of animal feces; for example, under large bird roosts or in buildings or caves containing bat colonies. Wear protective masks to reduce or prevent the inhalation of fungal spores.

Protection from vector-borne diseases in high-risk areas involves personal measures such as using mosquito or tick repellents, wearing special clothing, or simply tucking pant cuffs into socks to increase the chance of finding crawling ticks before they attach. Additional preventive methods include checking your clothing and body and your pets for ticks and removing the ticks promptly after returning from infested sites. If possible, avoid tick-infested areas or locations with intense mosquito activity during the transmission season. Reduce outdoor exposure to mosquitoes especially in early evening hours to diminish the risk of infection with mosquito-borne diseases.

Equally important preventive measures are knowledge of the diseases present in the general area and the specific habitats and times of year that present the greatest risk of exposure. Knowledge of and recognition of the early symptoms of the diseases and the conditions of exposure are essential in preventing severe illness. Also important are medical evaluation and treatment with proper antibiotics; for example, if you become ill following some field activity in a known plague-endemic area and you recognize the early symptoms of the disease, seeking medical care and informing the attending physician of your possible exposure to plague will aid in the correct treatment of your illness and reduce the risk of complications or even death.

In addition to taking personal precautions, risk of acquiring vector-borne diseases can be reduced in specific locations through area-wide applications of insecticides to control mosquito or flea vectors or acaricides to control tick vectors. Reduction in host populations (for example, rodents) and their ectoparasites (fleas or ticks) may be needed to control transmission of such diseases as plague or Lyme disease. Vaccination of wildlife hosts as a means of reducing zoonotic diseases is being investigated and may soon be available for diseases like rabies.

Conclusion

Wildlife workers tend to ignore the risks associated with handling wildlife species and working in natural environments. Diseases of wildlife or diseases present in their habitats can infect humans and some can cause serious illness or even death. Becoming aware of the potential diseases present and taking precautions to decrease exposure will greatly reduce chances of becoming infected with one of these diseases.

You can prevent infection with zoonotic diseases and reduce the seriousness of an illness by observing the following recommendations:

1. Become aware of which zoonotic diseases are present in your area and their clinical symptoms.
2. Obtain any pre-exposure vaccinations that are available, particularly for rabies.
3. Take personal precautions to reduce exposure to disease agents and vectors such as ticks, mosquitoes, and fleas.
4. Practice good sanitation procedures when handling or processing animals or their products.
5. If you become ill, promptly seek proper medical treatment and inform the physician about possible exposures.

Table 10.1. Some important wildlife diseases that affect humans.

Disease	Agent	Method of transmission	Wildlife host	Type of human illness/ symptoms
Direct				
Rabies	virus	Animal Bite, aerosol	Striped skunk, raccoon, fox, bats, other mammals	Paralysis, convulsions, coma, death
Hantavirus	virus	Animal Bite, aerosol	Deer mice, other wild and commensal rodents	Fever, headache, muscle aches, nausea, vomiting, back pain, respiratory syndrome
Leptospirosis	bacteria	Urine, contamination ingestion	Urbanized wild rodents: rabbit, fox, skunk, raccoon, opossum, deer	Fever; jaundice; neurological pain; pain in abdomen, joints or muscles; nausea; may be fatal
Brucellosis	bacteria	Contamination ingestion	Hoofed animals, predators (coyotes, wolves)	Intermittent fever, chills, headache, weakness, weight loss
Rat-bite Fever	bacteria	Rodent bite	Commensal rodents	Abrupt onset with chills and fever, headache, muscle ache, rash on legs and arms, arthritis
Salmonellosis	bacteria	Ingestion of food contaminated by feces from infected animals	Rodents, swine, cattle, birds, poultry, pet turtles	Sudden onset of headache, fever, abdominal pain, nausea, diarrhea, vomiting
Ornithosis	chlamydia	Inhalation of contaminated air	Fowl	Fever, chills, headache, muscle pain, loss of appetite, sweating, pneumonia
Histoplasmosis	fungus	Inhalation of spores	None — grows in soil under bird and bat roosts	Mild fever, flu-like illness, pneumonia, hepatitis, endocarditis, death
Cryptococcosis	fungus	Inhalation is suspected	None — grows in droppings in pigeon nests	Meningitis, lung, liver and bone infection, skin lesions or ulcers.
Trichonosis	nematode	Ingestion of under or uncooked meat containing larval cysts	Swine, bear, wild and domestic carnivores, wild and domestic rodents	Nonspecific gastroenteritis, loss of appetite, nausea, swollen eyelids, fever, chills, muscle aches
Ascarid roundworm	nematode	Ingestion of nematode eggs (from fecal contamination)	Raccoon	Larval stage invades and damages organs, including the brain
Direct and Indirect				
Plague	bacteria	Contamination from skinning animals, flea bites	Wild rodents (prairie dogs, ground and tree squirrels, chipmunks) rabbits, carnivores.	Fever, headache, severe discomfort, shaking, chills, pain in groin and armpits (swollen lymph nodes), death

Disease	Agent	Method of transmission	Wildlife host	Type of human illness/ symptoms
Tularemia	bacteria	Contamination from skinning animals, ticks, insect bites	Wild rodents, hares, rabbits, carnivore, birds, hoofed animals	Mild illness to severe meningitis, pneumonia, ulcer at inoculation site, swollen lymph nodes, death
Indirect: Tick-borne				
Colorado tick fever	virus	Tick	Wild rodents, hares, rabbits, marmots, carnivores	High fever, headache, muscle ache, lethargy, biphasic symptoms
Rocky Mountain spotted fever	rickettsia	Tick	Wild rodents, hares, rabbits, carnivores, birds	Rapid onset, fever, headache, muscle ache, nausea, vomiting, abdominal pain, rash, loss of muscle control, death
Ehrlichiosis	rickettsia	Tick	Unknown — possibly dogs and other carnivores	Fever, headache, nausea, vomiting, muscle ache, fleeting rash
Lyme disease	bacteria	Tick	Wild rodents, raccoon, deer, rabbits, birds	Skin lesions, fever, headache, fatigue, muscle ache, stiff neck, cardiac and neurological manifestations, arthritis
Relapsing fever	bacteria	Tick	Wild rodents who make their homes in old cabins or caves	Rapid onset, severe headache, muscle weakness, rigor, joint pain, recurring fever
Babesiosis	protozoa	Tick	Wild rodents	Gradual onset. Loss of appetite, fever, sweating, fatigue, muscle aches, prolonged anemia, can be fatal
Indirect: Mosquito-borne				
St. Louis encephalitis	virus	Mosquito	Mostly birds, some rodents	Fever, headache, musculoskeletal aches, malaise, low fatality
Eastern equine encephalitis	virus	Mosquito	Birds, bats	Fever, intense headache, nausea, vomiting, muscle aches, confusion, coma, high fatality
Western equine encephalitis	virus	Mosquito	Birds, jackrabbits, rodents	Fever, headache, nausea, vomiting, malaise, loss of appetite, convulsion, low fatality
California encephalitis	virus	Mosquito	Eastern chipmunk, tree squirrel, red fox, deer mouse	Fever, irritability, headache, nausea, vomiting, loss of muscle control, confusion, come low fatality.
Indirect: Flea-borne				
Typhus (murine)	rickettsia	Rat flea	Domestic rats, wild rodents, opossum	Fever, severe headache, chills, general pains, possible skin rash

USE OF TOXICANTS

When considering controlling pest animals through the use of toxicants, it is important to acquaint all affected parties with the intent of the control program including effectiveness, safety, and approximate cost.

Additionally, local officials in the proposed control area should be contacted and control plans discussed in detail prior to implementation. Local officials can include weed and pest supervisors and University of Wyoming Extension agents who are familiar with current control technology and can assist, advise, and coordinate the control program.

Label requirements may also mandate that additional agencies that are involved with controlling pest animals be contacted. These agencies can include the Wyoming Department of Agriculture, Wyoming Game & Fish Department, U.S. Forest Service, Bureau of Land Management, and the U.S. Fish and Wildlife Service.

Toxicology

Toxicology is a science that deals with poisons and their effects upon the target animals. Applicators of toxic materials such as those used in rodent control should have a basic understanding of how individual toxins effect target animals and be able to understand the terms used in describing the established lethal quantities or dosage rates of specific toxins for individual animal species.

Toxic substances are often incorporated in or on a food commonly attractive to the target animal species. This food is referred to as a bait, and is also the prepared formulation which contains the toxicant. When toxic materials are developed, laboratory tests are conducted to determine the effective quantity of concentration of toxic material necessary in a prepared formulation to control a specific pest.

The term used to describe the toxicity of a particular pesticide to specific animals is the Lethal Dose (LD). A LD50 is the amount of concentration of the toxicant necessary to kill 50% of a test population. From this established quantity of toxicant, a LD100 is determined, which is the amount of toxicant necessary to kill 100% of a population. A concentration of toxicant for field application would be that amount that would provide control at LD100.

An LD50 or an LD100 is expressed as the quantity of the toxin in milligrams lethal to an animal of a specific body weight, expressed in kilograms (mg/kg). Immature or smaller animals are usually more susceptible to toxins than larger or adult animals; a larger quantity of the toxin is normally necessary to control adult animals. When the LD50 or LD100 of toxic materials are provided for an animal species, the range usually given covers the minimum and maximum limits of bodyweight of each species. An example of a specific LD100, for a species, would be 1.0-2.0 mg/kg. The LD100 provides assurance the concentration of the toxicant is sufficient to control the largest and/or most resistant animals that may be found in any given population.

Grains Commonly Used in Rodent Baits

Three grains, barley, wheat and oats, have been found most useful and successful as carriers of rodent toxicants.

Wheat is commonly used for bait in gopher and house mouse control. Barley and oats are used in various forms for the control of other rodents and jackrabbits. These grains may be used whole or may be mechanically altered to improve their effectiveness and lessen their attractiveness to birds. There are specific terms used to describe mechanical alteration, and these terms are often incorporated in the description of bait formulas.

Whole grains

Whole grains are those that have not been mechanically altered. The hull remains in the case of barley and oats.

Rolled grains

The term lightly-rolled whole barley, wheat, and oats indicates these grains have been processed by steam rolling to provide a somewhat flattened grain. Barley and oats processed for stock feed are normally rolled so the grain is flat or crushed. These are generally not satisfactory for use in rodent control formulas. Crimped whole oats, barley, and wheat are very lightly rolled. For example, crimped barley is not over 2-1/2 times normal width.

Hulled grains

Barley with the hulls removed is known as hulled or potted barley. The term potted is taken from the name of the machines (potting machines) used in removing the hulls. Oat groats refers to oats from which the hulls have been removed. A squirrel oat groat is a light rolled oat groat. Oat grits, a product commonly used in chicken feeds, is prepared by hammer milling so small particles result. The product is also called steel cut oat groats.

Color Additives Used in Rodent Baits

Adding colored dyes and pigments to toxic rodent baits is based upon the following reasons:

1. To protect seed-eating birds through the application of a physiological principle, which indicates some species of diurnal birds distinguish and show an aversion to certain colors when these are applied to food, while lower animals, including rodents, do not.

2. To prevent possible accidental human consumption and to reduce the hazard of baits being diverted to livestock feed.

3. To aid in bait identification purposes, including the times when the bait is in storage and while being used in the field.

4. To aid in bait preparation by the manufacturer to assure thorough mixing, as indicated by the uniformity of color additives in the finished product.

5. The dyes and pigments that are used in baits have been selected to reduce as much as possible nonacceptance of the bait by the target pest due to an imparted taste, texture, odor, and color of the finished product.

Safety Precautions

Toxicants used in vertebrate pest control can be handled and used safely if the proper precautions are taken. All toxic baits, such as rodenticides, and the application equipment should be clearly marked and labeled “Poison” and stamped with skull and crossbones. It is extremely important for the applicator to avoid inhaling dust from the baits and skin contamination while handling and using these products.

Respirators or dust masks, rubber gloves, and aprons should be worn to avoid such exposures. In addition, the applicator should not allow the hands or application equipment to contact the face. Eating, drinking, chewing tobacco or gum and smoking should be prohibited during the use of these products. The hands and any clothing worn during the handling and application should always be washed with soap and water after using the products.

All pesticide products should be stored in a locked room or building separate of human habitations and livestock feed, when not in use, and clearly marked with signs warning others that pesticides are stored there. Do not leave poison baits where they will be accessible to children, irresponsible persons, or animals.

Endangered Species Labeling

Most pesticide products registered for use have specific label prohibitions against exposure where endangered species may be adversely affected. The taking of an endangered species by the use of a pesticide constitutes several state and federal offenses, including violation of the Endangered Species Act and using pesticide product inconsistent with its labeling.

Species that may be adversely affected in Wyoming include grizzly bears, gray wolves, black-footed ferrets, whooping cranes, Prebles meadow jumping mouse, and Wyoming toads. Applicators need to read, understand, and comply with all product labeling prior to use.

Specific information on endangered species requirements is available from the Wyoming Game & Fish Department, or from the U.S. Fish and Wildlife Service, Endangered Species Specialist, in Cheyenne at 307-772-2374.

Visit the EPA's endangered species website, https://www.epa.gov/endangered-species, and find details concerning product use in your specific area.

RODENTS

Pocket Gophers

Classification and legal status in Wyoming

Classified under the *Wyoming Game & Fish Commission Chapter 52: Non-game Wildlife Regulation* as non-game wildlife and may be taken (without permit) during the calendar year in the entire state.

See the *Wyoming Game & Fish Commission Chapter 52: Non-game Wildlife Regulation, Section 9. Mammals* at https://wgfd.wyo.gov/Regulations/Regulation-PDFs/Regulations_Ch52.pdf for additional information.

Damage prevention and control methods

Exclusion — Generally not practical. Small mesh wire fence may provide protection for ornamental trees and shrubs or flowerbeds. Plastic netting protects seedlings.

Cultural methods — Damage resistant varieties of alfalfa. Crop rotation; grain buffer crops; control of tap-rooted forbs; flood irrigation; plant naturally resistant varieties of seedlings.

Repellents — Synthetic predator odors are all of questionable benefit. There is no data available to suggest that the use of castor bean oil acts as a repellent.

Toxicants — **Baits** — Chlorophacinone; Diphacinone; Zinc Phosphide; Strychnine alkaloid (below ground use only). The following forms are available: 0.35% Strychnine Milo & 0.5% Strychnine Steam Rolled Oats — for use in hand probes and the burrow builder; 0.5% Strychnine Oat Groats.

Note: For information on using hand probes or the mechanical burrow builder, contact the Wyoming Department of Agriculture.

Fumigants — Carbon monoxide from engine exhaust. Others are not considered very effective, but some are used: aluminum phosphide and gas cartridges.

Trapping — Various specialized gopher kill traps. Common spring or pan trap (sizes No. 0 and No. 1).

Shooting — Not practical.

Other — Buried irrigation pipe or electrical cables can be protected with cylindrical pipe having an outside diameter of at least 2.9 inches (7.4 cm). Surrounding a buried cable with 6 to 8 inches (15 to 20 cm) of coarse gravel, 1 inch [2.5 cm] in diameter may provide some protection.

Damage and damage identification

Several mammals, most common are the Richardson ground squirrel, thirteen-lined ground squirrel, vole and the mole, are sometimes confused with pocket gophers because of variations in common local terminology, or in the similarity of behavioral characteristics. In addition, in the southeastern United States, pocket gophers are called "salamanders," (derived from the term sandy mounder), while the term gopher refers to a tortoise. Pocket gophers can be distinguished from the other mammals by their telltale signs as well as by their appearance. Pocket gophers leave soil mounds on the surface of the ground. The mounds are usually fan-shaped and tunnel entrances are plugged, keeping various intruders out of burrows.

Damage caused by gophers includes: destruction of underground utility cables and irrigation pipe; direct consumption and smothering of forage by earthen mounds; and change in species composition on rangelands by providing seedbeds (mounds) for invading annual plants. Gophers damage trees by stem girdling and clipping, root pruning, and possibly root exposure caused by burrowing. Gopher mounds dull and plug sickle bar mowers when harvesting hay or alfalfa, and silt brought to the surface as mounds is more likely to erode. In irrigated areas, gopher tunnels can channel water runoff, causing loss of surface irrigation water. Gopher tunnels in ditch banks and earthen dams can weaken these structures, causing water loss by seepage and piping through a bank or the complete loss of or washout of a canal bank. The presence of gophers also increases the likelihood of badger activity, which can also cause considerable damage.

Deer Mice

Classification and legal status in Wyoming

Classified under the *Wyoming Game & Fish Commission Chapter 52: Non-game Wildlife Regulation* as non-game wildlife and may be taken (without permit) during the calendar year in the entire state.

See the *Wyoming Game & Fish Commission Chapter 52: Non-game Wildlife Regulation, Section 9. Mammals* at https://wgfd.wyo.gov/Regulations/Regulation-PDFs/Regulations_Ch52.pdf for additional information.

Damage prevention and control methods

Exclusion — Rodent-proof construction will exclude mice from buildings and other structures. Use hardware cloth (114-inch [0.6 cm] mesh) or similar materials to exclude mice from garden seedbeds.

Habitat modification — Store food items left in cabins or other infrequently used buildings in rodent-proof containers. Store furniture cushions, drawers, and other items in infrequently used buildings in ways that reduce nesting sites.

Frightening — Not effective.

Toxicants — Anticoagulants; zinc phosphide.

Fumigants — None are registered.

Trapping — Snap, box-type (Sherman), or automatic multiple-catch traps.

Other methods — Alternative feeding — Experiments suggest application of sunflower seed may significantly reduce consumption of conifer seed in forest reseeding operations, although the tests have not been followed to regeneration.

Damage and damage identification

The principal problem caused by deer mice is their tendency to enter homes, cabins, and other structures that are not rodent-proof. Here they build nests, store food, and can cause considerable damage to upholstered furniture, mattresses, clothing, paper, or other materials they find suitable for their nest-building activities. Nests, droppings, and other signs left by these mice are similar to those of house mice. Deer mice have a greater tendency to cache food supplies, such as acorns, seeds, or nuts, than do house mice. Deer mice are uncommon in urban or suburban residential areas unless there is considerable open space (fields, parks) nearby.

Deer mice occasionally dig up and consume newly planted seeds in gardens, flowerbeds, and field borders. Their excellent sense of smell makes them highly efficient at locating and digging up buried seed. Formerly, much reforestation was attempted by direct seeding of clear-cut areas, but seed predation by deer mice and other rodents and birds, caused frequent failure in the regeneration. For this reason, to reestablish Douglas fir and other commercial timber species today, it is often necessary to hand-plant seedlings, despite the increased expense of this method.

In the early 1990s, the deer mouse (*P. maniculatus*) was first implicated as a potential reservoir of a type of hantavirus responsible for an adult respiratory distress syndrome, leading to several deaths in the Four Corners area of the United States. Subsequent isolations of the virus thought responsible for this illness have been made from several Western states, including Wyoming. The source of the disease is thought to be through human contact with urine, feces, or saliva from infected rodents.

Porcupines

Classification and legal status in Wyoming

Classified as a "predatory animal" under Wyoming Game & Fish Commission statutes and are not protected.

Damage prevention and control methods

Exclusion — Fences (small areas). Tree trunk guards.

Cultural methods — Encourage closed-canopy forest stands.

Repellents — None are registered. Some wood preservatives may incidentally repel porcupines.

Toxicants — None are registered.

Fumigants — None are registered.

Trapping — Steel leg hold trap (No. 2 or 3), body-gripping (Conibear®) trap (No. 220 or 330), or box trap.

Shooting — Day shooting and spotlighting are effective where legal.

Other methods — Encourage natural predators.

Damage and damage identification

Clipped twigs on fresh snow, tracks, and gnawing on trees are useful means of damage identification. Trees are often deformed from partial girdling. Porcupines clip twigs and branches that fall to the ground or onto snow and often provide food for deer and other mammals. The considerable secondary effects of their feeding come from exposing the tree sapwood to attack by disease, insects, and birds. This exposure is important to many species of wildlife because diseased or hollow trees provide shelter and nest sites.

Porcupines occasionally will cause considerable losses by damaging fruits, sweet com, alfalfa, and small grains. They chew on hand tools and other wood objects while seeking salt. They destroy siding on cabins when seeking plywood resins.

Porcupines offer a considerable threat to dogs, which never seem to learn to avoid them. Domestic stock occasionally will nuzzle a porcupine and may be fatally injured if quills are not removed promptly.

Prairie Dogs

Classification and legal status in Wyoming

Classified under the *Wyoming Game & Fish Commission Chapter 52: Non-game Wildlife Regulation* as non-game wildlife and may be taken (without permit) during the calendar year in the entire state. The prairie dog is also a "designated pest" under the Wyoming Department of Agriculture, Weed & Pest Control Act statutes, http://www.wyoweed.org/images/Designated_List.pdf.

Damage prevention and control methods

Exclusion — Wire mesh fences can be installed but they are usually not practical or cost-effective. Visual barriers of suspended burlap, windrowed pine trees, or snow fence may be effective.

Cultural methods — Modify grazing practices on mixed and mid-grass rangelands to exclude or inhibit prairie dogs. Cultivate, irrigate, and establish tall crops to discourage prairie dog use.

Frightening — No methods are effective.

Repellents — None are registered.

Toxicants — Zinc phosphide. Note: Zinc phosphide baits require pre-baiting and used when green forage is not available to be effective. When baiting for prairie dogs, you must visit and follow instructions on the EPA Bulletins Live! Website http://www.epa.gov/oppfead1/endanger/bulletins.htm. Further instructions for use will be included on the product label.

Anticoagulants — Chlorophacinone; diphacinone.

Fumigants — Aluminum phosphide. Gas Cartridges.

Trapping — Box traps, snares, or Conibear® No. 110 (body gripping) traps or equivalent.

Shooting — Shooting with .22 rimfire or larger rifles.

Other methods — Several home remedies have been used, but most are unsafe and are not cost-effective.

Damage and damage identification

Several independent studies have produced inconsistent results regarding the impacts of prairie dogs on livestock production. The impacts are difficult to determine and depend on several factors, such as the site conditions, weather, current and historic plant communities, number of prairie dogs, size and age of prairie dog towns, and the intensity of site use by livestock and other grazers. Prairie dogs feed on many of the same grasses and forbs that livestock feed on. Annual dietary overlap ranges from 64% to 90%. Prairie dogs often begin feeding on pastures and rangeland earlier in spring than cattle and clip plants closer to the ground. Up to 10% of the aboveground vegetation may be destroyed due to their burrowing and mound-building activities. Overall, prairie dogs may remove 18% to 90% of the available forage through their activities.

The species composition of pastures occupied by prairie dogs may change dramatically. Prairie dog activities encourage shortgrass species, perennials, forbs, and species that are resistant to grazing. Annual plants are selected against because they are usually clipped before they can produce seed. Several of the succeeding plant species are less palatable to livestock than the grasses they replace.

Other studies, however, indicate prairie dogs may have little or no significant effect on livestock production. One research project in Oklahoma revealed there were no differences in annual weight gains between steers using pastures inhabited by prairie dogs and steers in pastures without prairie dogs. Reduced forage availability in prairie dog towns may be partially compensated for by the increased palatability and crude protein of plants that are stimulated by grazing. In addition, prairie dogs sometimes clip and/or eat plants that are toxic to livestock. Bison, elk, and pronghorns appear to prefer feeding in prairie dog colonies over non-colonized grassland.

Prairie dog burrows increase soil erosion and are a potential threat to livestock, machinery, and horses with riders. Damage may also occur to ditch banks, impoundments, field trails, and roads.

Prairie dogs are susceptible to several diseases, including plague, a severe infectious disease caused by the bacterium *Yersinia pestis*. Plague, which is often fatal to humans and prairie dogs, is most often transmitted by the bite of an infected flea. Although plague has been reported throughout the western United States, it is uncommon. Symptoms in humans include swollen and tender lymph nodes, chills, and fever. The disease is curable if diagnosed and treated in its early stages. It is important the public be aware of the disease and avoid close contact with prairie dogs and other rodents. Public health is a primary concern regarding prairie dog colonies that are in close proximity to residential areas and schoolyards.

Ground Squirrels

Species: Franklin, Richardson, Columbian, Washington, and Townsend.

Classification and legal status in Wyoming

Classified under the *Wyoming Game & Fish Commission Chapter 52: Non-game Wildlife Regulation* as non-game wildlife and may be taken (without permit) during the calendar year in the entire state. The ground squirrel is also a "designated pest" under the Wyoming Department of Agriculture, Weed & Pest Control Act statutes, http://www.wyoweed.org/images/Designated_List.pdf.

Damage prevention and control methods

Exclusion — Limited usefulness.

Cultural methods — Flood irrigation, forage removal, crop rotation, and summer fallow may reduce populations and limit spread.

Repellents — None are registered.

Toxicants — Zinc phosphide. Chlorophacinone. Diphacinone. Note: Not all toxicants are registered for use in every state. Check registration labels for limitations within each state.

Fumigants — Aluminum phosphide. Gas cartridges.

Trapping — Box, burrow-entrance, or leghold traps.

Shooting — Limited usefulness.

Damage and damage identification

High populations of ground squirrels may pose a serious pest problem. The squirrels compete with livestock for forage; destroy food crops, golf courses, and lawns; and can be reservoirs for diseases such as plague. Their burrow systems have been known to weaken and collapse ditch banks and canals, undermine foundations, and alter irrigation systems. The mounds of soil excavated from their burrows not only cover and kill vegetation, but damage haying machinery. In addition, some ground squirrels prey on the eggs and young of ground-nesting birds or climb trees in the spring to feed on new shoots and buds in orchards.

Ground squirrels are more destructive than prairie dogs because they occur in larger numbers and over more diverse terrain. To be truly effective in controlling ground squirrels, cooperative efforts between landowners must be implemented, as the ground squirrel will quickly re-invade from areas that have not been treated.

Tree Squirrels

Classification and legal status in Wyoming

Classified under the *Wyoming Game & Fish Commission Chapter 11: Upland Game Bird and Small Game Hunting Seasons* as a “Small Game Animal,” requiring a license to take tree squirrels. For more information https://wgfd.wyo.gov/Regulations/Regulation-PDFs/REGULATIONS_CH11.

Damage prevention and control methods

Exclusion — Install sheet metal bands on isolated trees to prevent damage to developing nuts, fruit, and bark. Close external openings to buildings to stop damage to building interiors. Place an 18-inch (46 cm) section of 4-inch (10 cm) diameter plastic pipe or a one-way door over openings to allow squirrels to leave and prevent them from returning. Plastic tubes on wires may prevent access to buildings.

Cultural methods — Remove selected trees or their branches to prevent access to structures.

Repellents — Naphthalene (moth balls), Ro-pel, capsaicin, and polybutenes are registered for controlling tree squirrels.

Toxicants — None are registered.

Fumigants — None are registered.

Trapping — Leghold, box, cage, rat snap traps, or box choker traps.

Shooting — Effective where firearms are permitted. Use a shotgun with No. 6 shot or a .22-caliber rifle.

Damage and damage identification

Squirrels may occasionally damage forest trees by chewing bark from branches and trunks. Pine squirrels damage Ponderosa pine, jack pine, and paper birch. Tree squirrels may eat cones and nip twigs to the extent they interfere with natural reseeding of important forest trees. This is a particular problem in Ponderosa pine forests where pine squirrels may remove 60%–80% of the cones in poor to fair seed years. In forest seed orchards, such squirrel damage interferes with commercial seed production.

In nut orchards, squirrels can severely curtail production by eating nuts prematurely and by carrying off mature nuts. Pine, gray, and fox squirrels may chew bark of various orchard trees.

In residential areas, squirrels sometimes travel power lines and short out transformers. They gnaw on wires, enter buildings, and build nests in attics. They frequently chew holes through pipelines used in maple syrup production.

Squirrels occasionally damage lawns by burying or searching for and digging up nuts. They will chew bark and clip twigs on ornamental trees or shrubbery planted in yards. Often, squirrels take food at feeders intended for birds. Sometimes they chew to enlarge openings of bird houses and then enter to eat nestling songbirds. Flying squirrels are small enough to enter most bird houses and are especially likely to eat nesting birds.

In gardens, squirrels may eat planted seeds, mature fruits, or grains such as corn.

Voles

Classification and legal status in Wyoming

Most vole species in Wyoming are Classified under the *Wyoming Game & Fish Commission Chapter 52: Non-game Wildlife Regulation* as non-game wildlife and may be taken (without permit) during the calendar year in the entire state.

See the *Wyoming Game & Fish Commission Chapter 52: Non-game Wildlife Regulation, Section 9. Mammals* at https://wgfd.wyo.gov/Regulations/Regulation-PDFs/Regulations_Ch52.pdf for additional information.

Damage prevention and control methods

Exclusion — Recommended to protect trees, ornamental plants, and small areas.

Habitat modification — Eliminating ground cover reduces populations. Soil cultivation destroys burrows and reduces cover.

Frightening — Not effective.

Repellents — Effectiveness uncertain.

Toxicants — Zinc phosphide. Anticoagulants (registered in most states).

Fumigants — Not usually effective.

Trapping — Mouse snap traps or live traps (Sherman or box-type traps).

Shooting — Not practical or effective.

Damage and damage identification

Voles may cause extensive damage to orchards, ornamentals, and tree plantings due to their girdling of seedlings and mature trees. Girdling damage usually occurs in fall and winter. Field crops (for example, alfalfa, clover, grain, potatoes, and sugar beets) may be damaged or completely destroyed by voles. Voles eat crops and also damage them when they build extensive runway and tunnel systems. These systems interfere with crop irrigation by displacing water and causing levees and checks to wash out. Voles also can ruin lawns, golf courses, and ground covers.

Girdling and gnaw marks alone are not necessarily indicative of the presence of voles, since other animals, such as rabbits, may cause similar damage. Vole girdling can be differentiated from girdling by other animals by the non-uniform gnaw marks. They occur at various angles and in irregular patches. Marks are about 1/8-inch (0.3 cm) wide, 3/8-inch (1.0 cm) long, and 1/16-inch (0.2 cm) or more deep. Rabbit gnaw marks are larger and not distinct. Rabbits neatly clip branches with oblique clean cuts. Examine girdling damage and accompanying signs (feces, tracks, and burrow systems) to identify the animal causing the damage.

The most easily identifiable sign of voles is an extensive surface runway system with numerous burrow openings. Runways are 1–2 inches (2.5–5 cm) in width. Vegetation near well-traveled runways may be clipped close to the ground. Feces and small pieces of vegetation are found in the runways.

The pine vole does not use surface runways. It builds an extensive system of underground tunnels. The surface runways of long-tailed voles are not as extensive as those of most other voles.

Voles pose no major public health hazard because of their infrequent contact with humans; however, they are capable of carrying disease organisms, such as plague (*Yersinia pestis*) and tularemia (*Francisilla tularensis*). Be careful and use protective clothing when handling voles.

Woodrats (Packrats)

Classification and legal status in Wyoming

Woodrats are classified as non-game animals. In most states, they can be taken (controlled) when they threaten or damage property. Check with your local wildlife or agriculture department for laws and regulations specific to your area.

Damage prevention and control methods

Exclusion — Is the most effective method of eliminating damage. Woodrats may be excluded from buildings. No hole larger than 1/2-inch (1.3 cm) should be left unsealed. Make sure doors, windows, and screens fit tightly. If gnawing is a problem, edges can be covered with sheet metal. Coarse steel wool, wire screen, and lightweight sheet metal are excellent materials for plugging gaps and holes.

Repellents — No woodrat repellents, registered by the EPA.

Toxicants — Available for woodrat control include anticoagulants and zinc phosphide, registered under Special Local Needs 24(c) provisions. Registered products vary among states. When using toxic baits, follow label instructions carefully. Chorphacinone or diphacinone have also proven effective.

Trapping — Woodrats show little fear of new objects in their environment and are easily trapped. Baited snap traps, cage traps, burrow entrance traps, and glue boards are effective.

Damage and damage identification

Populations generally are fairly dispersed, but economic damage to agricultural crops can occur in limited areas. Agricultural damage results when woodrats clip small twigs and branches and when they debark citrus and other fruit trees and seedling and sapling conifers, especially redwoods. Loss of trees can occur.

Woodrats are sometimes a nuisance around cabins, outbuildings, and other infrequently used structures or vehicles. As the name packrat implies, they have a tendency to pack away small objects such as jewelry, cooking and eating utensils, can tabs, and other items. At times, this behavior can become a nuisance to backpackers and others. More seriously, woodrats may also shred upholstered furniture and mattresses for lining nests, and may take up residence in parked vehicles, gnawing on wires and other mechanical components.

Woodrats can be an important factor in the transmission of certain diseases, most notably plague, where this disease occurs. Dead or dying woodrats should not be handled.

Kangaroo Rats

Classification and legal status in Wyoming

Legal Status: Most kangaroo rats are considered non-game animals and are not protected by state game laws. Certain local subspecies may be protected by regulations regarding threatened and endangered species. Consult local authorities to determine their legal status before applying controls.

Damage prevention and control methods

Exclusion — Is most often accomplished by the construction of rat-proof fences and gates around the area to be protected. Most kangaroo rats can be excluded by 1/2-inch (1.3-cm) mesh hardware cloth, 30 to 36 inches (75 to 90 cm) high. The bottom 6 inches (15 cm) should be turned outward and buried at least 12 inches (30 cm) in the ground. Exclusion may be practical for small areas of high-value crops, such as gardens, but is impractical and too expensive for larger acreages.

Cultural methods — Alfalfa, corn, sorghum, and other grains are the most likely crops to be damaged by kangaroo rats. When possible, planting should be done in early spring before kangaroo rats become active to prevent loss of seeds. Less palatable crops should be planted along field edges that are near areas infested with kangaroo rats. High kangaroo rat numbers most often occur on rangelands that have been subjected to overuse by livestock.

Repellents — There are no registered repellents for kangaroo rats.

Toxicants — Zinc phosphide. At present, 2% zinc phosphide bait is federally registered. Carefully read and follow all label instructions.

Fumigants — There are no fumigants registered specifically for kangaroo rats. Aluminum phosphide and gas cartridges are registered for "burrowing rodents such as woodchucks, prairie dogs, gophers, and ground squirrels."

Trapping — **Live traps**. Trapping with box-type (wire cage) traps can be successful in a small area when a small number of kangaroo rats are causing problems. These traps can be baited successfully with various grains, oatmeal, oatmeal and peanut butter, and other baits. Do not release kangaroo rats in areas where landowners do not want them. **Snap traps**: Trapping with snap traps is probably the most efficient and humane method for kangaroo rats.

Other methods — Flooding.

Damage and damage identification

Kangaroo rats are nocturnal and harvest seeds and seed heads of mainly grass species. They are larder hoarders, meaning they collect food, store it, and feed on it during the winter. They can significantly reduce a pasture's ability to reseed itself and can impact the grazing quality of grass pasture. They can also dig up and consume newly planted vegetable seeds. Burrows are quite extensive and can be mistaken for gopher damage. They are extremely sensitive to temperature changes and will seal burrow opening with soil during the heat of the day.

CARNIVORES

Foxes

Classification and legal status in Wyoming

Red fox are classified as predators and may be taken at any time within the entire state, whether or not they are causing damage.

Gray fox are classified under the Wyoming Game & Fish Commission regulations as non-game wildlife, but may not be taken unless the following conditions exist:

1. It is determined to be unavoidable and does not result from conduct with lack of reasonable care, or

2. It results from control measures approved by the Wyoming Game & Fish Commission as necessary to address public health concerns. See the *Wyoming Game & Fish Commission Chapter 52: Non-game Wildlife Regulation, Section 4. Taking of Non-game Wildlife* at https://wgfd.wyo.gov/Regulations/Regulation-PDFs/Regulations_Ch52.pdf for additional information.

Damage prevention and control methods

Exclusion — Net wire fence. Electric fence.

Cultural methods — Protect livestock and poultry during most vulnerable periods (for example, shed lambing, farrowing pigs in protective enclosures).

Frightening — Flashing lights and exploders may provide temporary protection. Well-trained livestock guarding dogs may be effective in some situations.

Repellents — None are registered for livestock protection.

Toxicants — M-44 sodium cyanide mechanical ejection device. The M-44 is registered for use in Wyoming and is labeled for both red and gray fox. Contact the Wyoming Department of Agriculture for more information.

Fumigants — Gas cartridges for den fumigation, where registered.

Trapping — Steel leghold, cage, or box traps, or snares.

Shooting — Predator calling techniques, aerial hunting is available by permit through the Wyoming Department of Agriculture.

Other methods — Den hunting — Remove young foxes from dens to reduce predation by adults.

Damage and damage identification

Foxes may cause serious problems for poultry producers. Turkeys raised in large range pens are subject to damage by foxes. Losses may be heavy in small farm flocks of chickens, ducks, and geese. Young pigs, lambs, and small pets are also killed by foxes. Damage can be difficult to detect because the prey is usually carried from the kill site to a den site or uneaten parts are buried. Foxes usually attack the throat of young livestock, but some kill by inflicting multiple bites to the neck and back. Foxes do not have the size or strength to hold adult livestock or to crush the skull and large bones of their prey. They generally prefer the viscera and often begin feeding through an entry behind the ribs. Foxes will also scavenge carcasses, making the actual cause of death difficult to determine.

Pheasants, waterfowl, other game birds, and small game mammals are also preyed upon by foxes. At times, fox predation may be a significant mortality factor for upland and wetland birds, including some endangered species.

Rabies outbreaks are most prevalent among red foxes in southeastern Canada and occasionally in the eastern United States. The incidence of rabies in foxes has declined substantially since the mid-1960s for unexplained reasons. In 1990, there were only 197 reported cases of fox rabies in the United States as compared to 1,821 for raccoons and 1,579 for skunks. Rabid foxes are a threat to humans, domestic animals, and wildlife.

Skunks

Classification and legal status in Wyoming

Classified as predators and may be taken at any time within the entire state, no license required.

Damage prevention and control methods

Exclusion — **Buildings**: close cellar and outside basement and crawl space doors; seal and cover all openings including window wells and pits. **Poultry yards**: install wire mesh fences. **Beehives**: elevate and install aluminum guards.

Habitat modification — Removal of garbage, debris, and lumber piles.

Frightening — Lights and sounds are of limited value.

Repellents — Some home remedies such as moth balls or flakes or ammonia solution may be useful, but no repellents are registered.

Toxicants — None are registered.

Fumigants — Denning gas cartridges, (available from the Wyoming Department of Agriculture).

Trapping — Box or leghold trap.

Shooting — Practical only when animals are far from residential areas.

Other methods — Skunk removal. Odor removal.

Damage and damage identification

Skunks become a nuisance when their burrowing and feeding habits conflict with humans. They may burrow under porches or buildings by entering foundation openings. Garbage or refuse left outdoors may be disturbed by skunks. Skunks may damage beehives by attempting to feed on bees. Occasionally, they feed on corn, eating only the lower ears. If the cornstalk is knocked over, however, raccoons are more likely the cause of the damage. Damage to the upper ears of corn is indicative of birds, deer, or squirrels. Skunks dig holes in lawns, golf courses, and gardens while searching for insect grubs found in the soil. Digging normally appears as small, 3- to 4-inch (7- to 10-cm) cone-shaped holes or patches of up-turned earth. Several other animals, including domestic dogs, also dig in lawns.

Skunks occasionally kill poultry and eat eggs. They normally do not climb fences to get poultry. By contrast, rats, weasels, mink, and raccoons regularly climb fences. If skunks gain access, they will normally feed on the eggs and occasionally kill one or two fowl. Eggs usually are opened on one end with the edges crushed inward. Weasels, mink, dogs, and raccoons usually kill several chickens or ducks at a time. Dogs will often severely mutilate poultry. Tracks may be used to identify the animal causing damage. Both the hind and forefeet of skunks have five toes. In some cases, the fifth toe may not be obvious. Claw marks are usually visible, but the heels of the forefeet normally are not. The hind feet tracks are approximately 2-1/2 inches long (6.3 cm). Skunk droppings can often be identified by the undigested insect parts they contain. Droppings are 1/4 to 1/2 inch (6 to 13 mm) in diameter and 1 to 2 inches (2/5 to 5 cm) long.

Odor is not always a reliable indicator of the presence or absence of skunks. Sometimes dogs, cats, or other animals that have been sprayed by skunks move under houses and make owners mistakenly think skunks are present.

Skunks are the primary carriers of rabies in Wyoming. When rabies outbreaks occur, the ease with which rabid animals can be contacted increases. Rabid skunks are prime vectors for the spread of the virus. Avoid overly aggressive skunks that approach without hesitation. Any skunk showing abnormal behavior, such as daytime activity, may be rabid and should be treated with caution. Report suspicious behavior to local animal control authorities.

To prepare and secure a skunk for rabies testing, the animal should be shot in the body, taking care not to hit the head. The head should then be removed and submitted to the State Veterinary laboratory for analysis. Proper protective precautions should be exercised, (i.e., wearing of protective gloves) when preparing the animal for testing as the rabies virus is contagious.

OTHER MAMMALS

Bats

Classification and legal status in Wyoming

See Wyoming Game & Fish Commission regulations for additional information.

Damage prevention and control methods

Exclusion — Polypropylene netting check-valves simplify getting bats out. Quality bat-proofing permanently excludes bats. Initiate control before young are born or after they are able to fly.

Repellents — Naphthalene: limited efficacy. Illumination. Air drafts/ventilation. Ultrasonic devices: not effective, some even attract bats. Sticky deterrents: limited efficacy.

Toxicants — None are registered.

Trapping — Available, but unnecessarily complicated compared to exclusion and bat-proofing.

Other methods — Sanitation and cleanup. Artificial roosts.

Removal of occasional bat intruders — When no bite or contact has occurred, help the bat escape (otherwise submit it for rabies testing).

Conservation and public education — Information itself functions as a management technique.

Damage and damage identification

Bat Presence. Bats often fly about swimming pools, from which they drink or catch insects. White light (with an ultraviolet component), commonly used for porch lights, building illumination, street and parking lot lights, may attract flying insects, which in turn attract bats. Unfortunately, the mere presence of a bat outdoors is sometimes beyond the tolerance of some uninformed people. Information is a good remedy for such situations.

Bats commonly enter buildings through openings associated with the roof edge and valleys, eaves, apex of the gable, chimney, attic or roof vent, dormers, and siding. Other openings may be found under loose-fitting doors, around windows, gaps around various conduits (wiring, plumbing, air conditioning) that pass through walls, and through utility vents.

Bats are able to squeeze through narrow slits and cracks. For purposes of bat management, one should pay attention to any gap of approximately 1/4 × 1-1/2 inches (0.6 × 3.8 cm) or a 5/8 × 7/8 inch (1/6 × 2.2 cm) hole. Such openings must be considered potential entries for at least the smaller species, such as the little brown bat. The smaller species require an opening no wider than 3/8 inch (0.95 cm), that is, a hole the diameter of a U.S. 10-cent coin (Greenhall 1982). Openings of these dimensions are not uncommon in older wood frame structures where boards have shrunk, warped, or otherwise become loosened.

The discovery of one or two bats in a house is a frequent problem. If unused chimneys are selected for summer roosts, bats may fall or crawl through the open damper into the house. Sometimes bats may appear in a room, then disappear by crawling under a door to another room, hallway, or closet. They may also disappear behind curtains, wall hangings, bookcases, under beds, into waste baskets, and so forth. Locating and removing individual bats from living quarters can be laborious but is important. If all else fails, wait until dusk then the bat may appear once again as it attempts to find an exit.

Roosting sites. Bats use roosting niches that are indoors (human dwellings, out-buildings, livestock quarters, warehouses), semi-enclosed (loading docks, entrance foyers), partially sheltered (porches, carports, pavilions, highway underpasses, bridges), and open structural areas (window shutters, signs). Active bats in and on buildings can have several economic and aesthetic effects, often intertwined with public health issues (Frantz, 1988). Unusual roosting areas include wells, sewers, and graveyard crypts. Before considering control measures, verify that bats are actually the cause of the problem.

Rub marks. Surface areas on walls, under loose woodwork, between bricks, and around other bat entryways often have a smooth, polished appearance. The stained area is slightly sticky, may contain a few bat hairs, and is yellow-brown to blackish brown in color. The smooth gloss of these rub marks is due to oils from fur and other bodily secretions mixed with dust, deposited there as many animals pass repeatedly for a long period over the same surface. Openings marked in this way have been used heavily by bats.

Noise. Disturbing sounds may be heard from vocalizations and grooming, scratching, crawling, or climbing in attics, under eaves, behind walls, and between floors. Bats become particularly noisy on hot days in attics, before leaving the roost at dusk, and upon returning at dawn. Note that rustling sounds in chimneys may be caused by birds or raccoons and scratching and thumping sounds in attics and behind walls may indicate rats, mice, or squirrels.

Guano and urine. Fecal pellets indicate the presence of animals and are found on attic floors, in wall recesses, and outside the house at its base. Fecal pellets along and inside walls may indicate the presence of mice, rats, or even roaches. Since most house bats north of Mexico are insectivorous, their droppings are easily distinguished from those of small rodents. Bat droppings tend to be segmented, elongated, and easily crumbled. When crushed, they become powdery and reveal shiny bits of undigested insect remains. In contrast, mice and rat droppings tend to taper, are unsegmented, are harder and more fibrous, and do not become powdery when crushed (unless extremely aged).

The droppings of some birds and lizards may occasionally be found along with those of bats. However, bat droppings never contain the white chalky material characteristic of the feces of these other animals.

Bat excrement produces an unpleasant odor as it decomposes in attics, wall spaces, and other voids. The pungent, musty, acrid odor can often be detected from outside a building containing a large or long-term colony. Similar odor problems occur when animals die in inaccessible locations. The odor also attracts arthropods, which may later invade other areas of a building.

Bat guano may provide a growth medium for microorganisms, some of which are pathogenic (histoplasmosis, for example) to humans. Guano accumulations may fill spaces between walls, floors, and ceilings. It may create a safety hazard on floors, step, and ladders, and may even collapse ceilings. Accumulations also result in the staining of ceilings, soffits, and siding, producing unsightly and unsanitary conditions.

Bats also urinate and defecate in flight, causing multiple spotting and staining on sides of buildings, windows, patio furniture, automobiles, and other objects at and near entry/exit holes or beneath roosts. Bat excrement may also contaminate stored food, commercial products, and work surfaces.

Bat urine readily crystallizes at room temperature. In warm conditions under roofs exposed to sun and on chimney walls, the urine evaporates so quickly it crystallizes in great accumulations. Boards and beams saturated with urine acquire a whitish, powder-like coating. With large numbers of bats, thick and hard stalactites and stalagmites of crystallized bat urine are occasionally formed.

Although the fresh urine of a single bat is relatively odorless, that of any moderate-sized colony is obvious, and the odor increases during damp weather. Over a long period of time, urine may cause mild wood deterioration (Frantz and Trimarchi 1984). As the urine saturates the surfaces of dry wood beams and crystallizes, the wood fibers expand and separate. These fibers then are torn loose by the bats crawling over such surfaces, resulting in wood fibers being mixed with guano accumulations underneath.

The close proximity of bat roosts to human living quarters can result in excreta, animal dander, fragments of arthropods, and various microorganisms entering air ducts as well as falling onto the unfortunate residents below. Such contaminants can result in airborne particles of public health significance (Frantz 1988).

Ectoparasites and other arthropods. Several arthropods (fungivores, detritivores, predators, and bat ectoparasites) are often associated with colonies of bats in buildings. Their diversity depends upon the number of bats, age, and quantity of excreta deposits, and season. Some arthropods contribute to the decomposition of guano and insect remnants but may also become a pest of stored goods and/or a nuisance within the living quarters. Bat ectoparasites (ticks, mites, fleas, and bugs) rarely attack humans or pets and quickly die in the absence of bats. Ectoparasites may become a nuisance, following exclusion of large numbers of bats from a well-established roost site. Fumigation with insecticides may be required.

Rabies. Bats are distinct from most vertebrate pests that inhabit human dwellings because of the potential for transmitting rabies. Bats are not asymptomatic carriers of rabies. After an incubation period of 2 weeks to 6 months, they become ill with the disease for as long as 10 days. During this latter period, a rabid bat's behavior is generally not normal. It may be found active during the daytime or on the ground incapable of flying. Most human exposures are the result of accidental or careless handling of grounded bats. Even less frequently, bats in this stage of illness may be involved in unprovoked attacks on people or pets (Brass, per. commun.; Trimarchi et al. 1979). It is during this stage the rabid bat is capable of transmitting the disease by biting another mammal. As the disease progresses, the bat becomes increasingly paralyzed and dies as a result of the infection. The virus in the carcass is reported to remain infectious until decomposition is well advanced.

Moles

Classification and legal status in Wyoming

Consult Wyoming Game & Fish Commission regulations for additional information.

Damage prevention and control methods

Exclusion — Generally not practical, except in very small, high-value areas where an above-ground and underground barrier (sheet metal, brick, wood, concrete) might restrict moles.

Cultural methods — Packing the soil destroys burrows, and sometimes moles if done in early morning or late evening. Reduction in soil moisture and food source removal by the use of insecticides discourages moles and generally results in lower populations.

Frightening — Ineffective.

Repellents — None are registered.

Toxicants — None are registered.

Fumigants — Aluminum phosphide. Gas cartridges.

Trapping (most effective control method) — Out O' Sight® Trap, bayonet or harpoon trap (Victor® Mole Trap), easy-set mole eliminator, cinch mole trap, Death-Klutch gopher trap.

Shooting — Not practical.

Damage and damage identification

Moles remove many damaging insects and grubs from lawns and gardens; however, their burrowing habits disfigure lawns and parks, destroy flower beds, tear up the roots of grasses, and create havoc in small garden plots.

It is important to properly identify the kind of animal causing damage before setting out to control the damage. Moles, voles, and pocket gophers are often found in the same location, and their damage is often confused. Control methods differ for the two species.

Moles leave volcano-shaped hills that are often made up of clods of soil. The mole hills are pushed up from the deep tunnels and may be 2 to 24 inches (5 to 60 cm) tall. The number of mole hills is not a measure of the number of moles in a given area. Surface tunnels or ridges are indicative of mole activity.

Pocket gopher mounds are generally kidney-shaped and made of finely sifted and cloddy soil. Generally, gophers leave larger mounds than moles. Gopher mounds are often built in a line, indicative of a deeper tunnel system.

Cottontail and Jackrabbits

Classification and legal status in Wyoming

Cottontail Rabbits: Classified under Wyoming Game & Fish Commission statutes as a "Small Game Animal," requiring a license to take cottontail rabbit. Contact the Wyoming Game & Fish Commission for additional information.

Cottontails in rural areas spend their entire lives on a few acres; in urban areas, they may not venture far from a single backyard. Since jackrabbits reside in open rangelands, they may need to travel several miles from their dens to areas containing their preferred food.

Jackrabbits: Classified as predators and may be taken at any time in the entire state, no license required.

Economic importance

Rabbits can cause damage any time of the year. During spring, rabbits prefer young, growing vegetation, like tulips, garden vegetables (carrots, peas, beans, lettuce, beets), clover and turfgrass. In winter, rabbits gnaw through the tender bark of young trees and shrubs to eat the green, inner bark.

Prevention and Control of Damage

The presence of rabbits does not always result in economic damage to plants. Most 2- to 3-foot high shrubs can survive having most of the 1- and 2-year-old twigs removed. However, the desirable bud, flower, or fruit development may be impaired. The key to effective and economical rabbit control is being able to predict and intercept damage with methods that are relative to the predicted loss in value.

Exclusion — A 1-inch mesh fence of poultry netting (chicken wire) works well to protect gardens and perennial flower beds from rabbit damage. Bury the bottom edge of the fence about 4 inches below the ground to prevent rabbits, particularly jackrabbits, from digging under it. The buried portion should be flared outward from the protected area to better prevent digging.

Nurseries, tree farms, and other large areas can be protected with a double-strand electric fence or electrified plastic-net fence. Place electric wires at 3 to 4 inches and at 8 to 12 inches above the ground. Consult local regulations before installing electric fences.

To protect individual trees, place cylinders of black plastic drain tile, cut to length and slit down one side, around the trunks. Poultry netting supported by stakes can be placed around the trunks of young trees and shrubs. Shrub stems growing through the netting will become susceptible to damage by rabbits.

Habitat modification and plant selection — Reduce harborage for rabbits by removing brush piles and tall weeds, particularly those near new windbreaks. Mow or spray to remove vegetation within 3 to 4 feet of recently planted trees and shrubs. Some trees and shrubs may need protection for as long as 10 years before they become mature enough to discourage rabbit feeding. Conversely, to guard against jackrabbit damage, encourage taller and denser vegetation.

Among herbaceous plants, preferred species within the rose and lily families are preferred. Horticulturists and others have compiled the following partial list of species most often eaten by rabbits.

Most often eaten:

- Annual and Perennials
  - Aster
  - Coneflower
  - Hosta
  - Hybrid lily — Asiatic, Oriental
  - Impatiens — Young flowers on young plants
  - Pansy
  - Phlox
  - Rudbeckia
  - Tulip

- Shrubs and Young Trees
  - *Acer* spp. (maples)
  - *Amelanchier* spp. (serviceberry, juneberry)
  - *Aronia* spp. (black chokeberry, red chokeberry)
  - *Carpinus* spp. (ironwood)
  - *Cornus* spp. (dogwood)
  - *Euonymus* spp. (burning bush, wahoo)
  - *Gleditsia* spp. (honeylocust)
  - *Hydrangea quercifolia* (oakleaf hydrangea)
  - *Tilia* spp. (linden)
  - *Malus* spp., (apples, flowering crabapples)
  - *Rubus* spp. (raspberries and related brambles)
  - *Sorbus* spp. (mountain ash)
  - *Spiraea* spp. (spirea)
  - *Pinus strobus* (Eastern white pine)
  - *Populus* spp. (willow, poplar, cottonwood)
  - *Prunus* spp. (plum, cherry, almond, peach)
  - *Rhus* spp. (sumac)
  - *Rosa* spp. (rose)
  - *Quercus* spp. (oaks)

Plants with strong aromas and/or dense hair are typically avoided by rabbits. Some tree species rarely damaged by rabbits include black walnut, juniper, spruce, and fir. Be aware you cannot depend on rabbit-resistant plants if winter conditions are severe and food sources are limited.

Frightening devices — Scarecrows, owl, or snake effigies, spinning aluminum pie pans, and glass jars of water have been used to frighten rabbits. Commercial, water-driven scarecrows with motion detectors that spray water when movement occurs near them are available. Dogs confined by fences, tethers, or long leashes may help frighten rabbits away. In general, frightening devices may be limited in range to a few feet and provide short-lived protection because rabbits become used to them.

Repellents — Most rabbit repellents aren't registered for use on plants destined for human consumption. Repellents fall into two categories: taste and odor.

- **Taste repellents** attempt to make the plant less palatable for rabbits and are typically applied directly to the plant. Examples are those containing capsaicin or hot pepper extract (Deer-off™, Get Away™, Scoot™, Shotgun™). Their effectiveness tends to be short-lived and requires reapplication after sprinkler irrigation, rain, or new growth occurs. The duration and effectiveness of some repellents can be extended by mixing them with an antitranspirant, such as VaporGuard™ or Wiltpruf™.
- **Odor repellents** keep rabbits away from an area by fear or foul smell. A wide variety of active ingredients are used, including: ammonium or potassium salts of soaps (M-pede™; Ro-Pel™), eggs (DeFence®), thiram (Spotrete™), zinc dimethyldithiocarbamate (Earl May® Rabbit Scat), predator urine (Shake-Away™), or garlic (Sweeny's® Deer & Rabbit Repellent). They are typically applied to soil in the perimeter area and/or on plant foliage to repel rabbits.

Check the label for proper application rate, method, and site before applying any repellent.

Because daffodils are poisonous to rabbits, plant them in place of tulips to ensure reliable, spring-blooming bulbs.

Toxicants — No toxicants are registered for rabbits.

Trapping or shooting — Both trapping and shooting can temporarily reduce local rabbit populations.

Integrated pest management — A combination of methods usually best controls rabbit damage, and the methods selected depend on the situation. For a windbreak in a rural area, the best combination of methods may be to plant older, less-browsed species of trees, to add a different species each year, and then apply a commercial repellent with a spreader-sticker. A spreader-sticker is a product added to the repellent to increase duration and effectiveness of the repellent. Antitranspirants are excellent spreader-stickers. Ivory Liquid (add 1 teaspoon per gallon of mixed repellent) also acts as a spreader-sticker. Apply repellents several times during the winter during the first few years of tree growth.

For the gardener, the best approach may be to build a rabbit-proof fence to guard young sprouting plants. For perennial flower beds, the best approach may be to use motion-activated water sprays or a vigilant dog to scare rabbits. Homeowners might also resort to a low, aesthetic plastic-mesh fence as flower blossoms emerge.

For young trees and shrubs in a backyard, methods of control include low fences around clusters of plants, individual tree guards, or tree guards incorporated with chemical repellents.

Birds

Federal acts and bills related to bird damage control

The following federal acts and bills should be referenced prior to the implementation of any bird damage control program:

- USFWS Title 50, Code of Federal Regulations, Part 21, *Migratory Bird Permits*. Revised 9/14/89. 37 pp.
- *Migratory Bird Treaty Act*. (16 USC 703-711). Sec. 703: Taking, killing, or possessing migratory birds unlawful. Sec. 704: Determination as to when and how migratory birds may be taken, killed, or possessed.
- *Endangered Species Act of 1973*.(As amended by P.L. 94-325, June 30, 1976; P.L. 94359, July 12, 1976;
- P.L. 95-212, December 19, 1977; P.L. 95-632, November 10, 1978; and P.L. 96-159, December 28, 1979)
- FWS/LE Law 8, Revised 6/25/84. 36 pp.
- USFWS SO CFR Part 17. *Endangered and Threatened Wildlife and Plants*. FWS/LE Enf 4-Reg-17. (Revised 1/1/89). 69 pp.
- USFWS SO CFR Part 10. *General Provisions*. FWS/LE Enf 4-Reg-10. 15 pp.

Introduction

Birds, especially migratory birds, provide enjoyment and recreation for many and greatly enhance the quality of our lives. These colorful components of natural ecosystems are often studied, viewed, photographed, hunted, and otherwise enjoyed.

Unfortunately, bird activities sometimes conflict with human interests. Birds may predate agricultural crops, create health hazards, and compete for limited resources with other more favorable wildlife species. The management of bird populations or the manipulation of bird habitats to minimize such conflicts is an important aspect of wildlife management. Problems associated with large concentrations of birds can often be reduced through techniques of dispersal or relocation of such concentrations.

Dispersal techniques

Two general approaches to dispersing bird concentrations will be discussed in this section:

1. Environmental or habitat modifications that either exclude or repel birds or make an area less attractive, and

2. The use of frightening devices.

Habitat modifications

Habitat modifications include a myriad of activities that can make habitats less attractive to birds. Thinning or pruning of vegetation to remove protective cover can discourage birds from roosting. Most deciduous trees can withstand removal of up to one-third of their limbs and leaf surface without causing problems. Adverse effects are minimized during the dormant season. Thinning often enhances commercial timber production. Dramatic changes are not always necessary; however, sometimes subtle changes are effective in making an area unattractive to birds and causing bird concentrations to disperse or relocate to a place where they will not cause problems. Bird dispersal resulting from habitat modifications usually produces a more lasting effect than other methods and is less expensive in the long run.

Frightening devices

The use of frightening devices can be extremely effective in manipulating bird concentrations. The keys to a successful operation are timing, persistence, organization, and diversity. Useful frightening devices include broadcast alarm and distress calls, pyrotechnics, exploders, and other miscellaneous auditory and visual frightening devices. No single technique can be depended upon to solve the problem. Numerous techniques must be integrated into a frightening program.

Electronic devices. Recorded alarm and distress calls of birds are very effective in frightening many species of birds and are useful in both rural and urban situations. The calls are amplified and broadcast. Periodically move the broadcast units to enhance the effectiveness of such calls. If stationary units must be used, increase the volume to achieve greater responses. Electronically produced sounds such as Bird-X, AV-ALARM, or other sound generators will frighten birds but are usually not as effective as amplified recorded bird calls. This should not discourage their use, however. The greater the variety and disruptiveness of sounds, the more effective the method will be as a repellent.

Pyrotechnics. Pyrotechnic devices have long been employed in bird frightening programs. Safe and cautious use of these devices should be emphasized. The 12-gauge exploding shells (shell crackers) are very effective. They are useful in a variety of situations because of their long range. Fire shell crackers from the hip (to protect the eyes) from single-barrel, open bore shotguns and check the barrel after each round to be sure no obstruction remains. Some types of 12-gauge exploding shells are corrosive, requiring that the gun be cleaned after each use to prevent rusting. Though more expensive, smokeless powder shells will reduce maintenance.

Pyrotechnics should be stored, transported, and used in conformance with laws, regulations, and ordinances.

Several devices are fired from 15-mm or 17-mm pistols are used to frighten birds. For the most part, they cover a shorter range than the 12-gauge devices. They are known by many brand names but are usually called “bangers” if they explode, and “screamers” if they do not. Both types should be used together for optimal results. Noises up in the air near the birds are much more effective than those on the ground. The use of a shotgun with live ammunition is one of the most available but least effective means of frightening birds. Shotgun fire, however, may increase the effectiveness of other frightening devices. Live shotgun shells should not be included in a frightening program unless there is certainty no birds will be crippled and later serve as live decoys. Also, live ammunition creates safety problems in urban areas and is often illegal. Rifles (.22 caliber) fired from elevated locations are effective where they can be used safely.

Rope firecrackers are an inexpensive way to create unattended sound. The fuses of large firecrackers (known as fuse-rope salutes or agricultural explosive devices) are inserted through 5/16- or 3/8-inch (8-or 9.5-mm) cotton rope. As the rope burns, the fuses are ignited. The time between explosions can be regulated by the spacing of the firecrackers in the rope. The ability to vary the intervals is an asset since birds can become accustomed to explosions at regular intervals. Burning speed of the rope can be increased by soaking it overnight in a saltpeter solution of 3 ounces per quart (85 g/I) of water and allowing it to dry. Since the burning speed of the rope is also affected by humidity and wind speed, it is wise to time the burning of a test section of the rope beforehand. Because of the fire hazard associated with this device, it is a good idea to suspend it over a barrel, or make other fire prevention provisions.

Exploders. Automatic LP gas exploders are another source of unattended sound. It is important to elevate these devices above the level of the surrounding vegetation. Mobility is an asset and will increase their effectiveness, as will changing the interval between explosions.

Other frightening materials. Other frightening devices include chemicals such as Avitrol® and a great variety of whirling novelties and flashing lights, as well as innovative techniques such as smoke, water sprays, devices to shake roosting vegetation, tethered balloons, hawk silhouettes, and others. While all of these, even the traditionally used scarecrow (human effigies), can be useful in specific situations, they are only supplementary to a basic, well-organized bird frightening program. Combining different devices such as human effigies (visual) and exploders (auditory) produce better results than either device used separately.

Bird dispersal operations

Again, the keys to successful bird dispersal are timing, persistence, organization, and diversity. The timing of a frightening program is critical. Birds are much more apt to leave a roost site they have occupied for a brief period of time than one they have used for many nights. Prompt action greatly reduces the time and effort required to successfully relocate the birds. As restlessness associated with migration increases, birds will become more responsive to frightening devices and less effort is required to move them. When migration is imminent, the birds' natural instincts will augment dispersal activities.

Whether dealing with rural or urban concentrations, someone should be in charge of the entire operation and carefully organize all dispersal activities. The more diverse the techniques and mobility of the operation, the more effective it will be. Once initiated, the program must be continued each day until success is achieved. The recommended procedure for dealing with an urban blackbird/starling roost is given below. Many of these principles apply to other bird problems as well.

Urban roost relocation procedure

Willing and effective cooperation among numerous agencies, organizations, and individuals is necessary to undertake a successful bird frightening program in an urban area. Different levels of government have different legal responsibilities for this work. The best approach is a cooperative effort with the most knowledgeable and interested individual coordinating the program.

Public relations efforts should precede an urban bird-frightening effort. Federal, state, and/or local officials should explain to the public the reasons for attempting to relocate the birds. Announcements should continue during the operation and a final report should be made through mass media. These public relations efforts will facilitate public understanding and support of the program. They will also provide an opportunity to solicit citizen involvement. This help will be needed when the birds scatter all over town after one or two nights of frightening. Traffic control in the vicinity of the roost is essential. Consequently, police involvement and that of other city officials is necessary.

The public should be informed that the birds may move to a site less suitable than the one they left and that, if disturbed in the new roost site, they are likely to return to the original site. Sometimes, it is wise to provide protection for a new, acceptable roost site once selected by the birds. One can predict with some certainty blackbirds and starlings will move to one of their primary staging areas if that area contains sufficient roosting habitat. Fortunately, if the birds occupy roost sites where they still create problems, a continuation of the frightening program can more easily cause them to move to yet another site. With each successive move, the birds become more and more responsive to the frightening devices. Habituation is uncommon in properly conducted programs, especially if sufficient diversity of techniques and mobility of equipment is maintained.

Birds are much easier to frighten while they are flying. Once they have perched, a measure of security is provided by the protective vegetation and they become more difficult to frighten.

Dispersal activities should end when birds stop moving after sunset. A continuation of frightening will only condition birds to the sounds and reduce responses in the future. With blackbird/starling roosts, all equipment and personnel should be prepared to begin frightening at least 1-1/2 hours before dark. The frightening program should commence as soon as the first birds are viewed. Early morning frightening is also effective. This requires only about 30 minutes and should begin when the first bird movement occurs within the roost, which may be prior to daylight. This movement precedes normal roost exodus time by about 30 minutes.

On the first night of a bird-roost frightening program, routes for mobile units should be planned and shooters of exploding shells should be placed so as to build a wall of sound around the roost site and saturate the roost with sound. Shooters should be cautioned to ration their ammunition so they do not run out before dark. The response of the birds is predictable. As flight lines attempt to enter the roost site in late afternoon, they will be repelled by the frightening effort. A wall of birds about 1/4 mile (0.4 km) from the roost site will mill and circle almost until dark. At that time, virtually all of the birds will come into the roost site, no matter what frightening methods are employed.

By the second and third nights of the frightening program, flexibility will be necessary in adapting dispersal techniques to the birds' behavior. As larger numbers of birds are repelled from the original roost site, they will attempt to establish numerous temporary roosts. Mobile units armed with pyrotechnics and broadcast alarm and distress calls should be prepared to move to these areas, disturb the birds, and send them out of town. Frightening efforts by residents should be encouraged through mass media. Efforts must continue each morning and evening in spite of weather conditions. Complete success is usually achieved by the fourth or fifth night.

A bird-frightening program can be used to deal with an immediate bird problem, but it can also be an educational tool that prepares individuals or municipalities to deal with future problems in an effective manner. Those interested in resolving the problem should bear part of the financial burden of the bird-frightening program. This requirement will immediately eliminate imagined bird problems. When a city or individual is willing to pay a part of the bill for a bird frightening operation, it is obvious a genuine problem exists.

Summary

Large concentrations of birds sometimes conflict with human interests. Birds can be easily dispersed by means of habitat manipulation or various auditory and visual frightening devices. Timing, persistence, organization, and diversity are the keys to effective bird dispersal programs. The proper use of frightening devices can effectively deal with potential health and/or safety hazards, depredation, and other nuisances caused by birds.

Pigeons (Rock Doves)

Classification and legal status in Wyoming

Classified under the *Wyoming Game & Fish Commission Chapter 52: Non-game Wildlife Regulation* as non-game wildlife and may be taken as provided for in the appropriate federal laws. Feral pigeons are not protected by federal law, but may be protected within municipalities.

See the *Wyoming Game & Fish Commission Chapter 52: Non-game Wildlife Regulation, Section 6. Birds* at https://wgfd.wyo.gov/Regulations/Regulation-PDFs/Regulations_Ch52.pdf for additional information.

Damage prevention and control methods

Exclusion — Screen eaves, vents, windows, doors, and other openings with 1/4-inch (0.6-cm) mesh hardware cloth. Change angle of roosting ledge to 45° or more. Install porcupine wires (Cat Claw™, Nixalite™), ECOPIC™, or Bird Barrier™ to roosting sites. Construct parallel or grid-wire (line) systems.

Habitat modification — Eliminate food supply. Discourage people from feeding pigeons in public areas. Clean up spilled grain around elevators, feed mills, and rail car clean-out areas. Eliminate standing water.

Frightening — Visual and auditory frightening devices are usually not effective over long periods of time. Avitrol® (a chemical frightening agent).

Repellents — tactile: Various nontoxic, sticky substances (4-The Birds™, Hotfoot™, Tanglefoot™, Roost No More™, and BirdProof'™).

Odor: Naphthalene flakes.

Toxicants — oral: DRC-1339, used under supervision of USDA-APHIS-Wildlife Services only. Avitrol®, depends on bait concentration.

Fumigants — Generally not practical.

Trapping — Several live trap designs are effective.

Shooting — Where legal.

Other control methods — Nest removal.

Damage and damage identification

Pigeon droppings deface and accelerate the deterioration of buildings and increase the cost of maintenance. Large amounts of droppings may kill vegetation and produce an objectionable odor. Pigeon manure deposited on park benches, statues, cars, and unwary pedestrians is aesthetically displeasing. Around grain handling facilities, pigeons consume and contaminate large quantities of food destined for human or livestock consumption.

Pigeons may carry and spread diseases to people and livestock through their droppings. They are known to carry or transmit pigeon ornithosis, encephalitis, Newcastle disease, cryptococcosis, toxoplasmosis, salmonella food poisoning, and several other diseases. Additionally, under the right conditions, pigeon manure may harbor airborne spores of the causal agent of histoplasmosis, a systemic fungus disease that can infect humans.

The ectoparasites of pigeons include various species of fleas, lice, mites, ticks, and other biting insects, some of which readily bite people. Some insects that inhabit the nests of pigeons are also fabric pests and/or pantry pests. The northern fowl mite found on pigeons is an important poultry pest.

Pigeons around airports can also be a threat to human safety because of potential bird-aircraft collisions and are considered a medium priority hazard to jet aircraft by the U.S. Air Force.

House or English Sparrows

Classification and legal status in Wyoming

House or English Sparrows are classified under Wyoming statutes as predaceous birds allowing for control of these birds in the entire state at any time during the calendar year. In addition, it is also legal to destroy the nest and eggs of predaceous birds. Federal law does not protect House or English sparrows because they are an introduced species. Many listings for various other species of sparrows are classified under the *Wyoming Game & Fish Chapter 52 Regulations* as non-game wildlife and may or may not be protected under federal law.

See the *Wyoming Game & Fish Commission Chapter 52: Non-game Wildlife Regulation, Section 6. Birds* at https://wgfd.wyo.gov/Regulations/Regulation-PDFs/Regulations_Ch52.pdf for additional information.

Damage prevention and control methods

Exclusion — Block entrances larger than 3/4-inch. Design new buildings or alter old ones to eliminate roosting and nesting places. Install plastic bird netting or overhead lines to protect high-value crops.

Cultural methods — Remove roosting sites. Plant bird resistant varieties.

Frightening — Fireworks, alarm calls, exploders. Scarecrows, motorized hawks, balloons, kites. 4-Aminopyridine (Avitrol®).

Repellents — Capsicum. Polybutenes. Sharp metal projections (Nixalite® and Cat Claw®).

Trapping — Funnel, automatic, and triggered traps. Mist nets.

Shooting — Air guns and small firearms. Dust shot and BB caps.

Other methods — Nest destruction. Predators.

Damage and damage identification

House sparrows consume grains in fields and in storage. They do not move great distances into grain fields, preferring to stay close to the shelter of hedgerows. Localized damage can be considerable since sparrows often feed in large numbers over a small area. Sparrows damage crops by pecking seeds, seedlings, buds, flowers, vegetables, and maturing fruits. They interfere with the production of livestock, particularly poultry, by consuming and contaminating feed. Because they live in such close association with humans, they are a factor in dissemination of diseases (chlamydiosis, coccidiosis, erysipeloid, Newcastle's, parathypoid, pullorum, salmonellosis, transmissible gastroenteritis, tuberculosis, various encephalitis viruses, vibriosis, and yersinosis), internal parasites (acariasis, schistosomiasis, taeniasis, toxoplasmosis, and trichomoniasis), and household pests (bed bugs, carpet beetles, clothes moths, fleas, lice, mites, and ticks).

In grain storage facilities, fecal contamination probably results in as much monetary loss as does the actual consumption of grain. House sparrow droppings and feathers create janitorial problems as well as hazardous, unsanitary, and odoriferous situations inside and outside of buildings and sidewalks under roosting areas. Damage can also be caused by the pecking of rigid foam insulation inside buildings. The bulky, flammable nests of house sparrows are a potential fire hazard. The chattering of the flock on a roost is an annoyance to nearby human residents.

Nestlings are primarily fed insects, some of which are beneficial and some harmful to humans. Adult house sparrows compete with native, insectivorous birds. Martins and bluebirds, in particular, have been crowded out by sparrows that drive them away and destroy their eggs and young. House sparrows generally compete with native species for favored nest sites.

European Starling

Classification and legal status in Wyoming

Starlings are classified under Wyoming statutes as "predaceous birds" allowing for control of these birds in the entire state at any time during the calendar year. In addition, it is also legal to destroy the nest and eggs of predaceous birds. Federal law does not afford protection to starlings.

Damage prevention and control methods

Exclusion — Close all openings larger than 1 inch. Place covering at 45° angle on ledges. Porcupine wires on ledges or rafters. Netting to prevent roosting on building beams or to protect fruit crops. PVC or rubber strips to cover door openings; netting where frequent access is not needed.

Cultural methods and habitat modification — Reduce availability of food and water at livestock facilities: remove spilled grain and standing water; use bird proof feeders and storage facilities; feed livestock in open sheds; where appropriate, feed in late afternoon or at night; lower water level in waterers. Modify roost sites by closing buildings; exclude from roost areas with netting (for example, under roof beams); modify specific perch sites. For tree roosts, prune branches of specific trees or thin trees from groves.

Frightening — Frightening devices include recorded distress or alarm calls, various sound-producing devices, chemical frightening agents (Avitrol®), lights, and bright objects. Use with fruit crops and starling roosts. Also useful at livestock facilities in warm climates and at facilities located near major roosts.

Repellents — Soft sticky materials (polybutenes) discourage roosting on ledges. Starling repellent is under development: methyl anthranilate (grape flavoring). If successful, it may be useful for protecting fruit and as a livestock feed additive.

Toxicants — **Starlicide** (USDA Wildlife Service only licensed applicant): toxic bait for use around livestock facilities and, in some situations, at roost sites. **Toxic perches**: can be useful for certain industrial and other structural roost situations.

Fumigants — None are registered.

Trapping — Nest-box traps, for use during nesting season. Decoy traps may be useful around orchards or livestock facilities. Proper care for trap and decoy birds is necessary.

Shooting — Helpful as a dispersal or frightening technique. Not effective in reducing overall starling numbers.

Damage and damage identification

Starlings are frequently considered pests because of the problems they cause, especially at livestock facilities and near urban roosts. Starlings may selectively eat the high protein supplements often added to livestock rations.

Starlings may also be responsible for transferring disease from one livestock facility to another. This is of particular concern to swine producers. Tests have shown that the transmissible gastroenteritis virus (TGE) can pass through the digestive tract of a starling and be infectious in the starling feces. Researchers, however, have also found healthy swine in lots with infected starlings. This indicates that even infected starlings may not always transmit the disease, especially if starling interaction with pigs is minimized. TGE may also be transmitted on boots or vehicles, by stray animals, or by infected swine added to the herd. Although starlings may be involved in the spread of other livestock diseases, their role in transmission of these diseases is not yet understood. Starlings can cause other damage by consuming cultivated fruits such as grapes, peaches, blueberries, strawberries, figs, apples, and cherries. They were recently found to damage ripening (milk stage) com, a problem primarily associated with blackbirds. In some areas, starlings pull sprouting grains, particularly winter wheat, and eat the planted seed. Starlings may damage turf on golf courses as they probe for grubs, but the frequency and extent of such damage is not well documented.

The growing urbanization of wintering starling flocks seeking warmth and shelter for roosting may have serious consequences. Large roosts that occur in buildings, industrial structures, or, along with blackbird species, in trees near homes, are a problem in both rural and urban sites because of health concerns, filth, noise, and odor. In addition, slippery accumulations of droppings pose safety hazards at industrial structures, and the acidity of droppings is corrosive.

Starling and blackbird roosts near airports pose an aircraft safety hazard because of the potential for birds to be ingested into jet engines, resulting in aircraft damage or loss and, at times, in human injuries. In 1960, an Electra aircraft in Boston collided with a flock of starlings soon after takeoff, resulting in a crash landing and 62 fatalities. Although only about 6% of bird-aircraft strikes are associated with starlings or blackbirds, these species represent a substantial management challenge at airports.

One of the more serious health concerns is the fungal respiratory disease histoplasmosis. The fungus *Histoplasma capsulatum* may grow in the soils beneath bird roosts, and spores become airborne in dry weather, particularly when the site is disturbed. Although most cases of histoplasmosis are mild or even unnoticed, this disease can, in rare cases, cause blindness and/or death. Individuals who are weakened by other health conditions or who do not have endemic immunity are at greater risk from histoplasmosis.

Starlings also compete with native cavity-nesting birds such as bluebirds, flickers, and other woodpeckers, purple martins, and wood ducks for nest sites. One report showed that, where nest cavities were limited, starlings had severe impacts on local populations of native cavity-nesting species. One author has speculated that competition with starlings may cause shifts in red-bellied woodpecker (*Melanerpes carolinus*) nesting from urban habitats to rural forested areas where starling competition is less.

Section 11: Commercial Applicator Category 901 F or Private Applicator Category 01005—Chemigation

LEARNING OBJECTIVES

After studying this section, you should be able to:

A. Gain an understanding for the factors affecting chemigation.

B. Gain an understanding of chemigation systems.

C. Be able to calibrate chemigation equipment.

D. Gain an understanding of the management of chemigation systems

E. Gain an understanding of the laws and regulations governing chemigation.

INTRODUCTION

Chemigation is the term commonly used to describe the practice of applying agrichemicals (i.e. fertilizer—including livestock waste, insecticides, herbicides, fungicides, nematicides, and other chemicals) through an irrigation distribution system.

As irrigation technology has become increasingly more sophisticated over recent decades, chemigation has become common in many of the semi-arid western states of the U.S. including Wyoming.

Unquestionably, the widespread use of the practice is attributable, at least in part, to the several advantages it offers producers:

- excellent uniformity of chemical application,
- prescription application of chemicals,
- easy chemical incorporation and activation,
- reduced soil compaction,
- reduced mechanical damage to crop,
- reduced operator hazards,
- potential reduction of chemical requirements,
- potential reduction of adverse environmental impacts,
- economical (compared to cost of ground or aerial application), and
- effectiveness.

While there are advantages to chemigation, there are also some disadvantages and concerns:

- additional capital outlay is required for equipment;
- the practice requires more intensive management on the part of the producer; and
- there are both human and environmental safety considerations that must be taken into account.

This section is intended as a reference for producers and others seeking certification as chemigators. It is intended solely as a guide for safe and effective chemigation. Information in this section should never be used in place of directions contained in chemical injection and irrigation system operator manuals and/or chemical product labels and labeling.

FACTORS AFFECTING CHEMIGATION

Regardless of whether a fertilizer or pesticide will be applied, the first consideration is the needs of the growing crop. The decision to apply a pesticide, for example, would be made because the producer or a certified crop advisor scouted the field and determined that a pest was present in numbers exceeding the economic threshold.

Irrigation System Location

Equally important, especially when a pesticide is to be applied, is ensuring that the application does not endanger human health and safety, domestic animals, fish and wildlife (especially any endangered or threatened species), ground or surface water sources or neighboring crops. Applications over roadways or in close proximity to occupied buildings (e.g. an adjacent residential area) must be avoided. When applicable, use restrictions such as those listed above, are always found on product labels. Pesticide labels and labeling have the force of law; failure to comply may result in prosecution. Restrictions also may apply if wells used for chemigation are near municipal water wells. Check with local regulatory agencies about such restrictions before chemigating.

Drift and Runoff Potential

Potential for drift or runoff — or both — should be high on the list of concerns for any producer planning to chemigate. Pesticide labels prohibit both; thus whenever either occurs, it is a label violation and the person responsible is subject to prosecution.

Regardless of label prohibitions, common sense dictates that wind drift and runoff should be avoided. Any chemical loss from the target area, or any damage to nontarget crops, become additional and unnecessary production expenses. Add to that the potential costs for environmental damages, and there are more than enough reasons to avoid drift and runoff.

Drift potential during a chemigation event can be affected by several variables. Among them are: system type (volume gun, center pivot with end gun, solid-set) sprinkler type and position, operating pressure, droplet size, use/nonuse of an adjuvant, and weather conditions at the time of the application.

Researchers, applied chlorpyrifos (Lorsban 4E) with crop oil to R3 stage corn through a 1,260 foot-long center pivot equipped with high angle, high pressure (60psi) impact sprinklers. They found significant amounts of the pesticide at monitoring stations as far as 330 feet from the end of the pivot. When applied without crop oil, residues declined markedly at a distance of 200 feet to 265 feet from the end of the pivot. Drift in both cases was concentrated directly in line with the direction of air movement. Wind speed during the study averaged just under 14 mph.

Runoff can occur whenever the irrigation system is applying water at a rate greater than the infiltration rate of the soil. The occurrence of runoff depends not only on the irrigation system application rate and soil water infiltration rate, but also factors such as the field slope, soil surface roughness, and the presence of a crop canopy or residue. Runoff during chemigation may pose a potential hazard to ground and surface water, livestock, adjacent crops and wildlife.

Relatively high application rates are characteristic of the outer portion of center pivot irrigation systems, especially those operating at low pressures. Care should be taken to ensure that the sprinkler package is matched to field conditions. Depending on the type of chemical being applied and soil characteristics, the amount of water being used to apply the chemical can usually be adjusted to prevent runoff.

Soil Characteristics

Soils can differ considerably over relatively short distances. Several different soil textures are commonly found within a single field. The rate at which water and/or agricultural chemical(s) enters the soil (infiltration rate) differs according to soil texture. Thus, variations in soil texture will influence irrigation system management and chemigation operations.

For example, coarse-textured sandy soils have high infiltration rates. Assuming that other factors are equal (e.g. slope, compaction), there is less potential for runoff on coarse-textured soils than on fine-textured silty or clayey soils that have greater infiltration rates.

On coarse-textured sandy soils, chemigating with excessive amounts of irrigation water could result in leaching the chemical(s) below the crop root zone. Where fine-textured, clayey soils are to be chemigated, the situation is reversed. The potential for deep percolation of water and/or chemical(s) is decreased, but the potential for runoff increases.

Consult the Natural Resources Conservation Service (NRCS) soil survey maps for specific soil characteristics. UW Extension, NRCS, and the Natural Resources District, as well as certified crop consultants, can help provide assistance with irrigation management.

Topography

Topography of the field can substantially affect uniformity of water application through sprinkler irrigation systems lacking sprinklers with pressure regulators. Differences in elevation along the length of the sprinkler system will cause differences in pressure at each nozzle outlet. This results in uneven water distribution, especially with low pressure systems. Uneven water distribution can be corrected by using pressure regulators on each individual sprinkler. If distribution variances are not corrected, the irrigation system may be unsuitable for chemigation.

Figure 11.1. Sloping terrain such as that pictured here increases runoff potential.

IRRIGATION SYSTEM CHARACTERISTICS

Physical characteristics of an irrigation system can affect the capacity for applying agricultural chemicals. Most irrigation systems can be used to apply fertilizers or pesticides that must be incorporated into soil. However, only a sprinkler system can be used where foliar application is needed. Any system used to chemigate must have the appropriate injection equipment and anti-pollution safety devices installed, and the entire system must be in good working order. The section titled "Chemigation Equipment and Safety Devices" discusses system equipment requirements in detail.

Calibration

Accurate calibration of the chemical injection system is critical. Without calibration there is no way to determine whether the amount of chemical applied is too much, too little, or, by chance, just right. Over-application is needlessly expensive and if a pesticide is over-applied, the person responsible can be prosecuted for misuse of a pesticide. Under-application frequently does not provide the desired effect. See the section on *Calibration Procedures* for additional information, page 203.

Uniformity

When deciding if chemigation should be used as an application method using a sprinkler system, the uniformity of water and chemical application should be considered. The versatility of center pivot and some linear move sprinkler systems allow them to irrigate a broad range of field shapes using end guns and corner systems. Developments in sprinkler packages allow irrigators to install nozzles at various distances from the soil surface using several different nozzle types.

Technological advances have led to improvements in the water application by these systems.

End Guns

End guns can add more than 10 acres to the irrigated area of the center pivot if operated for the entire revolution. Intermittent use of end guns to accommodate roads, fence lines or farmsteads will result in different irrigated areas when the end gun is on than when it is off.

Thus, when a system is calibrated with the end gun off, fixed rate chemical injection pumps will apply less chemical per acre when the end gun is on. The opposite is true if calibration occurs with the end gun on. This leads to nonuniform chemical

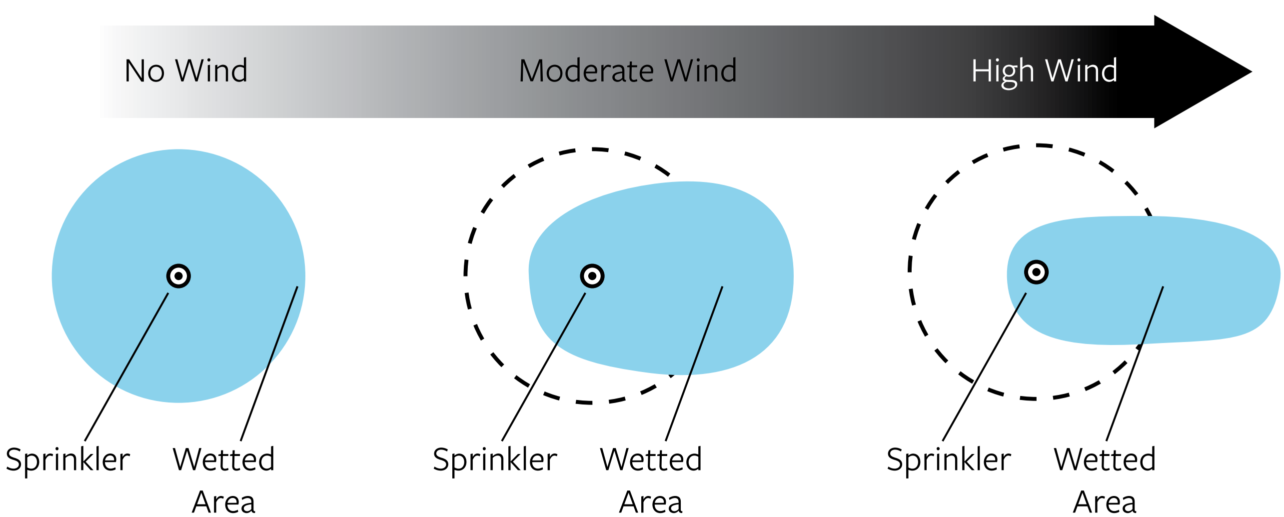


Figure 11.2. Wind impact on low-pressure spray heads on 5-foot drops.

application that can sometimes be seen from the air. If the sprinklers are pressure regulated, the change in chemical application is limited to the area irrigated by the end gun. Without regulators, the entire area irrigated while the end gun is running will have a different amount of chemical applied than when the system was calibrated.

The water application pattern of end guns is also affected by wind speed and direction. Where wind direction is parallel with the sprinkler system, it reduces the sprinkler throw or wetted radius significantly. Water and chemical meant for the area outside the main system can be deposited within the main irrigated area. A crosswind elongates the pattern in the direction parallel with the wind direction and reduces the pattern width in the direction perpendicular to the wind direction, see Figure 11.2, page 192.

Corner Systems

When the center pivot includes a corner system, the potential difference is much greater. Center pivot manufacturers have incorporated this fact into their designs. In all cases, the main system is slowed down as the corner arm extends and speeds up as the corner arm retracts. In this way the area irrigated per hour is kept very similar to when the corner system is retracted. There are two ways to deal with water application as the corner system extends outward:

1) **Increase the flow rate into the system to account for the added acres of the corner arm**. If successful, this would ensure that chemical application is similar for the entire irrigated area. The down side is that the main portion of the system applies more water when the corner is extended than when it is retracted. For the season, the overall difference in depth between corner and non-corner areas depends on the length of the corner arm and how many times water and chemical is applied to the field.

2) **Reduce the flow rate to the main system to account for the added acres of the corner arm**. This is accomplished by turning off some sprinklers on the main system as the arm extends. If successful, this would ensure that both water and chemical are applied at the same rate regardless of whether the corner is extended or not. The down side is that by turning off some sprinklers on the main system, water application uniformity is sacrificed for the main system. It is possible that the reduced uniformity may not affect yield, but the potential for yield impacts exists during heavy irrigation seasons.

Sprinkler Position

One goal of both chemical and water applications is that both be distributed as uniformly as possible. Recent sprinkler package developments have raised some concerns about the effect of nozzle position on water application uniformity. Research conducted in Kansas and Nebraska has demonstrated that nozzles positioned to operate within a corn canopy can lead to dry areas between adjacent nozzles. When positioned within 4 feet of the soil surface, the crop canopy intercepts the water application pattern to limit water application to an area within 5 to 10 feet from the nozzle. Reducing nozzle spacings to less than 7.5 feet is necessary to ensure uniform water and chemical application when nozzles operate in the corn canopy (Lamm, 1988, Yonts, et al., 2007)Irrigation Systems

There are three basic types of irrigation systems:

- sprinkler
- surface
- drip or trickle

Sprinkler Systems

There are several types of sprinkler systems and most are well-suited for chemigation. The sprinkler systems include:

- center pivot
- self-propelled linear move
- solid-set
- hand-move lateral
- side-roll lateral
- tow-line lateral
- hose drag traveler

This section focuses mainly on chemigating with center pivot and linear sprinkler systems.

Center pivot, linear systems

Center pivot and linear systems are most commonly used for chemigation. When properly designed, calibrated and operated, they provide a high degree of water and chemical application uniformity.

Center pivots can have a high rate of water application near the outer portions of the circle. If the soil infiltration rate is exceeded, runoff of the chemical-water solution may occur. Therefore, a nozzle package should be selected to minimize runoff potential. Work with an irrigation system dealer or University of Wyoming Extension personnel to select a nozzle package to match the field and crop.

In some situations, the quantity of irrigation water applied with the agrichemical will be small enough that runoff may not be a major concern. The amount of water applied by a center pivot during one irrigation is determined by the irrigation pumping rate, system length and the revolution time of the center pivot system. The minimum irrigation amount will be applied when the system is operated at the maximum rotation speed. Consult your system operator's manual for specific system water application depth information.

Solid-set, hand-move, and tow-lines

Each of these is a type of stationary sprinkler system. They differ from self-propelled systems in that they are set on a given area of the field and do not move while water is being applied. A limitation of hand-move and tow-line systems when used for chemigation is the potential for operator exposure to the chemical(s) being applied as the system is moved from one application site to the next. Another limitation of stationary systems is distortion of the water distribution by wind. Chemicals should not be applied through these systems if wind causes the spray to drift to nontarget areas.

Hose drag traveler

This type of system may be acceptable for chemigating when operated in low wind conditions. In general, travelers have poor application uniformity and susceptibility to wind drift limits their suitability for chemigating. Like the stationary systems, the hose and volume gun equipment present a risk of chemical exposure. These two factors make a hose drag traveler a poor system for use with chemigation.

Furrow Irrigation Systems

In general, furrow irrigation systems have limited potential for chemigation. Water distribution is typically nonuniform along the row. It is possible to get a substantially better distribution than the average, but it requires more time than many producers feel they can devote to the effort. Further, since there is no possibility of foliar application, any chemigation would be limited to application of fertilizer solutions, most typically nitrogen.

More recently, the development of equipment and management guidelines for surge-flow irrigation has made it possible to obtain a more uniform water application in comparison to conventional furrow irrigation. With experience, it is possible to program surge valves to make relatively uniform water applications when field conditions are good. This has stimulated renewed interest in fertigating through surge irrigation. The question is whether surge can give consistently uniform water applications across a field, so the operator can have confidence that the fertilizer application is uniform from one end of the field to the other and from row to row.

The University of Nebraska has conducted research using surge irrigation to fertigate silt loam soils with good intake rates. The results have shown that when properly managed, the uniformity of water distribution under surge irrigation is clearly better than for typical furrow irrigation. However, point-to-point variation in infiltration along a row and from row to row raises serious questions about using fertigation in furrows as a standard practice to apply supplemental N. There was more non-uniformity in distribution from top to bottom of the field than would be desirable for fertilizer distribution. Not surprisingly, there also was a large difference in infiltration between wheel-track and non-wheel-track rows. Local infiltration variability related to soil condition resulted in substantially more infiltration of fertilizer materials at some points than others. In addition, there were row-to-row differences in infiltration and fertilizer distribution on rows that were presumably identical in terms of tillage and wheel track history.

Runoff of high-nitrate water is another concern during fertigation with any furrow irrigation system. It is possible to operate a surge system to obtain nearly zero runoff. However, research on medium textured soils in Nebraska has shown that this results in a nonuniform distribution along the furrow. Allowing some runoff to occur will usually provide a more even distribution along the row.

This creates a problem of what to do with the high nitrate runoff water. If it goes to a reuse pit, it can become a point source of contamination. If it is held behind a dike at the end of the rows, it may result in areas of excessively high N application at the lower end of the field.

Because research results show non-uniform application, and potential for ground water and surface water contamination by high nitrate runoff, fertigating through either conventional or surge irrigation in furrows is not recommended on medium- and coarse-textured soils. An exception is in emergency situations where weather or some other problem has kept machinery out of the field until the crop is too tall to get through with conventional equipment.

Drip or Trickle Systems

Drip or trickle irrigation consists of frequent, slow application of water to soils through emitters located at selected points along water delivery lines. Most drip lines are placed 12–16 inches below the ground (subsurface drip irrigation), but they can also be placed on the soil surface or suspended above the ground.

Most drip systems only apply water to a portion of the soil. While some emitters are able to apply water to a larger area using a spray nozzle style emitter, most systems are not designed to apply water uniformly to the entire crop canopy. Thus, drip systems usually are not suitable for broadcast or foliar applications.

CHEMIGATION EQUIPMENT AND SAFETY DEVICES

Equipment required to apply chemicals through an irrigation system includes:

- chemical supply tank (with agitator)
- chemical injection system
- calibration tube
- required safety devices

Chemical Supply Tank

To avoid potential reactions with chemicals placed in it, the chemical supply tank should be constructed of a corrosion resistant material such as stainless steel or sunlight resistant plastic. Some pesticide labels may include statements that the product should only be placed in a specific type of tank. Product labels also will include a warning if chemical interaction is a potential problem.

The tank should be designed to prevent any wind-borne foreign materials, dirt, leaves, crop residue, and rainwater from getting into the tank. It also should be completely drainable with a sump at the drain port for ease in rinsing. Accurate, easily readable gallon marks should be on the outside of the tank.

Agitation in the chemical tank is required with some pesticides (tank mixes, dry flowables, flowables, wettable powders, or any other suspended formulations). Hydraulic agitation may be sufficient for some soluble chemicals, while mechanical agitation may be necessary for other types of chemicals. **Refer to the product label for specific instructions**.

Chemical Injection System

A mechanically durable, reliable and accurate chemical injection system, specifically designed for chemigating, is essential. Like the chemical supply tank, wettable parts should be made from stainless steel or other non-reactive materials. To help ensure uniform applications, a delivery accuracy of ±1% is desirable within the minimum to maximum operating range. It also should be easily adjusted while running.

The operating range of the injection pump should be consistent with intended chemical application rates. These can range from an ounce per acre for some insecticides to as much as 50 gallons per acre for some fertilizers. Consequently, injection rates may need to range from as low as 0.2 gallons per hour to as much as 400 gallons per hour depending on the irrigated area. No single pump can do all jobs. Controls on most pumps are graduated in units or percentages which represent the amount of liquid pumped at a particular setting. However, these settings may not be exact. Avoid operating a pump at its maximum output or near its minimum output. Such usage can result in inaccurate pumping rates. Piston pumps, in particular, lose suction capabilities proportionally as piston stroke length is reduced to pump smaller amounts. It always is best to operate the pump in the range from 10% to 90% of its rated capacity.

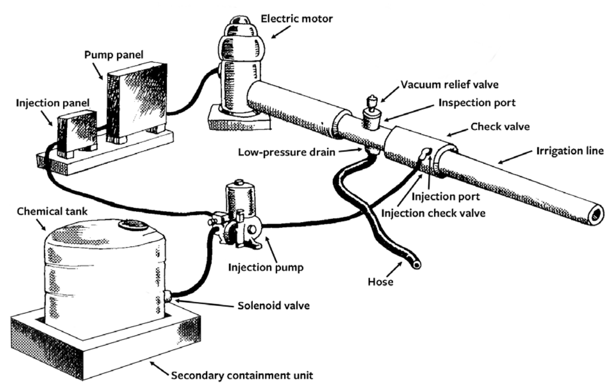


Figure 11.3. Motor drive chemigation system.[3]

3 Adapted from Extension Service, Cooperative, "Chemigation Safety: Equipment Selection and Installation" (2002). Fact Sheets . Paper 43. http://openprairie.sdstate.edu/extension_fact/43

There are three main types of injection devices used to add chemicals to irrigation water.

Chemicals may be injected by: 1) centrifugal pump, 2) positive displacement pump, or 3) pressure differential methods including venturi meters and water-driven pumps. The two main types of chemical injection pumps used are listed under the broad category of positive displacement pumps. In general, piston pumps are used to inject nitrogen fertilizers and diaphragm pumps are used to inject pesticides.

Piston pumps

Piston pumps (Figure 11.4) inject chemical into the irrigation water at a rate determined by the piston diameter, length of the stroke and the number of strokes per minute. Since the chemical pump is most often driven by an electric motor or the power take-off of the engine powering the water pump, the number of strokes per minute is nearly constant and determined by the installation. Piston pumps are calibrated by adjusting the length of the piston stroke. To do this the pump must be shut off. Consequently, accurate calibrations are somewhat tedious. Chemical or fertilizer comes into direct contact with the piston and seat allowing excessive wear and potential leakage to the environment. Moving parts, such as motor to gearbox coupling, eccentric arm, and plunger arm are generally exposed, creating danger to the operator and others.

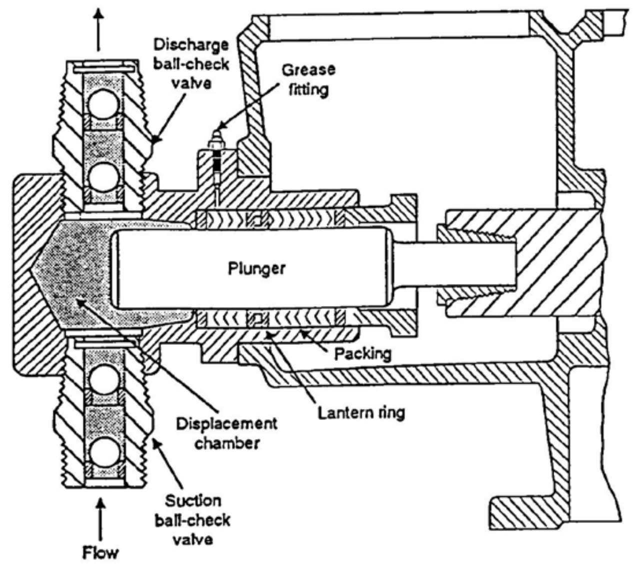


Figure 11.4. Cross-section drawing of the pump mechanism for a piston type chemical injection pump.[4]

Diaphragm pumps

Diaphragm pumps (Figure 11.5) are so named because they have a membrane or diaphragm separating the drive mechanism from the product being pumped. The mode of action remains that of a positive displacement pump but the chemical being pumped is not in direct contact with the piston. The chemical(s) to be injected determines the diaphragm material that is selected. Selecting an appropriate pump diaphragm will eliminate leakage problems that are associated with piston pumps. Advantages of a diaphragm pump include: a) easier to calibrate by simply turning an adjustment dial, b) easier to achieve precise injection rates due to fine gradations on the dial, and c) easier to adjust injection rates because the system does not need to be shut off for adjustment.

4 Poynton, James P. *Metering Pumps: Selection and Application*. M. Dekker, 1983.

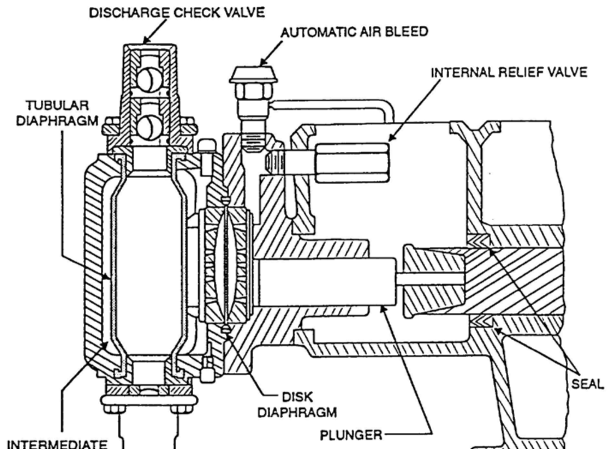


Figure 11.5. Cross-section of the pump mechanism for a diaphragm type chemical injection pump.[2]

Venturi meters

Venturi meters (Figure 11.6) use the difference between the inlet and outlet pressure of the meter to add chemical into irrigation water. As water passes through the throat of the meter, pressure energy is converted to velocity energy. In the process, a nearly perfect vacuum is developed at the throat. The vacuum creates a pressure differential that causes chemical to be forced out of the chemical supply tank into the bypass line. The chemical injection rate is varied by using a needle valve or orifice plate placed inline between the chemical supply tank and the meter. Systems with large pipelines place the venturi in a shunt or bypass line arrangement. To insure that the pressure in the bypass line is greater than the mainline pressure, a booster pump is installed in the bypass line. This eliminates the need for artificially creating a pressure differential by installing a throttling valve in the mainline.

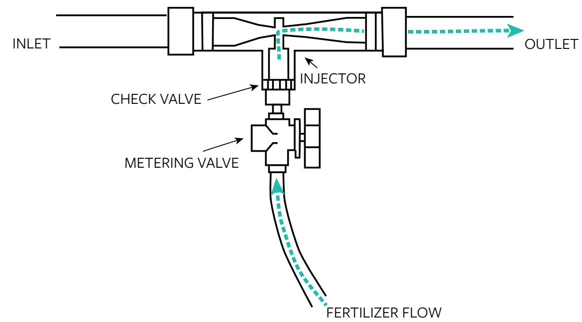


Figure 11.6. Schematic drawing of a venturi injector.

Venturi meters were primarily designed to operate in drip irrigation systems used for vegetable production and greenhouses. These systems typically have a water supply that can be maintained at a constant pressure. However, water pressure supplied to center pivots can vary if fields are not flat, end guns are used intermittently, and the pumping water level increases somewhat with pumping time. These factors cause the pipeline pressure to change, thus increasing or decreasing the chemical injection rate. Adding a booster pump greatly diminishes the effect of pressure differences on the injection rate, but, in general, the injection rate will vary depending on the pressure in the pipeline at the point of injection.

Calibration Tube

A calibration tube should be located in the chemical line between the chemical supply tank and the injection pump. It is used to measure output of the injection unit during calibration. It should be transparent for ease in viewing the liquid level, resistant to breakage, ultraviolet light (UV) stabilized (sunlight resistant), and graduated in units of volume (pints, ounces, milliliters, etc.). To properly calibrate an injection system, it is necessary to monitor the chemical injection rate for at least one minute and as long as five minutes. Therefore, calibration tubes must be large enough to hold the amount of chemical to be injected during that time. Capacity of the injection system will dictate the size of calibration tube. Fertilizer application will normally require a large 4,000–5,000 ml calibration tube while an insecticide should use a 1,000 ml calibration tube.

Required Safety Devices

Whenever proper safety devices are not installed and maintained on chemical injection and irrigation equipment, there is potential for polluting the water supply. This problem has been addressed by industry, federal regulators and state lawmakers. Three specific hazards are of concern if no safety equipment is present:

1. an unexpected shutdown of the irrigation pumping plant due to mechanical or electrical failure while it is unattended, causing concentrated chemicals or a mixture of chemicals and water to backflow into the water supply;

2. an irrigation pumping plant shutdown while the injection equipment continues to operate, possibly causing concentrated chemical or a mixture of water and chemical to backflow into the water source, and/or cause an undesirably high concentration of chemicals in the irrigation pipeline; and

3. a chemical injection system shutdown while the irrigation pump continues to operate, possibly causing water to backflow through the chemical supply tank and overflow chemical on the ground.

The American Society of Agricultural Engineers in 1982 issued an Engineering Practice document, "Safety Devices for Chemigation," (ASAE EP409.1). It addressed chemigation in its broadest sense, i.e. injecting any liquid chemical, fertilizer or pesticide, into an irrigation system. The document has been revised or reaffirmed several times, most recently in December 2013.

The U.S. Environmental Protection Agency, in its Pesticide Registration (PR) Notice 87-1, focused solely on pesticide applications. The document, dated, March 11, 1987, is directed at pesticide manufacturers whose product(s) are labeled for application by chemigation, https://www.epa.gov/pesticide-registration/prn-87-1-label-improvement-program-pesticides-applied-through-irrigation. The notice requires that container labels of such pesticides include statements listing the safety devices that must be in place for legal application of the product. Approximately two years later, the agency modified its requirements, providing a list of alternative chemigation safety equipment deemed to offer an equivalent level of protection.

Irrigation pipeline check valve

A check valve must be installed in the irrigation pipeline between the irrigation pump and the point of chemical injection into the irrigation pipeline to prevent water and chemical from draining or siphoning into the water source. ASABE adds that direction of flow should be clearly indicated on the outside of the device. It also must pass an Underwriters Laboratory, Inc. test for leakage. The check valve must be able to withstand for one minute a hydrostatic pressure double its rated working pressure without leakage at joints or at the valve seat. It also must be able to withstand for 16 hours an internal hydrostatic pressure equivalent to the head of a column of water five feet high retained within the downstream portion of the valve body.

Gooseneck pipe loop

Where system configuration and terrain are suitable, EPA regulations accept a gooseneck pipe loop downstream from the irrigation water pump as an alternative to having an irrigation pipeline line check valve and low pressure drain.

The bottom side of the pipe at the loop apex must be at least 24 inches above the highest sprinkler or other type of water emitter. The loop must contain either a vacuum relief or combination air and vacuum relief valve at the apex of the pipe loop. The pesticide injection port must be located downstream of the apex of the pipe loop and at least 6 inches below the bottom side of the pipe at the loop apex.

In the 1989 revision of its ruling on mandatory chemigation safety equipment, EPA allowed the gooseneck pipe loop as an alternative to having an irrigation pipeline check valve and low pressure drain.

Vacuum-relief valve

The vacuum-relief valve must be located on top of the irrigation pipeline between the irrigation pump and the irrigation pipeline check valve to prevent a vacuum that could cause siphoning when the water flow stops. Most systems have vacuum relief valves greater than 2-inches in diameter.

As an alternative to meeting the opening pressure requirement, a vacuum-relief valve can be placed in the chemical injection line between the injection pump and the chemical injection line check valve. The vacuum relief valve must: 1) be constructed of chemically resistant materials; 2) open at atmospheric pressure; 3) be at an elevation greater than the highest part of the chemical supply tank; and 4) be the highest point in the injection line.

Inspection port

In most cases, the vacuum-relief valve also serves as an inspection port. It is provided to check for malfunction of the irrigation pipeline check valve and low pressure drain. It must be sited between the irrigation pump and the irrigation pipeline check valve so that the inlet to the low pressure drain can be observed (Figure 11.7, page 201). A minimum 4-inch diameter opening is required for the inspection port.

Low-pressure drain

The low-pressure drain must be installed on the bottom of the horizontal pipe between the irrigation pump and the irrigation pipeline check valve. The drain must, in all instances, be located on the irrigation pipeline before the point of chemical injection. The drain must be constructed of corrosion resistant material, or coated to prevent corrosion, and must be installed at or below the bottom of the pipe. The drain opening must be at least 3/4-inch in diameter and open automatically when water flow stops. In addition, a hose or conduit 3/4-inch or greater in diameter must be attached to the low-pressure drain and the outlet must be at least 20 feet from the irrigation well or water source.

ASABE further recommends that the drain have a closing pressure of at least 1 psi but not exceeding 5 psi. They also recommend grading the soil surface, if necessary, to ensure that drainage is carried at least 20 feet from the irrigation water source. In the event that the mainline check valve leaks slowly, this drain will ensure that the solution will drain away from, rather than toward, the well or other water source.

Chemical injection line check valve

A check valve must be installed in the chemical injection line between the chemical injection pump and the chemical injection port on the irrigation pipeline. Its purpose is two fold: 1) to prevent gravity flow from the chemical supply tank into the irrigation pipeline, and 2) to prevent irrigation system water from flowing into the chemical supply tank causing an overflow. To help achieve these objectives, it is recommended that the injection port and check valve be placed in the irrigation pipeline above the liquid level in the chemical supply tank; an ideal location is in the upright column of the pivot. Regulations require that the valve be constructed of chemically resistant materials and designed to have a minimum opening (cracking) pressure of 10 psi (69 kPa).

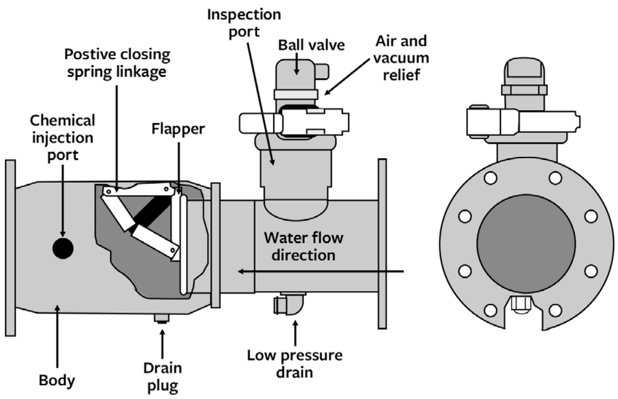


Figure 11.7. Schematic drawing of typical irrigation pipeline check valve.

Closed solenoid valve

Pesticide labels include requirements for a normally closed solenoid valve between the chemical supply tank and the chemical injection device. EPA's List of Alternative Chemigation Safety Equipment (March 22, 1989) approves three alternative devices in lieu of a normally closed solenoid valve:

1. "Functional spring-loaded check valve with a minimum of 10 psi cracking pressure. The valve must prevent irrigation water under operating pressure from entering the pesticide injection line and must prevent leakage from the pesticide supply tank on system shutdown. This valve must be constructed of pesticide resistant materials. [Note: this single device can substitute for both the solenoid-operated valve and the functional, automatic, quick closing check valve in the pesticide injection line.]

2. "Functional normally closed hydraulically operated check valve. The control line must be connected to the main water line such that the valve opens only when the main water line is adequately pressurized. This valve must prevent leakage from the pesticide supply tank on system shutdown. The valve must be constructed of pesticide resistant materials.

3. "Functional vacuum relief valve located in the pesticide injection line between the positive displacement pesticide injection pump and the check valve. This alternative is appropriate only for those chemigation systems using a positive displacement pesticide injection pump and is not for use with venturi injection systems. This valve must be elevated at least 12 inches above the highest fluid level in the pesticide supply tank and must be the highest point in the injection line. The valve must open at 6 inches water vacuum or less and must be spring loaded or otherwise constructed such that it does not leak on closing. It must prevent leakage from the pesticide supply tank on system shutdown. The valve must be constructed of pesticide resistant materials."

Simultaneous interlock

It is recommended that the irrigation pumping plant and the chemical injection pump to be interlocked so that if the pumping plant stops, the injection pump also will stop. This will prevent pumping chemicals into the irrigation pipeline after the irrigation pump stops.

On systems with an engine-driven irrigation pump, the chemical injection pump can be belted to the drive shaft or an accessory pulley of the engine. Another alternative includes operating the injection equipment using power generated by the pumping plant power unit. These types of installations are directly interlocked so that the injection device operates only when the irrigation pumping plant is operating.

SAFETY NOTE — Never operate an irrigation pump from a stationary power plant without a drive shaft shield between the engine and irrigation pump. See ASABE Standard S318.18, Safety for Agricultural Field Equipment (June, 2017), for shielding recommendations.

When the irrigation pump is powered by an electric motor, a separate electric motor usually powers the chemical injection pump. Electric controls for the irrigation pump, irrigation distribution system, and injection pump should be wired so that all three shut down if any one of the three fails.

Some agricultural chemicals have relatively low flash points making them very flammable. In such cases, wiring must conform to the National Electrical Code requirements specified for hazardous area applications. Check chemical labels for specific requirements.

Additional Safety Measures

As part of their "special use precautions," some pesticide labels will include a requirement that there be a functional pressure switch in either the irrigation line or the water pump that will stop the water pump motor whenever water pressure decreases to the point that it would adversely affect the pesticide distribution.

Two points are important:

1) It is essential to read all parts of the product label completely before chemigating with a pesticide.

2) Pesticide labels have the force of law; any deviation from label provisions constitutes misuse of a pesticide and subjects the violator to potential prosecution.

The American Society of Agricultural and Biological Engineers also recommends that several additional safety measure be implemented:

1. Provide a fresh water source near the chemical supply tank and injection pump for washing off any chemicals that contact the skin. The fresh water outlet from the irrigation system must be located between the irrigation pipeline check valve and the water supply. It should never be used as a port for injecting any agricultural chemical, nor should it be used as a source of drinking water. To minimize potential for skin contact, protective goggles, face shields, and chemical-resistant clothing should be worn when making chemical dilutions. Concentrated chemicals should generally be added to water in preparing dilutions in a chemical supply tank unless directions specify otherwise.

2. A strainer should be installed between the chemical supply tank and the injection pump to prevent clogging of the injection pump, check valve, or other equipment. The mesh size of the strainer will be dependent on the type of chemical being injected. For most chemicals, a 50-mesh screen should be used. This device should be inspected before and after each use.

3. Locate all chemical supply and mixing tanks, injection pumps, etc. a safe distance from potential sources of electric arc or spark to reduce the explosion hazard caused by the flammability of some chemicals.

4. The surface topography in the vicinity of the well or water source should be graded so that any spilled chemical drains away from, rather than toward, the water supply.

5. All equipment and accessories, including hoses, seals, gaskets, etc., that come in contact with chemical mixtures must be resistant to all formulations of agricultural chemicals being applied, including emulsifiers, solvents, and other carriers in addition to the active ingredient.

The equipment and measures described above will provide, in most cases, an acceptable level of operator safety as well as protect against contamination of the irrigation water source.

However, if your irrigation water source is near a municipal well field, additional antipollution protection equipment may be required. In such cases, contact your conservation district or the Department of Environmental Quality.

CALIBRATION PROCEDURES

The objective of each chemigation event is to apply the amount of chemical specified on the product label. Accurate calibration of the chemical injection system is critical. Without calibration there is no way to determine whether the amount of chemical applied is too much, too little or, by chance, just right. Over application is needlessly expensive and if a pesticide is over-applied, the person responsible can be prosecuted for misuse of the pesticide. Under-application frequently does not provide the desired effect. See the section on Calibration Procedures for additional information.

Calibrating a chemigation system is not difficult. It requires some time, simple equipment and accurate calculations. Do not rely solely on data provided by the manufacturer. Manufacturer's suggestions can eliminate the need for much trial and error, but in-field conditions do not necessarily match factory test sites. Research has proven that injection pumps with the same model number can deliver significantly different chemical injection rates. The same research found that injection rates were significantly impacted by the operating pressure of the irrigation system. Consequently, the only way to be sure that the injection rate is appropriate is to calibrate the injection pump for the current operating conditions.

Equipment Needs

Measuring equipment includes: a stopwatch, a measuring wheel or tape (preferably 100 ft), a pocket calculator, and marking flags or stakes large enough to be seen easily at a distance.

Calibration is a procedure to determine the amount of chemical that is applied to a given area during a predetermined amount of time. For convenience and accuracy, many chemical injection systems are sold with a calibration tube installed. Ordinarily it is a cylinder, graduated in units of volume, installed in the chemical injection system between the chemical supply tank and the chemical injection pump. The calibration tube should be clear, sunlight and breakage resistant, and hold enough chemical to inject for a minimum of five minutes.

Though not nearly as accurate as a calibration tube, a pressure relief/regulating valve also can be used for calibration. This valve can be used for "rough" calibrations of pump output by installing it on the end of the injection/metering pump output hose, setting the pressure equal to the irrigation line pressure at the point of injection and directing the output volume into a measuring container for a specific time period. This method is superior to open discharge pumping into a catch basin because pressure is maintained against the pump.

General Procedures

The injection equipment and safety devices required for applying agricultural chemicals through all types of irrigation systems are similar, as are the calibrating procedures. In general, it is necessary to determine the:

1. wetted area to be treated in acres,
2. total amount of chemical required (in gallons),
3. time required to treat the area (in hours),
4. chemical injection rate per hour,
5. calibration setting on the chemical injection pump.

Specific procedures will be outlined for calibrating center pivot, stationary sprinkler, and drip or trickle systems.

Calibrating a Center Pivot System

The calibration process is based on the given measurements of the irrigation system (length, end gun wetting area, etc.), some common mathematical constants and conversions, and the desired rate of chemical application. The following example illustrates the procedure.

1. Determine the area to be treated in acres

The simplest case is a complete circle without intermittent end guns or corner watering systems. The formula is:

Wetted area of the center pivot (ac) $= \pi \times WR^2 \div 43560$ sq ft/acre

WR = the wetted radius (pivot length in feet plus effective throw of end gun, if used) and

Assume: WR = 1300 ft
$\pi = 3.14$

$$\text{Wetted area} = 3.14 \times 1300^2 \div 43560$$
$$= 3.14 \times 1300 \times 1300 \div 43560$$
$$= 122 \text{ acres}$$

Determining irrigated area is more complex for partial circles, irregularly shaped fields, circles with intermittent end guns and other atypical situations. Methods for determining area in many of these situations are presented in *Appendix A*, page 220.

In most cases, it may be wise to leave the end gun off because the water pattern is easily distorted by wind. In addition, if an end gun shut off fails, an off-target application may result.

Finally, remember that when the end gun is turned off, the area treated is less and consequently the amount of chemical applied per acre will change if a constant rate injection pump is used add chemical to the distribution system.

2. Determine the total amount of chemical required to treat the area

```
Total amount chemical required = acres
treated × application rate/acre

Assume that 12 gallons of 28% UAN
solution will be applied per acre.

Chemical required =
122 acres × 12 gal/acre

= 1464 gallons of 28% UAN
```

3. Time required to treat area in hours

Time required to treat the area is the amount of time needed for the pivot to make one complete cycle or revolution.

Travel speed of any moving system, pivot or linear, must be measured accurately. For center pivots, the percent timer setting determines the percent of a minute the last tower moves. So for a percent timer setting of 20%, the last tower will move for 12 seconds out of each minute. When measuring the irrigation system travel speed it should be running "wet" (with water) at the speed and pressure that will be used while chemigating. If the system speed setting is changed or the irrigation pump engine throttle is adjusted, always recalibrate. Avoid determining pivot speed at one percentage setting and mathematically calculating the pivot speeds for other settings, other than to obtain a "rough" figure.

Wheel slippage can vary considerably from one percentage setting to another. In addition, travel speed is affected by wheel track depth so it is a good idea to record travel speed at the beginning, middle and end of the growing season.

Two measurements, **time** and **distance**, are required to calculate the travel speed of the pivot. The measurements can be taken in two ways:

1) record the time necessary for the outer pivot tower to travel a pre-measured distance (usually a minimum of 50 feet), or

2) measure the distance traveled by the outer pivot tower in a preselected time (usually a minimum of 10 minutes).

The end result of either method is travel speed in ft/minute. *Note: a measurement error of only a few feet or a few minutes can result in a significant error in the calibration process.* If the percentage timer is set at less than 100% when determining pivot speed, take the beginning and end time measurements at the same points in the move/stop cycle of the pivot. Measurements taken over greater distances or for longer times also will improve accuracy. If the terrain is rolling, check rotational speed at several locations in the field and calculate the average value. It also is wise to verify rotational speed several times throughout the season to account for differences in wheel track resistances due to cover, soil compaction and wheel track depth.

The first step in determining the treatment time is to determine the system travel speed by monitoring the outer pivot tower. In this example we will use Method 2 described above.

```
Travel speed =
distance traveled ÷ elapsed time.

Assume
        Distance traveled = 20 ft
        Time required = 10 min

Travel speed  = 20 ft ÷ 10 min
              = 2.0 ft/min
```

Travel speed, along with distance around the outside wheel track, become the basis for determining the amount of time needed for the pivot to make one complete cycle (revolution).

Circumference of the last wheel track and pivot travel speed are the two measurements needed to calculate revolution time.

Circumference is calculated by the formula:

```
Circumference of the last wheel track
= 2 × π × r

Where
r = the distance from the pivot point
to outside wheel track in feet.

Assume   r = 1280 ft
         π = 3.14

Circumference =
         2 × 3.14 × 1280 ft
         = 8038 ft
```

The sprinkler package printout will list the system length and distance between the pivot point and each sprinkler and tower position, including the last tower. The length required for this calculation is from the pivot point to the last wheel track. It does not include the overhang. If the original system information is not available, it is a good idea to accurately measure this distance with a wheel or measuring tape once and permanently record it in the control panel.

Revolution time is calculated by dividing the circumference of the last wheel track in feet by the travel speed in feet per minute.

```
Revolution time
         = circumference (feet/rev)
         ÷ travel speed (ft/min)
Revolution time
         = 8038 ft/rev ÷ 2.0 ft/min
         = 4019 min/rev
```

To convert the revolution time to hours, divide the above answer by 60.

```
Revolution time (hrs)
         = 4019 min/rev ÷ 60 min/hr
         = 67 hr/rev
```

It is a good chemigation management practice to record the revolution time of several irrigation events and store the percent timer settings and revolution times in the control panel for reference. Since each revolution includes a hundred or so potential revolution time measurement locations, each revolution provides a very accurate measurement of travel speed.

4. Chemical injection rate (per hour)

The injection rate is the total amount of chemical needed to treat the field (Step 2) divided by the revolution time in hours (Step 3).

```
Chemical injection rate (gal/hr)
     = total chemical needed (gallons)
     ÷ hours/revolution
Injection rate
     = 1464 gal ÷ 67 hr/rev
     = 21.8 gph
```

5. Calibration of the chemical injection pump

Knowing the chemical injection pump capacity in relation to the delivery rate needed can help establish an initial pump setting. To determine an initial (or estimated) chemical injection pump setting, the desired injection rate is divided by the pump's rated or maximum capacity.

```
Assume that the pump's maximum
injection rate is 60 gph.

Estimated pump setting
     = 21.8 gph ÷ 60 gph
     = 0.36 (36%)
```

Thus 36% is the suggested first setting for the initial calibration attempt. Increase or decrease the injection rate based on the quantity of chemical pumped from the calibration tube at 1 minute intervals. If the calibration tube scale is expressed in milliliters or ounces, it will be necessary to convert gallons per hour (gph) to that scale. To make this conversion, multiply the injection rate in gph by one of the following constants:

gph × 63.07 = milliliters/minute (ml/min)

gph × 2.133 = ounces/minute (oz/min)

If calibration tube scale is in milliliters:

21.8 gph × 63.07 = 1375 ml/min

If calibration tube scale is in ounces:

21.8 gph × 2.133 = 46.0 oz/min.

The application rate expressed in ml/min or oz/min becomes the injection rate at which the chemical injection pump must be set to achieve the desired chemical treatment.

Chemicals vary in viscosity and density. Always make the final calibration with the chemical to be injected and at the operating pressure of the irrigation system. When the desired injection rate has been bracketed, check the final adjustment by continuing to pump from the calibration tube over an extended period — at least 5 minutes.

There are some other points to bear in mind in calibrating a chemical injection pump. First, remember that book output values of chemical injection pumps are normally measured at the factory based on using a specific drive shaft speed. Any variance from the tested shaft speed will alter the pump output. Chemical injection pump wear also will alter output. When the chemical injection pump is belt driven from the drive shaft of the engine powering the irrigation pump, a tachometer is helpful.

Calibrating a Stationary Sprinkler System

Solid-set, hand lines, and wheel lines are examples of stationary irrigation systems that can be used for applying agricultural chemicals.

An advantage of the stationary system is being able to inject the chemical anytime during the irrigation process. A herbicide may be injected midway through the irrigation process to allow additional water to be applied for incorporation. A foliar insecticide, in contrast, will usually be applied near the end of the irrigation to limit the amount of water that is applied following the insecticide application to reduce wash off.

Here is an example of one way to calibrate a stationary sprinkler system for a fertilizer application.

1. Determine the acres to be irrigated in one set.

Multiply the lateral spacing along the main line by the length of the lateral and divide by 43,560 (square feet per acre). If more than one lateral is being operated simultaneously, also multiply by the number of laterals.

Assume that each set of the irrigation system has 10 laterals that are 800-foot long and spaced 40 feet apart.

Area irrigated = length (ft) × spacing (ft) × number of laterals ÷ 43560 (sq ft/acre)

= 800 ft × 40 ft × 10 ÷ 43560 sq ft/acre

= 7.3 acres

2. Determine the total amount of 28% UAN solution needed to treat the field.

Total amount chemical required
= acres treated × application rate/acre

Assume that 12 gallons of 28% UAN solution per acre.

Chemical required
= 7.3 acres × 12 gal/ac

= 87.6 gallons

3. Determine the depth of water to be applied during the application.

Assume that 1.0 inch of water will be applied and that the nitrogen solution will be injected during the first half of the irrigation period.

4. Determine the rate of water application by the irrigation system.

Attach a short piece of hose to the nozzle outlet(s) of one sprinkler, start the irrigation system, and measure flow for 1 minute. Repeat this procedure at several sprinklers along the lateral and determine the average sprinkler flow rate. Given the sprinkler flow rate in gallons per minute and the spacing between sprinklers and spacing between sprinkler laterals, the water application rate in inches per hour can be determined from application rate tables or with the following equation:

Water application rate (in/hr)
= [96.3 × qs] ÷ [Sl × Sm]

where:

96.3 = conversion coefficient

qs = flow rate from each sprinkler, gallons per minute

Sl = spacing between sprinklers on lateral, feet

Sm = spacing between laterals on mainline, feet

Assume:

Sprinkler flow rate = 4 gpm

Sprinkler spacing = 40 ft

Lateral spacing = 40 ft

Application rate
= [96.3 × 4 gpm] ÷ [40 ft × 40 ft]

= 0.24 in/hr

Water application rate also can be determined from the sprinkler manufacturer's application rate table. This method requires knowing the size of the sprinkler nozzles (usually stamped on the nozzle) and discharge pressure, then using these data to enter the application rate table. Adjust the irrigation time to apply the amount of water necessary for proper chemical application.

5. Determine the time required for a net water application of 1.0 inch.
First, divide the net depth of water to be applied (1.0 inch) by the rate of water application (Step 5).

```
Gross irrigation depth (in)
= net irrigation depth (in) ÷ irrigation
efficiency.
```

Assume:

```
Net irrigation = 1.0 in

Irrigation application efficiency = 80%

Gross irrigation depth
         = 1.0 in ÷ 0.8
         = 1.25 in
```

Then calculate the irrigation time to apply the gross irrigation depth.

```
Irrigation time
= Gross irrigation (in) ÷ Water
application rate (in/hr)

Irrigation time
         = 1.25 in ÷ 0.24 in/h

         = 5.2 hours
```

6. Fill the solution tank with 88 gallons of 28% UAN solution for each irrigation set (Step 2).

7. Determine the chemical injection rate.
Divide the total gallons to apply (Step 2) by the injection time required to apply the chemical.

```
Chemical injection rate (gph) = total
chemical required (gal) ÷ injection
time (hr)
```

Assume that UAN solution will be applied for the last 2.5 hours of the irrigation time.

```
Injection rate = 87.6 gal ÷ 2.5 hrs

               = 35 gph
```

8. Calibrate the delivery rate of the injection pump to make certain the rate is correct.
If chemical solution is to be applied throughout or during the last part of the irrigation, allow the irrigation system to operate long enough after the injection to completely flush the chemical from the system. The time required will normally be a minimum of 10 minutes and may be as long as 15 to 20 minutes.

Calibrating a Drip or Trickle System

To calculate the amount of chemical to apply per acre through a drip system, the lateral movement of water from the emitter must be measured. But, because the pattern of water movement is often irregular, it is difficult to calculate the area irrigated.

A more workable method is to apply solutions of a known chemical concentration for a definite period of time. The amount of chemical in solution is expressed in parts per million (ppm). For this example we will use a 170 ppm 28% UAN solution. Injection will occur for 6 hours. Based on the system design, each set or zone of the field will contain several acres.

To calibrate a drip irrigation system and injection pump, do the following:

1. Determine the gallons of water being delivered per hour per acre by the drip system.
Collect the water from 10 randomly selected emitters for a given period. If a short time period is used, water volume measurements must be very accurate made since the amount of water will be small. Calculate average flow per emitter and convert to the flow rate per hour per emitter. The amount of water delivered per acre can then be calculated by multiplying the number of emitters/acre by the flow rate. For subsurface drip irrigation systems, use manufacturer's published flow rates or use a flow meter to record the water flow rate over a larger area.

Assume:

Average flow rate for 10 randomly selected emitters was 0.6 oz/min.

Average flow rate
= 0.6 oz × 60 min/hr ÷ 128 oz/gal

= 36 oz/hr ÷ 128 oz/gal

= 0.28 gal/hr

Assume there are 8712 emitters per acre and each emitter delivers 0.28 gallon per hour.

The system flow rate per acre irrigated is calculated by multiplying the number of emitters by the average flow rate per emitter in gallons per hour.

System flow rate = number of emitters × average flow rate

System flow rate
= 8,712 × 0.28 gal/hr

= 2,440 gal/hr/ac

Determine the weight of the water applied.

Each gallon of water weighs 8.33 pounds. Multiply the number of gallons delivered per hour per acre by the drip system (Step 1) by the weight of one gallon of water.

Water weight
= 2,440 gal/hr/ac × 8.33 lb/gal

= 20,325 lb/hr/acre

To get the total weight of water applied to each zone, multiply the weight of the water applied per hour by the number of hours the system runs.

Total water weight
= weight per hour × hours of injection

Total water weight
= 20,325 lb/hr/acre × 6 hr

= 121,951 lb/acre

2. Determine the application rate assuming 28% UAN solution is used

A 170 ppm solution contains 170 pounds of nitrogen per 1,000,000 pounds of water. Multiply the nitrogen parts per million in solution by the total weight of the water applied during the irrigation period and then divide by 1,000,000.

```
N Application rate
= concentration (ppm) × water weight
(lbs/ac) ÷ 1,000,000 lbs water

N Application rate
= 170 ppm × 121951 lbs water ÷ 1000000
lbs water

= 20.7 lb of N per acre
```

3. Determine the total amount of 28% UAN solution required

```
Assume:
28% UAN solution contains 2.98 lb-N/gal

Application rate
= 20.7 lb/acre ÷ 2.98 lbs/gal

= 7.0 gal/ac
```

Multiply the 28% UAN solution application rate per acre by the number of acres treated to get the total UAN solution needed. Add 7.0 gallons of 28% UAN solution to the solution tank for each acre to be irrigated.

4. Determine injection rate per acre by dividing the gallons of 28% UAN solution per acre by the injection time in hours.

```
Injection Rate
= gallons per acre ÷ injection time

Injection Rate
= 7.0 gallons/ac ÷ 6 hours

= 1.2 gph/ac
```

Calibrate the delivery rate of the chemical injection pump to make certain the rate is correct. If the fertilizer will move rapidly in the soil, it is desirable to inject it during the last portion of the irrigation event. If the fertilizer does not move readily in the soil, it can be injected earlier.

If the application occurs at the end of the total irrigation time, operate the irrigation system long enough after the injection is done to completely flush the fertilizer from the system. The time required will depend on the length of drip lines and the size of the delivery pipelines.

MANAGEMENT

One disadvantage of chemigation, though it is a relatively minor one, is that it requires management. Anytime a chemical is applied through an irrigation system, several steps must precede as well as follow the application.

Most chemigation-related chemical accidents are the result of careless practices, poor selection of chemigation equipment, or lack of knowledge on how to handle chemicals safely. Time spent taking precautionary safety measures is an investment in the health and safety of yourself, your family and others, and in protecting the environment. It also helps assure that desired results are achieved.

Read, Comply with Product Label

If you plan to apply a pesticide, always read the product label before starting to chemigate and comply with all directions given. Ensure that:

1. the product is labeled for application by chemigation (some product labels may include a statement prohibiting use through any irrigation system);

2. the crop on which you plan to apply the pesticide is listed on the label;

3. the rate at which the product is applied does not exceed quantities or frequency specified;

4. all items of personal protective clothing and equipment (PPE) specified are used;

5. empty pesticide containers are triple rinsed and recycled or disposed of as directed;

6. restricted entry intervals are observed.

Equipment Maintenance and Inspection

Among the most frequent causes of chemical spills have been hose ruptures, hose clamp failures, and leaking connections — all defects that an adequate pre-operation inspection should detect. To help ensure safe chemigation events, equipment must be maintained properly. All hoses, clamps and fittings must be in good repair. It is strongly recommended that all chemical injection line hoses and clamps be replaced annually. Inspect them for deterioration before each chemigation operation.

All components that are in contact with chemicals, from the supply tank to the point of injection on the irrigation pipeline, should be constructed of chemically resistant materials.

Before chemigating, inspect equipment to be certain that the following items are functioning properly:

- the irrigation system main pipeline check valve and vacuum relief valve;
- the low pressure drain (also check drain hose for proper connection and breakage and ensure that it is draining to the desired location);
- the chemical injection line check valve;
- the irrigation system and pumping plant main control panel and the chemical injection
- pump safety interlock;
- the injection system including the in-line strainer;
- the irrigation pump and power source.

Plug First Nozzles on Center Pivots

To facilitate monitoring of the chemigation operation, the main control panel, water pump, chemical supply tank, chemical injection pump and the area around them must be kept free of chemical contamination. Plugging the nozzle outlets in the immediate area of this equipment will significantly reduce the possibility of inadvertent exposure to chemical contamination.

Personal Protective Clothing and Equipment

Pesticides by definition are products that are toxic, some more so than others. These products also pose some degree of threat to human health as well. Depending on the relative toxicity of the pesticide and the type of formulation, applicators and handlers normally need some type of personal protective clothing and equipment (PPE).

The relative toxicity of a pesticide is indicated on the product label by a signal word. Those labeled “**CAUTION**” are least toxic; those labeled “**WARNING**” are more toxic; those labeled “**DANGER**” are most toxic.

Chemicals can enter the human body by any of three "routes of entry:"

1. through the mouth (orally),
2. absorption through the skin (dermally), or
3. by breathing into the lungs (inhalation).

Route of entry statements appear on the label to indicate actions a user must take to avoid exposure. Here are some examples of these statements:

"May be fatal if swallowed. Harmful if absorbed through skin. Avoid breathing vapor or spray mist. Do not get in eyes, on skin, or on clothing."

Ordinarily the label next lists the specific items of protective clothing, personal protective equipment, and footwear (PPE) that must be used. The applicator is legally responsible for using all safety equipment and protective clothing listed. In general, the more toxic the pesticide, the greater the need for protective clothing and/or equipment.

Based on the example statements listed above, the product label would include PPE requirements such as:

"Applicators and other handlers must wear: coveralls over short-sleeved shirt and short pants, chemical-resistant gloves such as Barrier Laminate or Viton, chemical-resistant shoes plus socks, protective eyewear, chemical-resistant headgear for overhead exposure, chemical-resistant apron when cleaning equipment and mixing or loading."

Accidental Spills

One of the most frequent causes of accidental spills is rupture of a chemical supply tank.

Liquid fertilizer tanks, in particular, are often constructed of molded plastics or fiberglass. Weathering of these tanks over time tends to stress seams where the sections have been joined, and eventually the tank fails.

When a tank ruptures there are several consequences:

- The producer loses several hundred gallons of valuable fertilizer.
- The area onto which the product flows becomes contaminated. All contaminated soil must be excavated and disposed of, usually by spreading in an agronomically acceptable manner on nearby crop land.
- The incident must be reported (see details below).
- The spill may represent a threat to ground water beneath the spill site or nearby surface water sources.

To prevent such incidents, it is strongly recommended that secondary containment be provided.

If a spill occurs, apply the four "C's:"

- **Control** — plug the hole, return the tank to the upright position, or such other corrective action as may be necessary;
- **Contain** — dike the area with soil, or apply absorbents; avoid letting chemical flow away from the spill site into any surface water source;
- **Contact** — call the Wyoming Conservation District and the Wyoming Department of Environmental Quality immediately;
- **Clean up** — special precautions, such as removing the contaminated soil, may be necessary to prevent ground water contamination.

Regardless of the size of the spill, 1) avoid getting the chemical on your skin, clothing or shoes, especially if it is a pesticide; 2) keep persons, especially children, away from spills; 3) keep potential spill damage to a minimum.

Monitoring

During any chemical application, periodically monitor the irrigation system and chemical injection equipment to be certain that both are operating properly. Check the wind speed and direction periodically to ensure that wind drift will not transport chemical to a nontarget area.

Avoid Nontarget Application

Ground, surface water

Certain conditions may preclude chemigating. For example, if there is an uncapped abandoned well, flowing water in a creek channel or a wetland within the target area, chemigation would not be a legal option. Any person who contaminates ground water or applies an agricultural chemical to permanent or semi-permanent surface water areas, violates state as well as federal law and is subject to prosecution.

End guns

End gun shut-offs that fail to function and unfavorable weather conditions are among the common sources of nontarget or off-target applications. The use of end guns during chemigation is not recommended. Ordinarily end guns operate intermittently. As they turn on and off, the operating pressure of the system changes resulting in a nonuniform chemical application.

Spray drift

Spray from continuous move irrigation systems can be carried considerable distances by wind. Drift can result in violations of the law for misapplication of a pesticide and illegal pesticide residues in or on a crop. It also can damage your own or a neighbor's nontarget crops.

Wind variation

Wind variation also can have a detrimental effect on other types of sprinkler systems such as solid-set, hand-move laterals, side-roll laterals, and tow-line laterals. To minimize problems associated with wind drift, these steps can be taken:

- avoid use when winds are strong enough to cause significant drift (10 mph or greater);
- space the sprinklers and lines more closely together, if possible;
- operate at night when winds are relatively calm.

Runoff—Deep Percolation

The irrigation system should be managed so that runoff or deep percolation of the water-chemical mixture does not occur. If runoff does occur within the field, precautions should be taken to prevent runoff from leaving the field when chemical is being applied. With a given sprinkler package on a center pivot, reducing the application depth by making a faster revolution will reduce the potential for runoff and deep percolation. Good irrigation management practices must be used throughout the entire irrigation season to avoid movement of water below the crop root zone and with the potential for chemical leaching.

Flush Injection Equipment and Irrigation System

To prevent accumulation of precipitates, flush the injection system for at least 10 minutes with clean water after use. Flush the injection system while the irrigation system is still operating so that the water used for cleaning will be applied to the field where the chemigation application was made.

After injection is completed, operate the irrigation pump for at least 10 minutes to flush the irrigation system of any chemical. Some systems, especially drip systems, may take longer than 10 minutes to flush completely.

LAWS AND REGULATIONS

Federal and state laws and regulations, and some local regulations affect the practice of chemigation. Laws, regulations, court decisions and administrative rulings relating to agricultural chemical use and chemigation change frequently. Accordingly, they will be discussed here only in general terms.

Federal Laws and Regulations

Federal Insecticide, Fungicide and Rodenticide Act

All pesticide applications, including those made through an irrigation system, are subject to provisions of the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) as amended.

FIFRA provisions that will affect a chemigator include requirements to:

1. use pesticides only as directed by the label;
2. be a certified pesticide applicator or be supervised by a certified applicator if you plan to purchase or use any pesticide classified "For Restricted Use Only."

A pesticide label (i.e. the document affixed to the pesticide container) along with any supplemental labeling that may be provided, has the same force as federal law. A person who uses any pesticide in a manner inconsistent with its label provisions violates FIFRA and is subject to possible legal actions. Therefore, before buying or using a pesticide it is important to first read the product label and fully understand its contents. This is especially true for pesticides to be used in chemigation.

Note: Pesticide applicator training and certification and chemigation training and certification are totally separate requirements. Being a certified pesticide applicator does NOT exempt a producer who plans to chemigate from completing required chemigation training and certification. Similarly, being a certified chemigator does not exempt a producer who plans to use "Restricted Use Only" pesticides from having to complete a pesticide applicator training program.

The Office of Pesticide Programs of the U.S. Environmental Protection Agency (EPA) issued a Pesticide Registration (PR) notice to manufacturers in early 1987 outlining a number of requirements for labeling pesticides intended for use in irrigation systems. Such pesticides must be clearly labeled stating that this method of application is acceptable. Product containers must bear several "generic" warning statements along with a listing of safety devices that must be installed and functioning before the product can legally be applied. The requirements vary depending upon water source as well as type of irrigation system. Subsequently, the PR Notice was amended in 1989, (See Table 1) but the requirements parallel those outlined in the section titled "Chemigation Equipment and Safety Devices".

Like any other pesticide application, the site (crop) on which the pesticide is to be applied must appear on the label. It is a violation of FIFRA to use a pesticide if the crop is not listed on the label. A pesticide may be applied against any pest occurring on any crop or site specified on the label unless use of the pesticide is limited only to those pests specified on the labeling.

Applying more pesticide than the label specifies also violates FIFRA. Thus calibration is essential to ensure that the proper rate is being applied. (See *Calibration Procedures*, page 203.) It is permissible, however, to apply a pesticide at any dosage, concentration or frequency less than that specified on the label without exceeding annual per acre application rates. Because of possible ineffective pest control, chemical manufacturers do not warranty applications at less than label specified rates.

Clean Water Act

The objective of the Clean Water Act (CWA) is to restore and maintain the chemical, physical and biological integrity of the nation's waters. By definition, these include essentially all forms of surface water — streams, rivers, lakes, ponds, wetlands. The long-term objective is to eliminate all discharges of pollutants from all sources into these waters.

Agriculture has long been identified by EPA as a leading generator of nonpoint source pollution. Numerous studies conducted by the U.S. Geological Survey and others have noted both nutrient and pesticide loading of many rivers and streams in the Midwest. Nutrient loading in the Mississippi River and its tributaries has resulted in a hypoxia area in the Gulf of Mexico. The EPA has been working on a new water quality emphasis aimed at reducing the transport of sediment and agrichemicals from cropland into the surface waters of the US.

Federal Safe Drinking Water Act

There may be cases in which an irrigation well is situated close to a municipal water well. Any backflow of water and/or chemicals that enters an aquifer which is, or could be, used as a public drinking water source is a violation of the federal Safe Drinking Water Act (SDWA).

Under provisions of the SDWA, each state is required to prepare and implement an approved Wellhead Protection Program.

EPA issued a final list of unregulated contaminants in 1998 known or anticipated to occur in public drinking water supplies. The list will be used over the next few years by EPA as it weighs various regulatory options aimed at preserving drinking water quality. Over 30 pesticides or pesticide degradates are on the list.

In its 1996 amendments to the SDWA, Congress directed EPA to establish a national occurrence data base of both regulated and unregulated contaminants. Every five years EPA must establish a list of unregulated contaminants to be monitored. The agency issued a final rule in September 1999 with revisions to the "Unregulated Contaminant Monitoring Regulation for Public Water Systems." The contaminant list in the final rule, includes several pesticides.

Equipment Requirements for Chemigation with Pesticides (PR Notice 87-1)

TABLE 11.1. List of equipment requirements when injecting pesticides.

Sprinkler Chemigation	System Connected to Public Water Supply*	Flood (basin), Furrow and Border Chemigation
1. Check valve, vacuum relief valve, low pressure drain. 2. Automatic, quick-closing check valve in pesticide injection pipeline. 3. Interlocking controls between pesticide injection pump, and water pump. 4. Pressure switch to stop pump motor when water pressure drops	1. Reduced-pressure-zone backflow preventer (RPZ) or equivalent in water supply line upstream from the point of pesticide introduction Or Water from public water system discharged into a reservoir prior to pesticide introduction with complete physical break between the fill pipe outlet and the overflow rim of the reservoir at least twice the inside diameter of full pipeline. 2. Automatic, quick-closing check valve in the pesticide injection pipeline. 3. Normally-closed solenoid-operated valve on the intake side of the pesticide injection pump. 4. Interlocking controls between the pesticide injection pump and the water pump. 5. Metering pump, such as a positive displacement injection pump (e.g. diaphragm pump) design, constructed of materials compatible with pesticides, and capable of being fitted with the system interlock.	Same requirements as “Sprinkler Chemigation” with the addition of: Metering pump, such as a positive displacement injection pump (e.g., diaphragm pump) design, constructed of materials compatible with pesticides, and capable of being fitted with system interlock

*A system providing piped water for human consumption that has at least 15 connections or regularly serves an average of at least 25 individuals daily at least 60 days out of the year.

Federal Endangered Species Act

This law is intended to protect endangered and threatened species. Under terms of the law, the EPA is required to work with the U.S. Department of Agriculture and Department of the Interior to protect endangered species from pesticides while allowing agricultural production to continue. One of EPA's actions was to ask the U.S. Fish and Wildlife Service to revise and expand biological opinions on the effects of selected pesticides on both aquatic and terrestrial species.

Based on the FWS report, the EPA has implemented an Endangered Species Protection Program. EPA's program uses generic labeling of affected products directing users to follow use limitations found in county bulletins issued for any area that is habitat for, or is used by, an endangered or threatened species. Bulletins have been issued for 4 counties in Wyoming. The bulletins contain maps and habitat descriptions of the listed species, and affected pesticides are identified with directions for use.

EPA maintains a toll-free Endangered Species Hotline (800-447-3813) that pesticide users can contact to obtain a county map. The maps also can be obtained through the U.S. Fish and Wildlife Service.

Resource Conservation and Recovery Act

Bulk storage and disposal of pesticides or pesticide contaminated materials, such as containers and rinsate is subject, under some conditions, to the requirements of the Resource Conservation and Recovery Act. EPA or state permits may be required for bulk chemical storage. Be sure to follow label directions carefully in disposing of such materials. Chemical spills may be treated as improper or unauthorized disposal of hazardous materials. Be sure to notify state environmental officials immediately if a spill occurs and follow their instructions regarding spill containment and cleanup. Those responsible for spills will be liable for containment and cleanup costs under RCRA, the Comprehensive Environmental Remediation, Compensation, and Liability Act (CERCLA or Superfund) law, or both.

Chemical storage above certain threshold quantities is subject to the Emergency Planning and Community Right to Know Act. Designated state and local emergency response officials must be notified, and facility emergency response plans must be developed.

Hazardous Materials Transportation Act (HMTA)

The federal Department of Transportation (DOT) regulates hazardous materials transport under the HMTA. Many pesticides have been designated by DOT as hazardous materials, and are subject to DOT transportation regulations. In general, producers transporting hazardous materials intrastate on local roads between fields of the same farm are exempt from these regulations.

However, travel on a federal highway and interstate travel is regulated. Most pesticide manufacturers and distributors provide the information needed to follow HMTA regulations. Detailed information on hazardous materials transport is available through DOT's Research and Special Programs Administration, 800-467-4922.

Food, Agriculture, Conservation and Trade Act

Persons who apply restricted use pesticides are required to keep records of every RUP application. The recordkeeping requirements are part of the Food, Agriculture, Conservation and Trade Act of 1991, also known as the 1990 Farm Bill. Federal regulations require that records be kept only two years:

1. Brand or product name and EPA registration number of the pesticide applied.

2. The total amount of pesticide applied.

3. Location of the application, area treated and the crop, commodity, stored product, or site that the pesticide was applied. Location can be specified using the designation:

    - county, range, township, and section
    - an accurate map or written description
    - an identification system approved by the USDA Farm Services Agency
    - the legal property description

4. Month, day and year of application.

5. Name and certification number of the certified applicator who made or supervised the application.

Whenever a pesticide is applied through a sprinkler irrigation system it is recommended that detailed records be kept of the application. In addition to the information specified in the federal standards, it is strongly recommended that wind speed and direction as well as ambient air temperature should also be recorded at the start of the application and at 4-6 hour intervals throughout the application. While these records are not required by law, having them available will be invaluable in the event of drift damage claims.

Some communities may regulate the use or storage of agricultural chemicals within designated wellhead protection areas, or through traditional community zoning. Check with local zoning officials regarding local requirements.

Appendix A

LEAK TEST

1. A check valve shall withstand for 1 minute, without leakage at joints or at the valve seat, an interval hydrostatic pressure of two times the rated working pressure of the valve. Slight weeping of water at the valve seat is acceptable for metal-to-metal seats. Leakage past clappers with, or in contact with, resilient seats, is not acceptable.

2. For the purposes of this test, "slight weeping" is defined as leakage not exceeding 1 fluid ounce per hour (0.008 mL/sec) per inch (25.4 mm) of nominal valve size.

3. A check valve shall withstand for 16 hours, without leakage at the valve seat, an internal hydrostatic pressure equivalent to the head of a column of water 5 feet (1.5 m) high retained within the downstream portion of the valve body. No leakage shall occur as evidenced by wetting of paper placed beneath the valve assembly. This test is to be conducted with the valve in both the horizontal and vertical position if intended for such use.

DETERMINE IRRIGATED ACREAGE: DOT METHOD

The Dot Method can be very useful when calculating areas of non-circular or non-square fields. By simply counting the dots inside the field boundaries, and multiplying by a conversion factor, the acreage is determined. *Note, however, that the field or aerial photo must be to a known scale.*

1. Draw the field and irrigated area to scale or obtain an aerial photography and draw the system coverage on the photo. A scale of one inch = 660 feet is common with aerial photos and has a conversion factor of 0.156 acres/dot. On drawings of one inch = 330 feet, the conversion factor is 0.0391 acres/dot. Other conversion factors are listed on the overlay.

2. Lay the overlay over the map and insure that it does not shift during the counting process. When dots fall on the area boundary, count every other dot.

3. Note the small squares contain four dots and major squares contain 64 dots; the counting of squares can greatly speed up the computation.

4. After all dots are counted, multiply this sum by the conversion factor to obtain acres.

Corner Machine Acreage Equations — Square Field

DLRDU = Distance from pivot to last regular drive unit.

170' swing spans:

a. 85 end gun with 70' EGR

$$\text{Acres} = \frac{(\text{DLRDU})\ 1.898 \times 1.191}{10{,}000}$$

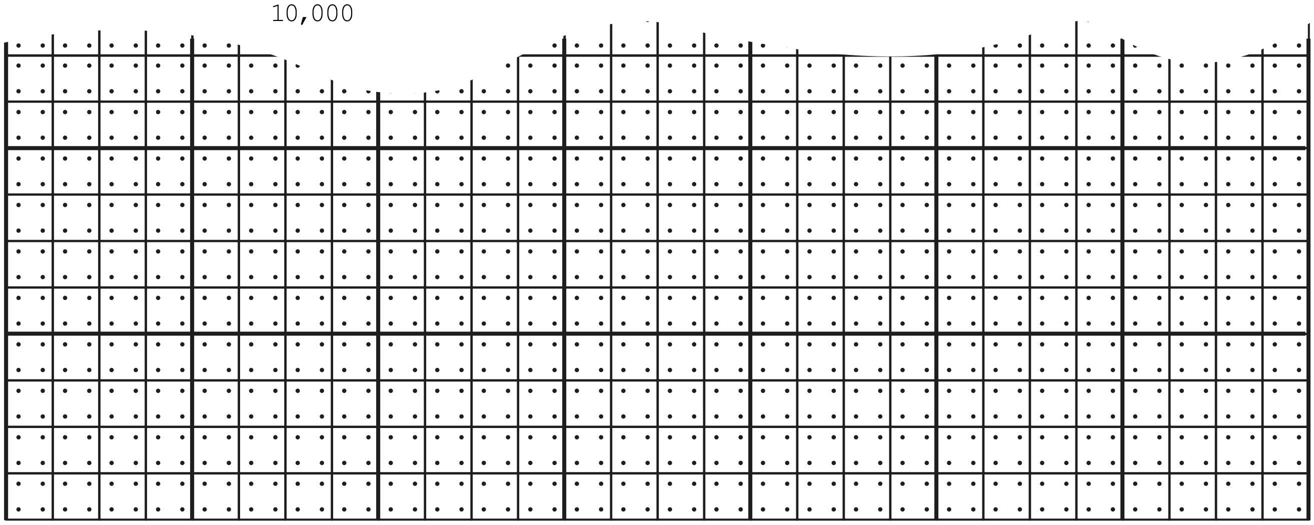
b. 100 end gun with 90' EGR

$$\text{Acres} = \frac{(\text{DLRDU})\ 1.898 \times 1.876}{10{,}000}$$

185' swing spans:

a. 100 end gun with 90' EGR

$$\text{Acres} = \frac{(\text{DLRDU})\ 1.898 \times 1.887}{10{,}000}$$



Sample modified acreage grid *— 64 dots per square inch. For maps of any scale, place an acreage grid over area to be measured; count dots and multiply by conversion factor to compute acreage. When dots fall on area boundary, count every other dot.*

Map Scales, Equivalents, and Conversion Factors

Fractional scale	Inches per mile	Acres per square inch	Conversion factor — each dot equals:
1: 7,920	8.000	10.000	0.156 acres
1: 9,600	6.600	14.692	0.230 acres
1: 15,840	4.000	40.000	0.624 acres
1: 20,000	3.168	63.769	0.966 acres
1: 31,680	2.000	160.000	2.500 acres
1: 63,360	1.000	640.000	10.000 acres
1: 125,000	0.507	2,490.980	38.922 acres
1: 250000	0.253	9,963.906	155.686 acres
1: 500000	0.127	39,855.627	622.744 acres

Appendix B

SAMPLE PROBLEM 1

Given: ϖ = 3.14

1 acre = 43,560 square feet

Area of a circle = ϖ × WR × WR Circumference = 2 × ϖ × r

1 gallon = 4 quarts

1 quart = 2 pints

You are the owner of a parcel of land that is irrigated by a center-pivot with a length of 1,290 feet (pivot point to the last sprinkler). The water throw of the last sprinkler is an additional 25 feet beyond the end of the last tower. There is no end gun. The distance from the pivot point to the last wheel track is 1,265 feet. The speed of the pivot at the last wheel track is 9.0 feet per minute when the percentage timer is set at 100%.

Problem #1: Calculate the number of acres irrigated by a center-pivot.

$$\frac{3.14 \times (1{,}315 \text{ ft})2}{43{,}560 \text{ sq ft/acre}}$$

$$= \frac{3.14 \times (1{,}315 \times 1{,}315)}{43{,}560}$$

= 124.6 acres

Problem #2: Assume an application of 3 pints per acre of an insecticide is recommended. Calculate the number of gallons of insecticide that is required to treat the entire field?

$$\frac{124.6 \text{ acres} \times 3 \text{ pts/acre}}{8 \text{ pts/gal}}$$

= 46.7 gallons

Problem #3: Calculate the revolution time or time of application to apply the insecticide if the percentage timer on the pivot is set at 100%?

$$\frac{2 \times 3.14 \times 1{,}265 \text{ ft}}{9.0 \text{ ft/min}}$$

$$= \frac{882.7 \text{ minutes}}{60 \text{ min/hr}}$$

= 14.7 hours

Problem #4: Calculate the injection rate in millimeters per minute?

$$\frac{46.7 \text{ gal}}{14.7 \text{ hr}}$$

= 3.18 gph or ml/min = 3.18 × 63

= 200 ml/min

SAMPLE PROBLEM 2

Given: ϖ = 3.14

1 acre = 43,560 square feet

1 gallon = 4 quarts

Area of a circle = ϖ × WR × WR

1 quart = 2 pints

Circumference = 2 × ϖ × r

450 gpm = 1 acre-inch /hour

You are interested in applying your pre-emergence herbicide through your center-pivot irrigation system. Your cropping system has the pivot split between corn and soybeans and you want to apply the herbicide only to the corn side of the field. The herbicide label indicates the product needs to be applied along with 0.50 inches of water. The flow meter at the well shows a pumping rate of the well at 900 gallons per minute. The wetted radius is 1,000 feet and the distance from the pivot point to the last wheel track is 990 feet. The speed of travel at the last wheel track is 6.5 feet per minute at the percentage setting of 100%.

Problem #1: Calculate the number of corn acres irrigated by the center-pivot?

$$\frac{3.14 \times (1{,}000\ \text{ft})2 \times 0.5}{43{,}560\ \text{sq ft/acre}}$$

$$= \frac{3.14 \times (1{,}000 \times 1{,}000) \times 0.5}{43{,}560}$$

= 36 acres (for 1/2 of the pivot)

Problem #2: Assuming an application of 1.5 pints per acre of the herbicide, calculate the number of gallons of chemical that is required to treat the corn acres?

$$\frac{36\ \text{acres} \times 1.5\ \text{pts}}{8\ \text{pts/gal}}$$

$$= \frac{54}{8}$$

=6.75 gallons (for 1/2 of the pivot)

Problem #3: Calculate the time to complete one half of a revolution. Consider the pivot's average application efficiency at 90%. Hint: Calculate the time to complete one revolution, then times by one half.

$$\frac{0.50\ \text{in}}{0.90} = 0.56\ \text{in}$$

0.56 in × 72.1 acres = 40.1 acre-in

$$\frac{900\ \text{gpm}}{450} = 2\ \text{acre-inches/hour}$$

$$\frac{40.1\ \text{acre-inches}}{2\ \text{acre-inches/hour}}$$

= 20.0 hrs × 0.5 (half revolution)

= 10.0 hrs (1/2 of a revolution)

Problem #4: Calculate the injection rate (to treat one half of the pivot) in ounces per minute?

$$\frac{6.75 \text{ gal} \times 2.13}{10.0 \text{ hr/rev}}$$

$= 1.44$ oz/min

SAMPLE PROBLEM 3

Given: $\varpi = 3.14$

1 acre = 43,560 square feet

Area of a circle = $\varpi \times WR \times WR$

Circumference = $2 \times \varpi \times r$

1 gallon = 4 quarts

1 quart = 2 pints

Your best management practices implementation plan recommends putting 30 lbs. of nitrogen through the pivot during June. Your application will accompany a normal irrigation of 0.75 inches of water at a pivot timer setting of 21%. At this setting the travel speed at the last wheel track is 2.9 feet per minute. The wetted radius (pivot point to the end of the throw of the last sprinkler) is 1,295 feet with no water application beyond that point. The distance from the pivot point out to the last wheel track is 1,250 feet.

Problem #1: Calculate the number of acres irrigated by the center-pivot?

$$\frac{3.14 \times (1295 \text{ ft})2}{43,560 \text{ sq ft/acre}}$$

$$= \frac{3.14 \times (1,295 \times 1,295)}{43,560}$$

$=$ 120.9 acres

Problem #2: Your fertilizer dealer supplies 32% Urea Ammonium Nitrate (UAN). Determine the total amount of 32% fertilizer necessary to apply 30 lbs of Nitrogen to the entire field?

$$\frac{30 \text{ lbs N}}{3.54 \text{ lbs N/gal (32\% UAN)}}$$

$= 8.5$ gals/acre of 32% UAN $\times$ 120.9 acres

$= 1,028$ gallons of 32% UAN

Problem #3: Calculate the total time of application?

$$\frac{2 \times 3.14 \times 1,250}{2.9 \text{ ft/min}} =$$

$$= \frac{2,707 \text{ min}}{60 \text{ min/hr}}$$

$=$ 45.1 hours

Problem #4: Calculate the injection rate in gallons per hour?

$$\frac{\text{Total volume}}{\text{Revolution time}} = \frac{1,028 \text{ gals}}{45.1 \text{ hrs}}$$

$= 22.8$ gph

References

American Society of Agricultural and Biological Engineers. "Safety for Agricultural Field Equipment." ASABE, ser. S318.18, June 2017. S318.18, elibrary.asabe.org/abstract.asp?aid=47815&t=3&dabs=Y&redir=&redirType=.

ASAE. 1998. Safety devices for chemigation. ASAE EP 409.1. Pages 880-882 in: ASAE Standards-Engineering Practices. American Society of Agricultural Engineers, St. Joseph, MI.

Byers, Mathew E., et al. "Drift during Center-Pivot Chemigation of Chlorpyrifos with and without Crop Oil." Bulletin of Environmental Contamination and Toxicology (1993) 51:60-67.

Ciampitti, I. A., Elmore, R. W., & Lauer, J. (2016). Corn Growth and Development [Poster]. Topeka, KS: Kansas State University Agricultural Experiment Station and Cooperative Extension Service. http://corn.agronomy.wisc.edu/Management/pdfs/Corn%20Growth%20and%20Development%20poster.pdf

Extension Service, Cooperative, "Chemigation Safety: Equipment Selection and Installation" (2002). Fact Sheets . Paper 43. http://openprairie.sdstate.edu/extension_fact/43

Frantz, S. C., and C. V. Trimarchi. 1984. Bats in human dwellings: health concerns and management. Proc. Eastern Wild. Damage Control Conf. 1:299-308.

Frantz, S. C. 1988. Architecture and commensal vertebrate pest management. Pages 228-295 in R. B. Kundsin, ed. Architectural design and indoor microbial pollution. Oxford Univ. Press, New York.

Greenhall, A. M. 1982. House bat management.Resour. Publ. No. 143. US Dep. Inter., Fish Wildl. Serv., Washington, DC. 33 pp.

Grisso, B., Hipkins, P., Askew, S., Hipkins, L., & Mccall, D. (2013). Nozzles: Selection and Sizing 442-032 [Publication]. VA: Virginia Cooperative Extension. http://pubs.ext.vt.edu/content/dam/pubs_ext_vt_edu/442/442-032/442-032_pdf.pdf.

Jensen, B., Liesch, P., Nice, G., Renz, M., & Smith, D. (2018). 2018 Pest Management in Wisconsin Field Crops A3646. Madison, WI: University of Wisconsin. https://learningstore.uwex.edu/Assets/pdfs/A3646.pdf.

Knezevic, S., Stephan F. Weise, & Swanton, C. (1994). Interference of Redroot Pigweed (Amaranthus retroflexus) in Corn (Zea mays). Weed Science, 42(4), 568-573. Retrieved from http://www.jstor.org/stable/4045456.

Lamm, F.R., 1998. In-Canopy Sprinkler Application for Corn: What Works and What Doesn't Work. Proceedings of the Central Plains Irrigation Short Course and Exposition. North Platte, NE pp. 70-73.

National Agricultural Statistics Service - Surveys - 2014 Agricultural Chemical Use Survey - Corn Highlights, USDA, May 2015, www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Chemical_Use/2014_Corn_Highlights/.

"New Labeling for Neonicotinoid Pesticides." EPA, Environmental Protection Agency, 12 Apr. 2017, www.epa.gov/pollinator-protection/new-labeling-neonicotinoid-pesticides.

Osorno, J., Endres, G., Ashley, R., Kandel, H., & Berglund, D. (2013). Dry Bean Production Guide A1133 [Pamphlet]. Fargo, ND: North Dakota State University. https://www.ag.ndsu.edu/publications/landing-pages/crops/dry-bean-production-guide-a-1133. Page 17.

Poynton, James P. *Metering Pumps: Selection and Application*. M. Dekker, 1983.

PRN 87-1: Label Improvement Program for Pesticides Applied through Irrigation Systems (Chemigation), https://www.epa.gov/pesticide-registration/prn-87-1-label-improvement-program-pesticides-applied-through-irrigation and the list of alternative chemigation safety equipment, https://agr.wa.gov/PestFert/ChemFert/docs/USEPAFIFRACompPol12_7Chemigation.pdf

Threadgill, E. Dale. 1985. Introduction to Chemigation: History, Development, and Current Status. In Proceedings of the Chemigation Safety Conference. University of Nebraska Center for Continuing Education. Lincoln, NE.

Trimarchi, C. V., M. K. Abelseth, and R. J. Rudd. 1979. Aggressive behavior in rabid big brown bats (Eptesicus fuscus). Pages 34-35 in Rabies Information Exchange, No. 1. US Dep. Human Health Services, Centers for Disease Control, Atlanta, Georgia.

Yonts, C. Dean, Norman L. Klocke, William L. Kranz, Derrel L. Martin, and Kelly Wertz. 2007. Application Uniformity of In-Canopy Sprinklers. G1712. University of Nebraska Cooperative Extension.

Resources

A Quick Test for Herbicide Carryover in the Soil (G1891), http://extensionpubs.unl.edu/publication/9000016366062/a-quick-test-for-herbicide-carryover-in-the-soil/

Alfalfa Insects 2, http://extensionpubs.unl.edu/publication/9000016366812/alfalfa-insects-i/

Alfalfa Insects I, http://extensionpubs.unl.edu/publication/9000016366819/alfalfa-insect-ii/

Common Weed Seedlings of the North Central States, http://fieldcrop.msu.edu/uploads/documents/Ncr607.pdf

Compendium of Herbicide Adjuvants, http://www.herbicide-adjuvants.com/

CropWatch, https://cropwatch.unl.edu

Disease and Pests series, https://apsjournals.aspnet.org/series/compendia

Endangered species requirements, Wyoming Game & Fish Department, or from the U.S. Fish and Wildlife Service, Endangered Species Specialist, in Cheyenne at 307-772-2374.

EPA Bulletins Live!, http://www.epa.gov/oppfead1/endanger/bulletins.htm.

Fieldwatch, BeeCheck, and Driftwatch, http://driftwatch.org

Grasshopper Identification Guide for Cropland Grasshoppers (EC1569), http://extensionpubs.unl.edu/publication/9000016363512/grasshopper-identification-guide-for-cropland-grasshoppers-summer-feeding-species/

Guide to Weed Management, https://marketplace.unl.edu/extension/ec130.html

How to Calibrate a Backpack Sprayer video, https://www.youtube.com/watch?v=waC51BtQX9A

How to Calibrate an ATV Sprayer video — https://www.youtube.com/watch?v=twoHQF4URdE

How to Comply with the Worker Protection Standard for Agricultural Pesticides manual, https://www.epa.gov/pesticideworker-safety/pesticide-worker-protection-standard-how-comply-manual

Protecting Endangered Species from Pesticides, https://www.epa.gov/endangered-species

Reducing Risk of Herbicide Injury video, https://youtu.be/ztF5rgAkhgc

Sugarbeet Insects, http://entomology.unl.edu/extension/crops/sugarbeet

The Handbook: Prevention and Control of Wildlife Damage, http://digitalcommons.unl.edu/icwdmhandbook/?utm_source=digitalcommons.unl.edu%2Ficwdmhandbook%2F22&utm_medium=PDF&utm_campaign=PDFCoverPages

University of Wyoming Extension, www.uwyo.edu/uwe

Upland Game Bird and Small Game Hunting Seasons, https://wgfd.wyo.gov/Regulations/Regulation-PDFs/REGULATIONS_CH11

USDA Win-PST software, http://go.usa.gov/Kok

Western Bean Cutworm in Corn and Dry Beans (G2013), http://extensionpubs.unl.edu/publication/9000016367337/western-bean-cutworm-in-corn-and-dry-beans/

Wheat Insects, http://entomology.unl.edu/extension/crops/wheat.shtml

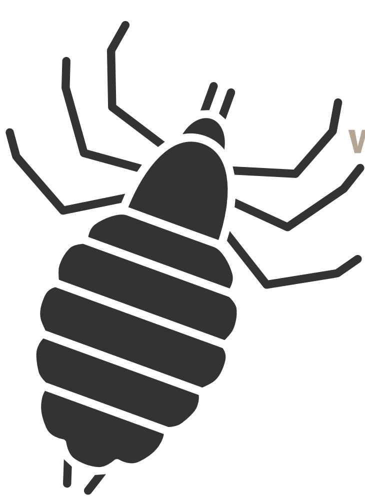
Wyoming bee hive locations, http://wyagric.state.wy.us/divisions/ts/sections-a-programs/plant-industry

Wyoming Department of Agriculture, Weed & Pest Control Act statutes, http://www.wyoweed.org/images/Designated_List.pdf

Wyoming Game & Fish Commission Chapter 52: Non-game Wildlife Regulation, Section 9. Mammals, https://wgfd.wyo.gov/Regulations/Regulation-PDFs/Regulations_Ch52.pdf

Wyoming noxious weed list, https://www.wyoweed.org/weeds/state-designated-weeds

Wyoming Pesticide Safety Education Program and Wyoming pesticide applicator information, https://uwyoextension.org/psep/



Wyoming Agricultural Pest Control: All 901 Categories

MP-127.901 • August 2018

University of Wyoming
Extension