K-State Research and Extension

IPM

INTEGRATED PEST MANAGEMENT
& PESTICIDE SAFETY EDUCATION

Agricultural Plant Pest Control

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Agricultural Plant Pest Control

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Directions for Using this Manual

This is a self-teaching manual. At the end of each major section is a list of study questions to check your understanding of the subject matter.

These study questions are representative of the type that are on the certification exam. By studying this manual and answering the study questions, you should be able to gain sufficient knowledge to pass the Kansas Commercial Applicators Certification examination. Correct answers appear on page 124.

Integrated Pest Management and the Environment

Definition of a Pest

The first step to managing pests is to identify them. A pest is any plant, animal, or microbe that is unwanted, troublesome, annoying or destructive. This manual covers three types of pests:

- insects and related arthropods,
- plant disease agents,
- weeds.

Crop plants can be pests (weeds) if present where they are not wanted, for example, volunteer alfalfa in corn, corn in soybeans, or rye in wheat. Plant disease agents can be desirable if they help control weeds. Where and when the organism occurs plays an important role in determining whether it is actually a pest.

Definition of a Pesticide

A pesticide is a substance or mixture intended to prevent, control, destroy, repel, or attract a pest. This includes the use of plant regulators, defoliants, and desiccants. Pesticides can be grouped by target:

- insecticides (kills insects)
- fungicides (kills fungus)
- herbicides (kills weeds)
- miticides (kills mites)
- nematicides (kills nematodes)
- rodenticides (kills rodents)

Integrated Pest Management

Integrated pest management (IPM) is a pest management strategy that focuses on long-term prevention through regular monitoring and a combination of control methods. IPM attempts to prevent losses from pests in ways that are effective, economical, and available, while maintaining safety of the crop, people, and environment. IPM is based on a thorough understanding of the pest, so cultural, mechanical, biological, genetic, and chemical techniques can be integrated to optimize control. Pest management tactics commonly used in field crop situations include the use of resistant varieties, crop rotation, following recommended tillage practices, and proper soil fertilization.

The integrated approach is important because of problems associated with exclusive use of chemical pesticides. Some pest species have no satisfactory pesticide available for control, so other methods are important. Adverse weather conditions may prevent application or reduce efficacy of pesticides that are applied. Safe pesticide application is impossible in areas close to dwellings, livestock, beehives or water resources. Inadequate coverage, poor placement, or improper timing can lead to poor control. And pests can develop resistance through the use of a single pesticide. Chemical pesticides can be responsible for destruction of natural enemies, outbreaks of secondary pests, environmental contamination, and cause health hazards for the applicator and people who come in contact with the treated area.

The reason for most pest control failures is not understanding the biology of the pest, its effect on the crop and how a particular control method works.

Worker Protection Standard (WPS)

The Worker Protection Standard is a federal regulation intended to reduce the risk of illness or injury to pesticide handlers and agricultural workers. A pesticide handler is a person hired to mix, load, transfer, apply, or dispose of pesticides and their containers. Agricultural workers are individuals hired to do manual labor, such as thinning, pruning, weeding, rouging, detasseling, or hand harvesting.

Worker Protection Standard requirements should be followed by individuals handling pesticides for production of agricultural plants on farms, forests, nurseries, and greenhouses when the product label refers to WPS, which is referenced in the "Agricultural Use Requirements" box of the label.

Employers who hire handlers and workers are required to provide:

- EPA approved pesticide safety training,
- personal protective equipment (PPE),
- decontamination supplies,
- emergency assistance,
- post application and safety information at a central location,
- a verbal warning or a sign at a treated site if the label requires it.

The commercial applicator business must inform its customer (a producer of agricultural plants) of the following information before each pesticide application:

- specific locations to be treated,
- time and date the pesticide is scheduled to be applied,
- product name, EPA registration number, and active ingredient,
- restricted entry interval (REI) for the pesticide,
- whether the label requires both treated area posting and oral notification,
- other safety requirements on the label for workers and other persons in the area.

On the other hand, the customer must inform the business of any other areas that may be treated with a pesticide or are under a restricted entry interval (REI) that are within ¼ mile on the same agricultural establishment.

For more information about Worker Protection Standards for agricultural pesticides, consult the manual "How to Comply with the Worker Protection Standard for Agriculture Pesticides: What Employers need to Know," or visit the agricultural compliance center at *http://www.epa.gov/agriculture/twor.html*

Integrated Pest Management and the Environment

Pesticide Selection

The decision to use a pesticide should be based on information obtained from scouting, knowledge of economic thresholds, and an awareness of potential benefits and risks associated with treatment. Improperly used, pesticides can cause detrimental effects to the applicator, the crop, or the environment. Pesticides can provide effective control, but they should be used judiciously and in combination with nonchemical methods that can be incorporated into the cropping system. Once a decision to use a pesticide has been made, several questions should be carefully considered.

- Is the target pest listed on the pesticide label?
- Does the label state that the pesticide will control the pest, or does the word "suppression" appear on the label?
- Are you familiar with relevant university research and recommendations?
- Is the recommended rate of application economical for your operation?
- How toxic is the pesticide? Dermally? Orally?
- Is the pesticide a restricted use product?
- Does the pesticide have the potential to contaminate groundwater, even when label recommendations are followed?
- Will the use of this pesticide expose humans to health or safety risks?
- Will the use of this pesticide threaten wildlife populations?
- Will the use of this pesticide affect what you plan to plant back?
- Are there any preharvest intervals that could affect harvest?
- Do the pesticides characteristics create potential for nontarget injury?

Although the use of pesticides can greatly enhance food and fiber production during pest outbreaks, misuse may create adverse environmental effects.

Pesticides can negatively impact groundwater, nontarget organisms, and threatened and endangered species if label directions are not followed. A pesticide's potential to move in the environment is related to its solubility, persistence, and ability to adsorb to the soil or organic matter as well as other properties. Knowledge about the specific pesticide allows the applicator to make an educated decision about which product is best for the situation.

Site conditions also play a role in whether a pesticide will stay in place or move. Field characteristics such as soil texture, percent slope, percent organic matter, and presence of cracks, channels, or other large openings in the soil profile combine to give each site a potential for run off or leaching. Agricultural land with coarse, sandy soil is more susceptible to the movement of chemicals into the groundwater than heavy clays.

The threat of contamination is higher in areas where the water table is close to the soil surface. Agricultural land that has coarse, sandy soil, little organic matter, and a high water table requires an applicator to use a higher degree of caution to prevent groundwater contamination.

Pesticide applicators should be aware of laws protecting animal and plant species classified as threatened or endangered under the Endangered Species Act. "Threatened" means the species is facing endangerment, while "endangered" means the species is nearing extinction. New and existing pesticides are evaluated by the EPA to determine potential harm to these species. Product labels warn applicators to be aware of these species and potential harm. Pesticide labels may instruct applicators to refer to a county bulletin for information on the protected species, the pesticide of concern, and specific use limitations. Bulletins may be accessed six months before pesticide application. For specific information on endangered species protection bulletins, go to *www.epa.gov/espp* and click on Bulletins Live!

It is important the applicator pay attention to preharvest intervals. A preharvest interval is the amount of time needed between the last application of a pesticide and harvest. Consult the pesticide label to determine the amount of time for a specific crop. Do not use the pesticide if harvest is anticipated before this time expires. Pesticide residue can remain in or on a feed or food commodity for some time, and these intervals are set to ensure the crop will meet established pesticide residue tolerances.

Protecting Bees

It is important to recognize potential hazards to honeybees when applying pesticides. Honeybees are important to the pollination of agricultural crops. These strategies can be used to reduce bee losses associated with pesticide use.

- Do not apply insecticides while crops are in bloom.
- Give beekeepers notice.
- Communication among growers, applicators, and beekeepers is essential.
- Use less toxic compounds.
- Use less toxic formulations.
- Apply chemicals while bees are not actively foraging.
- Choose application techniques wisely.
- Do not contaminate drinking water.

Integrated Pest Management and the Environment

Study Questions

These study questions are designed to help you learn the material on pages 6 through 9.

1. A pest is ____________.

a. destructive

b. beneficial

c. annoying

d. both a and c

2. What type of pesticide is used to kill weeds?

a. rodenticide

b. herbicide

c. insecticide

d. miticide

3. Which one of these is a control method promoted in integrated pest management?

a. biological control

b. cultural control

c. chemical control

d. all of the above

4. Agriculture land with _______ soils allows pesticides to move faster.

a. coarse, sandy

b. heavy clay

c. heavy loam

d. high organic matter

5. To protect honeybees from pesticides, do not apply insecticides __________.

a. during the month of May

b. while crops are in bloom.

c. within six months of harvest.

d. when the wind is from the south.

6. The potential for a given pesticide to contaminate groundwater depends on:

a. its ability to move in the soil.

b. its persistence.

c. its solubility.

d. all of the above.

The key to managing insects is to identify the insect causing the problem and develop an appropriate management plan. Of the tens of thousands of insects known to occur in Kansas, only a few dozen are common pests of the state's major field crops. Of the insects considered to be potential pests, most only occasionally reach levels justifying active management.

Learning to recognize common pests and knowing when and how they might damage crops is the first step in managing them. If insects are not correctly identified and treatments not properly timed, losses related to making unnecessary or ineffective insecticide applications can exceed damage related to infestations.

Characteristics commonly used to identify insect groups are wings, legs, and mouthparts. The number, shape, and function of wings are often used to identify adult insects. For example, bees have two pair of wings, while flies have only one pair. In beetles, the front pair of wings is often hardened and used to conceal or protect the more delicate second pair of wings. Grasshoppers have leathery front wings while true bugs have front wings that are part leathery and part membranous.

Legs can be modified for running, jumping, or digging, and the number of leg segments can be used to separate some groups of insects. Mouthparts also can be useful in recognizing insects. In addition, knowing the type of mouthparts various groups of insects possess can be critical in understanding what type of insects to look for when diagnosing plant damage. For example, holes chewed in leaves indicate a pest with chewing mouthparts and eliminates those with sucking mouthparts.

Common Insect Groups

Although there are more than two dozen groups or orders of insects, common field crop insects generally fall into one of five fairly easily recognized groups. Along with these common insect groups, a few other arthropods should be recognized to manage field crop pests.

Thrips (Order: Thysanoptera)

Thrips are tiny, slender insects. The order name means fringed wings. Winged adults have two pair of delicate, fringed wings. The group is unusual in that mouthparts are asymmetrical. The right mandible is greatly reduced or lacking, giving them a unique rasping-sucking feeding style that leads to distinctive scarring of leaf surfaces.

Thrips undergo gradual metamorphosis with three stages (egg, nymph, and adult). Nymphs are similar to adults except they are smaller and lack fully developed wings.

While many species are considered pests because they feed on plants, a few species can feed on other insects or mites and can be considered beneficial. While generally considered weak fliers, under ideal conditions populations can explode and lead to swarms that can be carried long distances by the wind. When abundant, they can be considered a nuisance if they enter homes and can bite exposed skin.

Bugs (Order: Hemiptera)

Bug is a common name for a large, diverse group of insects. The name Hemiptera refers to the forewing of many "true" bugs because wings are hardened near the base and membranous at the end, but the wings actually vary greatly among the group. The one thing members of the group have in common is sucking mouthparts. This group of insects can be subdivided into three smaller, commonly recognized groups: true bugs (stink bugs, plant bugs, etc.), hoppers (leafhoppers, treehoppers, planthoppers, etc.), and aphids. Adults of the true bugs have the distinctive forewing, mentioned above, which are held flat over the body when at rest. Hoppers have two pair of wings held roof-like over the back, while aphids lack wings or have delicate membranous wings. True bugs are fairly diverse with some species being plant feeders and others being predators, but all hoppers and aphids are plant feeders. All Hemiptera have gradual metamorphosis, but some species, including many of the aphids, bear live young rather than laying eggs.

Grasshoppers (Order: Orthoptera)

Grasshoppers are common summertime pests of a variety of crops and have caused much concern throughout the state since the 1800s. Newspaper reports from the 1870s describe "a flood of grasshoppers that made the sun dim" and literally ate all foliage, even eating the "peaches so that just the stones hung from twigs." They experience gradual metamorphosis: egg, nymph, and adult. They are generally easy to recognize by their large chewing mouthparts and long, jumping hind legs. Species determination is difficult but important because different species prefer different hosts. Some species are general feeders and pose a threat to many crops, while others may be specific and limit feeding to specific noneconomic weeds or grasses. Treatments are more effective when nymphs are small.

Moths, Butterflies, and Caterpillars (Order: Lepidoptera)

Caterpillars are the larval stages of moths and butterflies. They have chewing mouthparts and generally are the developmental stage responsible for damage and are susceptible to various management practices. Moths and butterflies are fairly easy to recognize because of the scales on their wings. Scales are particles that rub off easily when wings are touched.

Moths and butterflies are the adult stage. They have siphoning mouthparts that allow them to feed on nectar and other liquids. Moths are active at night and have antennae that vary in shape but are never knobbed at the tip. Butterflies, on the other hand, are daytime flyers with slender, knobbed antennae.

Both moths and butterflies undergo complete metamorphosis (egg, larva, pupa, and adult). The pupal stage is generally considered the inactive stage, but during this stage the caterpillar transforms into the adult butterfly or moth. Because eggs, caterpillars, and pupae look nothing like the moths and butterflies they become, observers must learn to recognize multiple stages of these crop pests.

Beetles, Weevils, Grubs, and Larvae (Order: Coleoptera)

Beetles and weevils belong to a diverse group of insects that vary greatly in shape, size, and ability to damage plants. The adults of this group are recognized for having two pair of wings, with the front wings, called elytra, being thick and stiff and serving as covers for the membranous hind wings.

Beetles go through complete metamorphosis. Coleoptera have chewing mouthparts in both larval and adult stages. Weevils are a subgroup or family of beetles that generally have mouthparts at the end of a long rostrum or snout as adults. Larvae of beetles vary greatly, from long and slender "wireworms" to short and plump grubs. To correctly identify and manage pest problems it is important to recognize multiple life stages.

Other Keys to Proper Insect Identification

In addition to a basic understanding of insect groups and life cycles, other clues can help identify pest problems. Time of year, host preferences, and injury symptoms can confirm a pest's identity. Some pests occur at specific times of the year. For example, army cutworms lay eggs in the fall, and larvae feed in late winter or early spring. Fall armyworms are active in late summer and early fall. Time of year that feeding injury occurs can narrow the list of possible pests.

Some pests are host specific. Knowing the host can help determine what pest is most likely to be causing the problem. In other cases, damage symptoms can be distinctive. For example, the rolled up leaves and purple striping caused by the Russian wheat aphid are often detected first. Leaves can be unrolled to confirm the presence of the aphids.

If timing, host, and damage symptoms do not match preliminary pest identification, identity should be confirmed. There is always a chance a pest has made a host shift or weather patterns may have affected when or where a pest occurs. It is also possible that a new pest has been introduced into an area. In this case, prompt submission of specimens for official identification can reduce the spread and alert other producers of a potential new pest.

Sampling

The key elements to sound pest management are correct identification and knowing how to sample a particular pest to determine its status relative to established management recommendations. To estimate pest populations, various sampling techniques may be required based on the type and life stage of pest(s), crop type and growth stage, and established treatment thresholds. A sample is a small portion that should accurately estimate the whole population from which it was taken.

When researchers develop treatment thresholds they must also develop sampling techniques that can be easily followed and provide reproducible results. This is why sampling techniques vary by pest, crop, and plant stage.

Another sampling consideration is where and when to take samples. In general, samples should be scattered throughout the field to gain a good representation of the pest population across the entire field. If there are noticeable differences in a field due to soil type, planting dates, plant emergence, or moisture levels, then separate samples from each area may be justified.

Many pests migrate into fields, so populations are often greater along field borders. Mostly, sampling guidelines recommend sampling several feet from field edges. This is especially important if the management plan calls for treating the whole field. If significant populations are only present along field borders and samples are only taken from the edge of the field, one will not have a true indication of populations throughout the field and treatments may be applied when they are not really needed.

For some pests, sampling field borders may be appropriate if border treatments can be applied to stop pest immigration. For example, grasshoppers and chinch bugs often move into fields from adjacent fields, so sampling and treating borders is often all that is needed to protect the whole field.

The number of samples needed per field varies with field size, pest, and population levels. Larger fields require more samples to accurately estimate pest populations. The number of samples (or the number of plants to be sampled) will vary by pest and established threshold levels. Some pests tend to have fairly even distributions and are easy to detect. Sampling a few plants may be all that is required to determine if populations exceed treatment thresholds. Other pests may have spotty distributions or low treatment thresholds and require more extensive sampling to determine pest status.

For some pests, sequential sampling programs have been developed to simplify the management decision-making process. Sequential sampling is an extensive program that has been developed from intensive research and is used to make accurate treatment decisions. Based on pest densities as indicated by sampling, this program will determine if more or less sampling is required relative to the treatment threshold. High or low densities may indicate treatment is needed or not needed, but either way, no more samples are necessary. If populations are near the action threshold, the sequential sampling program will indicate more samples are necessary before management decisions can be made.

A good understanding of the pest life cycle is critical to proper sampling. It is often helpful to know if populations are increasing or decreasing. Sometimes sampling for one stage of an insect can help time proper sampling for a treatable stage. Sampling corn borer pupae to determine moth emergence can help focus, or time, egg sampling and give an indication of the percentage of moth emergence. This information helps determine if oviposition is on the increase or if most of the moths have already emerged and oviposition has peaked.

In a few cases, the time of day can greatly affect numbers of pests that may be found. The sunflower moth is generally more active at night than in the daytime. When populations are low, samples may need to be taken in the evening or early morning to determine if treatments are justified.

Sampling plans for some pests are well defined and relatively easy to understand, for example, corn borer and alfalfa weevil. Other pests are much more difficult to sample and harder to predict such as spider mites and sunflower moths. But the basic principles are the same. Nothing takes the place of getting out in the field and monitoring pest populations. In general, the more samples and the more often they are collected, the more accurate they are in determining management decisions.

Insect Pest Management in Field Crops

Study Questions

These study questions are designed to help you learn the material on pages 11 through 15.

1. Pests of field crops generally fall into one of how many fairly easily recognized groups?

a. two

b. five

c. seven

d. twenty-four

2. Characteristics commonly used to correctly identify insects include which of the following?

a. wings

b. legs

c. mouthparts

d. all of the above

3. The key characteristic to identifying insects belonging to the order Thysanoptera (thrips) is:

a. fringed wings

b. chewing mouthparts

c. sucking mouthparts

d. none of the above

4. All members of the order Hemiptera (true bugs) have which one of the following characteristics?

a. chewing mouthparts

b. sucking mouthparts

c. utilize plants as hosts

d. lack wings

5. The developmental stage generally responsible for plant damage in the order Lepidoptera (butterflies and moths) is:

a. egg

b. larvae

c. pupa

d. adult

6. Beetles and weevils belong to a large, diverse group of insects that vary greatly in size and shape. This group is called:

a. Orthoptera

b. Lepidoptera

c. Coleoptera

d. Hemiptera

7. Even if the pest itself cannot be found, there are some other keys to help one determine the pest problem. These include:

a. time of year

b. type of host

c. type of damage

d. all of the above

8. True or False. When sampling a field for a pest, always concentrate along the field border because pests will be most numerous there.

a. true

b. false

9. True or false. The number of samples needed per field varies with field size, pest, etc. Generally, larger fields require more samples to get an accurate estimate of the population.

a. true

b. false

10. Sampling plans are relatively well-defined and easy to understand for the following pests:

a. corn borers and alfalfa weevils

b. spider mites

c. sunflower moths

d. all of the above

Alfalfa Pests

Alfalfa provides refuge for many arthropods (insects and mites). Most insects found in Kansas alfalfa fields are not pests, but there may be two to five pest species present in an alfalfa field at any one time. As with all crops and pests in Kansas, the key to profitable production is to know which pests affect forage production, how and when to treat, and whether or not treatment will be cost effective.

Insect Pests of Alfalfa

Insect	Distribution in Kansas	Importance as Pest
Alfalfa Weevil	Statewide	Early season – primarily first cutting. No. 1 alfalfa insect pest in Kansas.
Army Cutworm	Statewide, but primarily western two thirds	Occasional pest – eggs laid in fall. May be serious in first-year fields in fall or spring.
Blister Beetle	Statewide	Rarely damage crop. Main concern is hay infested with blister beetles which may be toxic if consumed by horses.
Cowpea Aphid	Statewide	Spring to midsummer – rarely occur in sufficient numbers to cause damage but can produce large quantities of honey dew.
Garden Webworm	Statewide, but more problematic in eastern two-thirds	May cause serious defoliation especially in mid- to late summer.
Grasshoppers	Statewide	Dry years seem to favor grasshopper survival. Damage usually in mid- to late summer starting from field borders.
Potato Leafhopper	Statewide	Probably more damaging than growers realize from second to fourth cutting.
Pea Aphids	Statewide, but more common in south central Kansas	Serious damage rarely occurs. May be problematic to first year crop if late spring frost. Beneficials usually control.
Spotted Alfalfa Aphid	Statewide	Most common after first cutting in mid-summer. Non resistant seedling plants most at risk.

Alfalfa Pests

Study Questions

These study questions are designed to help you learn the material on page 17.

1. *Considered the number one insect pest of alfalfa throughout Kansas:*
   a. grasshopper
   b. potato leafhopper
   c. pea aphid
   d. alfalfa weevil

2. *May feed on plants but the main concern is that toxin produced by this insect may be toxic to horses:*
   a. garden webworm
   b. alfalfa weevil
   c. blister beetle
   d. cowpea aphid

3. *Dry years seem to favor survival of this pest which can damage the crop from mid- to late summer:*
   a. alfalfa weevil
   b. grasshopper
   c. garden webworm
   d. cowpea aphid

4. *This insect is often overlooked by growers but probably causes considerable damage:*
   a. grasshopper
   b. potato leafhopper
   c. pea aphid
   d. alfalfa weevil

Corn Pests

Many pests may attack corn at any stage, from seed-infesting all the way to physiological maturity. Even as growers wait for plants to dry sufficiently so harvest can be accomplished, yield may still be lost due to prior feeding by stalk-boring insects, which causes plants to lodge or fall over. With the widespread use of seed treatments, crop rotation, Bt varieties, and the understanding of successful management strategies for most corn pests, producers can avoid major losses and have done so relatively successfully for years.

Key Pests of Corn

Insect	Distribution in Kansas	Importance as Pest
Armyworm	Statewide	Larvae defoliate from the ground up, often leaving only the midrib of the leaf – usually midsummer to fall.
Black Cutworm	Statewide, but more common in eastern half of Kansas	Damage usually occurs within first two weeks of planting. Larger larvae may sever plants resulting in reduced plant stand.
Chinch Bugs	Primarily eastern half of Kansas	Move from maturing wheat fields to seedling plants sucking plant juice causing wilting and sometimes death.
Corn Earworm	Statewide	Feeding in whorl-stage corn causes tattered, ragged looking leaves. Feeding during silking causes loss of kernels at the tip of the ear.
Corn Rootworms	Statewide	Larval root feeding may cause lodging. Continuous, susceptible varieties most at risk.
European Corn Borer	Statewide	Seldom problem prior to whorl stage. Main concern due to larval tunneling at ear shank causing ear droppage.
Fall Armyworm	Statewide	Larvae eat holes in whorl-stage; more problematic later if feed on ears, ear shank, or stalk.
Japanese Beetle	Slowly migrating from east to west across Kansas	Adult feeding on tassels and silks may reduce grain fill.
Southwestern Corn Borer	Western two thirds, usually south of I-70.	Seldom problem prior to silking. Main concern due to stalk tunneling weakening stalk and consequent girdling, causing lodging.
Spider Mites (Twospotted and Banks Grass)	Statewide: more problematic in western half of Kansas	Mite colonies start developing from the ground up. As numbers increase, more leaves turn yellow and start to die. May reduce yield if significant leaf death occurs from tasseling through soft dough.
Western Bean Cutworm	Occasional: Western one third	Larvae feed on corn ears. Damage can be severe when numbers are significant.
White Grubs	Statewide	Larval feeding on roots in fields recently broken out of CRP or pasture may reduce plant stands.
Wireworms	Statewide	Damage may occur due to larval feeding early on seeds and roots in fields recently broken out of sod or where there is considerable crop residue.

Corn Pests

Study Questions

These study questions are designed to help you learn the material on page 19.

1. *The main problem associated with this pest is larval feeding on roots which may cause lodging. The insect is:*

   a. corn rootworm
   b. black cutworm
   c. Japanese beetle
   d. wireworm

2. *These insects seem to be slowly migrating from east to west across Kansas. The insect is:*

   a. corn rootworm
   b. black cutworm
   c. Japanese beetle
   d. wireworm

3. *Damage from this insect usually occurs within the first two weeks of planting but mainly in eastern Kansas. This insect is:*

   a. corn rootworm
   b. black cutworm
   c. Japanese beetle
   d. wireworm

4. *These insects often migrate from maturing wheat fields to suck plant juice from seedling corn. The insect is:*

   a. corn rootworm
   b. black cutworm
   c. white grubs
   d. chinch bugs

5. *Which of the following pests are not insects?*

   a. spider mites
   b. wireworms
   c. white grubs
   d. armyworms

Cotton Pests

Kansas cotton producers do not have a long history, so cotton pests have not been as problematic as in other regions of the Cotton Belt. Pests may become more common, so monitoring for signs and symptoms is recommended.

Information from traditional cotton-producing states will guide Kansas cotton producers, but adjustments will need to be made because of the relatively short growing season and reduced yield potential.

Key Insect Pests of Cotton

Insect	Distribution in Kansas	Importance as Pest
Cotton Bollworm (Corn Earworm)	Statewide where cotton is grown	Larvae feed on all plant parts. Damage occurs when larvae feed on squares and bolls, often destroying one terminal and up to eight bolls per larva.
Cotton Fleahopper	Statewide where cotton is grown	Nymph and adult feeding on young squares and flowers cause desiccation and results in "blasted" appearance.
Tarnished Plant Bug	Statewide where cotton is grown	Feeding on squares, bolls, anthers and terminals may cause boll reduction.
Thrips	Statewide where cotton is grown	Damage occurs as thrips move from maturing wheat field and feed on young leaves and terminals (less than six weeks old) delaying maturity and possibly killing terminal.

Cotton Pests

Study Questions

These study questions are designed to help you learn the material on page 21.

1. *Pest information from traditional cotton-producing states can help guide Kansas cotton producers but adjustments will need to be made because:*

   a. pests are not the same

   b. Kansas has more pests

   c. Kansas has fewer pests

   d. growing season is shorter

2. *Damage occurs as these insects move from maturing wheat fields. These insects are:*

   a. chinch bugs

   b. thrips

   c. fleahoppers

   d. bollworm

Sorghum Pests

Insects may attack sorghum at any stage but most frequently after germination. Seedling through physiologically mature plants are all at risk for damaging insect infestations, especially under droughty conditions. Sorghum is more often planted in dry land than other Kansas crops. This plus the stress of insect feeding often compounds the impact on the plant's development.

Key Insect Pests of Sorghum

Insect	Distribution in Kansas	Importance as Pest
Cattail Caterpillar	Eastern two-thirds	Highly visible leaf feeding causes concern but very little resultant damage.
Chinch Bug	Eastern two-thirds (May–June)	May be very destructive to young plants as wheat matures and nymphs move to adjacent sorghum. Often more severe during dry springs.
Fall Armyworm	Statewide (July–August)	Can be very common, especially visible during whorl stage when dramatic leaf feeding causes large holes in leaves, but rarely results in yield reductions.
False Chinch Bug	Statewide	Often mistaken for chinch bugs. Feed on sorghum as a last resort, but if populations are significant they can reduce yield by feeding on developing grain.
Greenbug	Statewide	May damage sorghum at any growth stage but have not been as problematic in recent years. Seed treatments are very effective for protecting seedlings, and foliar applications work well as rescue treatments. Natural enemies are important in controlling greenbug populations.
Sorghum Headworm (Corn Earworm)	Statewide (July–September)	Sorghum may be infested from bloom through milk stage. Significant yield loss can occur quickly because larvae feed directly on the grain.
Sorghum Midges	Southeastern half	Small larvae feed on developing seed. Destroyed seed give "blasted" appearance to head. Infestations common but rarely significant.
Sorghum Webworms	Statewide (most common in southern half)	Larvae feed on developing seeds and can cause significant damage but rarely infest large areas. Hot, dry conditions are detrimental.
Sugarcane Rootstock Weevils	Statewide	Adults and larvae feed on seedling plants. May be problematic for seedlings in dry years, and early season stalk tunneling may cause late season lodging.

Study Questions

These study questions are designed to help you learn the material on page 23.

1. Damage occurs if these insects migrate from maturing wheat fields to suck juice from seedling plants: These insects are:

a. chinch bugs

b. cattail caterpillars

c. fall armyworms

d. false chinch bugs

2. Larval feeding by this insect often causes a "blasted" appearance to sorghum heads. These insects are:

a. chinch bugs

b. sorghum midges

c. sorghum webworms

d. sorghum headworms

3. Early season stalk tunneling by these insects may cause late season lodging. These insects are:

a. sorghum midges

b. chinch bugs

c. sugarcane rootstock weevils

d. sorghum headworms

4. These insects seem to feed on sorghum as a last resort but may cause yield loss if they feed on developing grain. These insects are:

a. false chinch bugs

b. chinch bugs

c. sorghum headworms

d. greenbugs

Soybean Pests

Soybeans seem to be more tolerant of insect damage than most other Kansas crops. They are very resilient at replenishing lost foliage with no detrimental effects and filling in stand losses with additional branching. These plant characteristics need to be considered in insect management decisions.

Key Insect Pests of Soybeans

Insect	Distribution in Kansas	Importance as Pest
Bean Leaf Beetles	Statewide	May feed on leaves early causing round or oval holes. Beetles may feed on pods later in the season causing yield reduction sand may transmit bean pod mottle virus.
Blister Beetles	Statewide	Adult foliage feeding can be significant but is usually localized. Spot treatment is often sufficient.
Dectes Stem Borer	Western one half	Larvae tunnel within the stalk which may cause yield loss, but the main problem is due to late-season stem girdling that may lead to lodging.
Garden Webworm	Statewide	Larvae web together and skeletonize foliage as they feed. Can be devastating to young plants.
Green Cloverworm	Statewide	Larvae chew irregularly shaped holes in leaves from July through September. Cause considerable concern but often are controlled by naturally occurring fungus.
Potato Leafhopper	Statewide	Nymphs and adults suck sap from plant causing leaf to wrinkle and turn yellow (hopper burn). Damage has not been significant in Kansas.
Soybean Aphid	Statewide (since 2002)	Capable of causing severe damage but populations usually are controlled by natural enemies and lack of overwintering hosts (buckthorn).
Soybean Podworm (Corn Earworm)	Statewide	Larvae feeding on seeds within pods may cause significant yield loss quickly.
Stink Bugs	Statewide	Adult and nymph feeding on young seeds within pods may result in shrunken and deformed seeds.
Woollybear Caterpillars	Statewide	Large, highly visible, hairy larvae feed on exposed leaves that quickly become skeletonized but rarely in areas large enough to cause economic damage.

Soybean Pests

Study Questions

These study questions are designed to help you learn the material on page 25.

1. *These pests may feed on plants and may transmit bean pod mottle virus. They are:*

   a. blister beetles

   b. bean leaf beetles

   c. soybean aphids

   d. stink bugs

2. *These pests are very common later in the season and their leaf feeding causes grower concern but they are often controlled by a white fungus. They are:*

   a. garden webworms

   b. green cloverworms

   c. soybean aphids

   d. soybean podworms

3. *These pests were first detected in Kansas in 2002. They are:*

   a. garden webworm

   b. green cloverworms

   c. soybean aphids

   d. soybean podworms

4. *Both adults and nymphs may feed on beans inside the pod causing shrunken and deformed beans. These are:*

   a. soybean podworms

   b. soybean aphids

   c. bean leaf beetles

   d. stink bugs

Sunflower Pests

Kansas is the sunflower state for good reason — native sunflowers and closely related species occur in abundance throughout the state. These provide an ideal reservoir for many potential pests, but they also act as a host for many beneficial arthropods.

Likewise, cultivated sunflowers attract a variety of insects, both pest and beneficial. Because of the potential for damage due to the most common sunflower pests, it is quite common to make at least one insecticide application during the growing season.

Key Insect Pests of Sunflowers

Insect	Distribution in Kansas	Importance as Pest
Cutworms (various species)	Statewide	Larvae feeding during seedling stage may cause stand loss. Planting earlier or later helps avoid damage.
Sunflower Headclipping Weevil	Statewide	Adult, shiny black, small weevils cause considerable concern to growers by clipping heads along border rows but rarely enough to result in significant loss.
Sunflower Headmoth	Statewide	Most consistently serious sunflower pest. Larvae feed on and around seeds, quickly causing serious yield loss. Treatment(s) need to be applied early before larvae burrow into or under seeds.
Sunflower Stem Borers	Western half	Two species of borers that both tunnel in stalk. Significant populations may weaken it. Dectes larvae girdle plant, which may result in lodging.
Thistle Caterpillar (Painted Lady)	Statewide	Larvae are active defoliators but rarely occur in populations sufficient to cause economic loss.
Woollybear Caterpillars	Statewide	These hairy caterpillars may defoliate flowers enough to cause economic loss if they are in the reproductive stages and larvae are less than ½ inch long.

Sunflower Pests

Study Questions

These study questions are designed to help you learn the material on page 27.

1. *May cause dramatic damage to plant because of their unique habit of head clipping. These insects are:*
   a. cutworms
   b. sunflower headmoths
   c. headclipping weevils
   d. sunflower stem borers

2. *Most serious sunflower pest year after year is:*
   a. cutworms
   b. sunflower headmoths
   c. headclipping weevils
   d. stem borers

3. *Highly visible, hairy caterpillars that are often common late season and may defoliate sunflowers:*
   a. cutworms
   b. sunflower headmoths
   c. stem borers
   d. woollybears

Wheat Pests

Wheat is a unique crop because it is planted in the fall and harvested the following summer. This presents several management challenges that do not apply to other field crops. Probably the most important practice before planting is destruction of volunteer wheat. Most wheat pests, including diseases, use this "green bridge" between last season's crop and the new crop to survive. Planting date is also important because fields planted later have a much better chance of avoiding pest infestations.

Key Pests of Wheat

Pest	Distribution in Kansas	Importance as Pest
Army Cutworm	Western two-thirds	Larvae may cause "windowpaning" in leaves in fall, but majority of damage is in spring. May cause fields to fail to "green-up" due to plant feeding if larvae are numerous.
Armyworm	Statewide	May damage plants by leaf removal before soft dough stage. May clip beards and heads also.
Aphids (Bird Cherry-Oat and Greenbugs)	Statewide	Rarely damage plant by direct feeding but may transmit virus diseases. Seed treatments and natural enemies usually work well to control populations.
False Wireworms	Western two-thirds	Larvae usually feed on seed following drilling row. Fields with substantial residue and continuous wheat are most at risk.
Hessian Fly	Statewide	Fall infested plants turn dark green and may die. Larvae feeding in stems during spring may cause shrunken heads and result in lodging. Oversummer and winter as flaxseeds.
Wheat Curl Mite	Statewide (predominately in western half)	Direct feeding damage is usually negligible. But important vector of wheat streak mosaic virus and other viruses that may be destructive to plants.
Wheat Head Armyworm	Statewide	Larvae feed on wheat head and may damage kernels. Kernel damage may be confused with stored product pest damage and result in dockage at harvest.
Wheat Stem Maggot	Statewide	Larval feeding in stem results in conspicuous white heads. Rarely exceeds 1 to 2 percent of the field.
Winter Grain Mite	Statewide	These tiny mites have a dark-colored body with distinctively colored reddish-orange legs. May cause yellowing of leaves in cool, dry fall or spring weather. Heavy rain often mitigates mite feeding.

Wheat Pests

Study Questions

These study questions are designed to help you to learn the material on page 29.

1. *Destruction of volunteer wheat is a very important part of pest management for these wheat pests:*

   a. aphids

   b. Hessian flies

   c. wheat curl mites

   d. all of the above

2. *Oversummering and over-wintering stage of these insects is called flaxseed. The insects are:*

   a. aphids

   b. Hessian flies

   c. wheat curl mites

   d. wheat head armyworms

3. *Larvae often reduce early season plant stands by feeding on seeds right down the drill row. These insects are:*

   a. army cutworms

   b. army worms

   c. wheat stem maggots

   d. false wireworms

4. *Larval feeding in stem often results in a 1 to 2 percent field-wide occurrence of white heads. These insects are:*

   a. army cutworms

   b. wheat head armyworms

   c. wheat stem maggots

   d. false wireworms

Beneficial Organisms

Naturally occurring beneficial organisms often are important in helping regulate crop pests. These include predators, parasites (parasitoids), and pathogens.

Predators

Predatory insects are found in all crops. Some are generalist predators, meaning they will feed on a wide range of arthropods. Others concentrate on certain groups of arthropods as hosts and are considered to be more beneficial (or highly beneficial) because in large enough populations, they are often capable of reducing the pest population below the economic threshold.

Parasites (Parasitoids)

Many beneficial organisms are commonly referred to as parasites, but the correct term would be parasitoid. True parasites live in or on a host without preventing the host from reproducing. Parasitoids kill and often consume their hosts.

Pathogens (Fungi, viruses, bacteria, nematodes, etc.)

Insects are susceptible to many diseases resulting from exposure to bacteria, fungi, nematodes, and such. In some cases, these may provide some natural control of insect pests.

Consult *Crop Insects of Kansas*, S-152, K-State Research and Extension, for color images of these insects. See the appropriate crop insect management guide to obtain specific control measures.

Beneficial Organisms

Study Questions

These study questions are designed to help you learn the material on page 31.

1. *True or False. Predatory insects are found in all crops. Some are generalist predators and others are more specific for certain groups. The specific feeding predators are considered more beneficial.*

   a. True

   b. False

2. *True or False. Insects may be infested with many different types of pathogens, much like humans. However, viruses cannot infect insects.*

   a. True

   b. False

Insect and Mite Pests of Fruit Crops

Most of the important insect and mite pests of fruit trees in Kansas feed primarily on the developing fruit. Examples include the codling moth and plum curculio on apples, and the oriental fruit moth and plum curculio on peaches. Damage is either caused by feeding on the surface or tunneling inside the fruit. This may result in fruit dropping prematurely or decreased acceptance by consumers, reducing marketability. There are other insect and mite pests that feed on leaves, twigs, limbs, or trunks of fruit trees. Examples include spider mites, scales, and the peach tree borer. Fruit tree insect and mite pests may be grouped according to crop: apples or peaches.

Apple Insect and Mite Pests

Codling Moth

The caterpillar stage of codling moth *(Cydia pomonella)* is the familiar "apple worm." Codling moth also attacks pear, crabapple, English walnut, quince, and occasionally other fruit such as apricot and cherry. Caterpillar tunneling reduces marketability and consumer acceptance. Female moths lay 50 to 60 eggs on leaves, twigs, and mature fruit. Young caterpillars crawl around until they find fruit on which to feed. Early in the season, caterpillars enter at the calyx but later feed on the side of the apple. Once inside, the caterpillar usually tunnels toward the center, feeding on seeds. As the caterpillar feeds, it pushes out a mass of chewed material, which accumulates around the entrance hole. The caterpillar is whitish-pink in color, with a brown head. It takes 16 to 25 days to complete development. When full-grown, the caterpillar exits the apple and seeks a place under loose bark on the tree trunk or limb to spin a cocoon.

Caterpillars pupate, and then emerge as adults in 12 to 21 days (around early July). There are two to three generations per year. Codling moths primarily spend the winter as caterpillars in cocoons located under bark. The first moths of the season usually appear as the petals fall from apple blossoms. Peak adult emergence usually occurs four to 12 days later depending on weather conditions.

San Jose Scale

San Jose scale *(Quadraspidiotus perniciosus),* overwinters as a partially-grown scale. As temperatures increase and plant growth begins in the spring, scales resume development. Males emerge and mate with females in May. Females eventually die, but not before producing offspring. Young crawlers are born alive and move around before settling down to feed. There are two generations per year, with all life stages present during the growing season. San Jose scale can be detected by visually inspecting the tree trunk and scaffold limbs. Scales are usually found in protected areas underneath loose bark. If high scale populations are present, they may be observed on the fruit during harvest.

Insect and Mite Pests of Fruit Crops

European Red Mite

The European red mite *(Panonychus ulmi)* overwinters in the egg stage on fruit trees. Eggs hatch about the time Red Delicious are in the pink-bud stage, which is usually between seven to 10 days. Young mites or larvae migrate to opened leaves and begin feeding. Mites reach maturity (adults) in approximately nine days, then mate, after which females begin laying eggs. There may be eight to 12 generations per year, and populations increase rapidly during warm, dry conditions. Females lay eggs, which is the overwintering stage, around mid-September.

To detect the presence of mite eggs, visually inspect small twigs and branches early in the season. Larvae and nymphs may be detected by inspecting leaf undersides. However, only the adult stage is readily visible to the naked eye when using a 10X hand lens. The lower portion of the tree is the best location to search for mites. Leaves can be removed and then brushed over a white sheet of paper, and mites counted to determine abundance.

Adult female mites may be identified with the use of a 10X hand-lens. Females are distinctly red in color and rounded with bristles extending from the back. Each bristle arises from a conspicuous white spot. The immature life stages (larvae and nymphs) are usually located on the undersides of leaves, while females are located on both upper and lower leaf surfaces. Damage is caused by the mites withdrawing the contents of the leaf cells with their stylet-like mouthparts. This results in symptoms such as leaf bleaching, yellow stippling, and leaf bronzing.

Plum Curculio

Plum curculio *(Conotrachelus nenuphar)* is an insect pest that attacks apples, peaches, pears, and cherries. Damage is caused by both the adult (snout beetle) and larvae. In spring, adults feed on buds, blossoms, leaves, and new fruits. The major damage occurs when females lay eggs. Early feeding and egg-laying punctures can cause scarring and fruit distortion. This damage on the surface of peaches often causes severely deformed fruits, which is referred to as "catfacing." Larvae feed inside the fruit until full grown then drop to the ground to pupate. On fruits such as apple, the only larvae that survive to maturity are those that feed in fruit that has dropped prematurely from the tree. Feeding and female egg-laying also may cause fruit to drop prematurely.

Adult plum curculio is small, brownish-black in color, with white and orange mottling and prominent black bumps on the back. Adults have an extended snout with chewing mouthparts. Plum curculio overwinters as an adult in debris near and around the orchard. Adults first appear in spring when trees are in the pink stage. Females initiate egg-laying as soon as young fruit forms, continuing for up to four weeks. Each female can deposit between 60 to 150 eggs. There is only one generation per year. Adults are active in July, feeding mostly on apple and plum before hibernating.

Their feeding results in irregularly shaped holes in the flesh of large fruits.

Twospotted Spider Mite

The twospotted spider mite *(Tetranychus urticae)* is an occasional pest of fruit trees in orchards. Twospotted spider mite populations may become more problematic after pesticides have been applied to regulate populations of insect pests that are natural enemies. Twospotted spider mites have pale green, translucent bodies with two dark spots visible on both sides of the abdomen. This species resembles the young stages of European red mite, except eggs are pale green and not red like European red mite.

Peach Insect Pests

Oriental Fruit Moth

Oriental fruit moth (*Grapholita molesta*) attacks many orchard fruits, but prefers peaches. The white to pink colored caterpillar feeds within the fruit and causes severe damage in the summer. Damage also may be caused by the caterpillar tunneling into the rapidly extending terminal portions of twigs early in the season. The ends of infested twigs wilt and eventually die. After awhile, the caterpillar enters new fruit often through the stem end. There are four to five generations per year.

Plum Curculio

Refer to Apple Insect Pests.

Peachtree Borer

Peachtree borer *(Synanthedon exitiosa)* is one of the most destructive insect pests of peach trees. It also attacks plum, cherry and apricot. The caterpillar damages the tree by tunneling into the inner bark at or just below the soil. Feeding may girdle the tree, preventing movement of water and nutrients, and eventually killing it.

Evidence of an infestation includes masses of plant fluids, which appear "gummy" and are mixed with pieces of chewed wood and insect feces found at or below the soil surface. Early symptoms of an infestation may result in leaf yellowing of one or more branches and stunted growth, especially on young trees.

Adult peachtree borers are clear-wing moths. Females are wasp-like in appearance, dark, steel blue in color, with one or two orange bands on the abdomen. Front wings are opaque. Hind ones are clear except for the margins. Male moths are smaller and more slender with all four wings clear.

Moths appear from late June through mid-August. Egg-laying begins about two weeks after adult emergence with the eggs deposited on the trunk at or near the base of plants. A single female can lay between 500 to 600 eggs, with eggs hatching in about nine days.

Caterpillars tunnel into the bark and are 1 to 1¼ inches long and yellowish-white with a dark-brown head. Peachtree borer caterpillars overwinter under the bark and pupate in the spring. Empty pupal cases may be seen protruding from the bark at the base of the tree. There is one generation per year.

Insect and Mite Pests of Fruit Crops

Management

Management of insect and mite pests of fruit trees calls for a holistic approach that alleviates damage by implementing proper cultural, sanitation, mechanical, and pesticide practices, and preserves natural enemies.

Most insect and mite pests respond favorably to fruit trees that are overfertilized or stressed through overwatering or underwatering. Maintain plant health and apply only the amount of fertilizer needed based on plant needs and soil test results. This will prevent the buildup of twospotted spider mite populations.

Removal of weeds within the fruit orchard and surrounding areas will minimize migration of insect and mite pests. Many weed types serve as reservoir for specific insect populations. Spraying trees forcefully with water a couple of times per week may be effective in quickly removing all life stages (e.g., eggs, larvae, nymphs, and adults) of the twospotted spider mite.

Pheromone traps can be used to detect the presence and activity of adult codling moths. In general, eggs hatch within 10 to 16 days of adult emergence, but this varies depending on temperature. In orchards with low codling moth populations, the initial pheromone trap catches may not be a reliable indicator of first adult emergence compared to trap catches in orchards with higher populations of codling moth.

A non-pesticidal management strategy for dealing with the oriental fruit moth involves removing all fruit at harvest. Collecting and disposing of infested fruits may prevent moths from emerging. Insecticides must be applied before caterpillars enter the fruit. Use pheromone traps to capture adults, which will help in timing insecticide applications.

Pesticides (insecticides or miticides) may be used when necessary to regulate populations of the insect and mite pests discussed on pages 33–35. To protect fruit trees from damage, most pesticides should be applied early in the season. Insecticides must be applied to trees before eggs hatch into young caterpillars.

Apply as soon as pests are present or active, or at the first signs of leaf or fruit damage. More effective regulation occurs when pesticides are applied when immature stages (larvae or nymphs) are present. Young or immature stages are killed more easily than adults. Afterward, regularly monitor fruit trees to determine if or when another application may be required. San Jose scale populations may be managed by applying dormant oil sprays.

The frequency of pesticide applications required for regulation of insect or mite pest populations depends on several factors, including life stages present and migration of adults from weeds or other plants in adjacent fields.

For both insecticides and miticides, it is important to thoroughly cover upper and lower leaf surfaces because the life stages (e.g., eggs, larvae, nymphs, pupae, and adults) may be present on both, depending on the insect or mite pest. Apply insecticides when caterpillars are small and before plant damage is evident. For peachtree borer management, insecticides should be applied to the base of trees before caterpillars enter.

Study Questions

These study questions are designed to help you learn the material on pages 33 through 37.

1. *This caterpillar is the familiar "apple worm" but also attacks pear, crabapple, and English walnut. Which insect is it?*

   a. codling moth
   b. San Jose scale
   c. plum curculio
   d. peach tree borer

2. *The San Jose scale is best managed by:*

   a. spraying all four sides of the tree.
   b. applying oil.
   c. picking of the scales.
   d. cutting off affected parts of the tree.

3. *San Jose scale are usually found ________ of the apple tree.*

   a. on leaves
   b. on the roots
   c. beneath loose bark
   d. on fruit

4. *Bronzing of apple tree leaves is caused by the:*

   a. codling moth.
   b. European red mite.
   c. San Jose scale.
   d. plum curculio

5. *The adult plum curculio overwinters:*

   a. in debris in and around the orchard.
   b. in bunch grasses.
   c. in plum trees.
   d. underground around fruit trees.

6. *One of the most destructive pests of peach trees is:*

   a. peach tree borer
   b. plum curculio
   c. diamondback moth
   d. gypsy moth

7. *This insect pest that attacks most orchard fruits, but prefers peaches is the :*

   a. plum curculio
   b. codling moth
   c. oriental fruit moth
   d. gypsy moth

9. *__________ is important in the management of fruit insect and mite pests.*

   a. plant health
   b. overwatering
   c. overfertilization
   d. none of the above

Insect pests pose a perennial threat to vegetable production. Some pests feed on seedlings. Others attack growing plants and consume foliage or fruit. Uncontrolled insect pest populations are capable of destroying various crops. Continual monitoring and pest management is a demanding chore.

Healthy, vigorously growing plants are better able to withstand insect attacks. Proper irrigation, fertilization, and weed removal can help minimize insect injury.

To manage insect populations, vegetable plants should be inspected frequently. When damage is detected, the proper pesticide (insecticide or miticide) should be applied at the labeled dosage to reduce the pest population to an acceptable level. Thorough coverage of all plant parts is essential for achieving control.

Because insecticides used on vegetables do not have lasting effects, additional treatments may be needed when populations resurge. Excessive insecticide applications should be avoided to prevent plant injury and too much residue on crops. Minimal use of insecticides also helps conserve populations of naturally occurring beneficial parasitoids and predators.

Insect and mite vegetable pests can be categorized according to where they are found and how they feed.

Soil Insects and Other Pests

Soil insects include those whose immature developmental stages are found in the soil. They attack ungerminated seeds, reducing stands, or feed on underground portions of tender young plants. They leave feeding scars or create tunnels in true root crops (carrots, beets, turnips, rutabagas, radishes and parsnips) as well as potatoes. The two major pests in this group are wireworms and white grubs.

Wireworms

Wireworms are the larval stages of click beetles. Click beetles are elongated flattened beetles with large movable prothoraxes and pointed posteriors. While there are more than 800 species of click beetles in North America, few are cause for economic concern. Click beetle larvae/wireworms possess six short legs, have a hard shiny body, and are slender, cylindrical and yellow-to-brown. Larvae are especially numerous in weedy (grassy) fields and gardens or newly established areas previously in sod.

Wireworms are primarily a tunneling pest of root and tuberous crops, including potatoes. On potato seed pieces, wireworm feeding provides entry sites for soilborne pathogenic organisms, which cause seed pieces to decay and fail to produce plants. Those that do develop may be weakened, resulting in poor yields. Additional wireworm damage may create wounds that allow soft rot organisms to enter, which may reduce storage times.

Wireworm

May Beetle

Under favorable conditions, the life cycle of most common wireworms requires three to four years to complete. Wireworms overwinter in the soil either as partially grown larvae or newly formed beetles in earthen cells. As soil warms in the spring, beetles move to the surface. Click beetle adults are not a concern. After emerging from the soil and mating, the female burrows back into the soil and deposits eggs up to several inches deep. Some females may not lay all the eggs in one location. Rather, they fly to a nearby area, reenter the soil, and continue egg laying. This may result in spotty infestations.

During the second and third years, wireworm larvae cause severe feeding damage. During the third or fourth years, mature larvae transform to fragile pupae in earthen cells. After approximately three to four weeks, pupae change to adults and remain in earthen cells until the following spring. Because of their extended developmental cycle, all wireworm stages may be present in the soil during the growing season.

White Grubs

White grubs are the larvae of May/June beetles, which have a three-year developmental cycle. Adults live a few weeks during which they mate and deposit eggs in the soil. Larvae hatch, and grubs remain small and are not a concern for the first summer. After overwintering as second growth-stage larvae, they ascend the next spring and continue development. During the second summer, they grow large and are capable of inflicting damage. By summer's end, large larvae in the third and final growth stage descend again into the soil to overwinter. In the spring of the third year, larvae feed for a short time early in the season but are not considered a serious pest. They then descend deeper into the soil where they pupate. New beetles emerge from the pupa but remain in the soil throughout fall and winter. They emerge from the soil the next spring to mate and deposit eggs for the next generation.

As with wireworms, white grubs are numerous in weedy (grassy) fields or gardens or newly established fields or gardens previously in sod. Although capable of stretching out as they move, they are most commonly seen as c-shaped larvae with brown head capsules. White grub damage is similar to that described for wireworms.

Slugs

Slugs are not insects but are classified as mollusks, related to oysters and clams. They are brown and 1½ to 2 inches long. But some slugs may be up to 5 inches long. Slugs lay clusters of translucent, pearly shaped eggs under debris or buried beneath the soil surface. They can lay between 20 to 100 eggs several times per year. Slugs may damage some vegetables by feeding on tender foliage or leaves, and can cause serious damage to young plants such as lettuce. Slugs feed at night and leave slime trails that glisten during the day.

Sowbugs and Pillbugs

Sowbugs and pillbugs are not insects but are closely related to crayfish and crabs. Both sowbugs and pillbugs are about ⅜ inch long when fully grown. They are grayish to black and have seven pairs of legs. Sowbugs have two small, tail-like appendages located at the end of the body. Pillbugs do not have these appendages. Sowbugs and pillbugs are distinctly segmented. Pillbugs are capable of rolling into a ball when disturbed, whereas sowbugs do not. Sowbugs and pillbugs feed on young, tender vegetation or fruit and can cause damage to beans, lettuce, and other vegetable crops. They primarily feed at night. Both sowbugs and pillbugs require moisture for survival because they cannot control water loss from their bodies. Adults can live up to two years or more.

Sucking Insect and Mite Pests

Sucking insects include those with mouthparts modified into needle-like stylets capable of piercing a host plant's epidermis and withdrawing fluids. At the same time, salivary secretions injected into plants may clog vascular elements or cause distorted growth. Introduction of plant pathogenic organisms may cause plant decline. These feeding activities may result in a loss of plant vigor, stunted plant growth and reduced quantity and quality of produce.

Squash Bug

The squash bug *(Anasa tristis)* withdraws sap from the leaves and stems of squash, pumpkin and related crops. Winter varieties of squash, such as Hubbard, are most susceptible to squash bugs. Leaves wilt rapidly, becoming blackened and crispy. Early in the growing season, vine crops are easily killed by squash bugs. On older plants, one or more runners may be damaged or killed. Young squash bugs or nymphs usually are found in clusters feeding on the leaves, stems, and fruits.

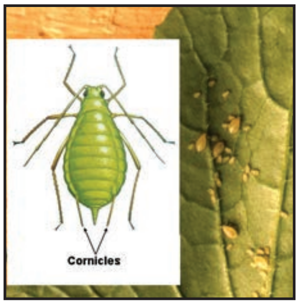
Adult squash bugs are brownish-black insects about ⅝ inch long. When newly hatched, a nymph possesses a dark head, antennae, thorax and legs. The abdomen is green. As nymphs develop, their bodies become distinctly grey. Both the adults and nymphs emit a disagreeable odor when disturbed or crushed.

Squash bugs overwinter as adults in protected places under debris, piles of boards, and packing crates, and also in buildings. They leave hibernation sites in late spring and fly to fields of squash or related crops, where they feed. After mating, eggs (1⁄16-inch long and light to dark brown) are deposited in clusters, usually on the undersides of leaves, but also on stems. Nymphs emerge in one to two weeks and remain clustered for a short time. They become adults in about five weeks. There are two generations per year.

Aphids

Aphids are small, soft-bodied insects that withdraw sap from leaves, stems, blossoms and pods of host plants. Heavily infested plants become stunted and may have distorted growth. Aphids are

Squash Bug



Aphid

notorious for the transmission of several important plant diseases.

Found singly or in clusters, aphid species vary in color. Cabbage aphid *(Brevicoryne brassicae)* is green to gray or powdery blue. Potato aphid *(Macrosiphum euphorbiae)* pink to green; melon aphid *(Aphis gossypii)* green to black; pea aphid *(Acyrthosiphon pisum)* green; and bean aphid *(Aphis fabae)* almost black. But aphids vary in color depending on the plant type fed on, so color should never be used to identify aphid to species.

Aphids overwinter as either eggs or adults. Aphids emerge or hatch in the spring, mature rapidly and give birth, without mating, to living young. Mature aphids may be wingless or winged. Winged aphids migrate to cultivated crops during the spring and summer where they start new colonies. Only females are produced during the summer, and due to their rapid reproduction rate, tremendous populations may develop in a short time. Aphids may be a continuous problem throughout the season.

With the approach of cooler weather and shorter fall days, both male and female forms are produced. Mated females deposit eggs that overwinter.

Leafhoppers

Leafhoppers are small wedge-shaped insects. Several different species attack certain vegetable crops. In addition to withdrawing plant fluids, phytotoxic saliva injections may cause yellowing, leaf-curling, and stunting. The nymphs and adults may be present on plants simultaneously. Leafhoppers are mobile when disturbed. Several species of leafhoppers also transmit plant pathogenic diseases.

Stink Bugs

Various species of stink bugs are commonly encountered on vegetable crops. Some are harmful to plants, such as the green stink bug *(Acrosternum hilare)* and harlequin bug *(Murgantia histrionica)*, while the spined stink bug *(Anaspis erythrocephala)* is a beneficial predator of certain plant pests. Stink bugs feed on the fruit of a wide-range of plants, including beets, beans, peas, squash, tomatoes, and corn. Stink bug feeding causes fruit to become shriveled and deformed. Insecticides should be applied when stink bugs are present and at the first signs of foliage or fruit damage.

Thrips

Thrips are small (2.0 mm long) insects that feed on tender plant tissue. They withdraw plant fluids with their piercing-sucking mouthparts causing stunted and deformed growth. Thrips are usually a problem on seedlings but may attack plants at any growth stage. Thrips also feed on certain weed species around or adjacent to vegetable crops.

Twospotted Spider Mite

The twospotted spider mite *(Tetranychus urticae)* feeds on a wide variety of plants and is one of the most common mites attacking vegetables, especially tomatoes, cucurbits, and beans. The adult female is pale to dark green with conspicuous dark spots on each side of the abdomen, which is the result of food showing through the transparent body wall.

Eggs are spherical, clear, and colorless when laid. They become opaque and ivory just before hatching. The emerging larva is colorless at first, turning green after feeding. Both nymphal stages are green to pale yellow in color. Twospotted spider mites usually overwinter as adult females in nearby debris. Overwintering females are pale orange to straw-colored and active, although they do not produce eggs during the winter. Twospotted spider mites are typically present on the undersides of plant leaves. Webbing is visible to the naked eye and all life stages occur in and beneath the webbing. Many female mites may be present on each infested leaf. Infestations usually begin near a leaf vein, spreading rapidly to nearby leaves and plants, depending on environmental conditions such as temperature.

The rate of population increase is highly dependent on the weather. Dry, hot weather (80 to 90˚F) is most favorable for mite development and reproduction, and may intensify feeding damage to plants. A single female mite produces from two to 20 eggs per day for a total of about 150 to 200 eggs during a two- to three-week lifespan. In general, development from egg to adult takes from five to 15 days.

As the host plant becomes seriously damaged, leaves turn yellow and brown, and mites begin to migrate to uninfested plants. Migrating mites occasionally form long chains of individuals hanging from the plant. Individual mites drop from the chains and walk or are carried by wind to other plants.

Feeding usually takes place on lower leaf surfaces, but they occasionally feed on upper leaf surfaces. Feeding by light to moderate infestations causes stippling on upper leaf surfaces. As feeding continues and mite populations increase, leaves become lighter in color as a result of the mites removing the chlorophyll (green content) from leaf tissue. Heavily damaged leaves turn tan or bronze, dessicate, and usually die. Twospotted spider mite populations may be a problem throughout the season, especially when temperatures are 80˚F or higher.

Twospotted Spider Mite

Vegetable Crop Pests

Corn Earworm Larvae

Corn Earworm Moths

Chewing Insects

Chewing insects may cause more damage to vegetables than either soil or sucking pests. They feed on all parts of plants, consuming both foliage and fruit. A wide range of chewing insects attack plants, including grasshoppers, leafminers, beetles, and numerous caterpillars.

Corn Earworms

The corn earworm *(Helicoverpa zea)* is considered a serious pest of sweet corn with feeding generally confined to the tips of the ears. While the total amount of corn consumed is negligible, the presence of caterpillars, their wet fecal pellets and associated soft rots may be repulsive to consumers who expect worm-free ears.

Corn earworms vary from light green, pink to brown, or nearly black. They are marked with alternating light and dark stripes extending the length of the body. The head capsule is yellow and the legs are dark or nearly black. Corn earworm also attacks tomatoes and beans, which is why they are called tomato fruitworm and bean podworm.

Moths vary in color. They are attracted to green silks upon which they deposit eggs mainly at dusk and during the evening hours. Eggs hatch in two to 10 days. Young larvae immediately move down to the eartips seeking protection under husks. They then begin feeding on the kernels. Larvae are cannibalistic, which accounts for finding a single worm per ear. Fully mature caterpillars drop to the ground and pupate in the soil. There may be two or three generations in Kansas.

Striped and Spotted Cucumber Beetles

Cucumber beetles are chewing insects that attack crops such as cucumbers, beans, melons, squash, and pumpkin. Cucumber beetles are particularly destructive to emerging seedlings that are emerging through the soil surface. Later in the season, adults feed on leaves, blossoms, and fruits. The larvae feed on roots and tunnel into underground parts.

The striped cucumber beetle *(Acalymma vittatum)* is about ⅕ inch long and has a black head, yellow thorax and striped yellow and black abdomen. Larvae are slender, white with brown heads, and measure ⅜ inch fully grown.

The spotted cucumber beetle *(Diabrotica undecimpunctata howardi)* is about ¼ inches long and has a black head and black legs. Its body is yellowish-green, with 12 distinct black spots on the wing covers. When fully grown, larvae are ½ inch long.

Both striped and spotted cucumber beetles overwinter as adults sheltered around the edges of fields or woodlots. Only striped cucumber beetles overwinter in large numbers in Kansas. Most spotted cucumber beetle adults migrate from the south. After leaving hibernation sites in the spring, beetles feed on nearby vegetation before appearing in large numbers on vine crops. Females deposit eggs in the ground near the base of plants on which they are feeding. Larvae feed for two to four weeks on the roots of host plants. Depending on weather conditions, there are one to two generations per year.

Overwintered striped cucumber beetles transmit bacterial wilt disease and mosaic, two serious diseases of vine crops. Either the diseases or feeding injury can cause serious damage resulting in complete crop loss.

Cabbage Caterpillars

Extensive populations of certain caterpillars can completely defoliate cabbage and other cole crops. They may consume cabbage heads near the base of the plant, which protects them from exposure to insecticide applications. Feeding injury causes a decay of the head and general poor appearance of the cabbage. The presence of the caterpillars and their frass may contaminate other cole crops, such as broccoli. Caterpillars may be a problem throughout the season.

There are three species of caterpillars that primarily attack cole crops: the imported cabbageworm, the cabbage lopper, and the diamondback moth.

Imported Cabbageworm

Imported cabbageworm *(Artogeia rapae)* is a velvety greenish caterpillar reaching 1¼ inches in length when full grown. Imported cabbageworms overwinter as chrysalids attached by strands of silk to old cabbage stalks or adjacent debris. During warm periods as early as March, white butterflies emerge and can be seen flying in search of hosts plants upon which to lay eggs. Elongated yellow eggs are primarily deposited on the undersides of leaves. Eggs hatch within a week, followed by rapid larval development in two to three weeks. In Kansas, there are three to four generations each year.

Cabbage Looper

The cabbage looper *(Trichoplusia ni)* is green and approximately 1½ inches long, with stripes along the back and sides. They tend to move in a looping motion. Caterpillars hibernate in a silken cocoon on old cabbage stalks or debris on the ground. The adult is a dark-brown moth that emerges from the cocoon in the spring and is primarily active at night. Females deposit pale yellow to white, round eggs on the undersides of leaves. Caterpillars emerge from eggs in about 10 days and are full grown in two to four weeks. They produce up to three generations per year.

Diamondback Moth

Diamondback moth *(Plutella xylostella)* caterpillars are green, very active, and about ⅓ inch long when full grown. They overwinter as adults under old cabbage stalks and plant debris. Females deposit small yellowish-white eggs on leaves. Caterpillars emerge from eggs and are full grown in about two weeks.

Cutworms

Cutworms attack almost every vegetable crop. Seedlings are particularly susceptible to cutworms because the main stem is slender, tender and easily severed. Cutworm larvae usually appear as dingy, grayish-black, smooth caterpillars that curl into a ball or c-shape when disturbed. Cutworm moths vary in color and wing patterns.

Several species of cutworms exist in Kansas. Life cycles vary considerably, but all involve an egg, larva, and pupa stage before becoming adults. Female moths

Imported Cabbageworm

Imported Cabbageworm Butterfly

Cabbage Looper Moth

Vegetable Crop Pests

Variegated Cutworm

Subterranean Cutworm

Colorado Potato Beetle Larvae

deposit eggs, which hatch into small caterpillars. The caterpillars have chewing mouthparts and damage plants during feeding. As caterpillars grow they shed their skins periodically until they reach 1 to 1½ inches long at maturity. They undergo a pupal stage, and then adult moths emerge from the pupae. Adult moths have siphoning mouthparts and feed on pollen and nectar.

Rainfall and temperature affect cutworm survival and abundance. Heavy rains may impair moths' egg laying ability. Flooding may force caterpillars to the surface, increasing exposure to natural enemies such as parasitoids and predators that can kill them.

There are two general categories of cutworms based on habitat and feeding behavior. Each category damages plants differently. One example of each category is discussed below.

Climbing Cutworms
Several species of climbing cutworms feed on the foliage, stems, and fruits of many plants. Like other cutworms, they feed primarily at night and hide in leaf litter or under boards or rocks during the day. However, feeding may occur on cool, cloudy days.

The variegated cutworm *(Peridroma saucia)* is an important climbing cutworm. In most areas of Kansas, this cutworm spends the winter as a caterpillar. The number of generations per year varies, but the generation that occurs April to July accounts for the most damage.

Subterranean Cutworms
These cutworms feed mostly below the soil surface. One important species is the black cutworm *(Agrotis ipsilon)*. This cutworm cuts a young plant at the soil surface, pulls the plant into a tunnel and consumes the entire contents. Several generations of this species develop annually. The greatest damage usually occurs from April through June when the first generation is feeding. Outbreaks of this insect frequently occur in areas that are constantly moist. The black cutworm overwinters as either a caterpillar or pupa.

Colorado Potato Beetle
The Colorado potato beetle (*Leptinotarsa decemlineata*) feeds on the leaves and terminal growth of plants such as potato, tomato, and eggplant. Potatoes are the preferred host plant. Both adult and larvae feeding may reduce yield or tuber size.

Colorado potato beetle eggs are orange-yellow, and found in clusters on the undersides of leaves. Larvae are reddish/pinkish with two rows of black spots on both sides of the body, about ½ inch long and shaped like a semicircle. Beetles are convex, ⅜ inch long and possess yellow and black stripes extending the length of the wing covers.

Colorado potato beetles produce two generations per year. Beetles overwinter in the soil. They emerge and mate in early spring. Females deposit about 500 eggs over a three- to five-week period on the underside of leaves. Eggs are laid in clusters of approximately 24. Larvae emerge in four to nine days and immediately begin feeding. Larvae undergo four instar stages in two to three weeks. They enter the soil, form a spherical cell, and then pupate. Adults emerge in five to 10 days and the life cycle is repeated a second time. Usually only the first generation is a concern. Insecticides should be applied when larvae first appear.

Stem Borers

Several types of caterpillars bore or tunnel into the stems of certain vegetables, including tomato, eggplant, pepper, potato, squash, sweet corn and bean. Plant stunting and wilting, coupled with the presence of small piles of moist excrement and plant material at the point of entry into the stem, are usually evidence of an infestation. A description of each borer type and the plants attacked is provided below.

Squash Vine Borer

The squash vine borer *(Melittia cucurbitae)* is the larva of the adult squash vine borer clearwing moth. Eggs are deposited primaily at the base of stems of squash, pumpkins, and to a lesser extent, other vine crops. The caterpillar hatches and immediately bores into the stem and feeds in the stem near the base of a runner. Caterpillars are white, wrinkled, with a brown-head. Squash vine borer damage resembles bacterial wilt disease, in which the plant exhibits symptoms of wilting but without signs of tunneling in the stems. Once a runner wilts, it is too late to save the plant.

European Corn Borer

While mainly a pest of field and sweet corn, the European corn borer *(Ostrinia nubilalis)* also attacks tomato, eggplant, pepper, and potato. Feeding may be confined to stems, but also in the fruit of pepper and corn ears. Mature caterpillars are ¾ to 1 inch long. The body is flesh-colored, and marked with small faint round spots. There are two generations per year. The damaging second generation, occurs from August through September. Sweet corn is a likely host this time of year. Infested plants have signs of shothole feeding injury on the leaves and caterpillars may be found deep within the plant canopy.

Stalk Borer

The stalk borer *(Papaipema nebris)* attacks corn, tomato, pepper, and potato. Injury is most common on plants located at the edge of fields because the caterpillars migrate in from weeds near field margins. Caterpillars are slender, creamy white, with purple stripes extending lengthwise on the body. There is a brown or purple band behind the head. Once caterpillars enter the stalks, management with insecticides is very difficult. There is one generation per year.

Leafminers

Leafminers are the immature or larval stages of small flies. The larvae feed between the upper and lower leaf surfaces, tunneling out plant tissue. They may attack spinach, pepper, and tomato. Leafminers pupate in the soil. The larvae may feed on many weed types growing around or adjacent to vegetable crops.

Blister Beetles

A number of blister beetle species attack vegetable crops, and most of these species vary in size and color. For example, some are black,

Colorado Potato Beetle

Squash Borer Larvae

Squash Borer Moth

Vegetable Crop Pests

Flea Beetles

Tomato Hornworm

some gray, some spotted, and some are striped with black and yellow. Blister beetles move in swarms and consume foliage before they are noticed. They are mostly associated with alfalfa, soybeans, potatoes tomatoes, eggplant, and beans. Blister beetles also secrete a fluid that causes blisters when in contact with the skin. These beetles should be handled carefully.

Flea Beetles

Flea beetles are small beetles with enlarged hind legs for jumping. Some are striped, but most are either black, brown, or green. They damage plants by chewing holes in the leaves. Flea beetles attack bean, pea, cabbage, carrot, eggplant, turnip, mustard, potato, and tomato. Apply insecticides when beetles are present on plants.

Tomato Hornworms

The tomato hornworm *(Manduca quinquemaculata)* is the most destructive and widespread insect pest of tomato. It is a large green caterpillar with a hard, curved horn on the back of the abdomen. Only a few large caterpillars are enough to cause significant plant damage. Apply insecticides when the caterpillars are small, and before plant damage in evident.

Melonworm and Pickleworm

The melonworm (*Diaphania hyalinata*) and pickleworm (*Diaphania nitidalis*) are insect pests with similar habits and feed on the same plant types. Young caterpillars feed on plant leaves. Later they tunnel into the stems and fruit. They can severely damage melons and cucumbers late in the season.

Webworms

The beet webworm *(Loxostege sticticalis)* and garden webworm *(Achyra rantalis)* attack many different types of vegetable crops. They spin a web on the plant and consume leaves. The beet webworm is a slender, yellowish-green caterpillar with a black stripe on the back. The garden webworm is light green to yellow and has black dots covering the body.

Grasshoppers

Grasshoppers vary in size, from ¾ to 1½ inches in length, and in color, depending on the species. Grasshopper females deposit eggs under the soil surface in pod-like structures. Each pod may consist of 20 to 120 elongated eggs. Female grasshoppers can produce between eight to 25 egg masses during their lifetime. Most grasshopper species overwinter as eggs, whereas other species may overwinter as nymphs. Eggs hatch into young grasshopper nymphs, which resemble adults. The life cycle from egg to adult takes from 40 to 60 days. But this depends on ambient and soil temperatures. After mating, female grasshoppers feed for about two weeks before they initiate egg-laying. This usually occurs from summer through fall. Grasshoppers feed on many plants, including most vegetables. Large numbers of both nymphs and adults can consume all portions of a plant. Because of their mobility, grasshoppers can migrate in from weeds around or from adjacent fields.

Management

Management of vegetable crop pests calls for a holistic approach that alleviates damage by implementing proper cultural, sanitation, mechanical, and pesticide practices, and preserves natural enemies. Most insect and mite pests respond favorably to vegetable crops that are overfertilized or stressed through overwatering or under-watering. Maintain plant health and apply fertilizer based on plant needs and soil test results. This will prevent buildup of aphid and twospotted spider mite populations.

Removal of weeds both within vegetable crops and surrounding areas adjacent to fields will minimize the migration of certain insect pests, including aphids, leafhoppers, flea beetles, thrips and most species of adult moths. Many weed types may serve as reservoir for specific insect populations. Spraying plants with water a couple of times per week may be effective in quickly removing all life stages (e.g., eggs, larvae, nymphs, and adults). This practice works best against aphids, thrips, and the twospotted spider mite.

Pesticides (insecticides and miticides) may be used when necessary to regulate populations of the insect and mite, and other pests discussed previously. Most soil insects can be controlled or regulated by applying a registered insecticide to the soil two weeks before planting. The insecticide should be applied uniformly to the soil surface and thoroughly mixed or incorporated into the soil at a depth of 4 to 6 inches. Cutworms, sowbugs, and pillbugs may be effectively dealt with by using baits that are impregnated with an insecticide and consumed by these pests. Also, insecticides may be applied directly to soils infested with cutworms before seeds or transplants are planted. But it is difficult to manage cutworms in established vegetable plantings even with insecticides.

Most pesticides need to be applied early in the season to protect vegetable plants from damage from both sucking and chewing insect and mite pests. Apply as soon as pests are present or at the first signs of leaf or fruit damage. More effective regulation occurs if pesticides are applied when nymphs are present. Young or immature stages are more easily killed than adults.

Afterward, monitor vegetable crops to determine if or when another application may be required. The number of applications will depend on several factors, including life stages present and migration of adults from weeds or other plants in adjacent fields. For both insecticides and miticides, thoroughly cover upper and lower leaf surfaces. Life stages (e.g., eggs, larvae, nymphs, pupae, and adults) may be present on both, depending on the insect or mite pest. Apply insecticides when caterpillars are small, before plant damage is evident. For corn earworm management, apply insecticides when silks first appear and treat at two- to three-day intervals until silks are dry (brown). On very early or late-planted sweet corn, applications may be necessary before silking, when adult females are laying eggs on stalks and flag leaves. During pollen shed, apply insecticides, preferably in the late afternoon, and avoid spraying tassels to reduce bee mortality.

Study Questions

These study questions are designed to help you learn the material on pages 39 through 50.

1. The three general categories of vegetable insect pests are sucking, chewing, and:

a. flying
b. biting
c. stinging
d. soil

2. ______ are the immature stage of May or June beetles.

a. wireworms
b. white grubs
c. cutworms
d. sowbugs

3. Squash bug nymphs are found in clusters feeding on leaves, stems, and fruits of squash and pumpkin plant. They:

a. damage the plants by chewing and shredding them.
b. can give humans a painful bite.
c. have a disagreeable odor when crushed.
d. are a dark gray when newly hatched.

4. The following is true of aphids on vegetable crops:

a. heavy infestations stunt plants.
b. the largest aphids are about one inch long.
c. they are usually found on the top sides of the leaves.
d. they cannot transmit disease.

5. One of the most common mites attacking vegetables, especially tomatoes, curcubits, and beans is the:

a. Banks grass mite
b. twospotted spider mite
c. brown wheat mite
d. potato mite

6. This insect group causes more damage to vegetables than do the other categories:

a. soil
b. chewing
c. sucking
d. flying

7. Cucumber beetle larvae destroy the ____________ of vegetable plants.

a. fruit
b. underground parts
c. leaves
d. blossoms

8. The imported cabbageworm caterpillar becomes full-grown in about:

a. two weeks
b. four weeks
c. six weeks
d. eight weeks

9. When disturbed, cutworms will:

a. emit a stinking odor.
b. sting.
c. curl into a ball of c-shape.
d. burrow quickly into the soil.

Vegetable Crop Pests

Study Questions

10. This distinctive yellow and black striped beetle is a serious pest in the United States and Eastern Canada. The female lays orange-yellow eggs on the underside of leaves. What is this pest?

a. Colorado potato beetle
b. click beetle
c. flea beetle
d. Mexican bean beetle

11. These caterpillars are flesh colored with light small round spots and may attack the stems of some vegetables. They commonly feed on fruit of pepper or corn. What pest is this?

a. European corn borer
b. squash vine borer
c. common stalk borer
d. southwestern corn borer

12. *The _______ is the most destructive and widespread pest of tomato.*

a. grasshopper
b. tomato cutworm
c. garden webworm
d. tomato hornworm

Crop Plant Diseases

Plant disease is a broad term that describes almost any abnormal growth pattern or disruption to normal plant function. Diseases are caused by pathogens that obtain nutrients from the living plants they infect. Every plant is susceptible to multiple diseases that are managed in an integrated fashion.

This section introduces key concepts of plant pathology while providing a few examples of important crop diseases to illustrate those concepts. A list of references is included for more information about specific diseases of major crops grown in Kansas.

Causes and Types of Plant Disease

Four major groups of plant pathogens — fungi, bacteria, nematodes, and viruses — are responsible for most of the common crop diseases in Kansas. All of these organisms are infectious and can be spread from plant to plant, causing disease outbreaks within plant populations. Understanding basic characteristics of these organisms can provide important insights into plant disease management. In the context of plant diseases, plants are referred to as hosts.

Fungi are the most common cause of plant disease in Kansas crops. Fungi consist of groups of cells that are typically arranged as tiny threadlike filaments. As fungi grow, they produce large numbers of these filaments that form the visual structures commonly referred to as molds or mushrooms. Unlike plants, fungi are not able to produce their own food through photosynthesis, and most fungi obtain food through the decay of dead plant material. Unfortunately, some fungi also attack living plants, resulting in disease.

Fungi can enter plants by mechanically forcing their way into their potential host or by using enzymes that weaken natural defenses. Other fungi enter plants through natural openings such as stomata, which are small pores that allow gas exchange in leaves or stems. This infection process is favored by extended periods of high relative humidity or the presence of dew on plant surfaces. Once inside a susceptible plant, the fungi begin to feed on and colonize plant tissue. The fungi obtain nutrients by producing toxins that damage plant cells, or by inserting specialized feeding structures directly into the cells.

Fungi reproduce through the production of spores, which function much like the seeds of flowering plants. Many fungi have the capacity to reproduce with or without the genetic recombination afforded by sex, and can produce thousands of spores every day. These spores are typically produced by specialized reproductive structures or fruiting bodies of the fungus.

The spores are spread throughout the environment by wind or the splashing produced by raindrops. Insects and farm equipment can also move fungal spores to neighboring plants. Many fungi that cause disease survive between growing seasons within colonized plant debris or by initiating specialized resting structures.

Crop Plant Diseases

Bacteria are single-celled organisms that are much smaller than fungi. Most bacteria have a cell wall that determines shape and may produce a slime coat that can improve survival in adverse conditions. Bacteria often have tiny whip-like appendages that help the bacteria move short distances in water or other liquids.

Bacteria reproduce by "fission," meaning one cell divides into two identical daughter cells. Bacteria can multiply extremely quickly, going from one cell to a colony of a million cells, sometimes in less than a day.

Many bacteria enter plants through wounds or natural openings in the plants when conditions for infection are favorable. The invasion of the plant by bacteria typically requires extended periods of warm, moist weather. Once inside the plant, the bacteria often produce enzymes or toxins that destroy plant cells. Bacteria generally can only move short distances themselves but are easily moved by splashing rain, insects, and contaminated tools used in plant propagation and pruning. Some bacteria can survive on plant surfaces for only short periods of time, while others can survive for months as decay organisms in the soil.

Viruses are tiny particles composed of nothing more than their genetic material (DNA or RNA) surrounded by a coat made of protein. Viruses depend on the cells of a susceptible plant for reproduction. Virus particles readily move from cell to cell within plants and often spread through the plant's vascular system, which brings nutrient rich sap to the plant's own cells.

This ability to move with the sap is also critical in spreading viruses to other plants, and contact with sap from infected plants can transmit the virus to a healthy plant. Contaminated pruning tools or direct contact of wounded plant tissues are two ways infected sap can be spread from plant to plant. The mechanical spreading of viruses is common in the propagation of woody plants including fruit trees and grapevines. The spread of plant viruses can also result from the feeding activities of insects, mites. or other organisms. Any organism that spreads a pathogen is generally referred to as a "vector." These vectors are so important to the spread of plant viruses that control of many viral diseases depends on managing the vector population.

Plant viruses generally do not survive for more than a few days or weeks without a living host plant. The seasonal break between annual crops that occurs when one crop matures and another has not yet been planted can serve as a natural barrier to plant viruses. The effectiveness of this break between crops is compromised if the virus is allowed to persist in weedy or volunteer plants. Weeds can also be important reservoirs of virus in new plantings of perennial crops.

Nematodes are microscopic, non-segmented, roundworms. These tiny worms are common and can be found in nearly every environment. In the soil, most species of nematodes feed on bacteria and other small life forms. Approximately 10 percent of nematodes are plant pathogens. Nematodes that feed on plants have a needle-like feeding structure called a stylet, which is used to pierce and ingest the contents of plant cells, similar to inserting a straw into a drink and then sucking up the liquid.

Most nematodes have a simple life cycle. They begin as eggs. This is followed by two juvenile stages and the adult stage. Reproduction occurs when nematodes reach the adult stage of their life cycle. A single female can lay hundreds of eggs and the entire life cycle (egg to adult) can be completed in several weeks. Most nematodes feed on plant roots, and high populations can severely damage a root system.

Most nematodes do not persist in the soil for extended periods of time and are vulnerable to cold and dry conditions. The population of plant pathogenic nematodes will drop rapidly in the absence of a susceptible crop. Crop rotation in annual crops can be an effective means of keeping nematode populations below damaging levels, but some weeds can reduce the effectiveness of these rotations. Nematodes can move only short distances through soil, but can be moved long distances by human activities. The long distance movement of nematodes is often associated with infested soil that can contaminate clothing or field equipment, irrigation water, or plant parts used for propagation (i.e., bulbs, rootstocks, tubers).

Recognizing Diseases

Plant diseases are recognized by visible changes to plant growth that they cause. These visible expressions of disease by the plant are called symptoms and include spots, cankers, galls, wilts, mosaic patterns, stunting or other deformities. In some cases, the pathogen will produce structures that can be seen with an unaided eye. Other pathogens can only be seen with a hand lens or microscope. These visible pathogen structures are considered signs of the disease.

Crop Plant Diseases

Damping-off

Leaf Spot

Leaf Spot

Diseases and Symptoms

Seed decay and damping-off occur when fungi or other pathogens attack a plant shortly after planting. These diseases often occur when adverse weather conditions slow germination or the early stages of seedling growth. In some cases, the seed is destroyed by the pathogens before germination takes place. This destruction of seed is generally referred to as seed decay. Seedlings are vulnerable to attack by many soilborne pathogens during germination and emergence. Damping-off occurs when pathogens destroy the root and stem tissues of the seedlings. Preemergent damping-off occurs when seedlings succumb to disease shortly after germination but before emergence from the soil. Postemergence damping-off occurs when the young plants develop stem lesions at the soil-level. The destruction of the stem tissue causes plants to fall over and die rapidly.

Spots, blotches, and blights are commonly associated with fungal and bacterial diseases of leaves and fruit. The term "spot" is generally used for lesions that remain confined in a localized area of the plant. The terms "blotch" and "blight" describe lesions that rapidly expand to destroy large portions of the infected leaves or fruit. Leaves and fruit may also develop abnormal color patterns in response to viral disease. These color patterns include symptoms such as ring-spots and mosaics.

Powdery mildew and rust diseases can be readily identified by visual evidence of the pathogens. The fungi that cause powdery mildews remain on the upper surfaces of leaves. This superficial growth of the fungus gives the leaves a powdery-white appearance. Rust diseases are named for the powdery orange-to-brown spores produced by the fungi that cause this type of disease.

Wilt diseases destroy or reduce a plant's ability to absorb and distribute water. Drought and many other problems also can cause plants to wilt, and it is often necessary to examine plants for additional symptoms to make a definitive diagnosis. Discoloration of vascular tissues or roots often helps confirm the cause of wilting.

Cankers often inhibit normal formation of wood and bark, resulting in sunken or discolored portions of the twigs, branches or trunk. The affected portions of woody plants, such as fruit trees or grapevines may die if a canker enlarges enough to completely encircle a branch or trunk. Stem lesions on herbaceous plants are also referred to as cankers.

Root rot diseases occur when healthy roots are invaded by a pathogen. Early symptoms are usually hidden below ground. Adverse environmental conditions such as drought, freezing, or poor drainage can predispose plants to root rots and decay organisms. The feeding activity of nematodes or insects also increases the risk of some root rot diseases because of the wounds they create. *(Photos on page 58.)*

Abiotic Disorders

Abiotic plant disorders often cause symptoms that resemble plant diseases. Abiotic disorders are sometimes referred to as physiological disorders or environmental stresses. Some of the most common abiotic disorders in Kansas are caused by extremes in temperature, moisture, or fertility. Disorders may also result from poor site selection, soil compaction, and chemical toxicities. In addition, abiotic disorders can weaken plants and increase their susceptibility to diseases caused by pathogens. Understanding the normal growth of various plant types will often help identify abiotic disorders and facilitate the differentiation from disease.

Temperature

Each plant species has an optimal temperature range, and exposure to temperatures outside that range can be stressful. In Kansas, rapidly fluctuating temperatures disrupts normal metabolism. For example, a warm spell in winter can cause a plant to emerge from dormancy prematurely, or an early fall frost can harm plant tissues that have not adapted to cold temperatures.

Peach trees are frequently damaged by cold winter temperatures, and this injury can make trees more prone to cankers. Vegetable plants such as tomato may fail to set fruit if temperatures are too hot or too cold at flowering. Likewise, grain sorghum will not pollinate when nighttime temperatures drop below about 55^0 F.

Moisture

Water is essential for plant growth, but too much or too little can be damaging. Excess water depletes the oxygen supply to roots. As root health deteriorates, the plant cannot take up enough water and nutrients. This condition is sometimes referred to as "wet feet," and certain plants are more vulnerable than others. Wet soils can also trigger certain root rot pathogens that are adapted for dispersal in saturated soil.

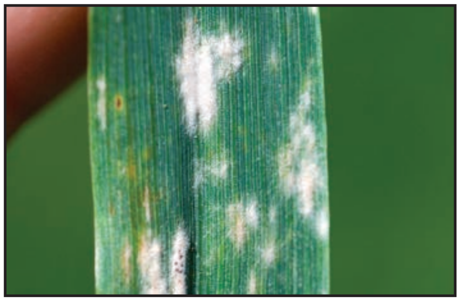
Fertility and Soil

Plants need the correct amounts of essential nutrients such as nitrogen, phosphorus, potassium, and a few minor elements including iron, sulfur, and zinc. These nutrients can come from the soil or from fertilizers — manufactured products as well as natural organic sources such as manures and compost — added to the soil. Fertility imbalances are damaging, and some fertility issues can mimic diseases.

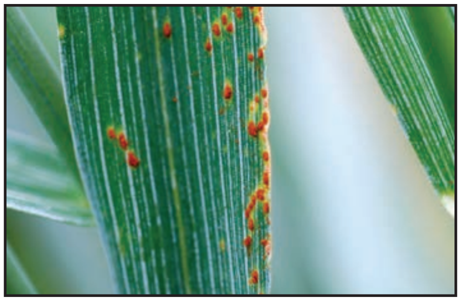
Chemical Injury

While pesticides and fertilizers can enhance plant health and lead to yield and quality benefits, misapplication can result in injury. Chemical injury to plants is referred to as phytotoxicity and it can be caused by several sources.

Herbicide drift, carryover, and spray tank contamination: Herbicides can drift from a neighboring field onto a nontarget crop. They can also persist in the soil from one crop to the next if cropping restrictions are not followed. Crop damage can occur



Powdery Mildew



Rust

Canker

Canker

Root Rot

Root Rot

Cold Injury

Nutrient Deficiency

if the spray tank is not adequately cleaned between use of different products. Herbicides are discussed in depth in another chapter.

Inappropriate rates: Pesticides can be applied at rates that are toxic to the plants. It is important to read the label and calibrate equipment to ensure proper application rates.

Incompatible tank mixes: Pesticides that are safe when applied alone can be highly phytotoxic when applied in combination. A classic example of this is when the fungicide captan is applied in a tank mix with oils, compounds that are commonly used in fruit pest and disease control. This mixture is so phytotoxic that these compounds should not be applied within 14 days of each other, and labels often advise against such mixtures. Read the label for advice on incompatibility.

Disease Management

Managing plant diseases requires an understanding of the plant, the environment, and potential pathogens in the area. Integrated pest management (IPM) should serve as the foundation for disease management whether in a crop field, orchard, greenhouse, nursery, or home landscape.

IPM has been defined in many different ways, but the general message is that management of plant health takes a holistic, common sense approach that uses host resistance and cultural methods as the foundation of disease control. Pesticides should be used only when the economic benefit is greater than the loss that will be incurred if they are not used. This is commonly known as the economic threshold of damage.

When organic growing methods are employed, only certain disease control materials may be used for pest control. Some "natural" pesticides can be used in organic growing, and there are lists of such products available online. One source of information is *www.omri.org* (Organic Materials Review Institute), but growers interested in organic production should check with their particular certifier.

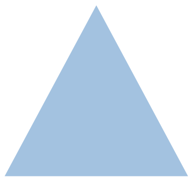
Foundation

Understanding the biology of plant diseases is critical to identifying appropriate disease management strategies. Plant pathologists often use diagrams to help conceptualize the critical stages of pathogen biology or illustrate the interaction between pathogen, plants, and the environment that result in disease.

The "plant disease triangle" is often used to identify factors that are important for disease development. In the plant disease triangle, the three sides of the triangle represent 1) the presence of a viable pathogen; 2) a susceptible host; and 3) an environment that favors disease. All of these factors must be present for disease to occur. When developing management strategies, it is important to consider all three parts of the disease triangle. For example:

- **Pathogen:** What strategies can be used to prevent the introduction of a pathogen to a field? How can chemicals be used to reduce pathogen growth?

- **Host:** Are resistant varieties or hybrids available?
- **Environment:** Are there cultural practices that can make the environment less favorable for disease?



Diagrams of disease cycles are also used to illustrate pathogen survival, movement, infection, colonization, and reproduction. Knowledge of these processes can provide important insights into management strategies that are important for a given disease. For example, if a pathogen is known to survive in the debris of a previous crop, debris removal may reduce the risk of severe disease in subsequent years.

Pathogen Exclusion

Quarantines can be an effective way to eliminate the introduction of a pathogen into a geographical area. This is particularly useful for diseases that may be moved by human activity such as the importation of foreign plant materials that may be infected with a disease not known to occur in the United States. Often, native plants have no resistance to these new diseases, or there may be no natural enemies of disease spreading insect vectors. Some of the worst plant disease epidemics, including Dutch elm disease, chestnut blight, and soybean cyst nematode were introduced from abroad.

Start with Clean Planting Material

Using clean, disease-free seed or propagating materials is the first step to disease management. This includes using seed from reliable sources such as certified seed producers. Hot water treated seed can eliminate bacterial pathogens on some vegetable seeds, but this can reduce germination, increasing seed costs. Fungicide-treated seed can be used to eliminate pathogens in or on the seed and to provide a zone of protection around the germinating seed in the soil. For example, fungicide seed treatments are an effective means of managing the common bunt of wheat. For vegetatively propagated plants, only use cuttings from reliable sources should be used. Inspect transplants carefully for unusual symptoms on foliage or roots. Use clean pots and sterile soil because some pathogens can survive in contaminated soil and pots.

Sanitation

Weeds, crop debris, volunteer plants and previously infected plants can harbor some plant pathogens as well as insects that spread certain plant diseases. Wheat streak mosaic, for example, is known to persist in volunteer wheat and several grassy weeds. In greenhouse, garden, or nursery locations, remove infected plants or plant parts such as foliage, fruit, or blossoms that may allow pathogens to survive between crops or planting cycles. Do not pile plant debris near the garden or greenhouse — remove it from the site, or burn it. Prune out infected twigs and branches on woody plants such as fruit trees

Herbicide Injury

or grapevines. Again, be sure to remove pruned tissue from the site so it does not serve as a source of new infection. Clean up soil and other debris in potting areas.

Host Resistance

Use of disease resistant or tolerant cultivars, when available, should always be one of the first lines of defense in developing pest management strategies. Terms such as resistance and tolerance are all used to describe a plant's reaction to plant pathogens. Resistance to plant disease among types of plants and varieties of the same crop may also be variable. In some cases, resistance is complete: the variety does not become infected. In other cases, resistance is not complete and the cultivar can be infected at low levels. The term "tolerance" is used to describe a variety that is minimally affected by the pathogen, even though it develops disease symptoms similar to plants with low or moderate levels of resistance.

Seed company and garden catalogs are a good source when looking for information about a variety's resistance to specific diseases. Soybean seed companies for example, indicate the "field tolerance" of a variety to Phytophthora root rot when listing the variety's characteristics. Kansas State Research and Extension also provides this type of information in Extension publications such as *Wheat Variety Disease and Insect Ratings*, MF-991.

Cultural Practices

Avoid Problematic Sites

Avoid planting susceptible varieties into sites with a history of disease problems. For example, if a certain kind of plant is highly susceptible to root diseases that are favored by saturated soils, do not plant it into locations with poor drainage. Choose the "right plant for the right place" based on drainage, soil type, shade, etc. If preparing a new planting, take the time to sketch out a map, considering shade, slopes, etc.

In agronomic situations, drainage can sometimes be improved to reduce problems from diseases such as Phytophthora root rot of soybeans or downy mildew of sorghum. Additionally, irrigation can be used to successfully manage charcoal rot, a disease favored by hot, droughty soils.

Tillage

In agronomic field situations, infected crop residues can be brought into contact with the soil with varying degrees of tillage allowing it to be more quickly degraded by soil microorganisms. Fire is sometimes used to remove crop residues and pathogens that survive in association with the residue. These tillage or burning practices must be balanced with needs for soil conservation, which often discourage the destruction of crop residues.

Manage Moisture and Humidity

Frequent rains, wet soils, and high relative humidity can favor many plant diseases. For some fruit and vegetable crops, opening up plant canopies by staking or trellising will change the canopy structure, keep plants off of the ground, and allow for greater air movement. Similar changes to canopy structure can be achieved in crop plants by adjusting row spacing and planting density. These changes to the crop canopy will reduce drying times following rain or heavy dews and reduce the risk of disease. In contrast, planting in shady areas may increase drying times following rains and dew, increasing disease risk. Watering in the evening increases the period of time that leaves are wet, which can trigger the development of certain diseases, especially foliar leaf spots and blights. Whenever possible, water in the morning.

Rotate Crops to Avoid Pathogen Buildup

Plant pathogen populations tend to increase at sites where the same crop is grown for multiple years. Crop rotation, whether in a home garden or on a commercial farm, can be an effective way to manage diseases. The length of rotation required to manage a disease problem varies considerably. Some soilborne diseases such as Sclerotinia white mold and soybean cyst nematode may require rotations as long as three or four years to reduce pathogen populations below economic thresholds. Where no-till farming is practiced, rotations to control residue-borne diseases need to be long enough so debris from the susceptible crop has completely decomposed. For example, in a two-year corn-soybean rotation using no-till practices, gray leaf spot infested residue may still be present on the soil when the next corn crop is planted. Make sure that the rotational crop is NOT also susceptible to the problematic disease or the rotation will not be effective. Sclerotinia white mold, for example, has a wide host range including tomatoes, asparagus, sunflowers, and soybeans.

Vector Management

Insects or arthropods spread many plant diseases and are considered to be disease vectors. Examples of disease spreading pests in Kansas include western flower thrips, leafhoppers, soybean aphids, and the wheat curl mite. In some cases, the management of the insect or arthropod is the primary means of achieving disease control. This can be done through timely pesticide application or by removing sites where vectors persist between cropping seasons. For example, control of volunteer wheat can help reduce the risk of severe outbreaks of wheat streak mosaic in western Kansas.

Pesticides

Pesticides can be classified in a number of different ways. For instance, plant pathogen controlling pesticides are classified based on the type of organism they control. The three most common groups are fungicides, bactericides, and nematicides. Likewise, insecticides are used to control insects, and herbicides are used to control weeds. Like human pharmaceuticals, pesticides have both a technical name that identifies the active ingredient and a trade name to identify a specific commercially licensed product. Some products contain a mixture of pesticides such as two different fungicides or a fungicide and an insecticide formulated together.

Fungicides can be classified in a number of different ways. At the largest scale, they can be classified as either contact or systemic materials. This classification is based on how they interact with the plant. A contact fungicide is applied to and remains on the plant surface. Because they work best when applied before pathogen spores arrive, they are sometimes referred to as "protectants."

There are advantages to using contact fungicides. One is that they are usually effective against a broad range of fungi. A second is that they attack multiple metabolic sites within the fungus simultaneously, making it difficult for a fungus to develop resistance to this class of fungicide. A disadvantage of contact materials is that they are often not rain-fast and need to be reapplied after a rainfall event or overhead irrigation. They also must be reapplied every five to 14 days to keep new growth protected and are most effective when applied to both the upper and lower leaf surfaces. This usually requires much larger volumes of water, which increases application costs. Some examples of contact chemicals are mancozeb, maneb, chlorothalonil, captan, and copper formulations.

Systemic fungicides, as the name suggests, are absorbed into the plant. Foliar systemic fungicides are usually considered to be locally systemic, which means they will only move short distances within a leaf. For example, if the product is applied to the top of the leaf, it can move downward through the leaf to protect the bottom side as well.

Some fungicides can move from the tip to the base of a leaf or from the base to the tip. Locally systemic fungicides generally will not move from leaf to leaf within a plant. This is an important concept, particularly for wheat growers. Agronomists have calculated that nearly 70 percent of the grain fill in a wheat plant comes from the flag leaf (the last leaf to emerge). For good disease control in wheat, the fungicide must come in contact with the flag leaf. Applications before the flag leaf emerges will not protect it.

Advantages of systemic fungicides include their ability to be rain-fast. That is, once they are absorbed into the plant, they cannot be washed off by rain or irrigation water. Some systemic fungicides can be applied for curative (sometimes referred to as kick-back) purposes. Curative applications are made after the infection process has begun. This curative action is usually limited to the first 24 to 48 hours of the infection process. Curative fungicides will not be affective against severely diseased plants. Systemic fungicides are typically effective for 14 to 21 days. Because of this, they can be used effectively with disease forecasting models. This can drastically reduce the number of fungicide applications that need to be made in a season.

The curative activity of a fungicide varies with pathogen sensitivity, environment, and type of plant treated. A disadvantage of systemic fungicides is that they have a narrow mode of action, sometimes targeting a single enzyme within the fungus. The narrow mode of action increases the risk that a fungal population will become resistant to a fungicide. Individuals within a pathogen population may be less susceptible or have cellular mechanisms that render a fungicide's mode of action ineffective. Resistance is most likely to develop when fungicides with the same mode of action are applied repeatedly in a given growing season. Fortunately, different systemic fungicide groups target different metabolic processes in the fungus.

Two of the most common classes of systemic fungicides used in agriculture are the strobilurins, also known as QoI fungicides, and the triazoles, part of a larger fungicide group known as demethylation inhibitors (DMI)). All QoI fungicides share a common biochemical mode of action: they all interfere with energy production in the fungal cell. Triazoles on the other hand, work by blocking the normal development of fungal cell walls. It is generally recommended that products with different modes of action be rotated and that no more than two applications of the same mode of action fungicide be made in a single year. Combining different modes of action in a single application by tank-mixing fungicide products also can reduce the risk of resistance developing within a pathogen population. Pesticide labels often provide specific resistance management strategies for a product.

For corn, wheat, sunflowers, and soybeans, examples of commonly used strobiluron fungicides include azoxystrobin, pyraclostrobin, and trifloxystrobin. Commonly used triazoles include propiconazole and tebuconazole.

Bactericides are compounds that kill or slow the growth of bacteria. They are sometimes referred to as antibiotics. They generally have a minor role in management of bacterial plant diseases. This is because they are very expensive and repeated use results in the same type of antibiotic resistance that is familiar in humans and animals.

Nematicides are used to manage nematodes, small plant pathogenic worms found in soil and in plant roots. Nematicides generally are some of the most toxic compounds used in agriculture and for that reason, are not usually recommended. Research has shown that nematicides will reduce early season populations of nematodes to an extent that normal yields can be achieved, but nematode populations typically rebound to preplant levels or even higher by the end of the growing season. Because of this, annual applications are typically required. Nematode management therefore is usually best achieved by a combination of resistant cultivars and extended crop rotations.

Scout to Improve Disease Management

Detecting diseases or disease spreading insects in early developmental stages is critical to an effective disease management program. Effective scouting requires familiarity with the crop and the common diseases and insects in a region. A scout should also be familiar with what time of the growing season the disease is most likely to occur. For instance, in Kansas, southern corn rust usually does not arrive until late July. Disease prediction models can also help identify weather patterns that have been favorable for disease and direct regional scouting activities.

Where established, scouts should also be familiar with the economic damage threshold for a disease. For example, thresholds for gray leaf spot of corn that would trigger fungicide applications are a function of the resistance rating of the cultivar, the stage of development of the crop, the positioning of lesions within the canopy, the expected yield of the crop, the cost of the fungicide application and the expected selling price. Tools designed to help assess the potential value of fungicide treatment are available for some crops (See "Economics of spraying field crops" at *http://www.agmanager.info/crops/prodecon/decision/default.asp)*.

In summary, diligent scouting efforts, combined with the use of host plant resistance, good cultural practices, and appropriate fungicide usage will provide homeowners, commercial horticulture crop producers, and commercial crop producers with a safe and effective disease management program.

Disease Diagnosis

With so many factors affecting plant health, it can be difficult to sort out the primary causes of plant damage. Symptoms caused by pathogens can resemble damage by abiotic factors and vice versa. In many cases, multiple factors are interacting and the problem requires a holistic strategy. Becoming familiar with reliable sources of information such as books, university fact sheets, and credible websites can aid in a proper diagnosis. Local K-State Research and Extension personnel also can assist in assembling these resources. A list of references is provided at the end of this section.

When solving plant health problems, it can be helpful to ask questions that may reveal important clues. Below are some questions to keep in mind as you attempt to diagnose a problem.

Which species and cultivars (varieties) are affected? Pathogens tend to be host specific. If multiple species or multiple plant families are affected, this may be a clue that an abiotic factor is involved.

Which plant parts are affected? Check the leaves, fruit, stem, crown, and roots. Comparison with healthy plants may be helpful.

What is the spatial pattern? Check for patterns. Are all the affected plants clustered together in a patch? Are they all in the same row? Are the diseased plants randomly scattered in a field?

How is the problem changing over time?
If symptoms appeared all at once in a uniform pattern, that can suggest an abiotic stress "event" such as a sudden exposure to toxic chemicals, low temperatures, etc. If the symptoms spread over time, it is more likely to be a pathogenic problem.

What cultural practices have been used?
Consider cropping decisions such as tillage and crop rotation. Lack of rotation can lead to a buildup of pathogens. Is overhead irrigation applied that could lead to splashing of bacteria or fungi?

Are insect vectors present?
Remember that insects can spread certain diseases.

What has the weather been like recently?
Did an unusual weather event coincide with the onset of symptoms?

Are there site problems?
Look for drainage problems, soil structure, presence of hardpans, slopes, etc.

Sample Submission

A skilled field practitioner should learn about the diseases of crops managed through experience and training. The above guidelines can aid in diagnosis. But many plant health problems require diagnosis by a trained professional using specialized microscopic techniques and laboratory tests. A local extension agent can assist with difficult diagnosis problems and, if required, submit a sample to a laboratory such as the K-State Plant Disease Diagnostic Lab.

A good sample with background information is the key to the most timely and accurate diagnosis.

The Physical Sample

The type of sample needed depends on the plant and the nature of the problem. In all cases, try to collect tissue at the transitional area between healthy and damaged areas. That zone, the "leading edge," is where pathogens are most active and most readily found. In tissues that are already far in decline or dried out, it is difficult to find the true pathogen among all the competing saprophytic (dead-tissue-eating) organisms in the decaying tissue.

If possible, send roots. For some tests, the diagnostic lab absolutely needs roots to make an accurate diagnosis. If the plant is small, dig up the entire plant, tie a plastic bag around the root ball, and place another plastic bag around the entire sample. For woody plants send several branches that are at least 12 inches long.

Packaging and Mailing

Pack the sample in a crush-proof container such as a padded envelope or a box with packing material. If possible, send the sample early in the week so that it does not spend a long weekend in a hot postal truck.

Background Information

Equally important to the physical sample is background information describing the patterns, plants involved, timing — all of the information in the "diagnostic questions" in the previous section.

Photos

Digital or print photos often add important information about the site and patterns and can greatly facilitate the diagnosis. When taking photos, take one or two of the overall site to show the environment. Then, take another few shots at closer range that show the primary symptoms of concern.

References

Each crop can be affected by multiple diseases. This study guide provides a framework for understanding crop diseases, but it will be important to learn more details about the specific crops you manage. Printed materials, websites, pesticide certification renewal classes, and other training programs can provide ongoing education.

The following three guides are updated annually by specialists in this region. Contact your local K-State Research and Extension agent or visit the K-State Plant Pathology website for ordering information.

Vegetables:
Midwest Vegetable Production Guide for Commercial Growers

Tree Fruit:
Midwest Tree Fruit Spray Guide

Small Fruit:
Midwest Small Fruit and Grape Spray Guide

Wheat:
Wheat variety disease and insect ratings (MF-991); Fungicide Efficacy ratings for wheat disease management (EP-130)

Crop Plant Diseases

Crop Plant Diseases

Study Questions

These study questions are to help you learn the material on pages 53 through 67.

1. *Discoloration in the vascular tissue (water conduction tissue) is a symptom of what kind of disease:*

   a. root rot

   b. leaf spot

   c. wilt

   d. rust

2. *The four major groups of plant pathogens include fungi, bacteria, virus and _________.*

   a. nematodes

   b. aphids

   c. moss

   d. blights

3. *Fungi often obtain their food through:*

   a. photosynthesis

   b. decay of dead plant material

   c. attacking living plants

   d. both b and c

4. *What are some ways in which plant viruses can spread?*

   a. seed

   b. insects

   c. tools

   d. all of the above

5. *What are some ways in which plant-infecting bacteria can spread?*

   a. seed

   b. infected transplants

   c. insects

   d. all of the above

6. *Which of the following insects is a common vector of plant viruses:*

   a. grubs

   b. aphids

   c. moths

   d. flies

7. *The three most common groups of pesticides used to manage plant diseases are:*

   a. herbicides, algaecides, and fungicides

   b. herbicides, bactericides, and nematicides

   c. fungicides, bactericides and nematicides

   d. algaecides, fungicides and antibiotics

8. *What is one advantage of a CONTACT fungicide:*

   a. prone to wash-off

   b. broad mode of action

   c. moves systemically in the plant

   d. can be used with small amounts of water

9. If plants in several different plant families are affected by symptoms, the cause is mostly likely to be:

a. fungus
b. virus
c. nematode
d. abiotic factor

10. The best type of sample to send to a diagnostic clinic is:

a. the smallest leaf possible, to save on shipping costs
b. plant tissue that has been dead for a long time
c. plant tissue from the transitional area between healthy and damaged areas
d. dry plant material

11. Crop rotation can reduce disease pressure only if:

a. spores blow in from distant fields each year
b. the pathogen survives locally in soil or crop debris
c. the disease is caused by a virus
d. the disease has a very wide host range

12. In integrated pest management (IPM) programs, the foundation of disease control is:

a. resistant cultivars
b. fungicides
c. cultural practices
d. a and c

13. Which factor is not part of the "disease triangle?"

a. susceptible host
b. favorable environment
c. the right time
d. pathogen presence

14. Which of the following is NOT an effective cultural management practice?

a. tillage
b. crop rotation
c. insect/vector management
d. quarantines

Weed Management in Field Crops

Barnyard Grass

Large Crabgrass

Weeds are major pests in field crops and can reduce the quantity and quality of the crop. Uncontrolled weeds can reduce crop yields, interfere with harvest, and result in contamination of the harvested crop. Weeds reduce crop yields by competing with the crops for water, nutrients, light, and space. Crop production strategies that provide the crop with a competitive advantage over weeds and minimize weed populations and early season competition will help protect crop yields and reduce the impact of weeds on the current and future crops. The best approach to managing weeds in cropland is to utilize an integrated weed management approach that incorporates cultural, mechanical, biological, and chemical methods of control.

Weed Identification and Biology

Weed identification is critical to an effective weed management program. Weeds can be divided into several categories based on their biology and life cycles. The two primary botanical groups of plants are monocots and dicots. Monocots have one cotyledon in the seed and include grasses and sedges. Grasses and sedges both have long narrow leaves with parallel venation. The seed of grasses remains in the soil when it germinates. The emerging shoot of grasses is enclosed in a structure called the coleoptile, which helps the young shoot push upward through the soil. When the coleoptile emerges through the soil surface and is exposed to sunlight, the true leaves emerge through the coleoptile above ground. Shortly afterward, a cluster of nodes called the crown becomes established at or just below the soil surface. New leaves and tillers can develop from the nodes in the crown of a grass plant. During early growth stages, all of the growing points are in the crown. Eventually, the stem starts to elongate, and the terminal growing point moves above ground and into the seed head.

Leaf width and length, the presence of auricles, ligules, and hairs on the leaf, and stem shape are important features for proper identification of grasses. Grasses can have round or flattened stems. Sedges are similar in appearance to grasses, except sedges have three-sided or triangular-shaped stems. It is important to distinguish sedges from grasses because control measures and herbicide choices are different for sedges than grasses.

Dicot plants have two cotyledons in the seed and are commonly referred to as broadleaves. The cotyledons of most broadleaf plants are pulled through the soil and unfold above the soil surface during emergence. The cotyledons are often called seed leaves and are the lowest growing points on the shoot following emergence of a young broadleaf seedling. The true leaves of broadleaf plants will develop above the cotyledons and will have a netlike venation pattern. The stem will continue to elongate on young broadleaf plants with nodes spaced along the stem. New leaves and branches can develop at each of the nodes along the stem. Eventually, flowers will develop at the terminal end, and/or in the leaf axils along the stem of broadleaf plants. Cotyledon shapes, leaf size and shape, leaf arrangement, and other leaf and stem characteristics such as hairs and spines are critical to the proper identification of broadleaf plants.

Weed Life Cycles

Different plant species can complete their life cycle in just a few weeks, or may live for many years. Plants that complete the life cycle in less than one year are commonly referred to as annuals; plants that complete their life cycle over a period of two years are called biennials; and plants that can grow indefinitely for more than two years are called perennials.

Annual plants can further be divided into two groups depending on the time of the year they grow. Summer annual plants germinate in the spring or summer, reproduce during the summer and die in the fall. Large crabgrass, pigweed, kochia, and devilsclaw are examples of summer annual weeds.

Winter annual plants generally germinate in the fall, go dormant over winter, resume growth early in the spring, and reproduce and die by summer. Some examples of winter annual weeds include henbit, tansy mustard, and downy brome. Summer annual weeds are most troublesome in summer crops such as corn, sorghum, soybeans, sunflowers, and cotton, but can also be a late season problem in winter wheat. Winter annual weeds are most troublesome in winter cereal crops such as winter wheat, but also are a preplant problem in no-till summer crops.

Biennial plants generally germinate in the spring or summer and grow vegetatively during the first year of growth, go dormant over winter, reproduce during the second summer of growth and die in late summer or fall. Biennial weeds are a problem primarily in pasture and noncropland areas, and sometimes in no-till crop production. Examples of biennial weeds are musk thistle, common mullein, and western salsify.

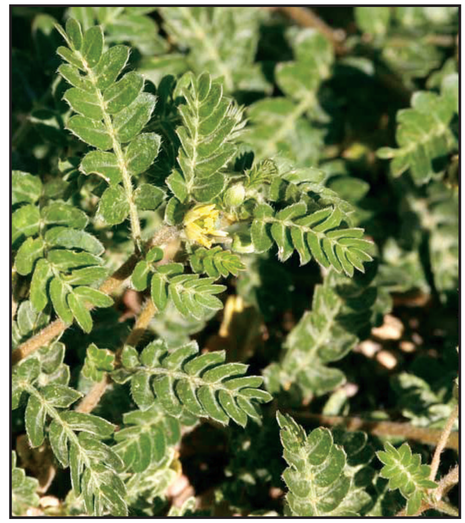
Perennial plants can grow and reproduce over multiple years. In addition to seed production, perennial plants often can reproduce vegetatively by spreading root systems, rhizomes, stolons, tubers, or bulbs. Perennial weeds that do not spread vegetatively are referred to as simple perennials. Some examples of simple perennial weeds include common dandelion and curly dock. Perennial weeds that spread vegetatively are often called creeping perennials and frequently occur in dense patches arising from the same parent plant. Field bindweed, johnsongrass, and Canada thistle are examples of creeping perennial weeds. Once established, perennial weeds generally are very difficult to control and can be a serious problem in any crop.

Weeds that are similar in biology and life cycle to the crop being grown tend to be most common and troublesome in that crop, such as shattercane in grain sorghum or cheat in wheat. Table 1, page 75, lists some of the common weeds in Kansas field crops, their life cycle, and the crops they commonly infest.

Giant Foxtail

Green Foxtail

Buffalobur



Puncturevine

Prairie Cupgrass

Devilsclaw

Redroot Pigweed

Witchgrass

Ivyleaf Morningglory

Velvetleaf

Cheat

Common Chickweed

Tansy Mustard

Jointed Goatgrass

Henbit

Western Salsify

Italian Ryegrass

Horseweed

Quackgrass

Common Dandelion

Yellow Nutsedge

Windmillgrass

Field Bindweed

Johnsongrass

Curly Dock

Common Milkweed

Table 1. Common Weeds in Kansas Field Crops

Common Name	Scientific Name	Crops
Summer Annual Grasses		
Barnyardgrass	*Echinochloa crus-galli*	Summer crops, alfalfa
Crabgrass, large	*Digitaria sanguinalis*	Summer crops, alfalfa
Fall panicum	*Panicum dichotomiflorum*	Summer crops, alfalafa
Foxtail, giant	*Setaria faberi*	Summer crops, alfalfa
Foxtail, green	*Setaria viridis*	Summer crops, alfalfa
Foxtail, yellow	*Setaria glauca*	Summer crops, alfalfa
Longspine sandbur	*Cenchrus longispinus*	Summer crops
Prairie cupgrass	*Eriochloa contracta*	Summer crops, fallow
Shattercane	*Sorghum bicolor*	Summer crops
Stinkgrass	*Eragrostis cilianensis*	Fallow
Witchgrass	*Panicaum capillare*	Summer crops, fallow
Summer Annual Broadleaf Weeds		
Black nightshade, eastern	*Solanum ptycanthum*	Summer crops
Buffalobur	*Solanum rostratum*	Fallow
Cocklebur, common	*Xanthum strumarium*	Summer crops
Devilsclaw	*Proboscidea lousianica*	Summer crops
Kochia	*Kochia scoparia*	All crops, fallow
Lambsquarters, common	*Chenopodium album*	All crops
Morningglory, ivyleaf	*Ipomoea hederacea*	Summer crops
Morningglory, tall	*Ipomoea purpurea*	Summer crops
Palmer amaranth	*Amaranthus palmeri*	Summer crops, alfalfa
Pennsylvania smartweed	*Polygonum pensylvanicum*	Summer crops
Prickly sida	*Sida spinosa*	Summer crops
Pigweed, redroot	*Amaranthus retroflexus*	Summer crops, alfalfa
Puncturevine	*Tribulus terrestris*	Summer crops
Ragweed, common	*Ambrosia artimisiifolia*	Summer crops, burndown
Ragweed, giant	*Ambrosia trifida*	Summer crops, burndown
Russian thistle	*Salsola iberica*	All crops, fallow
Sunflower, common	*Helianthus annuus*	All crops, fallow
Velvetleaf	*Abutilon theophrasti*	Summer crops
Venice mallow	*Hibiscus trionum*	Summer crops
Waterhemp, common	*Amaranthus rudis*	Summer crops
Wild buckwheat	*Polyngonum convolvulus*	Wheat, no-till

Common Name	Scientific Name	Crops
Winter Annual Grasses		
Brome, downy	*Bromus tectorum*	Wheat, alfalfa, burndown
Brome, Japanese	*Bromus japanicus*	Wheat, alfalfa,
Cheat	*Bromus secalinus*	Wheat, alfalfa
Jointed goatgrass	*Aegilops cylindrica*	Wheat
Ryegrass, Italian	*Lolium multiflorum*	Wheat
Winter Annual Broadleaf Weeds		
Bushy wallflower	*Erysimum repandum*	Wheat, alfalfa, burndown
Chickweed, common	*Stellaria media*	
Flixweed	*Descurainia sophia*	Wheat, alfalfa, burndown
Henbit	*Lamium amplexicaule*	Wheat, alfalfa, burndown
Horseweed (marestail)	*Conyza canadensis*	Wheat, alfalfa, burndown
Mustard, blue	*Chorispora tenella*	Wheat, alfalfa, burndown
Mustard, tansy	*Descurainia pinnata*	Wheat, alfalfa, burndown
Pennycress, field	*Thlaspi arvense*	Wheat, alfalfa, burndown
Pepperweed, greenflower	*Lepidium densiflorum*	Wheat, alfalfa, burndown
Shepherdspurse	*Capsella bursa-pastoris*	Wheat, alfalfa, burndown
Biennial Broadleaf Weeds		
Mullein, common	*Verbascum thapsus*	Pasture, alfalfa
Thistle, bull	*Cirsium vulgare*	Pasture, alfalfa
Thistle, musk	*Carduus nutans*	Pasture, alfalfa
Salsify, western	*Tragopogon dubius*	No-till burndown
Perennial Sedges		
Yellow nutsedge	*Cyperus esculentus*	All crops, no-till
Perennial Grasses		
Johnsongrass	Sorghum halepense	Summer crops, alfalfa
Quackgrass	*Agropyron repens*	Cool-season grasses
Tumblegrass	*Schedonnardus paniculatus*	No-till
Windmillgrass	*Chloris verticillata*	No-till

Common Name	Scientific Name	Crops
	Perennial Broadleaves	
Burcucumber	*Sicyos angulatus*	No-till
Canada thistle	*Cirsium arvensis*	All crops
Climbing milkweed	*Sarcostemna cynanchoides*	Summer crops
Curly dock	*Rumex crispus*	Alfalfa, wet areas
Dandelion, common	*Taraxacum officianale*	Alfalfa, no-till
Field bindweed	*Convolvulus arvensis*	All crops
Groundcherry, smooth	*Physalis subglabrata*	Summer crops
Hemp dogbane	*Apocynum cannabinum*	Summer crops
Horsenettle	*Solanum carolinense*	Summer crops
Milkweed, common	*Asclepias syriaca*	Summer crops
Swamp smartweed	*Polygonum coccineum*	Summer crops, wet areas
Woolyleaf bursage (bur ragweed)	*Franseria tomentosa*	All crops

Cultural Weed Control Practices

Sanitation and good agronomic practices that favor quick establishment and optimal growth of the crop compared to weeds are important cultural practices to help manage weeds. One of the most important cultural practices for managing weeds over multiple years is crop rotation. A diverse rotation of crops across years can result in a diversity of herbicide options, weed control practices, and timings. A diverse and integrated weed management program will help reduce the potential for developing serious weed problems, high weed populations, and herbicide resistant weeds.

Mechanical Weed Control

Tillage, mowing, and hand removal can be effective weed control practices depending on the crop production system, weed biology, and weed population. Tillage continues to be a primary method of weed control in tillage-based production systems, but may not be an option in no-till crop production. Tillage is most effective for control of seedling weeds and when dry conditions follow the tillage operation. Mowing is most effective to prevent seed production on annual and biennial weeds, but may require multiple operations. Hand removal is most practical for small scale situations, or where low weed infestations are present.

Biological Weed Control

Biological weed control involves the use of other organisms to reduce the populations and impact of weeds on crops or natural areas. Biological weed control has been most successful in noncropland and pasture situations. Examples of biological control include weed specific insects, diseases, or herbivores.

Chemical Weed Control

Herbicides are chemicals used to control weeds. Herbicides may be an important component of an integrated weed management program. However, herbicides must be used in accordance with all label guidelines to achieve good weed control while not causing harm to the crop, environment, wildlife, applicator, worker, or consumer.

Types of Herbicides

Herbicides can be grouped into categories based on selectivity, type of application, translocation in the plant, and mode of action. Herbicide selectivity refers to the differential response of plants to a herbicide. Herbicides that kill or suppress the growth of most plant species are considered nonselective. Nonselective herbicide use is limited to situations where control of all plant species is desired, or the herbicide is directed on the target weed and away from desirable plants.

Glyphosate and paraquat historically have been considered nonselective herbicides. However, glyphosate is a highly selective herbicide when used in conjunction with crops that have been genetically engineered with resistance to glyphosate.

Most herbicides used in crop production are selective, which means they kill certain weeds but do not injure the crop. Some herbicides are primarily for control of grasses, while others may control just broadleaves, or both broadleaf and grass weeds. Herbicide selectivity is relative and depends on several factors, including plant biology, plant genetics, environment, herbicide application rate, application timing, and application technique. Even a tolerant plant species may be susceptible to a selective herbicide if the application rate is too high or the herbicide is missapplied.

Translocation refers to the movement of an herbicide inside a plant once it is absorbed through the leaf surface. Systemic herbicides are translocated in plants, while contact herbicides are not translocated. Translocation of systemic herbicides to the site of action is important to herbicide performance.

Contact herbicides are not translocated. When applying foliar-applied contact herbicides, thorough spray coverage is essential to kill the entire plant. Contact herbicides generally are ineffective for long-term perennial weed control. Contact herbicides damage top growth that the spray solution reaches, but the underground portion of perennial plants remains unaffected and can rapidly initiate new growth.

Contact herbicides often are more effective on broadleaves than on grasses because the growing points of young broadleaf plants are aboveground and exposed to the spray treatment. In contrast, the growing point of young grasses is located in the crown region of the plant, which is at or below the soil surface, and difficult to reach with the spray. Thus, contact herbicides may not kill all the growing points of a tillered grass plant, and regrowth can occur.

Herbicide Mode of Action

Herbicide mode of action refers to how herbicides work. Herbicides can be classified into "families" based on chemical similarities and mode of action. The mode of action is the process by which a chemical kills or suppresses plant growth. Herbicides of the same chemical family usually have the same mode of action. Different chemical families of herbicides also may have the same mode of action.

Repeated use of the same herbicide or herbicides with the same mode of action eventually can lead to enhanced degradation, weed species shifts, herbicide resistance, increased carryover, and crop injury. Using herbicides with different modes of action in tank mixes and in rotation, along with other cultural weed control practices, will help prevent these problems from occurring.

Herbicide Modes of Action

ALS Inhibitors

Imidazolinone family – Arsenal, Beyond, Contain, Plateau, Pursuit, Raptor, Scepter

Sulfonylurea family – Accent, Affinity, Ally, Amber, Basis, Beacon, Cimarron, Classic, Escort, Express, Finesse, Glean, Harmony, Harmony Extra, Maverick, Oust, Peak, Permit, Spirit, Steadfast, Synchrony, Telar

Sulfonalmide family – Python, FirstRate, PowerFlex

Sulfonylaminocarbonyl-triazolinone family – Olympus, Olympus Flex, Osprey

Diterpene Inhibitors

Isoxazolidinone family – Command

EPSP Inhibitors

Amino acid derivative family – Roundup, glyphosate

HPPD Inhibitors

Isoxazole family – Balance, Huskie

Triketone family – Callisto, Impact, Laudis

Photosynthetic (PSII) Inhibitors

Triazine family – atrazine, metribuzin, simazine

Phenylurea family – Lorox, Karmex, Spike

Uracil family – Sinbar, Hyvar

Nitrile family – Buctril, bromoxynil

Benzothiadiazole family – Basagran

Photosystem 1 (PS1) Inhibitors

Bipyridillium family – diquat, Gramoxone, paraquat

PPO Inhibitors

Diphenylether family – Cobra, ET, Flexstar, Phoenix, Reflex, Ultra Blazer, Vida

N-Phenylphthalimide family – Cadet, Resource

Aryl-Triazolinone family – Aim, Spartan, Valor

Pyrimidinedione family – Sharpen, Kixor

Synthetic Auxin – Growth Regulators

Benzoic acid family – Banvel, Clarity, dicamba, Distinct, Status

Phenoxy family – 2,4-D, 2,4-DB, MCPA

Pyridine family – Garlon, Milestone, Remedy, Starane, Stinger, Tordon

Semicarbazone family – Distinct, Status

Lipid synthesis – ACCase Inhibitors

Aryloxyphenoxypropionate family – Assure II, Fusilade, Fusion, Targa

Cyclohexanedione family – Poast, Poast Plus, Select, Select Max, Section, Volunteer

Glutamine Synthetase Inhibitors

Phosphylated amino acid family – Ignite, Liberty

Mitosis Inhibitors

Dinitroaniline family – Balan, pendimethalin, Prowl, Treflan, trifluralin, Sonalan

Seedling Root and Shoot Inhibitors

Acetamides – Degree, Dual Magnum, Harness, Intrro, metolachlor, Outlook, Surpass

Herbicide Resistance

Herbicide resistance is defined as "the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the native population of that species." Plant species that are not controlled by a herbicide before any selection pressure or genetic manipulation would be considered naturally tolerant, but not herbicide resistant. Herbicide resistant weed populations are generally selected from the native population in field situations through repeated treatment over time with a given herbicide or herbicides having the same mode of action. Herbicide resistance may be based on differential absorption, translocation, metabolism, or an altered site of action.

Herbicide resistance can result from a single gene mutation or from a combination of multiple gene changes. Single gene mutations that alter the site of action generally indicates a relatively high level of resistance and population shifts can occur in just a few years. Some examples of single gene herbicide resistance in Kansas include waterhemp, Palmer amaranth, kochia, sunflower, bushy wallflower, and cheat resistance to the ALS-inhibiting herbicides, and Palmer amaranth, waterhemp, and kochia resistance to atrazine. Multi-gene resistance is often a lower level resistance that gradually increases over time and is more difficult to confirm. Waterhemp, marestail, giant ragweed, and kochia resistance to glyphosate appears to be a result of multigene herbicide resistance traits.

Herbicide resistant weed populations generally result from heavy reliance on a single herbicide or herbicide mode of action for weed control over time. Thus, an integrated weed management program that incorporates crop rotation, herbicide rotations, mixtures of herbicides with different modes of action, and other methods of weed control will help minimize the risk of developing herbicide-resistant weeds.

Herbicide Application

The optimum timing and method of herbicide application will depend on the herbicide, crop, and target weeds. Guidelines and directions for the proper application of each herbicide is provided in the herbicide label. Failure to follow label directions, warnings, and precautions can result in crop injury, poor weed control, off-target plant injury, environmental contamination, human hazards, and/or civil penalties.

Herbicides can have foliar and/or soil activity depending on the chemical. A number of factors can affect the activity or performance of soil-applied and foliar-applied herbicides.

Soil-Applied Herbicides

Soil-applied herbicides persist in the soil for a period of time and can be absorbed from the soil by plant roots and shoots. Herbicides applied to the soil and mechanically incorporated before planting the crop are commonly referred to as preplant incorporated treatments. Herbicides applied to the soil surface before the crop and weed emergence are commonly called preemergence applications.

Herbicide properties, soil properties, environmental conditions, weed susceptibility, and application rate will affect the performance of soil-applied herbicides. Most herbicides need to be in soil solution to be absorbed by germinating seedlings. Adequate precipitation or mechanical incorporation after application is required to get the herbicide into solution or "activate" the herbicide. The amount of precipitation required to activate the herbicide will depend on the individual herbicide and soil properties.

Herbicides are generally more active in coarse textured and low organic matter soils than in finer textured and higher organic matter soils. Consequently, herbicide rates may need to be adjusted for soil-applied herbicides depending on soil properties. Soil pH also can affect the activity and persistence of certain herbicides. For example, atrazine, and several of the sulfonylurea herbicides like Finesse and Amber, are more active and more persistent at high than at low soil pH. Consult the herbicide label for the recommended application rates, crop rotation guidelines, and use restrictions as it pertains to soil properties.

Foliar-Applied Herbicides

Foliar-applied or postemergence herbicides are applied to the foliage of emerged plants for control. Some postemergence herbicides may have both foliar and soil residual activity.The performance of postemergence herbicides will depend on species susceptibility, weed size, environmental conditions, spray adjuvants, and application techniques. Annual weeds and seedling perennial weeds generally are most susceptible to postemergence herbicides when the weeds are small and actively growing. The suseptiblity and benefits from controlling annual weeds decreases as they mature. Established perennial weeds usually are most susceptible when treated at the early bloom stage of growth or to active growth in the fall. Application at these times generally results in the greatest translocation to the roots and the best long-term control.

Weather conditions can greatly impact the performance of postemergence herbicides. Postemergence herbicides are most effective when applied to actively growing weeds with favorable growing conditions. Weeds that are under stress due to extreme temperature or moisture conditions tend to be less susceptible to most herbicides. On the other hand, crops under stress may actually be more susceptible to injury than crops growing with good conditions due to a diminished ability to metabolize the herbicide.

Spray adjuvants are chemicals added to the spray to modify the properties of the spray solution for improved handling or pesticide activity. Adjuvants are often recommended with certain postemergence herbicides to optimize their performance. There are many types of adjuvants that each have a different function. Consult the herbicide label for the recommended type and rate of adjuvant to maximize performance. Inappropriate adjuvant use could result in crop injury, poor weed control, and application problems.

Spray volume and droplet size may impact spray deposition, canopy penetration, coverage, and herbicide performance. Consult each herbicide label for the recommended spray application guidelines to minimize spray drift and optimize herbicide performance.

Weed Management Decisions

Knowledge of field history and scouting fields to identify emerging weed problems throughout the growing season are important for making effective weed control plans and decisions. Herbicides are just one component of an effective weed management program. Consult herbicide labels and other weed control guides, such as the latest edition of *Chemical Weed Control for Field Crops, Pastures, Rangeland, and Noncropland* (SRP 1045) to assist in making effective herbicide choices. The guide is available at *www.ksre.ksu.edu/library* by typing chemical weed control in the search box.

Study Questions

These study questions are to help you learn the material on pages 70 through 82.

1. *Weeds reduce crop yields by competing for:*

   a. moisture

   b. light

   c. soil nutrients

   d. all of the above

2. *Important features used to identify grassy weeds include:*

   a. leaf shape

   b. auricles and ligules

   c. leaf arrangement

   d. all of the above

3. *An example of a dicot plant includes a:*

   a. broadleaf

   b. sedge

   c. soybean

   d. both a and c

4. *Field bindweed, dandelion and johnsongrass are:*

   a. summer annuals

   b. perennials

   c. winter annuals

   d. biennials

5. *Winter annual grasses include:*

   a. downy brome

   b. cheat

   c. jointed goatgrass

   d. all of the above

6. *In cases where available herbicides will not control the weeds, which of the following management practices are helpful?*

   a. crop rotation

   b. tillage

   c. a and b above

   d. none of the above

7. *Glyphosate is an example of a:*

   a. non selective herbicide

   b. EPSP inhibitor

   c. selective herbicide when use with Roundup Ready crops

   d. all of the above

8. *A weed species that has developed resistance to herbicides in Kansas includes:*

   a. kochia

   b. cheat

   c. palmar amaranth

   d. all of the above

9. *Summer crops such as corn, sorghum, and soybeans tend to increase:*

   a. summer annual weeds

   b. fall annual weeds

   c. winter annual weeds

   d. perennials

10. *The risk of herbicide resistance can be decreased by using:*

    a. crop rotations

    b. herbicide rotations

    c. mixtures of herbicides that have a different mode of action

    d. all of the above

11. Perennial weeds can reproduce from:

a. stolons
b. seed production
c. tubers
d. all of the above

12. Examples of biennial broadleaf weeds are:

a. common mullein
b. musk thistle
c. western salsify
d. all of the above

Pasture and Rangeland Weed and Brush Control

Weeds common in rangeland and pastures in Kansas include annual species such as lanceleaf ragweed and common broomweed. Biennial plants that take two years to complete their life cycle, include musk thistle and common mullein. Troublesome perennial weed species include sericea lespedeza, Baldwin ironweed, woolly verbena, and goldenrods. Grasses such as prairie threeawn, longspine sandbur, Johnsongrass, Kentucky bluegrass, and old world bluestems may also be considered weeds if they are growing where they are not welcome. Shrubs such as buckbrush, smooth sumac, and roughleaf dogwood, as well as trees such as common honeylocust, osage orange, and eastern redcedar, may become problems on range and pastureland.

There are several options for control and management of brush and weed species:

- management
- mechanical
- biological
- prescribed burning
- chemical

Proper grazing management can reduce invasion of many problem weed and brush species. Stocking rate, the number of animals per unit area for a given period of time, is the most important factor influencing livestock and plant response to grazing. Overstocking can reduce the vigor of the most palatable species and allow invasion of plants that reproduce by seed. Maintaining a competitive cover can keep unwanted species at manageable levels. Grazing systems, such as rotational grazing, that incorporate periodic rest, can help keep a competitive cover. Improper grazing distribution that results in concentrated grazing usually disturbs the soil and allows unwanted species to invade. Unfenced pond dams are a typical disturbed site where noxious weeds and other unwanted species occur. Other grazing management principles include proper season of use and kind of animal. Cattle are primarily grass eaters, but will consume significant amounts of forbs and browse during the year. Sheep prefer palatable forbs, and goats will eat woody plants if available.

Mechanical control includes hand clippers, mowers, tree cutters, and bulldozers. Mowing of annual and biennial species before seed production can be an effective control method. Non-sprouting species, such as eastern redcedar, can be controlled by cutting below the lowest green branch. Repeated mowing or top removal will be necessary to control most perennial species. Timing for top removal should correspond with the low point in the food reserve cycle that generally occurs at floral bud initiation.

Release of the musk thistle head weevil *(Rhinocyllus conicus)* and rosette weevil *(Trichosirocalus horridus)* has provided reduced seed production and is an example of biological control. Attempts are being made to introduce a leaf feeding beetle *(Diorhabda elongata)* for biological control of saltcedar. Leafy spurge and spotted knapweed are also targets for using biological control. Because of grazing preference, sheep and

Pasture and Rangeland Weed and Brush Control

goats can be used to reduce and manage many broadleaf and woody plants.

Prescribed burning can be an effective method for brush and weed control. Late-spring burning when annual grasses, broadleafs, and woody plants are leafed out is the most effective time to burn. A single burn can effectively control eastern redcedar, but it is necessary to burn two to three consecutive years to control most woody species.

Herbicides can be applied on the soil, as a basal bark or cut-stump treatment, or applied to foliage. Properly applied, herbicides can be an efficient method of controlling unwanted species. Broadcast application of herbicides on rangeland and pasture should be done infrequently as many desirable nontarget species can be damaged. Care should also be taken when treating poisonous plants. Herbicide treatment usually increases plant palatability. Grazing animals may need to be removed from a pasture sprayed for poisonous plants for a period of time to reduce the chance of livestock poisoning. Refer to the latest edition of the K-State publication, *Chemical Weed Control for Field Crops, Pastures, Rangeland, and Noncropland* (SRP 1045) for specific herbicide recommendations.

In many cases an integrated approach can be used. For instance, grazing management that includes proper stocking rates combined with frequent use of prescribed burning can prevent most woody plants from gaining dominance in many areas of Kansas. Mechanical cutting of non-sprouting species such as eastern redcedar can be very effective. However, cut-stumps of sprouting species such as osage orange will require an herbicide to prevent resprouting.

Trees or woody vegetation should be cut close to the soil surface before application. Before spraying, brush off any soil or sawdust. Spray the stump immediately after cutting. It is especially important for the herbicide to cover the bark, crown buds, and all exposed roots to prevent resprouting. If a delay occurs in spraying, it may be necessary to use an oil-based product or freshen the stump surface by cutting or chopping to expose fresh tissue. Do not spray when basal stems are wet.

Plant identification is an important aspect of weed and brush control. The following list and illustrations categorize and identify many of the major weed and brush species on pasture and rangeland in Kansas.

Major Weeds in Pasture and Rangeland

Common Name	Scientific Name	Origin	Growth Habit
Broomweed	*Amphiachyris dracunculoides*	Native	Annual, summer
Cocklebur	*Xanthium strumarium*	Native	Annual, summer
Common ragweed	*Ambrosia artemisiifolia*	Native	Annual, summer

Common Name	Scientific Name	Origin	Growth Habit
Common sunflower	*Helianthus annuus*	Native	Annual, summer
Lanceleaf ragweed	*Ambrosia bidentata*	Native	Annual, summer
Snow-on-the-mountain	*Eurphorbia marginata*	Native	Annual, summer
Texas croton	*Croton texensis*	Native	Annual, summer
Downy brome	*Bromus tectorum*	Introduced	Annual, winter
Japanese brome	*Bromus japonicus*	Introduced	Annual, winter
Little barley	*Hordeum pusillum*	Native	Annual, winter
Bull thistle	*Cirsium vulgare*	Introduced	Biennial
Common mullein	*Verbascum thaspus*	Introduced	Biennial
Musk thistle	*Carduus nutans*	Introduced	Biennial
Tall thistle	*Cirsium altissimum*	Native	Biennial
Baldwin ironweed	*Vernonia baldwini*	Native	Perennial
Broom snakeweed	*Gutierrezia sarothrae*	Native	Perennial
Curlycup gumweed	*Grindelia squarrosa*	Native	Perennial
Sericea lespedeza	*Lespedeza cuneata*	Introduced	Perennial
Tall goldenrod	*Solidago altissimum*	Native	Perennial
Wavyleaf thistle	*Cirsium undulatum*	Native	Perennial
Western ragweed	*Ambrosia psilostachya*	Native	Perennial
Woolly loco	*Astragalus mollissimus*	Native	Perennial
Woolly verbena	*Verbena stricta*	Native	Perennial
Blackberry	*Rubus spp.*	Native	Perennial
Buckbrush	*Symphoricarpos orbiculatus*	Native	Perennial
Common honeylocust	*Gleditsia triacanthos*	Native	Perennial
Common pricklypear	*Opuntia humifusa*	Native	Perennial
Eastern redcedar	*Juniperus virginiana*	Native	Perennial
Mulitflora rose	*Rosa multiflora*	Introduced	Perennial
Osage orange	*Maclura pomifera*	Native	Perennial
Roughleaf dogwood	*Cornus drummondii*	Native	Perennial
Russian olive	*Elaeagnus angustifolia*	Introduced	Perennial
Saltcedar	*Tamarix ramosissima*	Introduced	Perennial
Siberian elm	*Ulmus pumila*	Introduced	Perennial
Smooth sumac	*Rhus glabra*	Native	Perennial
Yucca	*Yucca glauca*	Native	Perennial

Summer Annual Broadleaf Weeds

Broomweed

Cocklebur

Lanceleaf Ragweed

Common Ragweed

Snow-on-the-Mountain

Common Sunflower

Texas Croton

Annual or Winter Annual Grasses

Downy Brome

Little Barley

Japanese Brome

Biennial Broadleaf Weeds

Bull Thistle

Musk Thistle

Common Mullein

Tall Thistle

Perennial Broadleaf Weeds


Baldwin Ironweed


Sericea Lespedeza

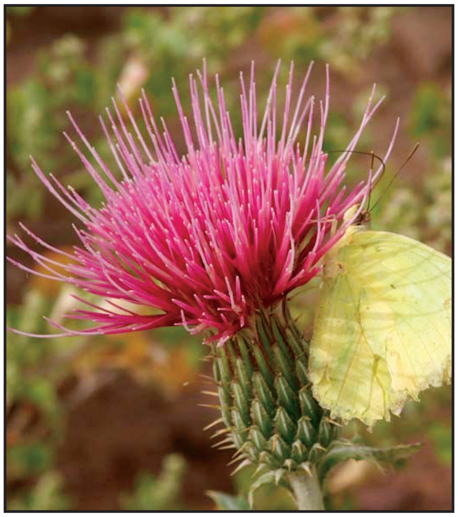

Western Ragweed


Brome Snakeweed


Tall Goldenrod


Woolly Loco


Curlycup Gumweed


Wavyleaf Thistle

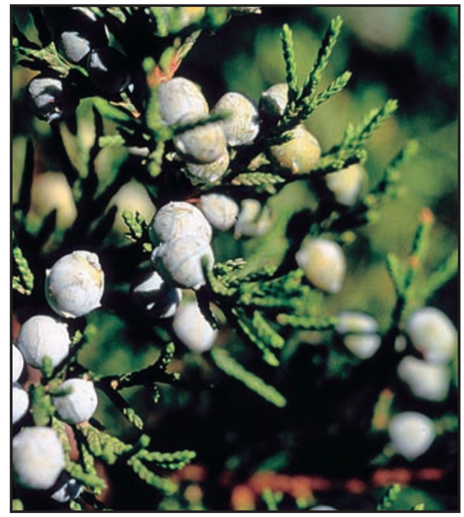

Woolly Verbena

Pasture and Rangeland Weed and Brush Control

Woody Plants

Blackberry

Buckbrush



Eastern Redcedar

Common Honeylocust

Multiflora Rose

Common Pricklypear

Osage Orange

Woody Plants

Roughleaf Dogwood

Siberian Elm

Russian Olive

Smooth Sumac

Saltcedar

Yucca

Pasture and Rangeland Weed and Brush Control

Study Questions

These study questions are to help you learn the material on pages 85 through 93.

1. *Broomweed, ragweed and sunflower are examples of:*

   a. summer annual broadleaf weeds

   b. winter annual and biennial weeds

   c. perennial broadleaf weeds

   d. woody plants

2. *Control options for the management and control of rangeland weed species include:*

   a. chemical control

   b. mechanical control

   c. biological control

   d. all of above

3. *An example of an insect that provides biological control is:*

   a. goats

   b. the rosette weevil

   c. sheep

   d. all of the above

4. *Saltcedar, Russian olive and multiflora rose are examples of:*

   a. native perennials

   b. introduced perennials

   c. summer annuals

   d. biennials

5. *The following are examples of woody plants:*

   a. sericea lespedeza and ironweed

   b. broomweed and sunflower

   c. sumac and yucca

   d. mullein and thistle

6. *An example of a woody plant that resprouts is:*

   a. elm

   b. osage orange

   c. eastern red cedar

   d. both a and b

Equipment and Calibration for Commercial Field Crop Applications

Commercial applicators are applying more and more pesticides in Kansas. Because of high costs and growing public concern about possible environmental hazards, pesticides must be applied accurately and uniformly. This chapter discusses the proper selection and use of spray nozzles, techniques to minimize spray drift, calibration and mixing pesticide formulations, the role of electronics in application, proper maintenance, and record keeping.

To minimize problems associated with pesticide use it has become increasingly important to improve application equipment and develop techniques that facilitate effective use of lower dosages, reduce drift and harmful residues, and protect applicators and the environment.

Nozzle Selection

Select the correct type and size of spray nozzle for each application. The nozzle determines the amount of spray applied to an area, the uniformity of the application, the coverage of the sprayed surface, and the amount of drift. You can minimize drift problems by selecting nozzles that give the largest droplet size while providing adequate coverage at the intended application rate and pressure. Although nozzles have been developed for practically every kind of spray application, only a few nozzle types are commonly used to apply crop protection products and fertilizer-pesticide combinations. Most crop protection products are applied with a nozzle type designed to produce a tapered flat-spray pattern. These nozzle types are extended range flat-fans, turbo or chamber style flat-fans and flooding flat-fans, and air-injection/venturi flat-fans of various designs. These nozzle types are described below in chronological order.

Flooding Flat-Fan Nozzles

(Old style nozzle. In use before other nozzles described. Several manufacturers have similar designs.) Flooding flat-fan nozzles produce a wide-angle, flat-fan pattern, and are used for applying herbicides and mixtures of herbicides and liquid fertilizers. Nozzle spacing should be 40 inches or less. These nozzles are most effective in reducing drift when they are operated within a pressure range of 8 to 25 psi. Pressure changes affect the width of the spray pattern more with the flooding flat-fan nozzle than with the extended range flat-fan nozzle. In addition, the distribution pattern usually is not as uniform as that of the extended range flat-fan tip. The best distribution is achieved when the nozzle is mounted at a height and angle to obtain at least double coverage or 100 percent overlap. Uniformity of application depends on the pressure, height, spacing, and orientation of the nozzles. Pressure directly affects droplet size, nozzle flow rate, spray angle, and pattern uniformity. At low pressures, flooding nozzles produce large spray drops; at high pressures, these nozzles actually produce smaller drops than flat-fan nozzles at an equivalent flow rate.

The spray distribution of flooding nozzles varies greatly with changes in pressure. At low pressures, flooding nozzles produce a fairly uniform pattern across the swath, but at high pressures the pattern becomes heavier in the center and tapers off toward the edges. The width of the spray pattern also is affected by pressure. To obtain an acceptable distribution pattern and overlap, you should operate flooding nozzles within a pressure range of 8 to 25 psi.

Nozzle height is critical in obtaining uniform application when using flood nozzles. Flooding nozzles can be mounted vertically to spray backwards, horizontally to spray downwards, or at any angle between vertical and horizontal. When the nozzle is mounted horizontally to spray downwards, heavy concentrations of spray tend to occur at the edges of the spray pattern. Rotating the nozzles 30 to 45 degrees from the horizontal will usually increase the pattern uniformity over the recommended pressure range of 8 to 25 psi. For uniform distribution over a range of pressures, mount the nozzles to obtain double coverage at the lowest operating pressure.

Extended Range Flat-Fan

(Replaced regular flat-fan, available from all nozzle manufacturers.)
Extended range flat-fan nozzles are frequently used for soil and foliar applications when better coverage is required than can be obtained from the flooding or turbo flooding flat-fan nozzles. Extended range flat-fan nozzles are available in both 80- and 110-degree fan angles. The pattern from this nozzle type has a tapered edge distribution. Because the outer edges of the spray pattern have reduced volumes, it is necessary to overlap adjacent patterns along a boom in order to obtain uniform coverage. The 80-degree fan nozzles are usually mounted on 20-inch centers at a boom height of 17 to 19 inches. The 110-degree nozzles could be mounted on 30-inch centers at a boom height of 20 to 22 inches or kept on 20-inch centers and lowered to 16 to 18 inches. Regardless of the spacing and height, for maximum uniformity in the spray distribution, the spray patterns should overlap about 50 to 60 percent of the nozzle spacing (25 to 30 percent on each edge of the pattern).

For soil applications, the recommended pressure range is from 10 to 30 psi. For foliar application when smaller drops are required to increase the coverage, higher pressures from 30 to 60 psi may be required. However, an increase in the likelihood of drift may result when pressures above 25 psi are used. Because of the potential for increased drift with this nozzle type and with newer more drift resistant nozzle designs, this nozzle type is not as highly recommended as it was when first introduced.

Turbo Flood Nozzles

Turbo Flood nozzles are nozzles that combine the precision and uniformity of extended range flat spray tips with the clog resistance and wide-angle pattern of flooding nozzles. The design of the Turbo Flood increases droplet size and distribution uniformity by incorporating a preorifice and chamber internally and a more refined exit orifice. The increased turbulence in the spray tip causes an improvement in pattern uniformity over existing flooding nozzles. At operating pressures of 8 to 25 psi, Turbo Flood nozzles produce larger droplets than standard flooding nozzles. Having larger droplets reduces the number of driftable size droplets in the spray pattern, so Turbo Flood nozzles work well in drift-sensitive applications. Turbo Flood nozzles, because of their improved pattern uniformity, probably need at least 50 percent overlap to obtain proper application uniformity. Turbo Flood nozzles are highly recommended for soil application of crop protection products.

Turbo Flat-Fan

The Turbo Flat-Fan nozzle is designed similar to the Turbo Flood incorporating the preorifice and chamber. It has been adapted to fit in a flat-fan style nozzle body with a greatly improved (uniform) wide angle spray pattern when compared to the extended range flat-fan and other drift-reduction flat-fan nozzles. This nozzle was specifically designed for use in the application of postemergence products. Turbo flat-fan nozzles are wide-angle preorifice nozzles that create larger spray droplets across a wider pressure range (15 to 90 psi) than comparable low-drift tips, reducing the amount of driftable particles. The wide spray angle will allow for a 20 or 30-inch nozzle spacing and requires 50 to 60 percent overlap to achieve uniform application across the boom. Position the tip so that the preset spray angle is directed away from the direction of travel. The Turbo flat-fan nozzle is excellent for use with electronic spray controllers where speed and pressure changes occur regularly.

Air-Injection/Venturi Nozzles

Nozzle manufacturers are increasingly focused on designs for maximum drift reduction. These designs involve the use of air incorporated into the spray nozzle to form an air-fluid mix. Several designs are on the market and are commonly referred to as air-induction, air-injection or venturi nozzles. Air is entrapped into the spray solution at some point (typically a venture section) within the nozzle. To accomplish the mixing, some type of inlet port and venturi is typically used to draw the air into the tip under a reduced pressure. The air-solution combination forms a larger spray droplet and provides energy to help transport the droplets to the target. By increasing the size of the spray droplets a reduction in spray drift occurs by minimizing the smaller driftable fines typically created in a spray tip. Current design of these tips calls for a higher pressure (70-80 psi) to perform adequately. Most all venturi nozzles are designed to spray a wide-angle flat spray pattern.

Venturi nozzles, which are more expensive, dramatically reduce drift potential. In addition to providing good protection against drift, research data on venturi nozzles indicates that they also provide adequate efficacy when used at the higher pressure. Before using, understand coverage needs (systemic vs. contact) for the crop protection products being used in order to ensure adequate droplet formation. It is also important to maintain at least 40 psi as an operating pressure to maintain uniform pattern development while properly atomizing the spray solution. Adding deposition aids or drift-reducing products to tank mix solutions sprayed using venturi nozzles also can have a major impact on pattern quality.

Please note special calibration requirements for the venturi nozzles. For example Greenleaf, designer of the TurboDrop venturi two-piece nozzle, requires the exit orifice to be two times the size of the venturi orifice. Otherwise the exit orifice may create a negative pressure effect in the venturi area resulting in failure of the nozzle to create the proper spray quality (actually reversing flow from the air inlets). Select and calibrate the TurboDrop nozzle based on the venturi orifice, which is color-coded to standard. A chart is available from the manufacturer for this purpose. Other venturi nozzle styles are one piece and do not have this precaution.

Air-Injection/Venturi Nozzles

(New design)

Air-injection/venturi nozzles have made a major impact on reducing drift. So much so that reduced coverage for certain application scenarios has influenced nozzle manufacturers to redesign these nozzle types so that they can improve coverage while still maintaining good drift reduction. The new design reduces the droplet spectra when compared to the earlier venturi styles, allowing for potential for better coverage while maintaining a reasonable amount of drift reduction. The design also allows for lower operating pressures (40 psi) when compared to the earlier designs.

Application Equipment and Techniques for Minimizing Particle Drift

Minimizing spray drift is and will continue to be a major focus for those involved in the agriculture industry. The most popular and least costly technology for reducing drift has been in the design of spray nozzles. Concern has been expressed that this increased emphasis in drift reduction is compromising crop protection product efficacy. A spray droplet standard (ASABE S-572.1) is in place that applicators can use to select the desired droplet spectra. This section will review common methods for minimizing drift while providing insight into using the new standard to properly set up spray equipment to increase efficacy while minimizing drift.

Minimizing Spray Drift

The misapplication of any crop protection product is a major concern. One form of misapplication is spray drift. Although drift cannot be completely eliminated, the use of proper equipment and application techniques will help maintain drift deposits within acceptable limits. The initial recommendation for drift control is to read the pesticide label. Instructions are given to insure the safe and effective use of pesticides with minimal risk to the environment. When drift occurs it is likely that the crop protection product you are using is wasted, and due to the high potential for sensitive areas in crop settings (flowers and other aesthetic plants, water, etc), it is very possible that some damage will occur outside the target area. The off-target damage from products like 2,4-D and glyphosate will be obvious, while applications of a fungicide or insecticide may not be as noticeable.

There are two ways chemicals move downwind to cause damage: particle and vapor drift. Vapor drift is associated with the volatilization of pesticide molecules and then movement off-target (2,4-D). Particle drift is the off-target movement of spray particles formed during or after the application. The amount of particle drift depends mainly on the number of small "driftable" particles produced by the nozzle. Although excellent coverage can be achieved with extremely small droplets, decreased deposition and increased drift potential limit the minimum size that will provide effective pest control.

Factors Affecting Spray Drift

Several equipment and application factors greatly determine the amount of spray drift that occurs. The type and size of nozzle and orientation, pressure, boom height, and spray volume, all affect the off-target movement. The ability to reduce drift is no better than the weakest component in the spraying procedure. See the summary of recommended procedures for reducing particle drift injury in this section.

The potential for drift must be considered when selecting a nozzle type. Of the many nozzle types available for applying pesticides, a few, especially the newer technology nozzles, are specifically designed for reducing drift by decreasing the amount of small driftable spray particles in the spray pattern. However, with selecting a nozzle type to deliver larger droplets for maximum drift reduction comes the potential for decreased coverage and efficacy.

Spray height is also an important factor in reducing drift losses. Mounting the boom closer to the ground (without sacrificing pattern uniformity) can reduce drift. Nozzle spacing and spray angle determines correct spray height for each nozzle type. Wide-angle nozzles can be placed closer to the ground than nozzles producing narrow spray angles. On the other hand, older style wide-angle nozzles also produce smaller droplets. When this occurs, the advantages of lower boom height are negated to some extent. However, the newer technology wide-angle drift reduction nozzles (air-induction/venturi) actually have been designed to reduce the number of small droplets and will assist in drift reduction.

Using larger nozzle sizes is another way of minimizing drift. Increasing the spray volume by using higher capacity spray tips (usually at lower pressures to maintain constant flow rates) results in larger droplets that are less likely to move off-target. Lower pressures also can increase droplet size reducing coverage, while higher pressures and lower flow rate nozzles will lead to more drift by producing finer spray droplets. Changing pressure alone will also change the flow rate per nozzle and the overall application rate. The only effective means of reducing drift by increasing spray volume is to increase nozzle size.

Although not directly an equipment factor, one of the better tools for minimizing drift damage is the use of drift control additives, commonly called deposition aids, in the spray solution to increase the droplet size. Tests indicate that downwind drift deposits can be reduced from 50 to 80 percent with the use of drift control additives. In some cases increased drift has occurred when drift control additives are added to the tank mix. Drift control additives make up a specific class of chemical adjuvants and should not be confused with products such as surfactants, wetting agents, spreaders, and stickers. Drift control additives are formulated to produce a droplet spectrum with fewer small droplets.

A number of drift control additives are commercially available, but they must be mixed and applied according to label directions in order to be effective. Some products are recommended for use at a rate of 2 to 8 ounces per 100 gallons of spray solution. Increased rates may further reduce drift but also may cause nozzle distribution patterns to be nonuniform. Drift control additives vary in cost depending on rate and formulation, but are comparatively inexpensive for the amount of control provided. It is wise to test these products in your spray system to ensure they are working properly before adapting this practice. Not all products work equally for all systems. They do not eliminate drift. Common sense must still remain the primary factor in reducing drift damage.

Focus on Droplet Size

Most applicators are familiar with how to use flow rate charts from spray equipment catalogs and websites to determine the nozzle orifice size needed to deliver a proper application volume (GPA or G/1000 sq. ft.). Applicators are also comfortable in making those applications with the benefit of an automatic rate controller to help improve the uniformity of application volume. However, a properly calibrated sprayer does not guarantee the application will achieve its highest level of efficacy or minimize drift. The next step in calibration is designed to achieve this, but is one that most applicators are not familiar with yet. This calibration step requires applicators to review droplet size charts to choose nozzle types and pressure levels that will meet a specified droplet classification listed on the label. The droplet size created by a nozzle becomes very important when the efficacy of a particular crop protection product is dependent on coverage, or the minimization of material leaving the target area is a priority. Droplet specifications or spray quality requirements may be printed on the label to guide applicators in selecting how to best apply that pesticide. Consulting the nozzle manufacturers' droplet sizing charts is *essential*.

To help applicators select nozzles according to droplet size, spray equipment manufacturers are including drop size charts with their respective catalogs and web sites. These charts classify the droplet size from a given nozzle at various pressure levels according to a standard set up by the American Society of Agricultural and Biological Engineers (ASABE). The standard (S-572.1) rates droplets as extra fine, very fine, fine, medium, coarse, very coarse, extra coarse, and ultra coarse (see chart on the next page). Droplet size categories are color-coded as shown in the chart. Remember, if the label specifies a particular droplet size category, you are required to set up the sprayer to meet that particular spray quality. The label is the law!

Strategies to Reduce Spray Drift

This following summary table provides several strategies that when used in combination, will result in the best chance to minimize drift. One strategy used alone will not necessarily prevent drift. A combination of strategies will provide the best insurance against the off-target movement of the crop protectant product used.

Calibration

Accurate calibration is the only way to know how much chemical is applied. Even with the widespread use of electronics to monitor and control the application of crop protection products today, a thorough sprayer calibration procedure is essential to ensure against misapplication. Failure to calibrate a sprayer can injure your crop, cause pollution, and waste money. In addition to calibrating the sprayer at the start of the season, you should recalibrate regularly. Abrasive pesticide formulations can

Procedures for Reducing Particle Drift Injury

Recommended Technique	Explanation
Select a nozzle to increase droplet size.	Use as large droplets as practical to provide necessary coverage.
Use lower end of pressure range.	Higher pressures generate many more small droplets with greater drift potential.
Lower boom height.	Wind speed increases with height. A few inches lower boom height can reduce off-target drift. High field travel speeds may result in an unstable boom leading to high boom positions and drift potential.
Increase nozzle size, resulting in higher application volumes.	Larger-capacity nozzles can reduce the amount of spray depositing off-target.

Recommended Technique	Explanation
Avoid high application ground speeds or major speed changes across the field.	Rate controllers adjusting to speed changes may result in pressure adjustments causing droplet size variability. Rapid speed increases may create high pressure resulting in more drift potential.
Avoid high wind speeds.	More of the spray volume will move off-target as wind increases. Wind currents can drastically affect spray droplet deposition. Structures drastically affect wind currents, for example, windbreaks, tree lines, buildings, hills and valleys.
Avoid light and variable winds	Light winds tend to be variable in direction making it hard to identify the sensitive areas.
Do not spray when the air is completely calm.	Absolutely calm air generally occurs in early morning or late evening and may indicate the presence of a temperature inversion. Calm air reduces air mixing, and leaves a spray cloud that may move slowly downwind at a later time.
Consider using buffer zones/no-spray zones. Be able to identify the sensitive areas.	Leave a buffer zone/no-spray zone if sensitive areas are downwind. Spray buffer zone when wind changes to a favorable direction.
Consider using new technologies.	Consider using drift reduction nozzles, i.e., chamber and venturi style nozzles. Also, boom shields, hoods, electrostatics, air-assist booms, pulse width modulation valves are all designed to reduce drift potential.
Use an approved drift-control additive/deposition aid when needed.	Drift-control additives/deposition aids increase the average droplet size produced by the nozzles. However, these additives should not become your only drift reducing technique. They will not protect against otherwise poor spraying practices.

ASABE Standard S-572.1 Spray Quality Categories

Category	Color
Extra Fine (XF)	purple
Very Fine (VF)	red
Fine (F)	orange
Medium (M)	yellow
Coarse (C)	blue
Very Coarse (VC)	green
Extra Coarse	white
Ultra Coarse	black

wear nozzle tips resulting in increased nozzle flow rate and the development of poor spray patterns.

To obtain uniform coverage, you must consider the spray angle, spacing, and height of the nozzle. The height must be readjusted for uniform coverage with various spray angles and nozzle spacings. Do not use nozzles with different spray angles on the same boom for broadcast spraying. Be sure nozzle tips are clean. If necessary, clean with a soft bristle brush. A nail, wire, or pocket knife can damage the tip and ruin spray pattern uniformity. While the sprayer is running, observe each spray tip for distortions in the patterns.

Worn or partially plugged nozzles produce nonuniform patterns. Misalignment of nozzle tips is a common cause of uneven coverage. The boom must be level at all times to maintain uniform coverage. Skips and uneven coverage will result if one end of the boom is allowed to droop. A good method for determining the exact nozzle height that will produce the most uniform coverage is to spray on a warm surface, such as a road, and observe the drying rate. Streaks in the spray pattern should be obvious. Replace nozzles that are not performing correctly.

When you are convinced the sprayer is operating properly, you are ready to calibrate. There are many methods for calibrating low-pressure sprayers, but they all involve the use of the variables in the equation on page 104. Any technique for calibration that provides accurate and uniform application is acceptable. No single method is best for everyone.

The calibration method described below has four advantages. First, it allows you to select the number of gallons to apply per acre and to complete most of the calibration before going to the field. Second, it provides a simple means for frequently adjusting the calibration to compensate for changes due to nozzle wear. Third, it can be used for broadcast, band, directed, and row-crop spraying. This method requires a knowledge of nozzle types and sizes and the recommended operating pressure ranges for each type of nozzle used. Finally, when using the method below, the applicator will have a better understanding of how each variable will affect the application rate. As each of the variables change, the influence on the rate (gallons per acre) is apparent.

The gallons of spray applied per acre can be determined by using the following equation:

Equation 1

$$GPA = \frac{GPM \times 5{,}940}{MPH \times W}$$

GPM = output per nozzle in gallons per minute

MPH = ground speed in miles per hour

W = effective width sprayed per nozzle in inches

5,940 = a constant to convert gallons per minute, miles per hour, and inches to gallons per acre

Equipment and Calibration for Commercial Field Crop Applications

The size of the nozzle tip will depend on the application rate (GPA), ground speed (MPH), and effective width sprayed (W) that you plan to use. Some manufacturers advertise "gallon-per-acre" nozzles, but this rating is useful only for standard conditions (usually 30 psi, 4 MPH, and 20-inch spacing). The gallons-per-acre rating is useless if any one of your conditions varies from the standard.

A more exact method for choosing the correct nozzle tip is to determine the gallons per minute (GPM) required for your conditions. Then select nozzles that provide this flow rate when operating within the recommended pressure range. By following the five steps described below, you can select the nozzles required for each application well ahead of the spraying season.

Step 1 – Select the spray application rate in gallons per acre (GPA). Pesticide labels recommend ranges for various types of equipment. The spray application rate is the gallons of carrier (water, fertilizer, etc.) and pesticide applied per treated acre.

Step 2 – Select or measure an appropriate ground speed in miles per hour (MPH) according to existing field conditions. Do not rely on speedometers as an accurate measure of speed. Slippage and variation in tire sizes can result in speedometer errors of 20 percent or more. If you do not know the actual ground speed, you can easily measure it. Instructions for measuring ground speed are given below.

Step 3 – Determine the effective width sprayed per nozzle (W) in inches.

For broadcasting spraying,
W = the nozzle spacing

For band spraying,
W = the band width

For row-crop applications, such as spraying from drop pipes or directed spraying,

$$W = \frac{\text{row spacing (or band width)}}{\text{number of nozzles per row (or band)}}$$

Step 4 – Determine the flow rate required from each nozzle in gallons per minute (GPM) by using a nozzle catalog, tables, or the following equation. Using Equation 2 allows the applicator to determine flow rates for each application scenario needed for the application season. This can be done before the application season begins, thus not interfering with critical time available during the application time.

Equation 2

$$GPM = \frac{GPA \times MPH \times W}{5{,}940}$$

GPM = gallons per minute of output required from each nozzle

GPA = gallons per acre from Step 1

MPH = miles per hour from Step 2

W = inches sprayed per nozzle from Step 3

5,940 = a constant to convert gallons per minute, miles per hour, and inches to gallons per acre

Step 5 – Select a nozzle that will give the flow rate determined in Step 4 when the nozzle is operated within the recommended pressure range. You should obtain a catalog of available nozzle tips. These catalogs can be obtained free of charge from equipment dealers or nozzle manufacturers. If you decide to use nozzles that you already have, return to Step 2 and select a speed that allows you to operate within the recommended pressure range.

Broadcast application:

Example 1: You want to broadcast a preplant incorporated herbicide at 15 GPA (Step 1) at a speed of 7 MPH (Step 2), using TurboFlood nozzles spaced 40 inches apart on the boom (Step 3). What TurboFlood nozzle tip should you select?

The required flow rate for each nozzle (Step 4) is as follows:

$$GPM = \frac{GPA \times MPH \times W}{5{,}940}$$

$$GPM = \frac{15 \times 7 \times 40}{5{,}940} = \frac{4{,}200}{5{,}940} = 0.71$$

The nozzle that you select must have a flow rate of 0.71 GPM when operated within the recommended pressure range of 10 to 40 psi. Table 2 shows the GPM at various pressures for several Spraying Systems TF nozzles. For example, the Spraying Systems TF-5 nozzle has a rated output of 0.71 GPM at 20 psi (Step 5). This nozzle could be installed for this application.

Herbicide Band Applications for Cost-Effective Weed Control

Band applications of herbicides can reduce costs for postemergence and preemergent weed control treatments. In band applications, the treated acre is the acres actually sprayed and, depending on the row spacing and the band width, is some fraction of the total field acres. Remember, herbicides are applied in bands at the same rate of active ingredients per treated acre as in broadcast applications. Treating a field with 30-inch rows in 15-inch bands has the effect of reducing the herbicide cost by one-half.

Equipment and Calibration for Commercial Field Crop Applications

When banding soil-applied herbicides to control weeds in row crops, use spray tips designed for band application. They are commonly referred to as even flat spray tips and are designated in the nozzle nomenclature with the letter 'E'. (See Table 1.) Even flat spray tips are designed to apply a uniform pattern on the target across the width of the angle. Extended range flat spray tips, on the other hand, are designed to apply a tapered edge pattern and would not uniformly cover the targeted band width. For even spray tips, the nozzle spray angle and height above the target will determine the spray width.

Band applications also can be used to apply postemergence materials. To obtain thorough coverage to all plant material it may be necessary to direct the spray in a multi-nozzle arrangement around and over the top of the plant. Special band-application row kits or drops are available for this purpose. Special attention should be given when using a multiple nozzle kit to properly calibrate for the correct nozzle orifice size.

Over-the-Row Band Application

Example 2: You want to apply a preemergence herbicide in a 15-inch band over each 30-inch corn row. The desired application rate is 15 GPA at 7.5 MPH. Which even flat-fan nozzle should you select?

The required flow rate is as follows:

$$GPM = \frac{GPA \times MPH \times W}{5{,}940}$$

$$GPM = \frac{15 \times 7.5 \times 15}{5{,}940} = \frac{1{,}687.5}{5{,}940} = 0.28$$

Table 1. Explanation of Typical Nozzle Numbering Systems

Extended Range Flat-Fan **Turbo Flat-Fan** **Venturi Flat-Fan**	XR 11004 TT 11004 AI 11004	XR – Extended Range Flat-Fan TT – Turbo Flat-Fan AI – Air-Induction/Venturi Flat-Fan 110 – 110 degree fan angle 04 – 0.4 gallon per minute flow rate @ 40 psi
Even-Fan	TP8002E AI 9502E	E – Even spray pattern 80 – 80 degree fan angle, 95 degree fan angle 02 – 0.2 gallon per minute flow rate @ 40 psi
Turbo Flooding	TF-4	TF – Turbo Flood 4 – 0.4 gallon per minute flow rate @ 10 psi
Turf Flood	TTJ04	TTJ – Turbo Turf Flood 4 – 0.4 gallon per minute flow rate @ 40 psi
Turbo Flooding	QCTF 40	QCTF – Quick attach Turbo Flood 40 – 4.0 gallons per minute @ 10 psi

Table 2. Turbo Flooding Flat-Fan Nozzle Chart

Spraying Systems Orifice Designation	Liquid Pressure (PSI)	Capacity	
		Gal/min (GPM)	Oz/min (OPM)
TF-2	10	.20	26
	20	.28	36
	30	.35	45
	40	.40	51
TF-2.5	10	.25	32
	20	.35	45
	30	.43	55
	40	.50	64
TF-3	10	.30	38
	20	.42	54
	30	.52	67
	40	.60	77
TF-4	10	.40	51
	20	.57	73
	30	.69	88
	40	.80	102
TF-5	10	.50	64
	20	.71	91
	30	.87	111
	40	1.00	128
TF-7.5	10	.75	96
	20	1.1	136
	30	1.3	166
	40	1.5	192
TF-10	10	1.0	128
	20	1.4	180
	30	1.7	221
	40	2.0	256

Table 3. Banding and Directed Application Nozzle Chart

Spraying Systems Orifice Designation	Liquid Pressure (PSI)	Capacity	
		Gal/Min (GPM)	Oz/Min (OPM)
TP8001E	30	0.087	11
	40	0.10	13
	50	0.11	15
	60	0.12	15
TP80015E, AI95015E	30	0.13	17
	40	0.15	19
	50	0.17	22
	60	0.18	23
	70	0.20	26
	80	0.21	27
TP8002E, AI9502E	30	0.17	22
	40	0.20	26
	50	0.22	28
	60	0.24	31
	70	0.26	33
	80	0.28	36
AI9525E	30	0.22	28
	40	0.25	42
	50	0.28	36
	60	0.32	41
	70	0.33	42
	80	0.35	45
TP8003E, AI9503E	30	0.26	33
	40	0.30	38
	50	0.34	44
	60	0.37	47
	70	0.40	51
	80	0.42	54
TP8004E, AI9504E	30	0.35	45
	40	0.40	51
	50	0.45	58
	60	0.49	63
	70	0.53	68
	80	0.57	73
TP8005E, AI9505E	30	0.43	55
	40	0.50	64
	50	0.56	72
	60	0.61	78
	70	0.66	84
	80	0.71	91

Spraying Systems Orifice Designation	Liquid Pressure (PSI)	Capacity	
		Gal/Min (GPM)	Oz/Min (OPM)
TP8006E, AI9506E	30	0.52	67
	40	0.60	77
	50	0.67	86
	60	0.73	93
TP8008E, AI9508E	30	0.69	88
	40	0.80	102
	50	0.89	114
	60	0.98	125
TP8010E	30	0.87	111
	40	1.00	128
	50	1.12	143
	60	1.22	156

The nozzle you select must have a flow rate of 0.28 GPM when operated within the recommended pressure range. The Spraying Systems TP8003E or AI9503E nozzles shown in Table 3 have a rated output of 0.28 GPM at approximately 35 psi. Either of these nozzles could be used for this application.

Now that you have selected and installed the proper nozzle tips (Steps 1–5) you are ready to complete the calibration of your sprayer (Steps 6–10 below). Check the calibration every few days during the season or when changing the crop protection products being applied. New nozzles do not lessen the need to calibrate because some nozzles "wear in," increasing their flow rate more rapidly during the first few hours of use. Once you have learned the following method, you can check application rates quickly and easily.

Step 6. Determine the required flow rate for each nozzle in ounces per minute (OPM). To convert GPM (Step 4) to OPM, use the following equation:

Equation 3

$OPM = GPM \times 128$
(1 gallon = 128 ounces)

From Example 1, the required flow rate = 0.71 GPM

$OPM = 0.71 \times 128 = 91$

From Example 2, the required flow rate = 0.28 GPM

$OPM = 0.28 \times 128 = 36$

Step 7. Collect the output from one of the nozzles in a container marked in ounces. Adjust the pressure until the ounces per minute (OPM) collected is the same as the amount you determined in Step 6. Check several other or all of the nozzles to determine if their outputs fall within 5 percent of the desired OPM.

If it becomes impossible to obtain the desired output within the recommended range of operating pressures, select larger or smaller nozzle tips or a new ground speed, then recalibrate. It is important for spray nozzles to be operated within the recommended pressure range. The range of operating pressures is indicated at the nozzle tip. Line losses, nozzle check valves, etc., may require the main pressure gauge at the boom or at the controls to read much higher.

Step 8. Determine the amount of pesticide needed for each tankful or for the acreage to be sprayed. Add the pesticide to a partially filled tank of carrier (water, fertilizer, etc.). Then add the carrier to the desired level with continuous agitation. Examples for determining the amount of pesticide to add to the tank are illustrated later.

Step 9. Operate the sprayer in the field at the ground speed you measured in Step 2 and at the pressure you determined in Step 7. You will be spraying at the application rate you selected in Step 1. After spraying a known number of acres, check the liquid level in the tank to verify that the application rate is correct.

Step 10. Check the nozzle flow rate frequently Adjust the pressure to compensate for small changes in nozzle output due to nozzle wear or variations in other spraying components. Replace the nozzle tips and recalibrate when the output has changed 5 percent or more from that of a new nozzle, or when the pattern has become uneven.

Remember, to apply crop protection products accurately, you must maintain the proper ground speed. Because speedometers do not always provide an accurate measure of speed, you may want to check the accuracy of the speedometer with an electronic kit or radar gun. If your sprayer does not have a speedometer or if your speedometer is not accurate, you must measure the speed at all of the settings that you plan to use in the field. By measuring and recording the ground speed at several gear and throttle settings, you will not have to remeasure speed each time you change settings.

To measure ground speed, lay out a known distance in the field you intend to spray or in another field with similar surface conditions. Suggested distances are 100 feet for speeds up to 5 MPH, 200 feet for speeds from 5 to 10 MPH, and at least 300 feet for speeds above 10 MPH. At the engine throttle setting and in the gear you plan to use during spraying with a half-loaded sprayer, determine the travel time between the measured stakes in each direction. Average these speeds and use the following equation to determine ground speed.

Speed (MPH) = $\frac{\text{distance(feet)} \times 60}{\text{time (seconds)} \times 88}$

1 MPH = 88 feet per 60 seconds

Example: After measuring a 200-foot course, you discover that 22 seconds are required for the first pass and 24 seconds for the return pass.

Average time = $\frac{22+24}{2}$ = 23 seconds

MPH = $\frac{200 \times 60}{23 \times 88} = \frac{12{,}000}{2{,}024} = 5.9$

Once you have decided on a particular speed, record the throttle setting and drive gear used.

Mixing Formulations

To determine how much pesticide to add to your spray tank, you must know (1) the recommended pesticide application rate, (2) the capacity of the spray tank, and (3) the calibrated output of the sprayer.

Follow the label instructions or university recommendations to determine the rate at which to apply the pesticide. The rate is usually indicated in pounds per acre for wettable powders, and in pints, quarts, or gallons per acre for liquids. Sometimes the recommended rate is given in pounds of active ingredient per acre (lb a.i./A) rather than the amount of product per acre. In these cases, you must convert the quantity of active ingredient to the corresponding quantity of the actual product.

You should verify that the sight gauge marks are accurate for your spray tank. Misapplication often occurs because tank capacities are measured inaccurately. To determine tank capacity, add measured volumes of water (5 to 50 gallons) and mark the level on the gauge as you fill the tank. You can use flow meters to measure the quantity of water as it flows into the tank. Flow meters are much easier to use than containers when calibrating sight gauge marks on large tanks.

The calibrated output of your sprayer determines the number of gallons that will be applied per acre. Pesticide labels recommend ranges of application rates for various types of equipment. Sometimes crop protection products are applied in fertilizer solutions. In these cases, the desired fertilizer application rate determines the number of gallons per acre that must be applied. Also, most fertilizers are more dense than water and will have different flow characteristics. Adjustments for differences in flow rate are required to achieve the calibrated application rate.

Once you have figured out the exact capacity of your tank and have calibrated your sprayer accurately, you can determine how many acres you can spray with every tankful of spray solution. Divide the number of gallons the tank holds by the number of gallons you intend to apply to each acre. The amount of pesticide to add to the tank is determined by multiplying the number of acres sprayed per tankful by the recommended pesticide application rate. The following examples illustrate this procedure.

Equipment and Calibration for Commercial Field Crop Applications

Maintenance and Cleaning

Proper maintenance and cleaning are important to keep foreign materials out of the sprayer. These materials can clog nozzles and damage the pump and other sprayer components. Thoroughly clean spray equipment to prevent injury to crops susceptible to a previously applied pesticide. Some pesticides will cause equipment to deteriorate if they remain in the sprayer for an extended period of time. The

Example (Dry Formulation): An atrazine recommendation calls for 1½ pounds of active ingredient per acre (lb a.i./A). You have purchased AAtrex 90DF (90 percent dry flowable). Your sprayer has a 400-gallon tank and is calibrated to apply 20 gallons per acre. How much AAtrex should you add to the spray tank?

Step 1. Determine the number of acres you can spray with each tankful.

$$\frac{\text{tank capacity (gallons per tank)} = 400}{\text{spray rate (gallons per acre)} = 20} = 20 \text{ acres per tankful}$$

Step 2. Determine the number of pounds of pesticide product needed per acre. Since not all of the atrazine in the bag is an active ingredient, you will obviously have to add more than 1½ pounds of the product to each "acre's worth" of water in your tank. To determine how much more, divide the percentage of active ingredient (in this case, 90) into the total (100).

$$1\tfrac{1}{2} \text{ lb a.i./A} \times \frac{100\%}{90\%} = 1\tfrac{1}{2} \times 1.11 = 1.66 \text{ pounds of product per acre}$$

For each "acre's worth" of water in the tank, you will need 1.66 pounds of product to apply 1½ pounds of active ingredient per acre.

Step 3. Determine the amount of pesticide to add to each tankful. With each tankful you will cover 20 acres (Step 1), and you want to apply 1.66 pounds of product per acre (Step 2).

20 A×1.66 lb/A = 33.3 pounds of product per tankful

Example (Liquid Formulation): A trifluralin recommendation calls for 1 pound of active ingredient per acre. You have purchased Treflan 4E (4 pounds per gallon formulation). Your sprayer has a 500-gallon tank and is calibrated to deliver 20 GPA. How much Treflan should you add to the spray tank?

Step 1. Determine the number of acres that you can spray with each tankful.

$$\frac{\text{tank capacity (gallons per tank)} = 500}{\text{spray rate (gallons per acre)} = 20} = 25 \text{ acres per tankful}$$

Step 2. To determine the amount of product needed per acre, divide the recommended amount of active ingredient per acre by the concentration of the formulation.

$$\frac{1 \text{ lb a.i./A}}{4 \text{ lb a.i./gal.}} = \tfrac{1}{4} \text{ gallon per acre}$$

Step 3. Determine the amount of pesticide to add to each tankful. You will cover 25 acres with each tankful (Step 1), and want to apply ¼ gallon (1 quart) of product per acre (Step 2).

25 A×1 qt/A = 25 quarts (6.25 gallons) of Treflan per tankful

Example (Adjuvant): It is often recommended that a small amount of an adjuvant, such as a spreader-sticker or a surfactant, be added to the chemical you plan to spray. The amount to be added is frequently given as percent concentration.

If you use an adjuvant at ½-percent concentration by volume, how much should you add to a 500-gallon tank?

Solution 1:

1 percent of 100 gallons = 1 gallon (100×0.01 = 1)

½ percent of 100 gallons = ½ gallon

You will need ½ gallon for 100 gallons, or 2½ gallons for 500 gallons (½×5 = 2½).

Solution 2: $\tfrac{1}{2}$ percent = 0.5 percent = $\frac{0.5}{100}$ = 0.005

0.005×500 gallons = 2.5 gallons of adjuvant per 500-gallon tank following practices will help you maintain and clean your spray equipment properly.

1. Use only water that appears clean enough to drink. Small particles often found in water from ditches, ponds, or lakes can clog nozzles and strainers. If you are in doubt, filter the water as you fill the tank.
2. Check and clean strainers daily. Partially plugged strainers will create a pressure drop and reduce the nozzle flow rate. Most sprayers have three different strainers: one on the suction hose to protect the pump, another in the line between the pump and the boom, and a third, which has the smallest openings, in the nozzle body.
3. Do not use a metal object for cleaning nozzles. Metal objects will destroy the orifice. When a nozzle becomes clogged, always remove it for cleaning.
4. Flush a new sprayer before using. A new sprayer invariably contains metal chips and dirt from the manufacturing process. Remove the nozzles and strainers. Then flush the sprayer and boom with clean water. Thoroughly clean each nozzle before reinstalling.
5. Clean your sprayer according to the type of pesticide formulation used. Residues from some formulations are more difficult to remove from the tank. To remove residues of oil-based herbicides, such as esters of 2,4-D and similar materials, rinse the sprayer with kerosene, diesel fuel, or a comparable light oil. Do not use gasoline.

   After rinsing the equipment with oil or a water detergent solution, fill the tank one-quarter to one-half full with a water-ammonia solution (1 quart of household ammonia to 25 gallons of water) or a water-trisodium phosphate (TSP) solution (1 cup TSP to 25 gallons of water). Circulate the solution through the system for a few minutes, allowing a small amount to pass through the nozzles. Let the remainder of the solution stand at least six hours; then pump it through the nozzles. Remove the nozzles and strainers and flush the system twice with clean water.

   Equipment in which wettable powders, amine forms, or water-soluble liquids have been used should be thoroughly rinsed with a water-detergent solution (2 pounds of detergent to 30 to 40 gallons of water). Water-soluble materials should be treated as water-soluble liquids. Allow the water-detergent solution to circulate through the system for several minutes. Remove the nozzles and strainers, and flush the system twice with clean water.
6. When it is time to store your sprayer, add 1 to 5 gallons of lightweight oil, depending on the size of your tank, before the final flushing. As water is pumped from the sprayer, the oil will leave a protective coating inside the tank, pump, and plumbing. To prevent corrosion, remove the nozzle tips and strainers, dry them, and store in a can of light oil, such as diesel fuel or kerosene.

7. Corrosive fertilizer solutions should not be used in certain sprayers. Liquid fertilizers are corrosive to copper, galvanized surfaces, brass, bronze, and steel. You can irreparably damage an ordinary sprayer after one use with a liquid fertilizer. Use sprayers made completely of stainless steel or aluminum for applying liquid fertilizers. Aluminum is satisfactory for some nitrogen fertilizers, but not for mixed fertilizers.

Record Keeping

The number of days available for applying pesticides to field crops is limited, and applicators work under considerable pressure to treat as many acres per day as possible. It is tempting to cut corners to increase output, but decreased profits often result because more mistakes are made in application. In planning your spraying schedule, you must allow sufficient time for calibration, equipment maintenance, and record keeping.

The competence of the operator is the essential element in achieving accurate and uniform application. The operator must know how, when, and where to use each pesticide, and under what conditions not to use a particular pesticide. He or she must understand calibration procedures, be aware of the importance of uniform application, and know how to communicate with the farmer. The operator needs as much information as possible about every application site. What pesticide rate should be used? Where is the field located, and how many acres does it contain? What nozzle type, boom pressure, and travel speed are required?

Record keeping is the key in providing the proper information to the operator so that application errors can be avoided. You should begin keeping records of the pesticides and rates used during your first consultation. A detailed map of each field, including notes about what products are to be applied, will allow the operator to compare the load he or she receives with what the map shows.

Written records prepared at the time of application are required for every field treated. Numerous record forms are available that are easy to complete. Each commercial operation is unique and will need to adapt the forms to suit their needs. The form should indicate where the application started, where it ended, where pesticide transfer (nursing) took place, whether the application quantity was long or short, what the weather conditions were, including wind velocity and direction, and the extent of calibration or mechanical problems. All operators make occasional errors, and these errors should be a part of the record.

Many misapplications are the result of operator fatigue. Provide as much support as possible to assist with refueling, washing, and general equipment maintenance and allow a minimum amount of rest each day. Remember it is easier and less expensive to apply pesticides properly than to handle complaints because of misapplication.

Study Questions

These study questions are to help you learn the material on pages 95 to 114.

1. Calibration is the process of:

a. measuring the horsepower of your sprayer.
b. measuring and adjusting the amount of pesticide applied by the equipment.
c. measuring the size of the field.
d. measuring the boom length.

2. The correct type and size of spray nozzle is essential for __________.

a. drift reduction.
b. uniform coverage.
c. the correct application rate.
d. all of the above.

3. Drift can be minimized by ____________.

a. decreasing nozzle size.
b. spraying when the air is completely calm.
c. increasing nozzle size.
d. none of the above.

4. In order to determine how much pesticide to add to the tank, you need to know __________.

a. the pesticide application rate.
b. the capacity of the tank.
c. calibrated output.
d. all of the above.

5. Vapor drift is the result of:

a. using the wrong pesticide.
b. the volatilization of an active ingredient.
c. spraying with too high a pressure.
d. spraying too fast.

Requirements for Effective Aerial Application

- good cooperation between pilot and grower when developing an aerial application program
- consideration of the environmental effects
- recognition of potential dangers to people, animals, and other crops
- correct and well-maintained equipment
- accurate and uniform application
- a competent pilot
- adherence to the planned aerial application program

Limitations of Aerial Application

- weather hazards
- difficulty in treating areas with fixed obstacles
- difficulty in treating irregular field size and shape
- the distance from the application to the landing area
- the danger of contamination of nearby areas due to misapplication or drift

Dispersal Equipment

Fixed and rotary wing aircraft are used for aerial application. It is important that metering and dispersal equipment meter correct quantities of pesticide formulations and deliver them uniformly. In order to correctly calibrate, the equipment must be accurate.

Liquid Systems

Liquid dispersal systems may be wind-driven, hydraulic or electric motor powered, or directly powered by the aircraft engine. A liquid dispersal system includes these components:

- tank/hopper
- agitation system
- pump
- hoses, metal piping and fittings
- control valves with suck-back features
- filters (screens)
- pressure gauge
- one or more booms
- nozzles

Tank – The tank should be leakproof and resistant to corrosion. Materials used for tanks and hoppers include fiberglass, stainless steel, high-density polypropylene, or polyethylene. The tank also should have a mechanism, such as a large valve or port (door, gate) through which the load can be dumped in case of emergency. The aircraft must have a gauge or visual level viewable from the cockpit to measure tank contents. Tanks should be fitted with an air vent to prevent a vacuum from developing. Baffles limit the amount of sloshing of liquid in the tank.

Agitation System – Agitation is required by many of the pesticide formulations such as emulsifiable concentrates, wettable powders, and flowables, during application in order to maintain the spray mixture. Hydraulic agitation or recirculation of all or part of the pump output into the tank is a common form of agitation.

Pump – The pump system must be able to deliver large quantities of liquid pesticides per unit of time. This ensures uniform and proper flow volume, produces the desired atomization from nozzles, and maintains suspensions. Pumps must be able to meet the system's nozzle output, flow volume, and agitation requirements. Extra capacity for line friction loss and to operate nozzle anti-drip check valves are also important. The most common centrifugal pumps are made from aluminum with bronze or steel internal parts.

Piping and Fittings – Main piping and fittings should have a large diameter of up to 3 inches in order to apply high volumes of liquids, and a smaller diameter of 1 inch for low-volume applications. Hoses should be large enough to carry the flow and corrosion resistant. Helicopters slower application speed makes smaller piping adequate.

Filters – Nozzle clogging and wear may be prevented by using correctly sized filter screens and line filters. Screens range in size from 10 to 200 mesh. They should be located between the tank and the pump, or when using a centrifugal pump, they should be located between the pump and the boom. Line filters should be cleaned daily during spray operations.

Boom – The boom provides support to the nozzles along the wingspan of the aircraft. Clearance between control surfaces of the wing and the boom is essential when the boom is located near the trailing edge of the wing. On fixed wing aircraft, drop booms or drop pipes are commonly used to place the nozzles in clean air flow. End caps on the boom may be removable for cleaning and make it easier to flush the boom and nozzles. However, end caps will prevent positioning of nozzles at or near the boom ends.

Nozzles – Aircraft systems use special nozzles which are equipped with antisiphon or nondrip check valves. Select the appropriate nozzle based on the manufacturers' recommendations. Nozzle selection, location, calibration and testing are critical to the effectiveness of the aircraft spray system. A uniform spray pattern depends on correct nozzle placement on the boom.

Propeller rotation shifts the spray pattern from right to left as the pilot sees it. Adjustments to the number of nozzles, lowering the nozzles, and possible shifting under the fuselage may be required to compensate for this. Placing end nozzles inboard will prevent the wingtip vortex from trapping fine droplets, causing uneven distribution and drift.

Common nozzle types available for aerial application are straight stream, flat-fan, variable orifice flood, hollow-cone, and rotary atomizers. Nozzle orientation on the boom greatly affects droplet size. Orienting nozzles with the direction of flight obtains more shear and liquid break-up. In higher speed applications, orienting nozzles parallel to the direction of travel will reduce the secondary atomization effects dramatically. Research also documents that at higher application speeds, higher application pressure (40+ psi) will reduce the number of driftable fines on nondeflector nozzle types. Research also indicates that using nozzles that produce larger droplets can result in more secondary air shear. The density, viscosity, and surface tension of the pesticide and the evaporation conditions in the air can affect the droplet size.

Nozzle placement on a helicopter boom may be uniform except where the spray may hit parts of the aircraft such as the skids. A rear section boom is sometimes used to help keep spray off the helicopter. The angle of the nozzle in relation to the direction of travel affects droplet size. Flight speed also may affect droplet size.

Dry Systems

Granular dispersal systems may be used for applying dry formulations such as pellets, impregnated granules, fertilizers, and seeds. The application equipment and size, shape, density, and flowability of the material affect the swath width, application rate, and pattern. A hopper with agitation must be provided to prevent bridging of fine material that are less than 60 mesh. Frequent inspection of metering gates is required to ensure against leakage and to make sure it is set correctly. The use of granular systems is on the decline for agricultural work.

Calibration

Calibration is important for aerial applications because large areas are covered in a short time. Calibrate often to ensure that equipment is calibrated correctly and does not exhibit wear.

The application rate (gallons per acre) is determined by the chemical being applied and the crop being treated as listed on the label. An applicator can calculate acres per minute by converting the airspeed from miles per hour to feet per minute using the formula below:

$$\frac{\text{MPH} \times 5{,}280 \text{ feet/mile}}{60 \text{ minutes/hour}} = \text{feet/minute}$$

Then, multiply the effective spray width by the feet per minute airspeed to determine the area, in square feet, covered in one minute. Divide by 43,560 square feet/acre to convert the area into acres as illustrated in the equation below:

$$\frac{\text{Feet/minute} \times \text{swath width}}{43{,}560 \text{ square feet/acre}} = \text{acres per minute}$$

Using acres per minute being treated and spray mix requirements from the label, select nozzles from the manufacturers' data. Give careful attention to the nozzle type and the pressure at which they must operate to deliver the correct volume and droplet size. This pressure must be used in all calibrations and the airspeed should be exactly the same as will be used in the field.

Liquid Systems

Follow these basic steps in sprayer calibration.

- Figure the acres your aircraft's system treats per minute at the speed and height you plan to fly.
- Determine the gallons you must spray per minute to apply the recommended rate.
- Select the nozzle size and of number of nozzles needed to deliver the correct number of gallons per minute at your system's operating pressure. Use the nozzle manufacturers' guidelines.
- Make a trial run.
- Determine the amount of chemical to add to the tank.

Example: Your aircraft has a 400 gallon tank. The effective swath width is 65 feet. You plan to spray at 140 mph at the height of 8 to 10 feet. The chemical is to be applied at the rate of 1 pint per 3 gallons of spray per acre. The operation pressure will be 30 psi.

Step 1. Determine acres per minute using the formulas presented above.

$$\frac{140 \text{ mph} \times 5{,}280 \text{ feet/mile}}{60 \text{ minutes/hour}} = 12{,}320 \text{ feet/minute}$$

$$\frac{12{,}320 \text{ feet/minute} \times 65 \text{ feet}}{43{,}560 \text{ square feet/acre}} = 18.\ 4 \text{ acres/minute}$$

Step 2. Determine gallons per minute (GPM) required. In this example. 3×18.4 = 55.2 gallons per minute. Be sure the pump can deliver this volume.

Step 3. Select the nozzles. First determine the GPM per nozzle that would deliver the required 55.2 gpm flow. Most agricultural aircraft can accommodate about 50 nozzles. The GPM per nozzle is determined this way:

$$\frac{\text{total flow}}{\text{Number of nozzles}} = \text{GPM per nozzle}$$

$$\text{Our example: } \frac{55.2}{50} = 1.1 \text{ GPM per nozzle}$$

Based on this calculation and the manufacturer's charts, select a nozzle delivering 1.1 gpm in the desired pressure of 30 psi. You may find that the nozzle closest to your needs delivers at only 0.95 GPM. This small difference can be adjusted by increasing the pressure.

Step 4. Make a trial run to test the system. After installing 50 of the selected nozzles, make a trial calibration test flight to be sure you are spraying at the correct rate. Fill the tanks with water to a known level on a level apron or strip. Fly the aircraft at the selected 140 mph airspeed and at the selected pressure for a timed period (60 seconds in this example). Bring the aircraft back to the same point and measure the amount of water needed to refill the tank to the original mark. Divide the number of gallons used by the number of acres (18.4 in this example) treated to determine the gallons you are spraying per acre.

Step 5. Determine the amount of chemical to add to the tank.

Chemical per tank = acres per tank × chemical recommended per acre

$$\textit{Acres per tank} = \frac{\text{gallons per tank}}{\text{gallons per acre}}$$

In the example above:

$$\frac{\text{400 gallons per tank}}{\text{3 gallons per acre}}$$

$$= \text{133.3 acres per tank}$$

133.3 acres per tank × 1 pint per acre = 133.3 pints (16.7 gallons) per tank

Granular Systems

Make several test flights with the spreader installed to determine the quantity of material metered out for a given gate setting. If the dispensing equipment can be run with the aircraft on the ground, the material can be caught in large linen or paper bags and weighed. Blank granulars should be used when flight is needed to calibrate the system. Operate the spreader for a measured period of time (at least 30 seconds). Weigh the quantity needed to refill the hopper. It may take three or more trial gate settings to determine the one that will give the required amount in pounds per acre being applied. To find the pounds per acre being applied, divide the pounds per minute by the acres per minute.

Drift Reduction

- Make applications when air movement is away from sensitive areas. Selecting proper wind direction can be used as an aid to avoid drift.
- Use the largest droplet size compatible with proper coverage required from the mode-of-action of the pesticide being used.
- Orient nozzles so their discharge is parallel to the direction of the air flow around them.
- Select a nozzle that will expose a minimum amount of the spray to the air stream to limit shear formation of smaller droplets. These nozzles include straight stream nozzles and narrow angle fan nozzles.
- Position outboard nozzles at no more than 75 percent of the wingspan for both fixed wing and rotary wing aircraft span. Nozzles placed beyond this boom position contribute to vortex-influenced drift and non-uniform deposition, and do not increase the effective swath width of the aircraft.
- Make applications at a height of 8 to 10 feet from boom to target canopy. Flying too low can lead to narrow swaths, non-uniform distribution, and streaking. It may also lead to increased drift potential due to the excessive control surface movements generally associated with "wheels in the crop" flying.
- Do not use excessive aircraft speeds. As air speed increases,

the amount of particle breakup and "rooster tailing" potential increases. Higher airspeeds also increase the hazards of low-altitude flying due to reduced pilot reaction time.

- Equip the spray boom for immediate/positive shut-off through properly installed bleed lines and well-maintained equipment.
- Use an appropriately sized buffer zone away from sensitive areas.
- Use a viscosity-modifying adjuvant to help control particle size, suppress the formation of driftable fines, and reduce evaporation during critical humidity and temperature conditions. Test these products in your spray system to determine effectiveness.
- Develop a good customer follow-up policy and use it.
- Keep accurate and detailed records.
- Attend educational meetings frequently and read available information to increase your knowledge about factors that contribute to drift.

Pattern Testing

Check the swath pattern to make sure the distribution across the swath is as uniform as possible. Both helicopters and fixed-wing aircraft create wind currents (vortices) that affect the swath pattern. The pattern tests must duplicate field situations; therefore the airspeed, height of flight, spray pressure, and nozzle arrangement should be the same as for the actual application. The best time for testing is early morning before the sun heats the ground and causes thermal turbulence. It is desirable to choose a time when the wind is blowing steadily and from one direction at less than 10 miles per hour so that pattern nonuniformities can be identified and corrected. For best results, fly into the wind during the test. The best way to test a liquid pattern is to add tracer (dye or florescent material) to the water in the tank(s) of the aircraft. For dry pattern testing, use a blank (nontoxic) material with properties similar to the formulation to be applied. Collect the test material on paper (for liquids) or in buckets (for dry materials) placed across the flight path on the ground. Observation of the collected materials will show the actual swath pattern.

A rectangular pattern gives perfect distribution if flight swaths are spaced perfectly. The trapezoidal and triangular patterns are better because they allow for some error in spacing swaths. They give uniform distribution across the field except for the first and last swaths.

Operations

When an aircraft has been calibrated, the airspeed, spraying pressure (or gate setting for dry materials), height of flight and effective swath width are fixed. Applications must be made at the same settings.

Pressure

Pressure should be around 30 psi (pound per square inch) or higher. Choose the pressure that will combine with selected swath width, airspeed, and nozzle type to give the correct rate of application and desired droplet size. Use pressure gauges to indicate boom pressure.

Field Flight Patterns

For rectangular fields, fly back and forth across the field in parallel lines. Flying parallel to the long axis of the field reduces the number of turns. Treatment should start on the downwind side of the field where low-speed crosswinds occur. This prevents the pilot from flying through the previous swath. To prevent skips and drift, stop flying if wind speed increases excessively.

If the area is too rugged or steep for this pattern, flight lines should follow the contours of the slopes. When the area is too steep for the contour work, make all applications downslope.

Swath Marking

Straight, parallel passes produce the most uniform spray pattern. Use a reliable method, such as differential global positioning systems (DGPS), to mark each swath to ensure uniform coverage and avoid excessive overlap or gaps.

Turnaround

At the end of each swath, the pilot should shut off the dispersal equipment and pull out of the field before beginning his turn. The turn should be completed soon enough to permit slight course corrections before dropping into the field again for the next swath. Be careful when executing a turnaround because a considerable number of aerial applications occur due to stalls.

Obstructions

If obstructions such as trees, power or telephone lines or buildings occur outside the field at the beginning or end of the swath, turn the equipment on late or shut it off early. When the field is completed, fly one or two swaths crosswise (parallel to the obstructions) to complete the job.

Obstructions inside the field should be treated in the same way. Skip the area around the obstruction and spot treat it later.

Areas next to buildings, residences, livestock, nontarget crops or waterways should be treated with extreme caution:

- Fly parallel to the sensitive area.
- Leave a border of untreated crop to avoid possible drift onto the area.
- Avoid making turns over dwellings.

Study Questions

These study questions are to help you learn the material on pages 116 to 122.

1. *Aerial dispersal systems may be wind driven or _____ powered by the aircraft engine.*
   - a. hydraulic
   - b. mechanical
   - c. chemical
   - d. a and b

2. *Aircraft nozzles must be equipped with a(n) ___________.*
   - a. spring-loaded flapper valve
   - b. tube-type valve
   - c. antisiphon or nondrip check valve
   - d. positive shut-off valve

3. *Calibration is very important in aerial application because:*
   - a. chemicals used for aerial application are much more toxic
   - b. vortices can change application rates
   - c. large areas are covered in a short time
   - d. much higher pressures are used during aerial application

4. *All pattern tests should be run _____________ to the wind direction.*
   - a. opposite
   - b. at right angles
   - c. parallel
   - d. at 45 degree angles

5. *A minimum spraying pressure for aerial application should be around:*
   - a. 10 psi
   - b. 30 psi
   - c. 70 psi
   - d. 110 psi

6. *At the end of each swath, complete the turn soon enough to allow ________ before let-down for the next swath.*
   - a. pesticide drift to settle out
   - b. for missing obstructions
   - c. flagmen to get in position
   - d. slight course corrections

Answers to Study Questions

Answers to Study Questions

Pages 6 – 9 (IPM)
1. d 2. b 3. d 4. a 5. b 6. d

Pages 11 – 15 (Insect Pests)
1. b 2. d 3. a 4. b 5. b 6. c 7. d 8. b 9. a 10. a

Page 17 (Alfalfa)
1. d 2. c 3. b 4. b

Page 19 (Corn)
1. a 2. c 3. b 4. d 5. a

Page 21 (Cotton)
1. d 2. b

Page 23 (Sorghum)
1. a 2. b 3. c 4. a

Page 25 (Soybeans)
1. b 2. b 3. c 4. d

Page 27 (Sunflowers)
1. c 2. b 3. d

Page 29 (Wheat)
1. d 2. b 3. d 4. c

Page 31 (Beneficials)
1. a 2. b

Pages 33 – 37 (Fruit)
1. a, 2. b 3. c 4. b 5. a 6. a 7. c 8. a

Pages 39 – 50 (Vegetable)
1. d 2. b 3. c 4. a 5. b 6. b 7. b 8. b 9. c 10. a 11. a 12. d

Pages 53 – 67 (Diseases)
1. c 2. a 3. d 4. d 5. c 6. b 7. c 8. b 9. d 10. c 11. b 12. d 13. c 14. d

Pages 70 – 82 (Weeds)
1. d 2. b 3. d 4. b 5. d 6. c 7. d 8. d 9. a 10. d 11. d 12. d

Pages 85 – 93 (Rangeland)
1. a 2. d 3. b 4. b 5. c 6. d

Pages 95 – 114 (Equipment)
1. b 2. d 3. c 4. d 5. b

Pages 116 – 122 (Aerial)
1. d 2. c 3. c 4. c 5. b 6. d

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Jointed Goatgrass

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