AGRICULTURAL

STATE OF MONTANA
DEPARTMENT OF AGRICULTURE
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PLANT

PEST

Commercial/Governmental Pesticide Manual

Agricultural Plant Pest Control

A Study Manual for Commercial and Governmental Pesticide Applicators

This manual is intended for applicators who apply pesticides to agricultural crops or rangeland. The Agricultural Plant Pest applicator must demonstrate practical knowledge of crops grown, their specific pests, and the pesticides used for their control. Practical knowledge is required concerning pesticidal activity in soil and water, pre-harvest intervals, re-entry intervals, phytotoxicity, potential for environmental contamination, non-target injury, and community problems resulting from the use of pesticides in agricultural areas.

The Appendices in this manual are additional reference material. The test will not include information from Appendix A - C. The information is only added for your benefit to identify pests in the field or for reference in the future.

To simplify information, trade named products and equipment have been mentioned. No endorsement is intended, nor is criticism implied, of similar products or equipment which are not mentioned.

A special thank you to Susan Kedzie-Webb at Montana State University for the illustrations in the Weeds - Part II section of this manual. Also acknowledgments to all those behind the scene, thank you for your help.

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PLANT DISEASES - PART I

THE NATURE AND CAUSES OF DISEASE IN PLANTS

■ Introduction

There are an estimated 100,000 parasitic plant diseases. Fortunately, about 80 percent occur rarely or on a limited scale and are considered relatively unimportant. The annual cost of plant diseases in the United States is five billion dollars.

Plant diseases are the result of the right combination of susceptible **host plants**, a virulent **pathogen** (disease causing agent), and suitable **climatic** conditions experienced during the growing season (Figure I-1). Variations from characteristic or normal climatic patterns are often responsible for sudden outbreaks of certain diseases that would not normally occur. Regional climatic conditions are a major factor in determining crops that can be grown profitably and the prevalence of diseases on these crops.

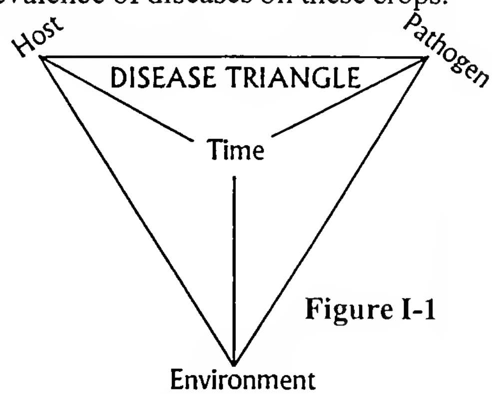


Figure I-1

Plant diseases are divided into parasitic or nonparasitic: ***Non-parasitic*** or physiological diseases include:

- nutrient deficiencies or excesses,
- environmental extremes,
- air pollution and pesticide injury,
- drought,
- genetic abnormalities, and
- other physiological disorders.

Parasitic diseases are caused by living organisms which can multiply and spread from infected to healthy plants. Organisms commonly causing parasitic plant diseases are *fungi, bacteria, viruses, mycoplasmas, and nematodes.*

■ Fungi

Fungi are simple microorganisms that lack chlorophyll and are unable to manufacture their own food. Fungi obtain their food from living plants and animals or from decaying organic matter. There are about 8,000 parasitic fungi causing 80,000 of the known 100,000 plant diseases.

Most disease-causing fungi are inconspicuous and can be seen only with the aid of a microscope. Commonly recognized fungi include yeast, mildews, and mushrooms.

Fungi may enter a plant through wounds, natural openings, or by penetrating directly through the epidermis - outer plant tissue (Figure I-2).

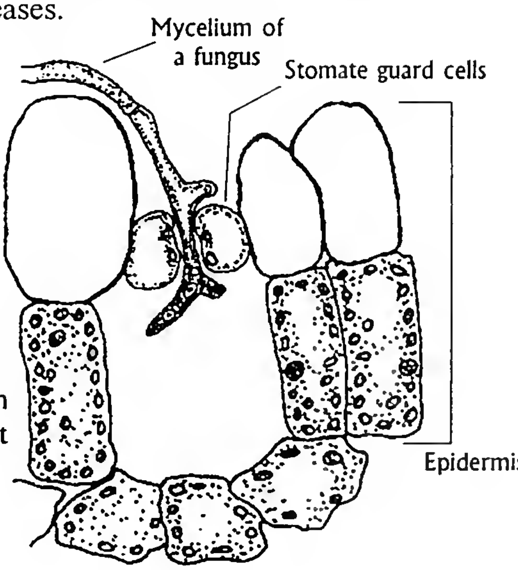


Figure I-2. Penetration of a stomate of a wheat leaf by a fungus.

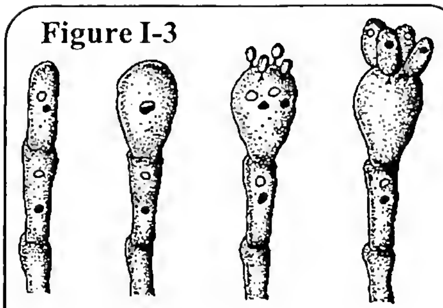


Figure I-3

Developing fungal spores.

Vegetative growth (mycelia, hyphae) of the fungus usually gives rise to reproductive structures producing fungal spores (Figure I-3) which act to spread the disease from infected to healthy plants. The life cycles of certain fungi are extremely complex and may involve a number of different spore stages and more than one plant host (Figure I-4).

Fungi cause local or general disintegration of plant cells or tissue, stunting of plant organs or entire plants, or abnormal vegetative growth, all of which are detrimental to the plant and may result in its eventual death.

Fungi may affect plant growth by:

- Removing or blocking the movement of nutrients essential to plant growth.
- Producing and secreting certain substances [enzymes or toxins] which affect the structural and metabolic activity of plants.

Fungal pathogens can spread spores and mycelium through plant materials, wind, water, animals, and insects. Below is a disease cycle of bunt smut of wheat.

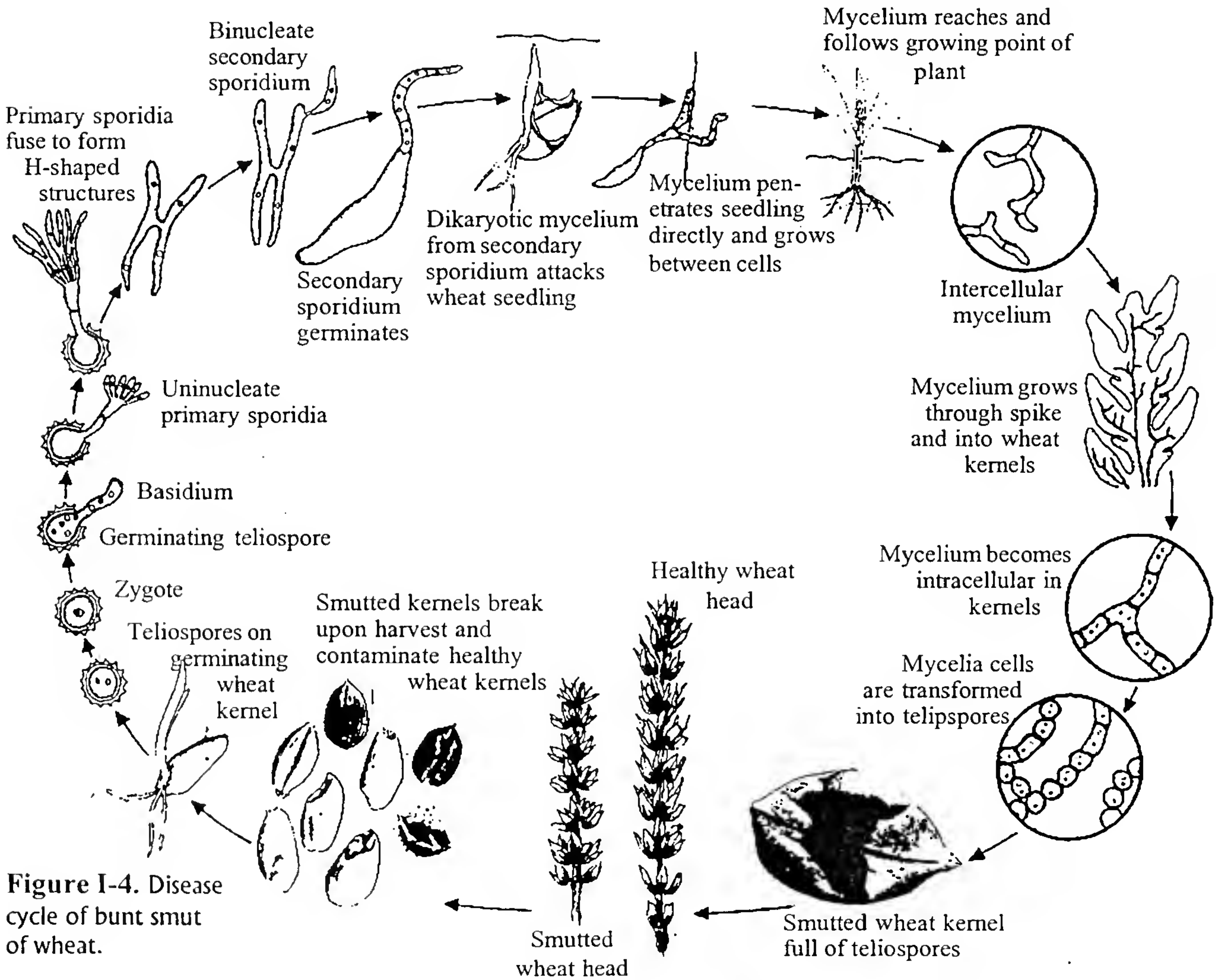


Figure I-4. Disease cycle of bunt smut of wheat.

Bacteria

Bacteria are one-celled microorganisms (Figure I-5) found in air, soil, and water and are common on or in all plants, animals, and humans. Individual cells can be seen only with a high powered (900 x) microscope. There are over 170 species of bacteria causing diseases in plants.

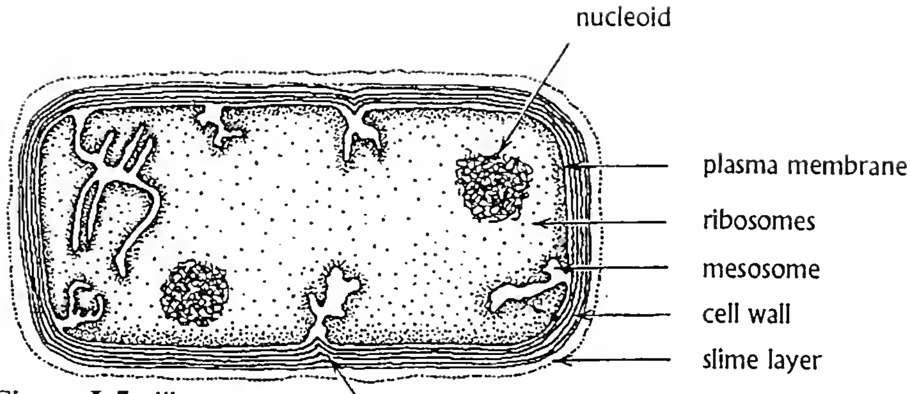


Figure I-5. Illustration of a bacteri cell.

Bacteria reproduce by simple cell division at extremely rapid rates. If a single bacterium divided to produce two new cells and all its descendants did likewise every 20 minutes for just 12 hours, 70 billion bacteria would be produced. In 24 hours, 2,000 tons of bacteria would be derived from just a single cell. It's no wonder that flowers, fruits, and vegetables sometimes rot and wilt so quickly. Fortunately, bacterial reproduction is limited by nutrients, temperature, and availability of space.

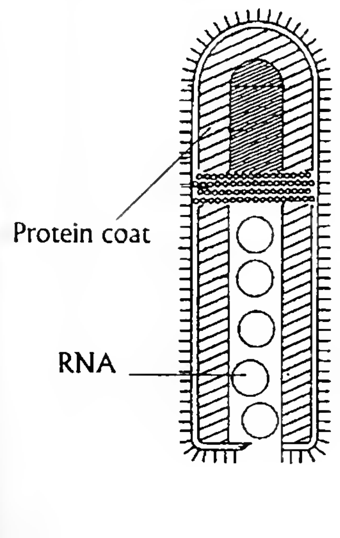
Bacteria enter plant tissue through wounds or natural openings such as the stomata of leaf surfaces. Once inside, pathogenic bacteria multiply rapidly, kill cells or cause them to grow abnormally, break down tissue, and often migrate throughout the plant. Certain bacteria, such as fire blight, produce chemical toxins that poison the plant.

Bacteria are spread by people through cultivation, pruning and transporting diseased plant material, such as seeds, bulbs, nursery stock, or transplants. Animals, insects, mites, nematodes, splashing rain, flowing water, and windblown dust are also common disseminating agents for bacteria.

Viruses

Viruses are complex macro-molecules composed of ribonucleic acid (RNA) with a protective protein "overcoat" (Figure I-6). They resemble the chromosomes present in all living plant and animal cells - both are self-reproducing nucleoproteins. Viruses can only function and reproduce in a *living cell.*

Viruses divert normal growth and development processes in plant cells, causing stunting, yellowing, mosaic, ringspot, or streak symptoms. Identification of viral diseases usually requires the inoculation of specific indicator plants or special laboratory techniques.



Some plant viruses, such as potato mosaic viruses, are very infectious and can be spread easily from diseased to healthy plants by contact. Others are transmitted by vectors, such as the wheat curl mite spreading wheat streak mosaic virus. Most viruses can be spread by grafting or budding or by vegetative propagation (e.g. cuttings, root division). Viruses are also disseminated through infected seed or plant pollen. Viruses often overwinter in weeds or in the bodies of insects or mites.

Figure I-6. Maize mosaic virus

Mycoplasma-Like Organisms (MLOs)

MLOs are microorganisms of an intermediate size between viruses and bacteria, generally without cell walls. They possess many virus-like properties and are not visible with a light microscope. MLOs are made up of RNA + DNA strands with ribosomes and a unit membrane. They are spherical or pleomorphic (i.e. exist in different forms or shapes). Spiroplasmas are similar to MLOs but are spiral in form. Rickettsia-like bacteria are similar to MLOs, but bacilliform.

Most of these organisms cause "yellow" or "witches' broom" type symptoms in plants. Antibiotic drugs, including tetracycline, are effective in controlling aster yellows and other diseases caused by MLOs. Plant infecting MLOs have been found in leafhoppers. This insect is the principle vector of certain yellows-type diseases.

Nematodes

Nematodes are microscopic, unsegmented roundworms (Figure I-7). They occur in water and soil. Most are harmless, feeding primarily on decomposing organic material and soil organisms.

Parasitic nematodes injure plants by sucking out plant juices through hollow, spear-like mouth parts (stylet). Nematode feeding lowers natural resistance, reduces the vigor and yield of plants, and affords easy entrance for wilt or rot producing fungi and bacteria. Nematode-damaged plants are often more susceptible to winter injury, drought, disease, and insect attack.

Some nematodes enter plant tissues to complete their life cycle, while others remain outside with only their feeding parts attached to the roots. All plant-parasitic nematodes reproduce by laying eggs. Larvae hatch from the eggs and initiate disease during their feeding (Figure I-8).

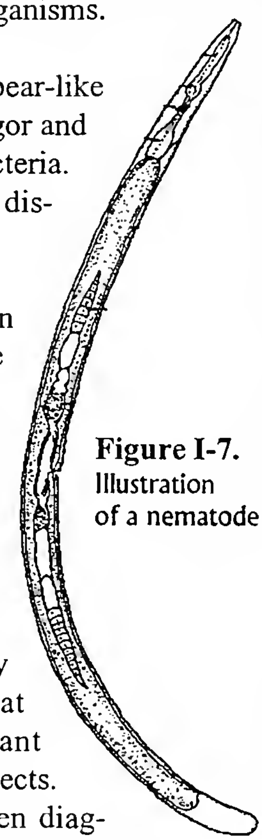


Figure I-7. Illustration of a nematode

Nematodes generally take several years to build up damaging population levels in soils. They are easily spread by any agent that moves infested soil, plant parts, or contaminated objects. Nematode damage is often diagnosed based on plant symptoms but correct identification is done by a trained nematologist working in a well-equipped laboratory with a compound microscope.

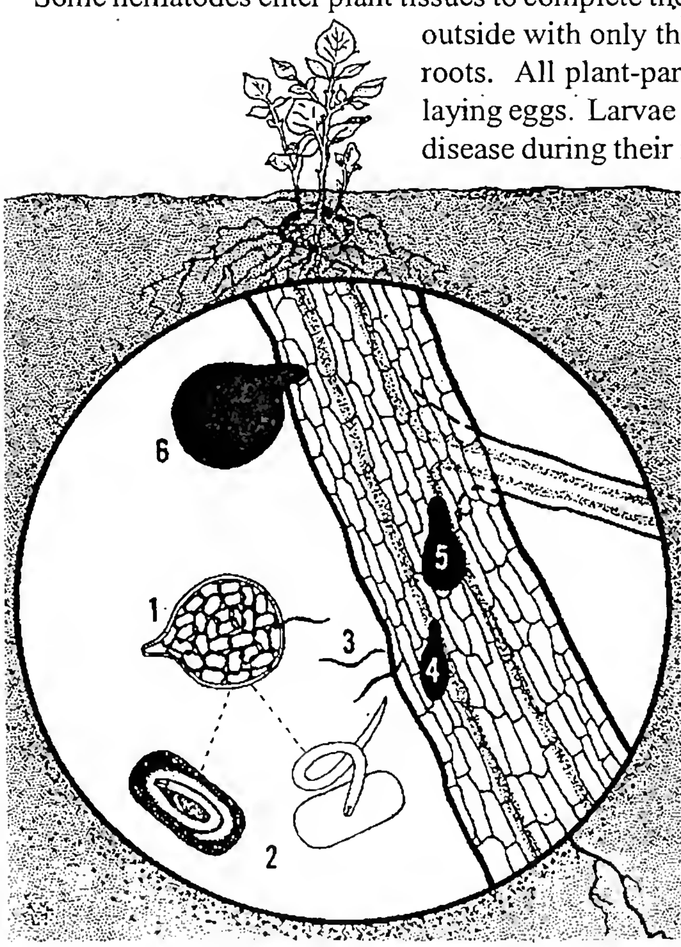


Figure 1-8. Potato cyst nematode life cycle. 1) cyst showing enclosed eggs; 2) enlarged egg showing enclosed, coiled larva; 3) larvae entering root; 4) and 5) swollen females feeding in root; 6) mature female breaking through root surface.

THE PRINCIPLES OF PLANT DISEASE CONTROL

■ Introduction

Effective plant disease control is based on thorough knowledge of diseases likely to appear in an area, the plants susceptible to attack, plus an early and accurate diagnosis of the problem.

Control measures must start at the ***early*** onset of disease - preferably before symptoms appear. Control starts with the purchase of the best seed or planting materials available, continues with proper seedbed preparation, and is maintained throughout the growing season.

Five fundamental principles of plant disease control are recognized. These are: *Exclusion, Eradication, Protection, Host Resistance,* and *Biological.* Often there is considerable overlap among and between these principles. All five may be used alone or concurrently to protect plants.

■ Exclusion

Exclusion is the prevention of disease-causing organisms from entering and becoming established where susceptible plants are growing - in a garden, locality, state, or country - through federal and state embargoes, quarantines, inspections, and disinfection of plants, seeds, and other propagative plant parts. More than 150 countries now have established quarantine regulations.

About 650 USDA plant quarantine inspectors are our first line of defense against alien pests. Each year, at a cost of about $40 million, these technically trained people intercept some 650,000 lots of prohibited plant material through inspection of people, baggage, mail packages, plus ship and airplane stores.

More than 50 percent of the major plant diseases and pests in the United States have been introduced from foreign countries. Since 1912, our plant quarantine system has saved America billions of dollars by reducing sharply the rate at which destructive plant pests have gained entry from other countries and offshore islands. Examples of alien pests include chestnut blight, Dutch elm disease, and white pine blister rust. These diseases and other pests cause losses of several billion dollars each year in the United States.

Other methods of exclusion include certification of plants, cuttings, and seed. This may include heat or chemical disinfection of small plants, seed, bulbs, corms, and other parts by producers or governmental agencies ***before*** shipment (see under Eradication below). Indexing to ensure planting stock is free of fungi, bacteria, and viruses is also an important exclusion practice.

Sometimes restricted entry of planting material is allowed. The plants are grown in isolation and are inspected frequently over one to two years before distribution is permitted.

■ Eradication

Eradication is the elimination of the disease-causing agent or pathogen ***after*** it has become established by rotation; removal of diseased plants or infected parts; destruction of wild or other overwintering host plants; seed or plant treatment; surgery; soil treatment; and a variety of sanitary measures.

✔ *Crop Rotation*

Continuous culture of one kind of plant provides an opportunity for the perpetuation and increase of pathogens and build up of disease. This is prevented by rotating annuals or biennials in seed and flower beds and by growing the same or closely related plants in the same soil only once in three to five years. This practice "starves out" most host specific pathogens. These organisms normally persist in soil only as long as host plant residues persist, usually only a year or two. Rotation is ***not*** effective against common soil inhabitants - fungi and bacteria that survive in soil up to 10 years or more in the absence of host plants. Many root-rot and wilt-producing fungi (e.g. *Aphanomyces, Fusarium*, *Phytophthora*, *Pythium*, *Rhizoctonia*, and *Verticillium*) may survive indefinitely in soil, making eradication by rotation impractical.

✔ *Destruction of Overwintering Hosts*

Perennial and biennial weeds are often a source of disease-causing pathogens. Eradication of these weeds breaks the life cycle of the pathogen and helps control disease. Examples include a wide range of virus and mycoplasma diseases of all types of plants. Aphids, leaf-hoppers, and thrips feed on weed hosts, pick up the virus or mycoplasma, fly to host plants, feed, and infect them. Chokecherries, wild plums, and other *Prunus* species are the primary source of infection to flowering cherries, plums, and almonds. Viruses and mycoplasmas causing cucumber mosaic, aster yellows, tobacco mosaic, spotted wilt, plus tomato and tobacco ringspots infect hundreds of different weeds, crops, and landscape plants alike. Control of weeds by cultivation, mulches, and herbicides is an important practice. Volunteer crop plants can also serve as an overwintering host and should be destroyed.

✔ *Seed or Plant Treatment*

Control of pathogens ***within*** seed, bulbs, corms, and other parts, by wet or dry heat or a systemic plant health product, is common. Hot water dips are used to kill root knot and other nematodes in roots of numerous plants. Such treatment of dormant plants or propagative parts also controls a wide range of organisms causing seed, bulb, corm, stem, rhizome and root rots, wilts, and leaf spots, mites as well as insects.

Successful eradication by hot water is dependent on killing pathogens and pests at a certain temperature and time which causes little or no injury to the treated plant or part. Effective hot water treatment must be done with properly calibrated equipment to prevent injury to the host plant.

Systemic fungicides, such as carboxin (Vitavax), thiophante (Topsin), and thiophanate methyl (Fungo-50) are used for eradicating fungi within plant tissues. Streptomycin is useful as an aid to prevent fire blight and some other bacterial infections.

✔ *Surgery*

Pruning and removal of twigs and branches of woody plants affected with fire blight and other bacterial or fungal cankers is widely practiced. Other examples include removal of wood-decay in tree trunks and limbs, excision of crown gall-diseased tissue, and cutting out bacterial soft rot in iris rhizomes. Proper sanitation of cutting utensils and disposal of diseased materials is important to prevent the spread of disease.

✔ *Soil Treatment*

This method is useful for potted plants, seed beds, greenhouses, and certain outdoor plantings. Annual treatment is usually necessary to control nematodes, soil-borne fungi and bacteria, insects, mites, and other pests. Preplant soil fumigants that control a wide range of soil-borne organisms and pests include methyl bromide, chloropicrin, and metam-sodium (Vapam). Dazomet (Basamid) is used as a soil sterilant.

Steam or dry heat is widely used to pasteurize soil for potted plants, greenhouses, and some outdoor beds. Soil treated with steam or certain fumigants needs to be covered with plastic to retain the steam or chemical in soil for the required time. It is then important not to contaminate treated soil with untreated soil or plant material that may be infected.

✔ *Sanitation*

Sanitation practices include a clean and deep plowdown, disinfection of tools, machinery and storage facilities, plus destruction of diseased plant refuse.

➢ *Clean plowing or burial of plant debris* helps reduce the overwintering or oversummering inoculum of pathogens causing foliar and fruit diseases. It works best for low-growing annuals or biennials that can be shredded to facilitate complete burial in the soil.

➢ *Disinfecting machinery and tools* with steam, hot water under pressure, or methyl bromide is essential to prevent spread of soilborne pathogens from one greenhouse or flower bed to another.

➢ *Disinfecting storage areas*, crates, baskets, and sacks helps prevent carryover from one season to the next of various storage-rot fungi and bacteria in bulbs, corms, rhizomes, tubers, and roots. Sweeping the storage area clean, followed by thorough spraying of all surfaces with copper sulfate is very effective. If the storage area is air-tight, chloropicrin or tear gas may be used. Wait at least 12 to 24 hours - or until all chemical odor has gone - between treatment and storage of fresh plant materials.

➢ *The destruction of plant refuse* is valuable for preventing the over-wintering of bacteria, leaf, stem and flower-infecting fungi, and insects, mites, nematodes, and other pests.

➢ *Eradication of alternate hosts* is successful in special situations and aids in reducing the development of new races of rust fungi. Examples of this practice include programs to eradicate *Ribes spp.* (currants and gooseberries), which are alternate hosts of white pine blister rust and eradicate junipers and red cedars, the alternate host of a rust fungus that will also attack chokecherry, crab apple, hawthorn, mountain ash and other useful tree species. Probably the most well known eradication program in Montana was eradication of the barberry, an alternate host to the stem rust found on small grains. Destruction of the less desirable host plants is usually needed for a distance of several hundred yards or more around the crop to be effective.

■ Protection

Placement of a ***protective*** barrier between the susceptible part of the host plant and the disease agent or pathogen is a common method of disease control. This method assumes that the pathogen is likely to be or is already present where susceptible host plants are grown. Protection usually means application of sprays or dusts to the plant before air, water, or insect-borne fungal spores arrive. The spores germinate in drops of water into which some fungicide has dissolved. The spores are thus killed before entrance into the plant can occur. Protection also includes killing of insects, mites, or other inoculating agents before these pests can feed and infect plants with pathogens carried on or in their bodies.

To be successful, protective chemicals must be specific to the pest (fungi, bacteria, mycoplasma, nematode) and applied at the recommended label rate and the appropriate time. Several applications are usually needed to keep new leaf and fruit tissue covered with a protective film. Most modern fungicides have a short residual of 7 to 10 days. Rain also washes some pesticide away and reduces control.

Creation of an unfavorable environment for the pathogen during growth, storage, and shipment is an effective means of protection. It includes such practices as:

➡ *Producing crop seed in low rainfall areas* where moisture is supplied by furrow irrigation. Under these dry conditions fungi and bacteria are not as likely to infect host plants. The result is healthy, pathogen-free seed.

➡ *The time and depth of planting* often helps prevent certain diseases. Soil moisture and temperatures that favor plant growth and not the pathogen can help prevent disease development. Examples: Deep planting may result in excessive *Phytophthora* crown rot to woody plants, pre-emergence, damping off of seedlings, and decay or shoot blight of flowering bulbs. Early or late plantings often escape migrations of virus and mycoplasma-carrying insects from weeds to crops. As a general rule, it is advisable to plant cool season crops in cool soil and warm season crops in warm soil to minimize soil-borne diseases.

➡ *Excessive soil moisture in the field* commonly increases seed decay, damping off, and root rot diseases. Where possible, avoid planting annuals and most perennials in areas where soil drainage is poor or where water stands for several days following rains.

➡ *Fertilize based on soil or tissue tests*. Essential macro- and micro-elements, when kept in balance, increase plant resistance to many fungal and bacterial infections. For example, excessively high applications of nitrogen, when available potassium and calcium are low, greatly increases losses from such diseases as fire blight, stem and storage decays, *Botrytis* blights, powdery and downy mildews, many leaf spots, and rusts. A deficiency of an essential element such as boron, copper, iron, magnesium, manganese, and zinc may be involved directly in the development of noninfectious diseases.

➡ *Control of temperature and moisture when possible* can prevent development of leaf, flower, and fruit diseases as well as foliar nematodes. Free water on the foliage, from careless watering late in the day, is necessary for infection by most bacteria and fungi as well as all nematodes. High relative humidity, unless controlled by heat and increased air circulation, favors development of powdery mildews, *Botrytis* blights, leaf molds, and other diseases. Wider spacing of plants in flower beds and landscape plantings promotes rapid drying following wet periods and thus checks development of foliage, flower, and fruit diseases.

➡ *Care in handling plants and propagative parts during harvest and storage* helps decrease disease problems. Sorting out bruised, cut, or rotted bulbs, corms, roots, and tubers at harvest prevents storage rots, especially when combined with temperature and humidity control.

➡ *Chemotherapy,* the treatment of disease by chemicals working internally to kill, inactivate, or protect against the pathogen without injury to the host plant, is another method of control. Systemic fungicides are absorbed and transported within plants to control certain diseases for several weeks or months. To be effective, a chemical must be taken up by the seed, leaves, roots, or stems and be transported in an active state to where infection occurs. Some fungicides with systemic activity include benomyl, chloroneb, TBZ, carboxin, oxycarboxin, and propiconazole.

■ Host Resistance

Development of resistant host varieties is usually the most effective and economical means of controlling plant diseases. Plant species, evolving over countless centuries, are normally highly resistant to prevalent native pathogens. When people introduce hosts or pathogens into new areas, widespread devastation is not uncommon. Good examples are Dutch elm disease and chestnut blight, both native to the Orient but devastating to landscape trees in the United States.

The primary objective developing resistant plants is to combine disease resistance with other desirable agronomic or horticultural qualities. A few examples: new bluegrass cultivars resistant to *Helminthosporium* leaf spots; various flowers resistant to *Fusarium* wilt; crepe myrtles resistant to powdery mildew; and firethorns resistant to scab. One of the most successful breeding programs has been the development of stem rust resistant wheat varieties.

■ Biological Control

Biological control can be defined as the regulation of pest organisms by their natural enemies. Classical biological control is the control of pests by introduced natural enemies. Natural biological control is control of a species having the potential of becoming a serious pest but failing to do so because they are restrained by natural enemies. The preservation and augmentation of naturally-occurring biological control agents is a key consideration in pest management.

One area of biological control is competition of soil microbe antagonists with soil-borne plant pathogens. Soil is enriched with organic matter and nonpathogenic soil organisms that can successfully compete and replace several common soil-borne plant pathogens. An example of this is the use of the fungus *Trichoderma* that competes with *Sclerotinia*, *Pythium*, *Fusarium*, *Rhizoctonia*, and *Thielaviopsis*. This is often referred to as "suppressive soil." Several biological products are labeled to suppress soil microorganisms. An example is, Mycostop (*Streptomyces*) for *Fusarium* wilt. In addition, Kodiak (*Bacillus*) is a labeled seed treatment and soil drench.

Another successful biological control program is the control of crown gall (*Agrobacterium tumefaciens*) by a highly competitive, non-pathogenic strain of *Agrobacterium radiobacter*. This bacterium produces a protein (bacteriocin) which acts as an inhibitor of related bacterial strains, thus preventing crown gall infection of young nursery stock through ecological exclusion. Research for bacteriocins of other important plant pathogens continues. Bacteriocins have potential as excellent biological control agents because they tend to have a narrow host range and testing is fairly simple. They are common proteins and should, therefore, be environmentally safe.

Some microorganisms are also found that produce antibiotics against other organisms. This phenomenon is not clearly understood but it has potential as another biological control tool. In general, antibiotics are not as host specific as bacteriocins.

■ Integrated Control of Plant Diseases

Integrated control of plant diseases involves the same practices utilized in integrated insect pest management. Plant disease management includes selection of adapted, resistant varieties; environmental manipulation; biological control; and the use of protectant chemicals based on economic thresholds of the disease level. Effective use of these management principles requires detailed knowledge of the host, the pathogen, and the environmental effect on their interaction.

Integrated pest management is probably used more than many people realize. Many growers use different types of control methods without realizing that they are using an integrated pest management program. Development of integrated plant disease management is hampered by the formation of new races or biotypes of plant pathogens; weather conditions that are conducive to epidemics; absence of records on disease occurrence, spread, severity and estimated crop losses; lack of adequate biological controls; lack of personnel trained in field diagnosis; and the absence of data on the economic thresholds of plant diseases.

There is tremendous potential for improving integrated plant disease management. There is need for more plant disease research followed by educational efforts, regulatory work by state and federal agencies, and input from the private farmer or grower regarding requirements to produce and protect quality food and fiber.

PROCEDURES IN FIELD DIAGNOSIS ON AN UNKNOWN PLANT DISEASE

■ Introduction

Plant disease diagnosis is based upon observation of symptoms and signs. Some basic information is needed for accurate diagnosis, including:

① Know what a normal, healthy plant looks like. Be acquainted with the major varieties and their growth habits.

② Know what diseases have been described as occurring in the crop.

③ Know which of these diseases commonly occur in your area.

④ Know the symptoms that will be useful in distinguishing between the different diseases that you are likely to encounter.

⑤ Look for signs of rodent, insect, or other animal damage that may be causing the injury.

⑥ Mineral deficiencies cause many plant diseases, usually when they are lacking or tied up in forms unavailable to the plant.

⑦ Check the water table, particularly if it is near the surface. High water tables may cause a "physiological drowning out", or salt injury. A soil auger is essential for such determinations. The plant, on the other hand, may be declining from lack of water. Here again, an auger may be useful. The quality of the water must also be considered. Does it contain toxic quantities of salts, factory wastes, or other contaminants, such as pesticides?

■ Field Diagnostic Factors

The following are some questions and points that must be considered when investigating a disease in the field:

☞ *The Distribution of the Disease*

✓ Is it over the entire field or does it occur in spots?

✓ If it occurs in spots, what is different about these spots? Are they in low or high ground or could there be some other difference such as a sand or gravel layer near the surface, or soil dumping area, soil compaction, poor drainage, etc?

☞ *The Crop History and the Method of Handling*

✓ Is this the first time for this crop to be planted in this location, or has the crop been planted continuously in this same location?

✓ What about the fertilization practices, spray program, irrigation program, or unusual weather conditions during the past month or season?

✓ Has anything unusual been done in the field during the past few years?

✓ Have herbicides or soil sterilants been used?

✓ Have insecticides or fungicides been applied?

✓ Has there been smog or other toxic gases in the area?

✓ What was the source of planting stock or seed? Was this seed certified, registered, or inspected?

☞ *Make a Thorough Examination of a Number of Infected Plants*

✓ Examine infected plants throughout the entire field or area in a systematic pattern. Observe the symptoms.

✓ Are the symptoms systemic, as in the case of root rots, wilts, and certain physiological disorders associated with nutrition?

✓ Are the symptoms localized, such as on the leaf margins or along the veins, or scattered at random over the leaf surface?

✓ How does the diseased plant differ from the healthy plant in color, size, and degree of maturity?

✓ Are there signs of the cause of the trouble, such as fungal fruiting bodies, mycelium, sclerotia, molds, mildew, and rust or perhaps indications of insect injury such as chewed leaves, tunnels in stems or roots, droppings (frass), holes, or mite eggs?

✓ Are the terminal shoots, blossoms, or fruits wilted, discolored, or rotted?

☞ *Examine Symptoms in Detail*

◆ ***Foliar***

Study the injury, observing its color, size, shape (angular or circular) and note the margins, observing whether they are definite or indefinite.

✓ Is there a water-soaked appearance, a velvety growth or discrete black spots on the injured tissue? Note whether the disease spot of the leaf is cut out, resulting in a shot-hole condition and whether there are accompanying symptoms such as yellowing of the diseased leaves.

✓ Are there malformations or overgrowths on the leaves, stems, or roots?

✓ Has defoliation occurred, partially or fully?

✓ What is the color of the damaged leaves at the time defoliation occurred?

- ***Stem Cankers***
  Check the extent of the area covered by the canker, either large or small, and whether the dead area extends deep into the stem or occurs only near the surface. Note whether the surface is smooth, rough, or scaly. On some cankers, fruiting bodies of the fungus may be seen resembling blisters or nailheads or small pimple-like dots.

- ***Fruit Rots***
  ✓ Does the rot occur on immature fruit or only on ripening fruit near harvest?

  ✓ What is the size and location of the spot (lesion) on the fruit?

  ✓ Is the tissue sunken and is there evidence of fungal fruiting bodies?

  ✓ Is the rot dry, watery, soft, pithy, or spongy?

- ***Root Rots***
  Declines in plants often result from infection by certain soil fungi. These are seldom discovered until the above ground part of the plant begins to show disease symptoms. Such foliage may be wilted and light colored, either on one side or over the entire plant. Check for fungus growth beneath the bark or for discolored vascular system.

☞ *Consider All the Symptoms and Information Available*

✓ Have similar symptoms been seen before either in this crop or related crops?

✓ Can you pick out one or more key symptoms such as mottling, yellowing, or necrosis that might suggest a recognized virus or deficiency?

✓ Is there a pronounced wilting or a dying of the crown or terminal leaves?

✓ What is the condition of the root system?

■ Laboratory Aids to Correct Diagnosis

After a thorough examination of specimens in the field, and a consideration of the distribution, previous occurrence, and cropping history, you probably will have suspected that the disease in question is one of several that, from previous reading, you know occurs on the crop under consideration. You know that the disease may be caused by a virus, mycoplasma, fungus, bacterium, nematode, or change or variation in climatic or cultural condition of the host. How do you determine which of these, or possibly a combination of these causes is involved?

If you cannot track down the answer in reference books or from local authorities, submit a specimen(s) to the Plant Disease Clinic at Montana State University. Please use a Specimen Identification Form that you can get from your county agent. Specimens will be checked with a microscope for the following:

- Is there evidence of mycelium or spores on the surface of the lesions?

- Is it in the phloem (suggestive of virus diseases) or xylem (suggestive of fungus diseases)?

- If the vascular tissue is discolored, is there evidence of mycelium?

- If possible the organism will be cultured, portions of tissue will be plated out on appropriate agar media and the organism isolated in pure culture.

- To prove absolutely beyond a doubt the relationship of the organism with the disease, inoculation must be made into healthy plants, again reproducing the symptoms initially observed. The final step is to recover the same organism from the inoculated plants that were first obtained from the diseased plants. This sequence is referred to as Koch's postulates of pathogenicity.

If a virus is suspected, tests may be made in the greenhouse using various host plants that will aid in identification of the virus. It will be necessary here to demonstrate transmissibility by mechanical inoculation, budding, or grafting. For positive identification, it may be even necessary to make tests of the physical properties of the virus and to determine the vector, probably an insect, and demonstrate virus transmission by the vector. Accurate, rapid diagnosis is important for initiating effective control. The above questions indicate what information is important in this diagnosis.

PROTECTIVE CHEMICALS

■ Introduction

Chemicals used for the control of plant diseases are specific to the type of microorganism causing the disease. Fungicides control fungal pathogens, bactericides control bacteria, antibiotics control mycoplasmas, and nematicides control nematodes. There are no chemical controls for viral diseases or physiological disease. Correct diagnosis of the disease organism is critical prior to the use of any protective chemical.

■ Fungicides

A fungicide is a chemical that kills or inhibits fungal growth. Fungicides are widely used to protect plant seeds, foliage, fruit, and roots against disease-causing fungi, as well as to preserve wood against decay. Wood preservatives are not covered in this manual. No single fungicide is suitable for all purposes or is effective against all fungi.

➡ *Protective fungicides* are applied to seed, foliage, flowers, fruits, or soil as sprays, dusts, or granules to keep disease-causing fungi from entering plants. These materials provide external protection, but do not kill fungi established within a growing plant or seed. An exception is the case of powdery mildew and sooty mold fungi, which are superficial and can be killed by surface dusts or sprays after infection has occurred without injuring the host plant. They also do not protect against disease-causing organisms entering through the roots, such as root rots, wilts, and clubroot. They do not control bacterial diseases, protect against viruses or MLOs, or control nematodes.

Most fungicides in use today possess protective qualities. Those that are only protective include zineb, thiram, ferbam, ziram, sulfur, iprodione, chlorothalonil, captan, dithane, inorganic copper materials (copper sulfate), and some others. These chemicals must be applied before an infection starts. They require frequent applications at seven to fourteen day intervals, depending on the weather conditions. During rainy weather, sprays need to be applied at shorter intervals.

Practically all dust and granule formulations function as protective fungicides and should be used accordingly. Dusts should be applied when the air is calm and foliage is lightly covered with moisture. Early mornings or evenings are ideal times.

➡ *Protective-contact fungicides* are used the same as protective fungicides, however, another dimension of effectiveness is that of destroying established infections. A commonly used term is "kickback" which means that an infection may be stopped after becoming established. For example, dodine will still provide control if applied 72 hours after apple scab infection has occurred. Thus, it has a 72 hour kickback for apple scab. In other words, dodine can prevent infection, and it also has good contact toxicity to fungus growth. "Contact toxicity" means that the fungicide may either kill or merely inhibit further growth. Protective-contact fungicides include benomyl, difolatan, folpet, dodine, limesulfur, thiabendazole or TBZ, maneb and zinc iron.

➡ *Systemic fungicides, or chemotherapeutants*, are chemicals that are absorbed and distributed within the plant, destroying established infections and hence controlling certain diseases for several weeks or months. Very few chemicals now available work in this way. Examples would include chloroneb (Demosan), carboxin (Vitavax), difenoconazote (Dividend), thiophanate (Topsin) and terrazole (Koban). To be effective, a systemic fungicide must be taken up by the seed, foliage, roots, or stem(s) of the plant and be transported in an active state to where disease infection occurs.

■ Bactericides

Bactericides are used primarily for the control of bacteria. Some may have limited activity on fungi as well. A bacteriostat prevents growth or multiplication of bacteria, but does not necessarily kill them. There are very few active ingredients that are effective against bacteria.

Copper compounds, such as Bordeaux (copper sulfate + hydrated lime), copper ammonium carbonate, copper sulfate, and copper oxides, are important and effective dormant season disease control products. Bordeaux mixture is generally useful under rainy conditions.

Streptomycin and oxytetracycline are antibiotics that are typically systemic when applied to foliage. They can be absorbed by leaf tissue to inhibit bacterial infection, but do not move systemically from leaf to leaf.

Plant protectant chemicals that have both bacterial and fungicidal properties include the copper compounds listed above, soil fumigants (chloropicrin and methyl bromide), and bleach.

■ Use Precautions And Application Efficiency

Read and follow all label recommendations when using any plant protectant chemical. To get the best operation from any application equipment, observe and follow the guidelines below. Also refer to the equipment section in the *Basic Pesticide Manual*.

- Use the appropriate equipment for the area to be treated. Smaller areas may require the use of a backpack sprayer or hand duster, while large areas may require a field sprayer.

- Use the manufacturer recommended nozzle size.

- Check both nozzles and the pump for wear on a regular schedule.
  - ✳ Check engine and pump speeds.
  - ✳ Make sure all belts to the fan and pumps are under the proper tension.
  - ✳ Keep all moving parts of equipment lubricated with the manufacturer's recommended lubricant.

- Wash the equipment with clean water after completing spray applications.

- Drain all water from equipment before cold weather.

- Refer to the label for product compatibility before mixing any sprays.
- Use only recommended label rates.
- Time all applications according to label directions.

Plant Disease Review Questions

1. Plant diseases are the result of the right combination of:
    a. susceptible host plants
    b. virulent pathogen
    c. suitable climate conditions
    d. all of the above

2. Fungal pathogens can spread spores and mycelium through:
    a. erosion
    b. water
    c. animals
    d. b and c

3. Bacteria are:
    a. complex macro-molecules composed of ribonucleic acid.
    b. one-celled microorganisms.
    c. microscopic, unsegmented roundworms.
    d. none of the above.

4. What are the five fundamental principles of plant disease control?
    a. Biological, protection, IPM, chemical, and exclusion.
    b. Host resistance, eradication, exclusion, biological, and protection.
    c. Exclusion, elimination, resistant varieties, IPM, and protection
    d. Exclusion, eradication, protection, host resistance, and elimination.

5. The crop history and the distribution of the disease must be considered when investigating a disease in the field.
    a. True
    b. False

6. Viral diseases can be controlled by the following chemicals:
    a. Captan and copper sulfate.
    b. Benomyl, dodine, and folpet.
    c. There are no chemical controls.
    d. Vitavax and Dividend.

7. Crop rotation, seed and soil treatment, and destruction of overwintering hosts all describe biological control for plant disease.
    a. True
    b. False

8. Creation of an unfavorable environment for the pathogen during:
    a. growth, storage, and shipment is an effective means of protection.
    b. germination, shipment, and death is an effective means of protection.
    c. growth, shipment, and regrowth is an effective means of protection.
    d. none of the above.

9. Non-parasitic or physiological diseases include:
    a. air pollution and pesticide injury
    b. nutrient deficiencies
    c. mycoplasmas
    d. a and b

10. The disease triangle includes the following principles:
    a. Pathogen, host, eradication and the environment.
    b. The environment, time, habitat, and the pathogen.
    c. Host, pathogen, environment and time.
    d. Time, habitat, eradication and precipitation.

WEEDS - PART II

INTRODUCTION

A weed can be defined as:

- ➨ a plant growing where it is not wanted;
- ➨ a plant out of place; or
- ➨ a plant that is more harmful than beneficial.

Any plant can be a weed in a given circumstance. Kentucky bluegrass that spreads into a flower bed is a weed; volunteer wheat in a sugar beet field is a weed. A plant is a weed only in terms of its impact on human activities.

Plants commonly referred to as weeds have characteristics that give them the ability to spread and compete well with many cultivated and rangeland plants. Most major weeds have at least several of the following characteristics:

- ➢ Continuous seed production for as long as growing conditions permit;
- ➢ Unique ways of dispersing and spreading, including vegetative propagation and seed production;
- ➢ Ability of seeds to remain dormant in soil for long periods of time;
- ➢ Ability to grow under adverse conditions;
- ➢ Adaptation to a wide variety of soil and climatic conditions;
- ➢ Compete well for soil moisture, nutrients and sunlight; and
- ➢ Genetic adaptability, with a wide gene base for competition with beneficial plants.

Economic losses caused by weeds occur every year in Montana. Weeds cause losses to agricultural production by:

- ◆ Decreasing crop yields by removal of water and nutrients from the soil. Many weeds need more water to produce one pound of dry matter than do most of the cereal grains.
- ◆ Weed seed contamination in grains reduce the value of these products.
- ◆ Dairy animals that eat certain weeds may produce milk with an unpleasant odor or off-flavor.
- ◆ Weed control may require extra tillage operations in preparing soil for planting.
- ◆ Irrigation costs are increased by weeds growing in and along irrigation ditches. This often results in decreased water flow and added weed control costs.
- ◆ Weed infestations may serve as a source of plant diseases and insect pests. Weeds may also act as alternate hosts for diseases and insect vectors.
- ◆ Some weeds are poisonous to humans and livestock.

To produce crops efficiently, it is necessary to reduce the effect of competition by weeds. Although weeds cannot be entirely eliminated, they can be reduced to manageable levels.

SOURCES OF WEED INFESTATIONS

❖ ***Humans*** are the most effective agent in the dissemination of weeds. Most exotic weeds found in the United States are here because of the movement of people and their products. Weed seeds are moved in hay and seed products; by machinery and vehicles; and in common carriers, railroads and trucks hauling cargoes of grain, hay, livestock, and other farm commodities. Movement along travel corridors scatter seeds along rights-of-way and highways, which become sources of infestation to adjoining fields.

❖ ***Wind*** spreads seeds over great distances. Many weed seeds have structural features which aid their distribution by wind (Figure II-1). Some seeds have wings, like those of maple trees, or they may have long, silky hairs or parachutes attached to them. Tumbleweeds (such as Russian thistle) are especially adapted for seed dispersal when blown along the ground.

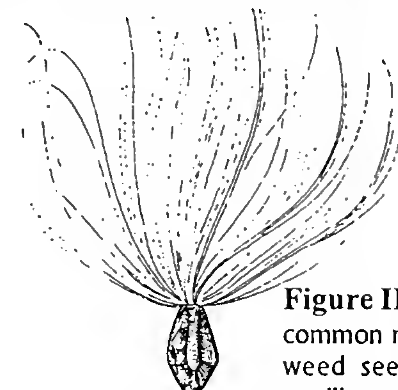


Figure II-1. common milkweed seed is readily carried by the wind.

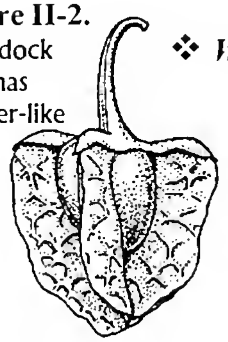


Figure II-2. curly dock seed has bladder-like floats.

❖ ***Water*** also effectively spreads seeds. Most weed seeds will float if they fall on the surface of streams, lakes or irrigation canals (Figure II-2). Flood waters, running streams, and irrigation water all contribute to spreading weed seeds. Irrigation canals, when first filled, often carry heavy loads of weed seeds downstream where they may be washed ashore or deposited in silt along the way.

❖ ***Wild and domestic animals*** also aid in the dispersal of seed. The viability of most weed seeds is unaffected by passage through the digestive tracts of animals. Many weeds, such as cocklebur, sandbur, and beggar-ticks, have awns or hooks on the seeds that attach to the hair (Figure II-3).

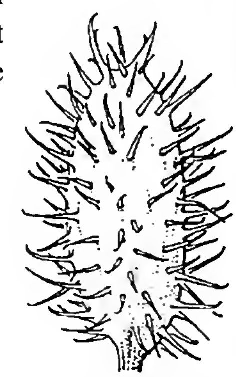


Figure II-3. common cocklebur clings to clothing and animal fur.

❖ ***Planting contaminated*** small grain, legumes, or grass seed is another way to spread weeds (Figure II-4). Farmers then plant weeds with the crop seed, often giving the seed a competitive advantage. The planting of certified seed may help prevent the spread of weeds. Mechanical seed cleaning can also remove weed seeds from grain prior to planting.

❖ ***Farm machinery*** spreads weed seeds, especially in wet weather when seeds stick to muddy implements and vehicles. Plows and cultivators drag roots, rhizomes, tubers or seeds to another area. Combines and hay balers spread weeds from field to field. All farm machinery should be cleaned before moving it from one area to another.

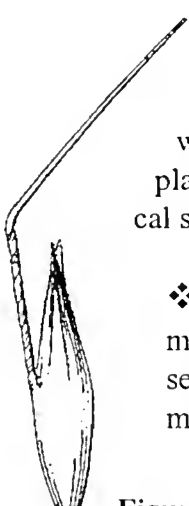
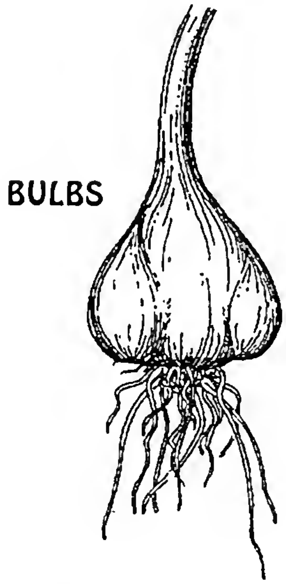
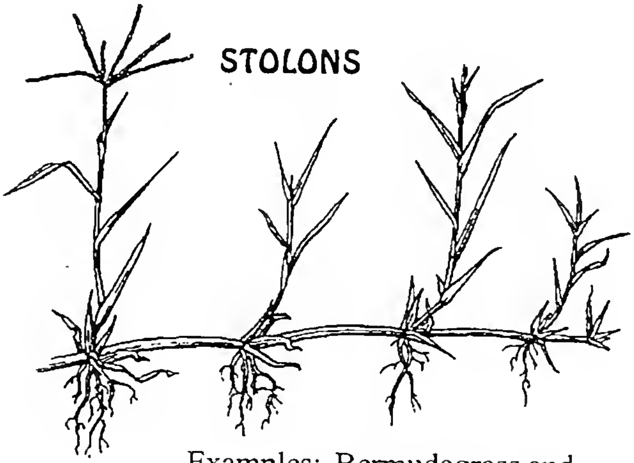


Figure II-4. bent awn on the lemma of wild oat seed twists with changes in moisture to bury the seed in the soil.

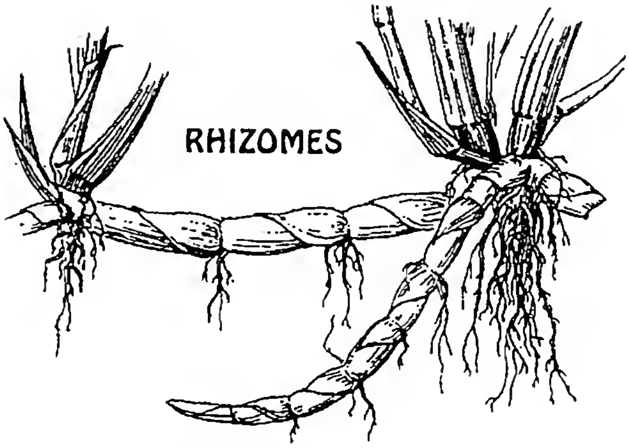
Infestations of perennial weeds are aided by different types of rooting systems. Identifying the root system of a weed is beneficial when selecting a control method. The following are some of the common types of root systems of perennial weeds.



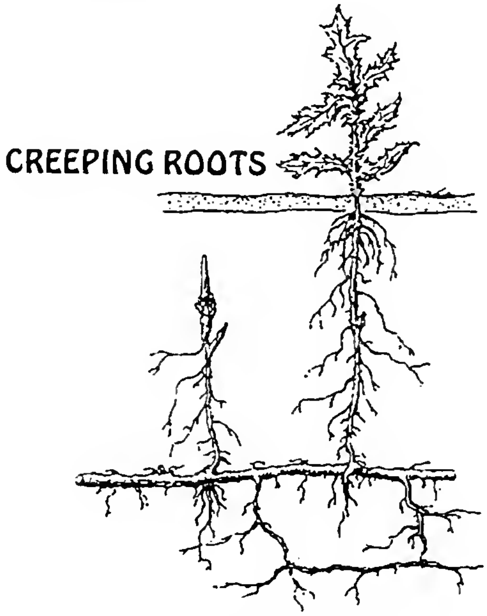
Examples: wild garlic, bulbous bluegrass, and wild onion.



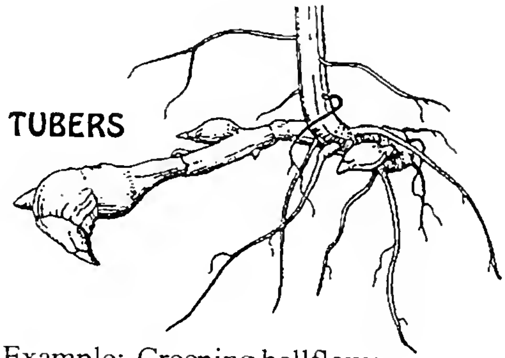
Examples: Bermudagrass and strawberries.



Examples: Saltgrass, sweet pea, and oxeye daisy.



Examples: Canada thistle and leafy spurge.



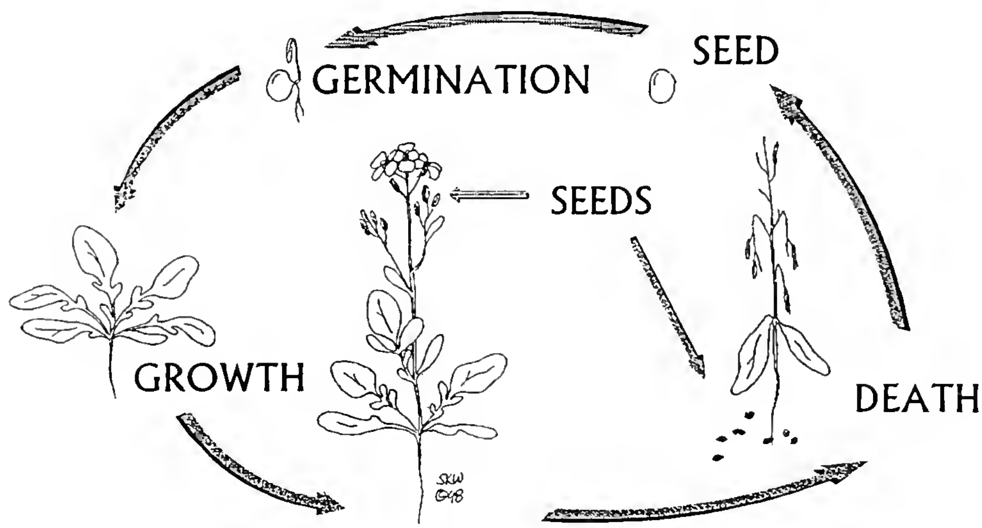
Example: Creeping bellflower

CLASSIFICATION OF WEEDS

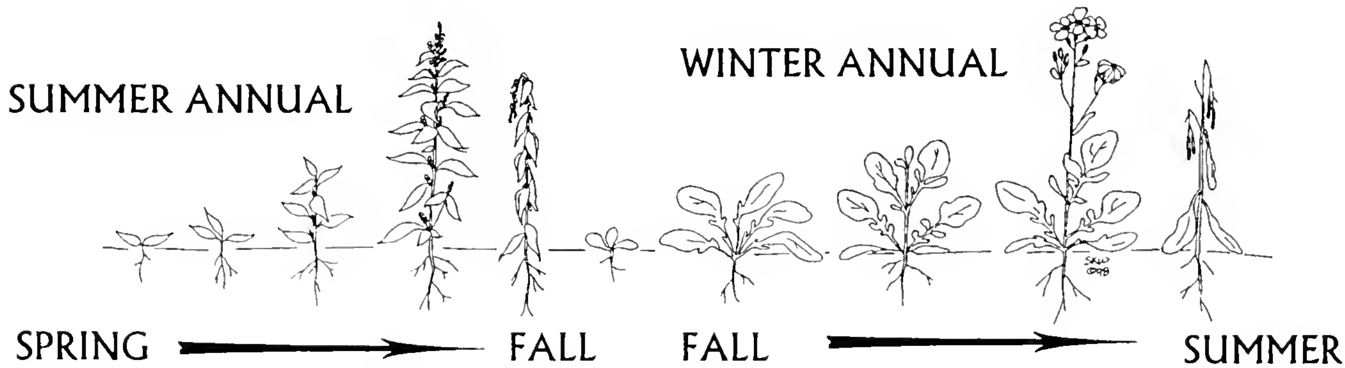
Weeds can be classified by life cycle or plant structure. Identification and control practices are determined in part by understanding these classifications.

■ Life Cycle

The life cycle (or growth habit) of each weed species describes how long each plant lives and timing of development.

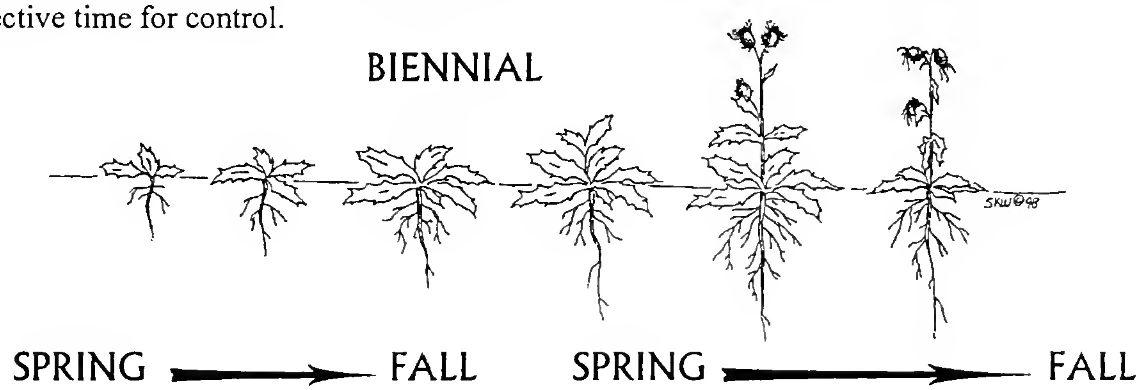


Annuals complete their life cycle from seed to mature plant in less than one year. Summer annual plants germinate in the spring, flower, produce seed in mid- to late-summer, and die in the fall. Winter annuals germinate from late summer to early spring, flower, and produce seed in mid- to late-spring and die in the summer. Plant growth as a winter or summer annual often depends on geography and climate.

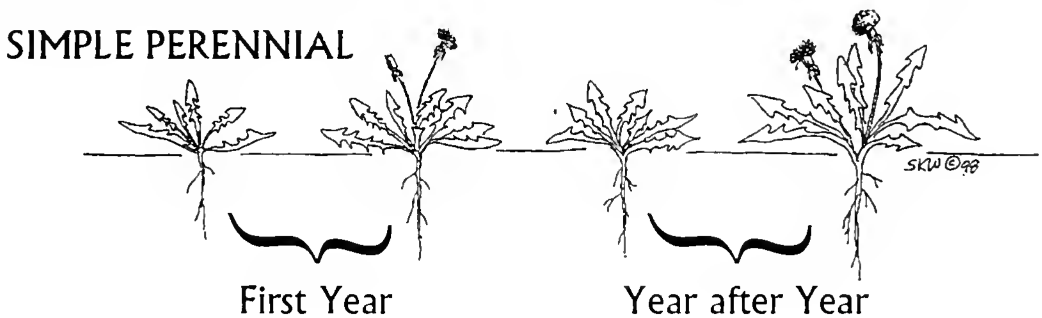


Kochia, lambsquarters, redroot and prostrate pigweed, Russian thistle, green and yellow foxtail, and crabgrass are all examples of summer annuals. Winter annuals include common chickweed, downy brome, field pennycress and many other mustards.

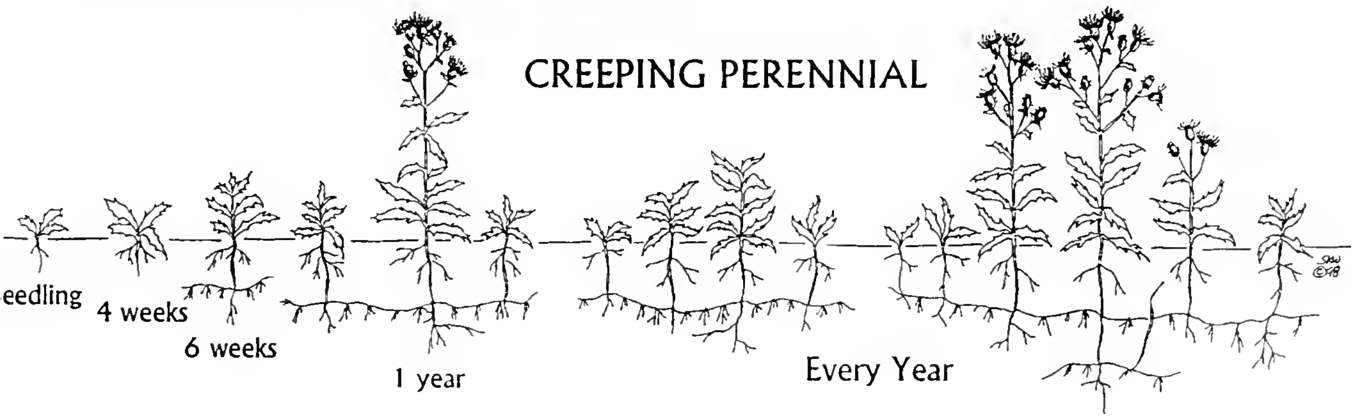
Biennials live for two growing seasons. Seeds germinate in the spring, summer, or fall of the first year and plants overwinter as a basal rosette of leaves with a thick storage root. Plants flower and produce seed the summer of the second year and die in the fall. Common biennials include common mullein, burdock, wild carrot, bull thistle, and musk thistle. Effective control of biennial plants is very similar to control for annuals. Early spring or fall spraying of the rosette is an effective time for control.



Perennials produce vegetative structures, allowing them to live for more than two years. They reproduce by seed in addition to spreading vegetatively. Simple perennials overwinter by means of a vegetative structure, such as a perennial root with a "crown," but they reproduce almost entirely by seed. Dandelion, curly dock, and spotted knapweed are common examples of simple perennials.

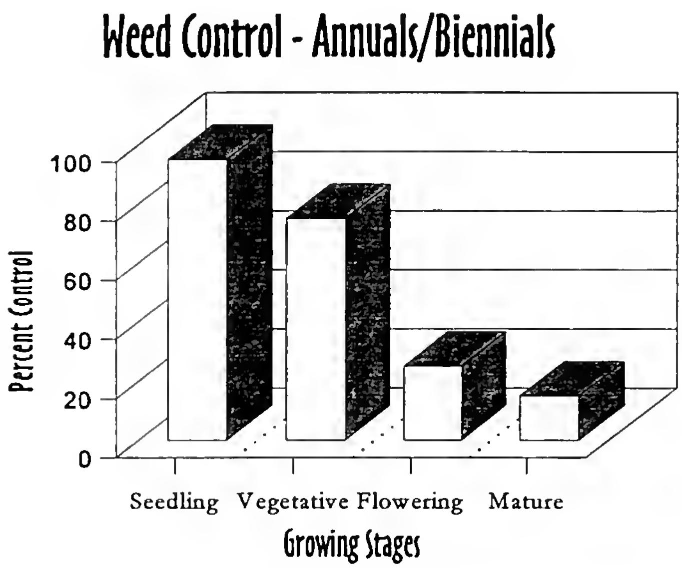


Creeping perennials overwinter and produce new, independent plants from vegetative reproductive structures. These structures include rhizomes, tubers, bulbs, stolons, and creeping roots. Most creeping perennials can also reproduce and spread from seeds. Quackgrass, Canada thistle, leafy spurge, and field bindweed are creeping perennials.

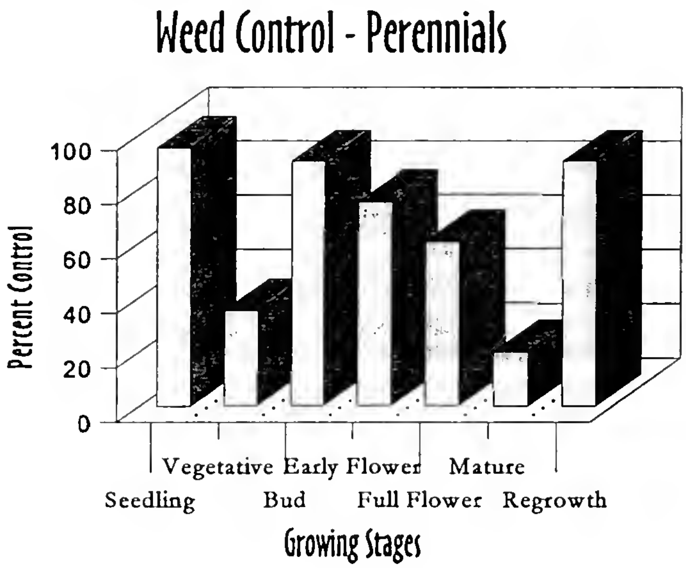


■ Weed Control for Annual, Biennial, and Perennial Weeds

Control of annual and biennial weeds must be accomplished before the plant produces seed. This is most effective when the plant is in the seedling stage. Weeds are small and succulent and less energy is required for control at this stage. Control during the vegetative stage is possible but more difficult since the plant is putting energy into the production of stems, leaves and roots. Chemical control of annuals during the flowering stage is not feasible because most of the plant's energy is going into seed production. Often flowering annual plants will set viable seed even after control. Maturity and seed set completes the annual plant life cycle. Control is not effective at this stage.



Perennial weed control must be aimed at either the seedling or the regrowth stages of development. Chemical control during the vegetative growth stage is generally less effective. Control is more effective at the bud stage than the flowering stage. Control at maturity is not feasible since the above ground portions of the plant die back at this time. Fall treatment of regrowth is most effective because the plant is translocating nutrients to the root system and will also translocate herbicide to kill the roots. To achieve effective control of perennials, underground plant parts must be killed. Long-term management is essential for effective control.



Plant Structure

Differences in plant structure or morphology are important to recognize. For weed control purposes plants are divided into three main categories-grass, broadleaf and woody.

Grass plants have one seed leaf (monocot). They typically have parallel leaf venation (Figure II-5a), narrow, upright leaves and flower parts in threes or multiples of threes (Figure II-5b). Examples include quackgrass, green foxtail and downy brome.

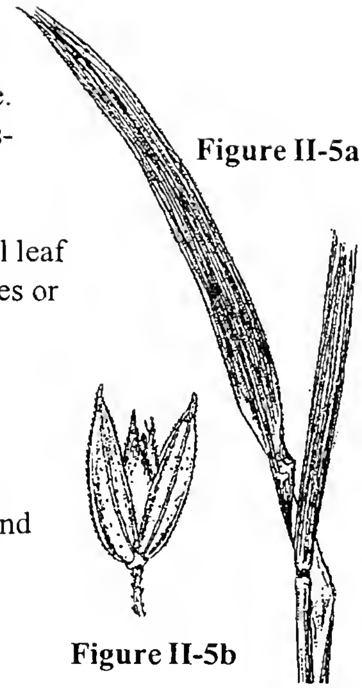


Figure II-5a

Figure II-5b

Broadleaf plants have two seed leaves (dicots). They generally have broad, net-veined leaves (Figure II-6a) and flower parts in four, five or multiples thereof (Figure II-6b). Examples include kochia, sunflower, and Canada thistle.

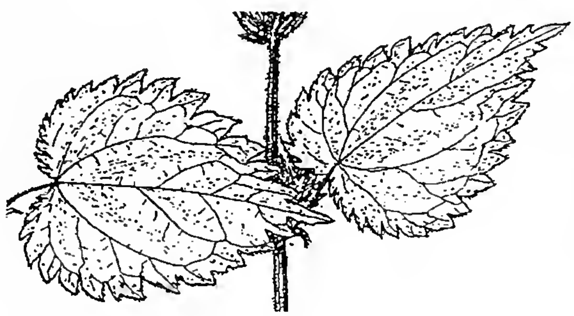


Figure II-6a

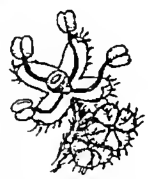


Figure II-6b

Woody plants persists from year to year with woody aerial stems and include brush, shrubs, and trees. Brush and shrubs have several stems and are generally less than ten feet tall. Trees have a single stem and are over ten feet tall. Multiflora rosa, sagebrush and salt cedar are examples of woody weed plants (Figure II-7).

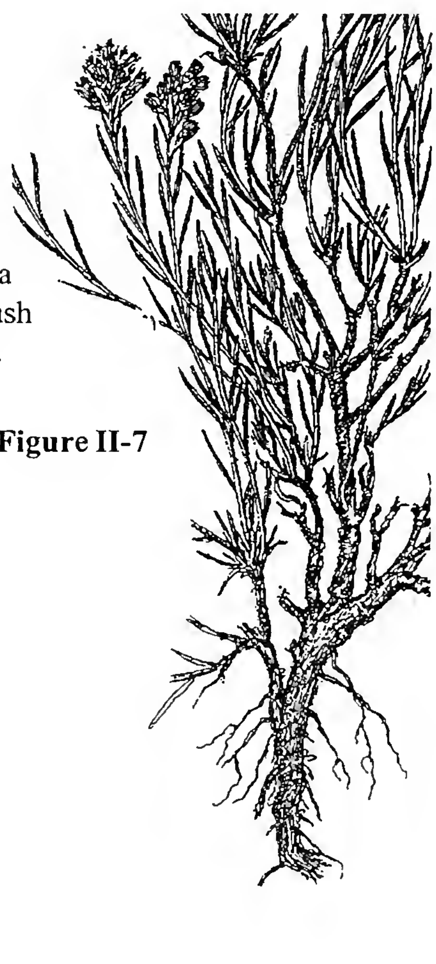


Figure II-7

METHODS OF CONTROLLING WEEDS

For a weed control program to be successful, weeds or undesirable plants must be destroyed without damaging crops or desirable plants. Good farming and land management practices should be first in any weed control program. Causes of weed problems should be identified and corrected by implementation of an integrated weed management program, including all effective control methods.

The most effective or economical method or combination of methods for weed control depends upon an accurate assessment of the situation.

■ Prevention

Prevention is the most practical and economical method of controlling weeds. Once weeds are established they are difficult and costly to control and may persist for many years as dormant seeds in the soil.

Preventative control measures should be adopted whenever practical. They include: a) the use of clean, certified seed; b) cleaning all implements, vehicles, and harvesting equipment before moving it from infested areas: c) keeping irrigation ditches, fence rows, roadsides and other non-crop areas free from weeds; d) not bringing infested soil, hay, straw, or manure into clean areas; e) spot treating small infestations or isolated individual plants; and f) not allowing new weeds to set seed or reproduce.

■ Cultural and Mechanical Control

Cultural and mechanical control includes *cultivation, mowing, mulching, crop competition,* and *crop rotation.*

Cultivation stimulates the germination of weed seeds by bringing them to the soil surface. These weed seedlings are then easily controlled with a second tillage operation. Tillage is most effective on annual weeds. Repeated tillage operations (every two to three weeks throughout several growing seasons) may control some perennial weeds, such as Canada thistle. Other perennials, such as field bindweed, are spread rather than controlled by cultivation. Handhoeing can be effective in ornamental settings and some high value crops.

Mowing can be an effective weed control practice under certain conditions. It should be part of an overall crop management program. Mowing controls weeds by preventing seed production, depleting underground food reserves, and by favoring growth of more competitive plants. Plants must have a relatively tall growth habit to prevent seed production. Mowing must be done prior to pollination and fertilization. Since most plants regenerate, repeated mowing is required for adequate weed control. It is important to remember that repeated mowing may change upright, single stemmed plants into prostrate, several stemmed plants that can still set seed.

Mulches control weeds by excluding light. They are most effective on small areas with high value crops that are already established, such as tomato transplants or flower plants. Mulching material should be thick enough to exclude light, relatively cheap, and easy to work with. Straw, sawdust, wood chips, bark chips, grass clippings, heavy plastic and paper clippings are all good mulches. Perennial weeds are difficult to control with mulches due to the persistent nature of their vegetative growth.

Crop competition can be an effective tool. Early spring seeding can allow cereal grains to germinate earlier than weeds. If the crop is established before the weeds germinate, it will often crowd out the weeds. Crops need to grow rapidly and establish early, taking the nutrients and water the weed would normally use.

"Smother" crops may be valuable in a weed control program. They compete with weeds for water, light, and nutrients. The main competitive crops valued in weed control are crested wheatgrass, sweet clover, sunflower, rape, barley, rye, soybeans, alfalfa, and silage corn. These crops grow quickly, produce an abundance of shade, and can be harvested early enough to permit fall cultivation.

Crop rotation is another method for weed control. Certain crops have their own characteristic weeds, and these weeds tend to accumulate when the same crop is repeated year after year. These repeated plantings favor disease and insect problems resulting in weak, patchy stands which are easily invaded by weeds. Crop rotation allows use of alternative control methods, including a wider variety of herbicides, to control weeds.

■ Biological Control

Biological weed control is the use of a living organism to control weeds. Insects are the most commonly used agent but fish, nematodes, snails, and plant pathogens (fungi, bacteria) offer additional means of controlling plants.

Biological controls can be useful for suppression of unwanted plants, generally in a non-crop situation. Development of a biocontrol agent is long-term and expensive. Research is needed to find host specific agents and anywhere from 5 to 10 different agents are needed to give economic control of a single weed species. Biological control is generally not recommended in cropland situations because of a lack of adequate economic threshold data for weeds. Biological control insect agents are generally too slow acting to be effective in cropland situations. Plant pathogens show more promise in this area and some are registered pesticide products (examples - Mycostop for fungi on field crops and Noyall for *Agrobacterium* on nursery stock).

There are several excellent examples of weed control by insects. The most outstanding is prickly pear cactus control in Australia. Over 60 million acres of infested land were reclaimed using a moth assisted by a scale insect. Another example is found in California and the Pacific Northwest where St. Johnswart (or goatweed) has been reduced on millions of acres to about 1% of its former range by a leaf feeding beetle.

Some results in Montana using biocontrol agents include:

➡ The St. Johnswart beetle, *Chrysolina hyperici*, was first introduced to Montana in 1948, with supplemental releases made over the years. The beetle is cyclical in areas where it is established and has not shown the same dramatic results in Montana as was found in

California. This may be because the insect is limited to only one generation per year in the colder Montana climate.

- A weevil, *Rhinocyllus conicus*, is well established on musk thistle in Montana. It is effective at reducing seed production of this biennial species.

- A biological control program on spotted knapweed in Montana includes the release of several gallfly species (*Urophora affinis* and *U. quadrifasciata*), a root boring moth (*Agapeta zoegana*), and a root boring weevil (*Cyphocleonus achates*). Research continues on several other root and seed head insects.

- Dalmatian toadflax has two insects established on it, a foliage eating moth (*Calophasia lunula*) and a seed head beetle (*Brachypterolius pulicarius*). Several root boring moths and seed head weevils were cleared for release in 1996 and research continues on these insects. Some work is also being done on common toadflax biological control agents.

- A wide range of biological control agents have been introduced on leafy spurge. The most effective to date have been a complex of flea beetles, *Aphthona* species. Research is also targeting plant pathogens that could be used in combination with insect agents.

- Research on plant pathogens for several weeds continues. The fungus, *Sclerotinia sclerotiorium*, attacks a broad host range of weed species, including Canada thistle, and spotted knapweed.

- Sheep and goats can be used to suppress growth and prevent seed production of leafy spurge in environmentally sensitive areas.

■ Chemical Control

Herbicides are an important weed control tool in Montana. Research over the past few decades has produced increased knowledge and new, safer chemicals for use in weed control. Herbicides will continue to play an important role in weed control in Montana. The *Chemical Weed Control* chapter (page 30) further discusses weed control with chemicals.

■ Integrated Weed Management

Integrated weed management (IWM) is an ecological approach to managing unwanted plants. It is a *systems approach* to weed management that uses all suitable methods in a compatible manner to reduce weed populations to levels below those causing acceptable economic or ecological consequences.

Factors to consider *prior* to making a management decision include:

- Weed species present and size of infestation.
- Environmental conditions: non-target vegetation, soil types, climatic conditions, and water resources.
- Site restrictions.

➡ Understand the overall management objectives for the area: different land managers and agencies have different goals and restrictions on their activities.

➡ Consider the many different control techniques and combinations available when developing a management plan.

All weed management tools must be used to effectively control weed infestations. Annual, biennial, and perennial weeds have certain growth habits that influence the type of control method or methods implemented. Soil type, weather conditions, recreational activity, wildlife or domestic grazing and future use of the land will influence your choice of weed control methods. Consider all information known about the weed and the site as you develop a long term management plan for control of a weed infestation.

CHEMICAL WEED CONTROL

Herbicides are effective tools when used properly. Since the early 1950's, thousands of chemicals have been evaluated for effectiveness as weed killers. Safe and effective herbicides are available for controlling many weeds growing in various environments including cropland, rangeland, gardens, lawns, ditchbanks, non-crop areas, and in irrigation, drainage, navigable, and drinking waters. Because of the many factors and principles involved in research on herbicides, information about chemical weed control is rapidly increasing. New recommendations are continually replacing old ones. Be sure to read and follow all label directions from a *current* product label.

■ Selective Herbicides

Chemicals which can be used to remove certain plant species with little or no effect on other species are referred to as selective herbicides. Selectivity depends on the amount of chemical used, the application method, the degree of foliage wetting, soil moisture and texture, temperature, and humidity. Since selectivity can be influenced by all of these factors, the same chemical may be either selective or non-selective, depending on the amount used. For example, atrazine used at a high rate is an effective soil sterilant (non-selective) and used at a lower rate is a selective herbicide for weed control in corn.

◆ Foliage applications are treatments made to the leaves of growing plants, usually as a spray or mist.

❒ *Translocated herbicides* move within the plant after the material is absorbed into the tissue. The greatest amount of transport is through the vascular system of the plant (phloem and/or xylem). Translocated herbicides may be effective in destroying roots as well as top growth of plants. Selectivity depends on physiological differences of plants. 2,4-D is a commonly used selective, translocated herbicide in Montana.

❒ *Contact herbicides* do not translocate or move in the plant. This group of herbicides kills only the plants or portion of the plant actually contacted by the chemical. In order to obtain effective control, adequate coverage of the foliage is essential. This may be accomplished by using a high volume of carrier or diluent to apply the herbicide. Dinitrophenols and certain petroleum oils are used as selective, contact herbicides.

◆ Soil applications are herbicide treatments applied to the soil. To be effective, the chemical must be carried into the soil by moisture or mechanical incorporation. Selectivity depends on the plant tolerance, soil texture, location of the herbicide in the soil, and difference in growth habit of the crop and the weed. These herbicides are generally translocated in the xylem.

◆ Selectivity can also be determined by timing of applications:

❒ Preplant treatments are made to the soil before the crop is planted. Typical preplant treatments are applied after seed bed preparation but directly before planting the crop. This type of treatment is considered pre-emergence with respect to weeds if applied prior to weed germination.

❑ Pre-emergence treatments are made to the soil after the crop is planted but before emergence of the crop or the weeds.

❑ Post-emergence herbicides are applied to the soil after the crop or weeds have germinated and started to grow. Other post-emergence treatments may include:

* Pre-harvest herbicide treatment applied before crop harvest to remove weed growth that could interfere with the harvesting operation.

* Post-harvest herbicides applied to kill weeds present after harvest as part of the weed control program for the next season.

■ Non-Selective Herbicides

Herbicides which are toxic to all plants may be used to control a wide variety of vegetation in an area. These chemicals can be used to control vegetation in non-cropped areas such as along fence rows, around electrical power lines and substations, right-of-ways, and storage areas.

◆ Foliage applications are applied to the leaves of growing plants as sprays or mists.

❑ Translocated herbicides move from the foliage to the roots, resulting in control of a wide variety of plant species. There are few herbicides that can be classified as translocated, non-selective. Glyphosate (Roundup) is one good example.

❑ Contact sprays kill vegetation at the point of contact. One treatment is usually sufficient to control annual weeds. Perennial plants are not effectively controlled with contact herbicides. Acrolein and paraquat are examples of non-selective contact herbicides.

◆ Soil applications include a wide variety of soil fumigants and soil sterilants that are applied directly to the soil. These are used where it is necessary to remove all plant growth.

❑ Soil fumigants are non-selective chemicals that are most often used to kill all plant growth, as well as other soil organisms, before planting a desirable species. They function as a vapor or gas which diffuses through the soil and has a short life in the soil. The treated area may be replanted, usually within a month or less. Methyl bromide is a commonly used soil fumigant.

❑ Soil sterilants are chemicals that kill all green plants for a period of up to two or more years. They are classified as:

* Temporary sterilants which kill plant life for four months or less.

* Semi-permanent sterilants which kill all plant life for four months to two years.

* Permanent sterilants which persist in the soil for longer than two years.

The length of time the herbicide residue remains depends on the herbicide used, the rate of application, and the soil moisture and texture.

■ Basics of Herbicide Selectivity

It is important to understand how herbicides kill plants, why a herbicide is phytotoxic to one species and not another, and how herbicides can be used to best accomplish the results desired. Selectivity is relative.

The most important factors that affect herbicide selectivity are: 1) structural differences in plants, 2) differences in absorption, 3) differences in translocation, 4) physiological differences, and 5) herbicide concentration. Combinations of these factors can be used to improve herbicide selectivity.

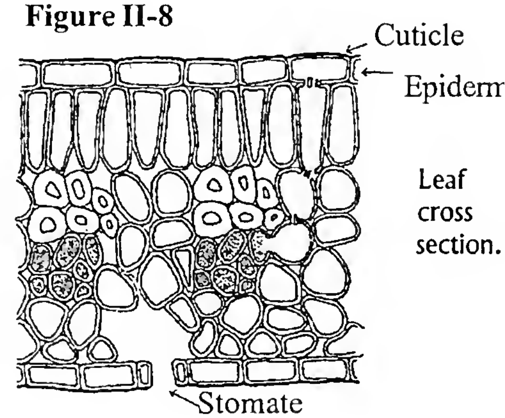
◆ Structural differences among plants permit selective applications. The narrow, upright leaves of a cereal plant lack the exposed leaf surfaces of a broadleaf plant. Water droplets can stick only to a small portion of an upright leaf surface. On the other hand, a broadleaf plant has a wide leaf surface which extends parallel to the ground and will hold more spray and therefore be affected more by the herbicide. Another important structural difference is the location of the growing point of the plant. The growing point of many grasses is protected because it is located at the base of the plant. Contact sprays may injure the leaves of the grass plant but not contact the growing point. Broadleaf plants have exposed growing point at the tips of the shoots and in the leaf axils. The growing point is therefore more accessible to the herbicide.

Waxiness, hairiness or pubescence of a plant may prevent spray droplets from adhering to the leaf. If the chemical droplet adheres to the leaf hairs without contacting the leaf surface, it will not be absorbed. On the other hand, hairs may collect and hold greater amounts of droplets, preventing the spray from running off the leaf surface. Waxy leaves may require use of an additive with the herbicide to dissolve the waxy layer and allow contact with the leaf surface.

◆ Absorption is the movement of a material into the plant from an external source. Some plant surfaces absorb herbicides quickly; other surfaces may absorb the chemical slowly, if at all. Parts of the plant leaf surface, the cuticle and the stomate, account for differences in absorption.

❖ The *cuticle* is a waxy layer or thin film on the leaf surface (Figure II-8) which retards the movement of water and gases (oxygen and carbon dioxide) into and out of the leaf. The cuticle varies in thickness in different plants and can vary within the same plant exposed to different environmental conditions. Shaded plants often have thinner cuticles than plants grown in the sun, and young leaves usually have thinner cuticles than older leaves. A herbicide must penetrate the cuticle layer and cell wall. High temperature and low humidity usually result in poor cuticle penetration.

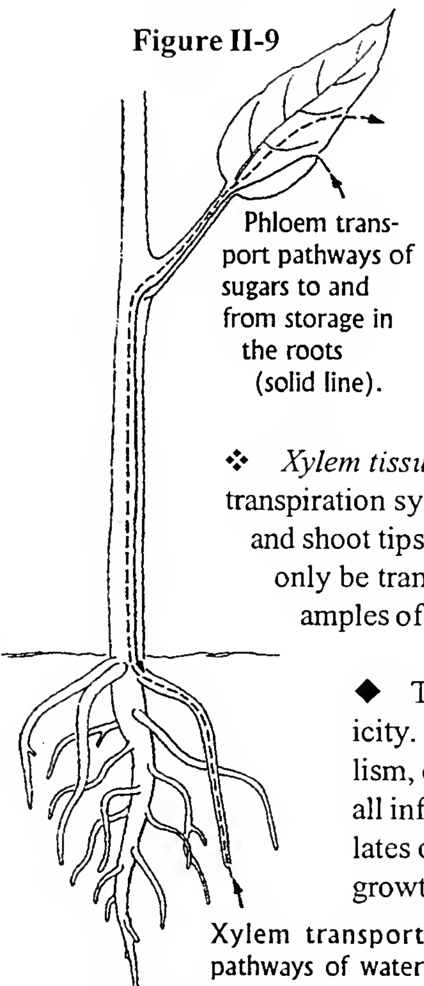
Figure II-8



❖ A plant leaf is perforated by small openings or pores called *stomates*; these open into the intercellular spaces within the leaf (Figure II-8 Pg. 32). The number and distribution of the stomates varies from plant to plant. The stomatal opening can be an effective port of entry for the herbicide if they are open at the time of application. This is why some foliar applied sprays are more effective when applied in the early morning or late evening when there is less sunlight and the stomates are more likely to be open. Stomatal penetration cannot occur unless the surface tension of the spray solution is significantly reduced by the use of wetting agents.

◆ After the herbicide is absorbed, it must be translocated within the plant to the site of action. There are two tissue systems in which a herbicide may move in the plant: the *phloem*, which conducts food from the plant leaf to the stem and roots; and the *xylem*, which conducts water and nutrients from the roots to the stem and leaves. Herbicides move through these conducting tissues to other parts of the plant.

Figure II-9



Phloem transport pathways of sugars to and from storage in the roots (solid line).

Xylem transport pathways of water conducting from the roots upward to the leaves (dashed line).

❖ *Phloem tissues* are composed of living cells. It is important, therefore, not to kill the stem and leaf tissues too quickly. Rapid foliage kill will result in poor transport and poor root kill. Movement in phloem will be toward the roots during maturation of the plant and near budding (Figure II-9). This indicates the importance of proper timing of a herbicide application, especially for the control of perennial weeds. It is necessary to apply a translocated herbicide when a perennial is storing up root reserves. Most growth regulators, including 2,4-D, as well as dicamba (Banvel), and glyphosate (Roundup), move readily in phloem tissue.

❖ *Xylem tissue* of a plant is made up of non-living cells. It is the water conducting, transpiration system in the plant and movement is only from the roots upward to leaf and shoot tips (Figure II-9). Any chemicals applied either to the roots or foliage will only be translocated toward the leaf tip. Atrazine, metribuzin, and diuron are examples of xylem conducting herbicides.

◆ The physiological differences between plants also affect herbicidal toxicity. Differences in enzyme systems, responses to pH changes, cell metabolism, cell permeability, variations in chemical constituents and polarities may all influence the selectivity of a herbicide to plants. Any herbicide that stimulates or blocks certain biochemical processes in a plant can affect the plant's growth and cause herbicidal action.

◆ Enzyme reactions may be blocked in one plant species, but not in another, by the same chemical. Activation of chemical into an active compound, such as 2,4-DB converted to 2,4-D by certain plants, is an example. Degradation of a herbicide to a harmless compound is another example; corn has enzymes that can degrade triazine herbicides into harmless compounds.

◆ The rate of application or concentration may determine whether a herbicide inhibits or stimulates plant growth. Under low concentrations 2,4-D can act as a growth hormone and increase the rate of respiration and cell division, resulting in stimulated plant growth. At higher rates, growth is excessive and results in death of the plant. The concentration of a herbicide at certain sites in the plant may determine the herbicide effectiveness.

■ Herbicide Formulations

Almost all herbicides must be combined with a liquid or solid carrier to uniformly distribute them during application. The formulation of a chemical is the manner in which the active ingredient and the carrier are mixed. Proper formulation of agricultural chemicals increases their effectiveness. Inert ingredients make the herbicide easier to handle, less likely to settle out or degrade during storage, and may minimize the hazard of handling the chemical. The way the herbicide is formulated may change its chemical characteristics, including solubility, volatility, and toxicity to plants.

Common types of formulations are classified as follows:

◆ Liquid Formulations

❒ Emulsifiable concentrates (EC) are nonpolar (oily) liquids containing emulsifiers, a substance promoting the suspension of one liquid in another. The active ingredient is not soluble in water, but is dispersed in water to form emulsions (droplets of oil surrounded by water). Agitation is usually required to prevent separation.

❒ Solution(s) are herbicides (liquid or powder) that are directly and rapidly soluble in the carrier liquid. These require no agitation once dissolved in solution. Often they need a surfactant for maximum activity.

❒ A suspension consists of a finely ground wettable powder (WP) dispersed in a liquid. Wettable powders are used if a solid concentrate is preferable to a liquid or if the solubility of a herbicide is so limited that it is impossible to formulate an economical solution or emulsifiable concentrate. These herbicides are nearly insoluble in water or oil but may be dispersed in them by forming a slurry. Adding it to the carrier and using constant agitation.

❒ Water dispersible liquids and granules are often referred to as flowables (F) or dry flowables (DF). These formulations readily disperse in the herbicide carrier. They require a moderate amount of agitation. Both liquids and granules can be added to water without first making a slurry. Water dispersible granules poor cleanly from the container, giving them handling advantages over dispersible liquids and wettable powders.

◆ Dry Formulations

❒ Granule formulations have been impregnated into coarsely ground carriers, such as clay or vermiculite, and formed into small pellets, generally less than 10 mm in size. These chemicals are used directly from the bag but require special application equipment, and usually require soil incorporation to be effective.

❒ Pellets are discrete particles usually larger than 10 mm. They are frequently used for spot treatments.

☐ Dusts are finely ground chemicals that may or may not be mixed with diluents. Their use is limited because of the hazard of drift and the high cost of the herbicide.

■ Spray Additives

Adjuvants or spray additives are often used to enhance herbicidal performance or handling. They include surfactants, anti-foaming agents, compatibility agents, crop oils, crop oil concentrates, and drift control agents.

◆ Surfactants (surface-active agents) bind two or more incompatible phases, such at water and oil, in more intimate contact by modifying forces between them. A surfactant is any material that affects the surface properties of spray solutions and includes wetting agents, emulsifiers, dispersing agents, detergents, and stickers.

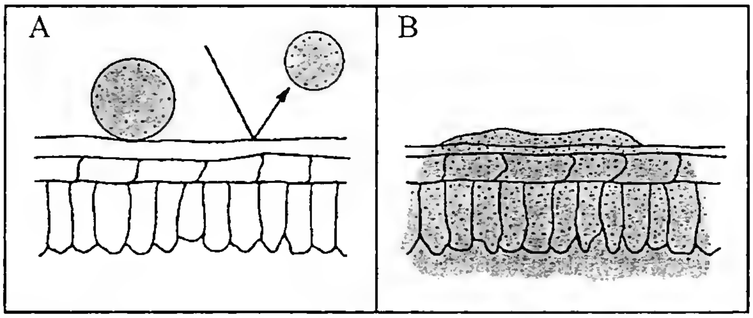


Figure II-10 a water soluble herbicide over the plant surface: (A) without wetting agent, (B) with wetting agent.

☐ Wetting agents are materials used to increase a liquid's ability to moisten a solid. They lower the surface tension, bringing the liquid into closer contact with the solid (Figure II-10). Wetting agents increase or decrease the effectiveness of herbicide sprays; they may also reduce selectivity, especially if selectivity depends on selective wetting or selective absorption.

☐ An emulsifier is a material used to disperse one liquid in another. An emulsion is one liquid dispersed in another, each maintaining its original identity.

☐ Dispersing agents reduce cohesion between particles. They are materials used to disperse the particles of a solid in a liquid. Some dispersing agents also act as wetting agents, but others have little or no effect on surface tension. Some wetting agents and dispersing agents are not compatible and interfere with each other if used together.

☐ Detergents are used to remove dirt or grime. They are usually wetting agents and surface active. Many common detergents have been used with herbicides as wetting agents and emulsifiers. Anti-foaming agents can be used to reduce foaming in a sprayer system so pumps and nozzles can operate properly.

☐ A sticker is designed to hold the active ingredient on the sprayed surface.

☐ A penetration agent is any substance that assists plant absorption of a herbicide. Such substances may dissolve the waxy cuticle or fatty portion of the cell wall or membrane of the plant to allow more rapid penetration.

☐ Anti-caking agents are used to prevent solid herbicide formulations from forming aggregates.

Surfactants are classified as ionic and nonionic, depending on their disassociation in water. Nonionic agents have no particle charge, while ionic agents have either a positive or negative charge.

Nonionic surfactants are classed as nonelectrolytes and are usually chemically inactive in the presence of usual salts. They can be mixed with most herbicides and still remain chemically inactive. Ionic surfactants ionize in an aqueous medium. These agents can be used to unite oil or water soluble properties of a molecule and allow alignment in water to reduce water surface tension.

◆ Compatibility agents aid suspension of herbicides when they are combined in tank mixes with other pesticides, herbicides or fertilizers. They are used frequently when a liquid fertilizer is the carrier solution.

◆ Crop oil and crop oil concentrates are non-phytotoxic light oils that also contain surfactants to allow mixing with water. They are added to water solutions to enhance herbicide foliar activity.

◆ Drift control agents reduce the fine particles in a spray pattern that are primarily responsible for herbicide drift and nontarget injury.

All adjuvants should be used in accordance with label directions and chosen only from those proven effective for herbicide applications. Refer to the manufacturer's recommendations and herbicide label recommendations.

■ Mixtures of Herbicides with Other Pesticides or Fertilizers

The use of herbicides mixed with other pesticides or with fertilizers is not new but it is growing in popularity. The biggest advantage to farmers is the savings in time and labor and number of trips across fields. Yields can be as good with combination applications as with split applications. Research has confirmed that herbicides applied with some fertilizers can perform as well as with single applications.

Most herbicides are specific and their activity is not the same toward all weeds. For example, trifluralin does not control nightshade species in beans and alachlor is weak on kochia. Because of these and other limitations of single herbicides, interest in mixing herbicides to control a broader spectrum of weeds and provide more consistent control over a wide range of climatic conditions has increased. Combinations can also lower the rates of application necessary and thus decrease crop injury and soil persistence.

There is a possibility of synergistic (additive) effects resulting in increased herbicidal activity beyond that of either single chemical. There can also be an antagonistic effect in which injury to the weeds may be less than with either chemicals alone. There are limitations and concerns about mixing chemicals without research data. Herbicides should not be mixed with other herbicides or fertilizers unless the combination has been thoroughly researched and is registered for use.

The following factors should be considered before mixing herbicides with any pesticide or fertilizer:

◆ Pesticides vary greatly in their physical and chemical compatibility with each other and with fertilizers. In many cases there can be a physical inactivation when two formulations precipitate out of solution. There can also be a chemical reaction and inactivation between two incompatible products. A small scale test for physical compatibility is recommended if the applicator has no previous experience with the mixture. Mix proper concentrations of the chemicals to be tested with the proper amount of carrier in a wide-mouth one quart jar. Agitate well and let stand over night. Check for precipitate in the bottom of the jar. This will only indicate physical compatibility - not possible chemical incompatibility, or synergistic or antagonistic effects.

◆ Agitation (keeping a herbicide uniformly dispersed in a mixture) is also important. It is a general rule to never add a wettable powder to the surface of a full or nearly full tank of liquid. Slurry the powder before adding it to the tank.

◆ Optimum placement of each product may rule out a combination application. Some fertilizers are incorporated fairly deep, while many herbicides need shallow incorporation or are left on the soil surface. Some fertilizers are broadcast while others should be soil incorporated. Each herbicide must be considered separately. Correct placement of the herbicide should have preference.

◆ The applicator must determine if the timing of the application, placement, and distribution of each component of the mixture is similar enough to be applied as a mixture.

Often the application time is different for herbicides and fertilizers. Optimum time for herbicide application is usually just before planting, during planting, or soon after planting. Fertilizers are often applied in the fall or early spring. Again, correct timing should have preference.

■ Herbicide Application

Ideal application techniques provide uniform distribution of the herbicide on plant foliage or in the soil. Chemical formulation will usually dictate what type of equipment should be used for application.

◆ Spraying is the most common method of application. A spray may be defined as liquid discharged so that it subdivides into particles that scatter and fall as dispersed droplets. Spraying permits reasonably uniform application and allows accurate direction of the herbicide to a given area (such as foliage or soil). Sprays may be applied from sprinkler cans, hand pumps, and compressed air and power sprayers. Most available herbicides can be sprayed using a water carrier. Water acidity or alkalinity can chemically affect a herbicide and inactivate it. If this is a concern water pH should be tested.

◆ Granules are spread by hand or with special mechanical spreaders designed specifically for such use. Applicators may broadcast the granules evenly over the entire spreader width or in bands over the crop row. These applicators are generally refined fertilizer applicators or seeders and may include equipment for soil incorporation. Granular herbicides have the advantage of being less bulky since they are premixed and eliminate the need to handle water. The equipment is also less complex. The major disadvantages include lack of uniform herbicide distribution and lack of versatility of equipment. Granulars are often more expensive than sprays.

◆ Fumigants are injected into the soil by both hand and power-operated equipment. The utility of this equipment is obviously limited and cost of application is generally very high. Fumigants demand caution in handling since they are highly volatile and extremely toxic. Usually airtight covers must be laid down over treated areas to prevent escape of vapors. Fumigants will give increased control for soil insects, nematodes, and some plant diseases, as well as weeds.

For more complete information on sprayer calibration and spray equipment maintenance, please refer to the Montana Department of Agriculture *Basic Pesticide Manual*.

CHEMICALS USED AS CROP AIDS

■ Defoliants and Desiccants

Materials generally referred to as harvest aid chemicals fall into two classes: 1) *defoliants* that induce the plant to drop its leaves but do not kill the plant; and 2) *desiccants* that kill plant foliage. These classifications often overlap, depending upon the amount of chemical applied. Before the use of chemicals to defoliate plants, root crops, such as potatoes, were defoliated mechanically with rubber flails or chains. In many areas, contact chemical vine killers, have replaced machines, giving growers a method of artificially hastening the maturity of the crop. Desiccation of seed alfalfa plants is common in some areas and has replaced mowing and wind-rowing in harvesting alfalfa seed. When weather conditions do not favor drying, bean fields can remain green until frost. Desiccation and pre-harvest drying is beneficial in these cases. There is also considerable interest in the use of desiccants to speed up drying of crops, such as soybeans, in the field rather than depending on heat for drying after the crop is harvested.

Some of the commonly used defoliants or desiccants registered by the EPA are: paraquat and diquat, DNEP, endothall, pentachlorophenol, sodium borate, and sodium chlorate.

➢ Timing of the desiccant is the most important factor affecting efficient use of the chemical. The crop must be sufficiently mature before growth is stopped. Often varying degrees of maturity are found throughout a field and the applicator must judge the correct time to defoliate. It is also important to know when harvesting can begin after treatment, as the crop will usually not stand up to much wet weather after a desiccant is applied. This is especially important when using a desiccant on an alfalfa seed crop or beans.

➢ Additives can improve defoliation and desiccation, especially when there are conditions of moisture stress or cool weather. Some harvest aid chemicals are formulated with additives.

■ Plant Growth Regulators

Plant growth regulators (PGRs) are used to regulate or modify the growth of plants. A plant is made up of many cells with specialized functions. Plant growth regulators can change or regulate the development of these cells. PGRs are used to thin apples, control the height of turf grass, control the height of some floral potted plants, promote dense growth of ornamentals, and stimulate rooting. They are used in minute amounts to change, speed up, stop, retard, or in some way influence vegetative or reproductive growth of a plant.

Maleic hydrazide is a plant growth regulator that restricts development of new growth by preventing further cell division. The older cells, although affected by the chemical, may continue to grow. In other words, cell division, but not cell maturity, is prevented. Maleic hydrazide is also sometimes used to control suckers.

Potted plants, such as chrysanthemums, Easter lilies, and poinsettias, may grow too tall. Plant height can be regulated with growth regulators that are applied at the proper stage of growth. Plant growth regulators are used to control vegetative growth and promote earlier flowering and development in some species. Some are used to kill shoot tips, resulting in additional branching.

Plant growth regulators are used on apples and peaches to increase fruit color and may result in earlier and more uniform ripening of fruit. They can also be used to thin the fruit, widen branch angles, produce more flower buds, prevent fruit drop, increase fruit firmness, reduce fruit cracking, reduce storage problems, and encourage more uniform fruit bearing.

Rooting hormones are used to increase the development of roots and speed up rooting of certain plants. Gibberellic acid stimulates plant growth. This is sometimes used to initiate uniform sprouting of seed potatoes and increase the size of sweet cherries.

ENVIRONMENTAL FACTORS INFLUENCING HERBICIDE EFFICACY

Rainfall, soil type and conditions, temperature, light and crop type all have a direct effect on herbicide efficacy. Understanding these effects aids in proper herbicide use, improves weed control, and reduces crop injury.

■ Rainfall

Time of germination of crop and weed seeds, their growth rate, and stage of growth at spraying time are partially determined by the incidence and amount of rain. Rain a few days before spraying can improve penetration of a herbicide into a plant by increasing the wettability of the leaf. Rain may mechanically damage the wax structure of the leaf surface, making the plant more susceptible to chemical absorption. The wax, cuticle and hair on the leaf surface, the angle of the leaf, and the humidity of the air help to determine how much chemical is retained and absorbed.

Rain, during or closely following application of a herbicide, may wash the spray from the leaves and reduce its effectiveness. The degree of leaf washing depends, not only on the quantity of rain and its intensity, but also on the structure of the crop-weed stand. The leaf penetration of herbicides ceases, or is reduced, a few hours after application when droplets have dried. Traces of rain, dew, or fog after spraying increase penetration.

The relative humidity at the time of chemical application and for many days after application, will effect the degree of weed kill. Moist air increases herbicide penetration, absorption, and translocation within the weed. Crop density and stand height also effects the relative humidity in the area.

■ Soil

Soil composition and moisture influences herbicide persistence. The length of time that a herbicide remains active or persists in the soil influences the length of time weed control can be expected. It also determines the length of time until a sensitive crop can be grown in a treated area. Persistence is a desirable or undesirable characteristic depending on the crops to be grown or the weeds to be controlled.

➢ Soil moisture, rainfall or irrigation is essential in a successful weed control program. Sufficient moisture stimulates uniform germination of weed seeds and vigorous growth of the plant. Chemical application under these conditions is more likely to succeed than when the soil is dry prior to treatment.

Dry conditions cause uneven germination of the weeds and delay crop development. As a result, proper timing of post-emergence herbicides is difficult. Weeds will be uneven in size and difficult to kill and the crop may be at a stage where injury could occur.

Water stress can affect herbicide retention, penetration, and absorption. Leaves grown under water stress have more cuticle per unit area and a lower wettability than leaves from plants not under stress.

➢ Factors having the greatest effect on herbicide soil residues are leaching, fixation on soil particles, chemical and microbial decomposition, and volatilization.

➡ Leaching is the movement of a herbicide through the soil. The extent to which a chemical is leached depends upon its solubility in water, the amount of water passed through the soil, and the adsorptive relationship between the herbicide and the soil. In general, water soluble herbicides and those not readily attached to soil particles are most readily leached.

➡ Fixation, or adsorption, of herbicides on soil particles reduces the concentration that is available in soil water. Soils heavy in organic matter or clay type soils tend to hold the herbicide for a longer period of time, thus slowing the rate of chemical release and either prolonging or lessening its effectiveness, depending on the rate of application.

➡ Chemical decomposition, involving reactions such as oxidation, reduction, and hydrolysis, destroys most herbicides and activates others. Very little is known about the effects of soil chemistry on herbicides.

➡ Microorganisms in the soil are responsible for much herbicide decomposition. Algae, fungi, and bacteria need food for energy and growth. Organic compounds in the soil, including herbicides, provide most of this food. Warm, moist, well-aerated, fertile soils are most favorable to soil microbes and, under ideal conditions, will quickly decompose most organic herbicides. The effect of herbicides on the microbe population is minor when used at normal field rates.

➡ Volatilization causes herbicide loss to the atmosphere as a gas. All chemicals have a vapor pressure and this usually increases as the temperature rises. The gases formed may be toxic to plants and may drift to susceptible plants. Water will leach the herbicide into the soil and aid soil adsorption. Once adsorbed, loss by volatilization is greatly reduced.

■ <u>Temperature</u>

Temperature conditions influence germination and growth rates of weeds and crops. Temperatures at the time of spraying are important in determining the plant response to the herbicide. High temperature generally increases the activity of herbicides. There is also an increase in translocation at higher temperatures. In general, high temperatures before and after spraying appear to increase weed susceptibility and mortality, but extremely high temperatures may reduce penetration by causing wilting, closing of leaf openings, and evaporation of the spray drops. High temperature also increase the incidence of herbicide drift or volatilization.

Temperature change produce metabolic differences in some plants which effect their susceptibility to herbicides. A plant at a low temperature may not produce a particular metabolic substance which is necessary to obtain a response to a herbicide. Tests indicate this occurs in plants such as big sagebrush or rabbitbrush, which do not respond to 2,4-D at low temperatures and low moisture. Temperature also has an effect on direction of movement in a plant.

Temperatures have important effects on the dissipation of herbicides from plant foliage or from soil. Some esters of 2,4-D evaporate readily. When such herbicides are applied at high temperatures their loss as vapors is quite rapid. These losses reduce herbicide effectiveness.

■ Light

Light is essential for optimum plant growth. Weed growth in a crop situation can be affected by shading. Growth response to shading will vary among species.

The leaf surface may be affected by light intensity. Leaves have less cuticle, cutin, and wax when grown in the shade. This might lead to differences in susceptibility of the leaf wax structure to weathering and abrasion. The leaf wettability increases when plants are grown in the shade.

Light (sunlight and ultraviolet light) can cause decomposition of some herbicides also. It is difficult to determine the relative importance of this phenomenon in the field where the herbicide may be lost through other factors, but it can be demonstrated under laboratory conditions. Loss from photodecomposition of such herbicides as the dinitroalinines when not soil incorporated can be important in a field situation.

All weed control practices alter the environment whether it is hand pulling, hoeing, cultivating, burning, chemical application, or use of biological control agents. Our concern is that the change in the environment does not produce harmful side effects to non-target plants, soil, water, animals, or man.

■ Drift and Volatility of Herbicides

Herbicides, if used correctly, can be useful tools in land management programs, but if used incorrectly, they can create serious problems. With greater emphasis on a healthy environment, it is important that herbicides be applied in a proper manner. People involved in application must understand such things as spray drift and spray volatility and take precautions to prevent damage to non-target organisms.

➢ Spray drift is the movement of spray particles out of an intended area. Drift is dependent mainly on 1) droplet size; 2) wind velocity; and 3) height above the ground. A water droplet 5 microns in diameter can drift over three miles, falling 10 feet, when the wind velocity is 3 mph. Certain atmospheric conditions associated with high temperatures can cause thermal updrafts-lifting spray droplets in the air and depositing them a considerable distance away.

In the last few years, several methods of reducing drift have been attempted. The most advertised method has been invert emulsions. Esters of 2,4-D make a milk-like "oil-in-water" emulsion that sprays like water. If the emulsion is reversed (inverted) to a "water-in-oil" liquid, and with proper spray equipment, the mixture can be sprayed in large droplets. Other methods for reducing drift include using shields, placing more nozzles on the boom, reducing pressures, and use of drift control additives.

➢ A considerable body of literature exists on the volatility of esters of 2,4-D and related compounds. Volatilization is the tendency of a sprayed material to vaporize after it has hit the soil or plant surface. Because of the small amount of material involved, volatility is usually a hazard only when extremely sensitive crops are nearby. For example, cotton is sensitive to as little as 1/1000 pound per acre of 2,4-D. Tomatoes and some ornamentals are also sensitive to 2,4-D damage.

Volatility can be controlled only by reducing the tendency of the chemical to vaporize. The major herbicide which causes economic crop damage due to volatility is 2,4-D. The crystals of 2,4-D acid and amines of 2,4-D are not volatile, while ester formulations have varying degrees of volatility depending on the type of alcohol used to make the ester. Butyl, ethyl, and propyl esters of 2,4-D are very volatile and should not be used if sensitive crops are growing in the area. Iso-octyl and propylene-glycol are examples of ester formulations which are classified as low volatile and do not vaporize easily. These esters are about 10 to 20 times less volatile. However, all forms of amines are less volatile than any of the ester forms. In the last few years, attempts to reduce volatility have resulted in the formulation of 2,4-D acid in oil mixtures and more recently, in oil soluble amine formulations. To spray an amine with oil will usually increase its effectiveness to equal that of an ester formulation.

■ Protection of Non-Target Plants

By far the greatest hazard associated with herbicides is the phytotoxic effect on non-target plants caused by incorrect or inaccurate application.

Examples of hazards that should be avoided are:

- ❒ Spray drift, in either particle or vapor form, deposited on plant foliage;
- ❒ Soil contamination resulting in root uptake by non-target plants;
- ❒ Excessive soil persistence causing injury to subsequent crops; or
- ❒ Sprayer contamination.

Because of the effects that herbicides produce on plants, their presence can be readily detected in terms of characteristic symptoms or death.

Spray drift of certain soil applied or persistent non-crop herbicides can injure susceptible non-target plants (beans, sugar beets) even when the drift occurs before seeding the crop.

Plant growth regulating (hormone-like) herbicides present the greatest visible hazard to non-target broadleaf plants. Conversion to a vapor associated with temperatures of about 90 degrees and higher can be a hazard with low volatile ester forms of 2,4-D and related herbicides. High volatile 2,4-D esters present an extreme vapor hazard and their use should be confined to areas where sensitive crops are not in close proximity.

All of the herbicides listed below are plant growth regulators and can promote abnormal plant growth when found in trace amounts. Once these herbicides are used, adequate decontamination of sprayers poses a problem, especially if the sprayer is multipurpose and must be used for application of other pesticides. Emulsifiable (oil-soluble) forms such as esters and oil soluble amines are more difficult to clean from spray equipment than the water soluble metallic and amine salts.

Herbicides that May Present a Drift or Equipment Contamination Problem

2,4-D	2,4,5-T
MCPA	picloram
MCPB	dicamba
silvex	fenac

There are several suggested decontamination procedures (see MDA, *Basic Pesticide Manual*). Using the right procedure and with enough effort, decontamination can be accomplished. When using sprayers for multiple use applications, extreme care should be exercised.

Remember that all herbicides are subject to drift under certain conditions. Good judgment should be used when applying any herbicide.

TOXICITY OF HERBICIDES

Any herbicide, in large enough doses, can pose a health hazard. However, at recommended rates, most herbicides are relatively non-toxic to humans and the environment. Herbicides, as with all pesticides, should be used only according to label directions. The information provided on the label is for the safety of the applicator as well as for anyone in the area and label directions, including use of safety equipment, should be carefully followed.

■ LD_{50} Values

Toxicity is the capacity of a substance to produce injury. The toxic action of greatest concern is the lethal dosage (LD) or the amount that will kill. Toxicity of a given substance varies with species, age, sex, and nutritional status of the test animal as well as with the route of administration (internal or dermal).

The basis used to express acute toxicity of a pesticide is LD_{50}, which is the average lethal dosage (LD) per unit of body weight required to kill one-half (50%) of a population of test animals. The usual test animals are white rats, but may be mice, rabbits, and sometimes dogs. The most common LD_{50} is the acute oral toxicity, that is, the single internal dosage necessary to kill half of the test animals.

The acute oral toxicity has limitations because it represents only the immediate toxicity of an internal dosage and not the chronic and cumulative effects or any skin absorption or irritation. Few herbicides are absorbed rapidly through the skin and most herbicides do not accumulate in the body to a toxic level. However, some do cause skin irritation. LD_{50} values are expressed in terms of milligrams of chemical per kilogram of body weight (mg/kg). Some conversion factors to convert to common terms are:

1 ounce = 28.38 grams = 28,380 milligrams
1 kilogram = 1,000 grams = 2.2 pounds

Therefore, an LD_{50} of 1,000 mg/kg would be 3 ounces of material per 180 pounds of body weight, while LD_{50} values of 100 would be 0.30 ounces per 180 pounds. Since toxicities depend on body weight, it would take only one-third of this amount to kill a 60-pound child and five times as much to kill a 900-pound animal.

LD_{50} values are expressed on active ingredient. If a material is only 50 percent active ingredient, it would take two parts of the material to make one part of the active ingredient. In some cases, adjuvants mixed with the active ingredient for formulating a pesticide may cause toxicity to differ from that of the active ingredient alone. For example, the LD_{50} of 2,4-D acid is 320 mg/kg, while that of the ester formulation is 500 to 600 mg/kg.

The acute oral LD_{50} values for the active ingredient of some common herbicides are given in the table below. Remember, the lower the LD_{50} value, the greater the toxicity. A common standard for comparison might be aspirin, which has an LD_{50} value of 1,200 mg/kg.

Herbicides (common name)	Acute Oral Toxicity	
	LD_{50} (mg/kg)	Test animal
Acrolein	46	rat
Endothall (acid)	51	rat
(sodium salt)	190	rat
(amine salt)	206	rat
Dicamba (acid)	2900	rat
Dinoseb (DNBP)	58	rat
Paraquat	120	rat
Picloram (Trodon)	8200	rat
2,4-D (various formulations)	300-1000	rat, guinea pig
Glyphosate (Roundup)	> 5000	rat

■ Toxicity Classification

All pesticides are classified according to their toxicity to man. The following table indicates the relative toxicity of most herbicides to man. To find the common names of herbicides associated with the list, refer to the family classification in Appendix C.

SIGNAL WORD	*TOXICITY CATEGORY*	***LD_{50}*** *LD_{50} is the amount of pesticide, measured in milligrams per kilogram (mg/Kg) of body weight, that will kill one-half of the exposed population*		
		Oral	common measuring unit	Dermal
DANGER - POISON 	**I** high toxicity	0 - 50	taste to 1 tsp.	0 - 200
WARNING	**II** moderate toxicity	50 - 500	tsp to Tbsp	200 - 2,000
CAUTION	**III** low toxicity	500 - 5,000	1 oz to 1 pt	2,000 - 20,000
	IV relatively nontoxic	over 5,000	more than 1 pt	over 20,000

Chemical Toxicity

Chemical Family	Toxicity Class			
	I	II	III	IV
acetanilides		✔	✔	
aliphatic carboxylic acid		✔	✔	
amino acids			✔	
benzoic acids			✔	✔
benzonitriles		✔	✔	
bipyridiliums	✔	✔		
carbanilates			✔	
dinitroanilines			✔	
diphenyl ethers			✔	
inorganic compounds			✔	
organic arsenicals		✔	✔	
phenols	✔			
phenoxy compounds (acetic)		✔	✔	
(butyric)			✔	
(propionic)		✔	✔	
(phthalic acids)		✔	✔	
pyridines			✔	
pyridazinones			✔	
thiocarbamates			✔	
s-triazines		✔	✔	
as-triazines			✔	
triazoles		✔	✔	
uracils		✔		✔
ureas			✔	

Weeds Review Questions

1. A weed can be defined as:
   a. a plant growing where it is not wanted.
   b. a plant out of place.
   c. a plant that is more harmful than beneficial.
   d. all the above.

2. Sources of weed infestations include:
   a. humans, wind, and water.
   b. wild and domestic animals, planting contamination, farm machinery.
   c. a and b
   d. none of the above

3. Perennial weeds may have the following types of root systems:
   a. rhizomes and stolons
   b. creeping roots
   c. bulbs and tubers
   d. all of the above

4. What growing stage is the best time for controlling annual weeds?
   a. flowering
   b. seedling
   c. vegetative
   d. mature

5. Perennial weed control is most effective in which growth stages?
   a. seedling or regrowth
   b. vegetative or regrowth
   c. full flower or mature plant
   d. bud or mature plant

6. Methods of controlling weeds include:
   a. biological
   b. chemical
   c. mechanical
   d. all the above

7. Pre-emergence treatments are:
   a. applied to the soil after the crop or weeds have germinated and started to grow.
   b. made to the soil after the crop is planted, but before emergence of the crop or the weeds.
   c. applied after the harvest of the crop.
   d. applied to the stack of hay or straw bales.

8. Rain a few days before spraying can improve penetration of a herbicide into a plant by increasing the wettability of the leaf.
   a. True
   b. False

9. Microorganisms in the soil are an important component of herbicide decomposition.
   a. True
   b. False

10. Spray drift is dependent only on droplet size.
   a. True
   b. False

11. A surfactant is any material that affects the surface properties of spray solutions and includes:
   a. granules
   b. stickers
   c. emulsifiable concentrates
   d. water dispersible liquids

12. The cuticle is a waxy layer or thin film on the leaf surface which retards the movement of water and gases out of or into the leaf.
   a. True
   b. False

AGRICULTURAL INSECT PESTS - PART III

ARTHROPOD RELATIVES OF INSECTS

A universal system has been developed to categorize all organisms into groups and subgroups. The animal kingdom for example, is first divided into a number of phyla. Each phylum is then divided into a number of orders, which in turn are divided into families followed by divisions into genera and species. Thus, the classification of the alfalfa weevil, an important economic pest, is as follows:

Kingdom → Animal
  Phylum → Arthropoda
    Class → Insecta
      Order → Coleoptera
        Family → Curculionidae
          Genus → Hypera
            Species → postica

Insects belong to the class insecta, which is in the phylum, Arthropoda. The Arthropoda is the largest group of animals which make up the animal kingdom. The following are important phyla of animals. The first nine are invertebrates (without a backbone). Only the Chordata are vertebrate animals (with a backbone).

- ❒ *Protozoa* (amoeba and other single-celled animals)
- ❒ *Porifera* (sponges)
- ❒ *Coelenterata* (jellyfishes, corals)
- ❒ *Platyhelminthes* (flatworms, flukes, tape worms)
- ❒ *Aschelminthes* (roundworms, trichina)
- ❒ *Mollusca* (snails, slugs, clams)
- ❒ *Echinodermata* (starfish, sea cucumbers)
- ❒ *Annelida* (segmented worms, earthworms)
- ❒ *Arthropoda* (insects, spiders, crayfish, millipedes)
- ❒ *Chordata* (fishes, amphibians, reptiles, birds, mammals)

Insects and their relatives which make up the phylum, Arthropoda, are characterized by having the following features in common: a chitinous exoskeleton and segmented bodies with appendages (legs, antennae). Five important types (classes) of arthropods include the Insecta, the Crustacea (crayfish, sowbugs or pillbugs, and fairy shrimp), Arachnida (spiders, daddy longlegs, ticks, mites and scorpions), Diplopoda (millipedes or thousand leggers), and Chilopoda (centipedes or hundred leggers). In terms of sheer numbers, insects make up nearly 7/8 of all arthropods. Included in this class are bugs, beetles, butterflies, bees, etc. All insects have 3 body parts (head, thorax and abdomen), three pairs of jointed thoracic legs and one pair of segmented antennae. This is the only class that has members which can fly, many having two pair of functional wings.

INSECT CLASSIFICATION

There are vast numbers of different types of animals in the world. Common names of insects often vary for one species from one locale to another. To avoid much of this confusion, a systematic and standardized arrangement of scientific names exists. The name of each insect consists of the Order, Family and Genus which are capitalized, followed by the Species and Sub-species (when applicable). The name of the person who described the species appears last. The genus and species name are underlined or written in italics. A shortened form of the complete scientific name consists of the genus and species.

Examples:

Pea aphid - Full scientific name: Acrthosiphon pisum (Harris) (Homoptera: Aphididae)

Short scientific name: Acrthosiphon pisum

Explanation:

Order ➠ Homoptera

Family ➠ Aphididae

Genus ➠ Acrthosiphon

Species ➠ pisum

Cereal Leaf Beetle - full scientific name: *Oulema melanopus (L)*

Short scientific name: *Oulema melanopus*

Explanation:

Order ➠ Coleoptera (beetle)

Family ➠ Chrysomelidae (leaf beetle)

Sub-Family ➠ Criocerinae (shining leaf beetle)

Genus ➠ *Oulema*

Species ➠ *melanopus*

There are approximately 26 orders of insects. This manual will deal only with those orders containing species considered injurious to plants, animals, humans or the beneficial types that aid in their control. Twelve such orders are described as follows in Table 1.

Table 1. Characteristics of Insect Orders (Wilson, Broersma, Provonsha, 1983).

ORDER	COMMON NAME	METAMOR-PHOSIS	MOUTH PARTS	WINGS	DISTINCTIVE FEATURES	HABITAT	ECONOMIC IMPORTANCE
BLATTIDAE	cockroach	incomplete	chewing	2 pr	legs adapted for running, large pronotum, short ovipositor	in buildings	cockroaches are an annoyance and transmit disease
COLEOPTERA	beetles	complete	chewing	2 pr	protective hard front wings (elytra), wings meet in straight line down back, large pronotum	aquatic & terrestrial	many phytophagous & destructive, other predaceous & beneficial
DERMAPTERA	earwigs	incomplete	chewing	2 pr	large forceps-like appendages at posterior end of body, thread-like antennae	terrestrial (nocturnal)	occasional pests
DIPTERA	flies	complete	sponging or piercing sucking	1 pr	one pair of wings, second pair replaced by halteres	wide variation	vectors of disease, phytophagous or zoophagous
HEMIPTERA	true bugs	incomplete	piercing-sucking	2 pr	front wings with both membranous & hardened areas (hemelytra, mouth parts arise from front of head)	aquatic or terrestrial	many phytophagous, some are beneficial predators
HOMOPTERA	leafhoppers treehoppers cicadas aphids scales	incomplete	piercing-sucking	2 pr	wings held roof-like, mouth parts arise from back of head	terrestrial	phytophagous, important vectors of diseases particularly viruses

ORDER	COMMON NAME	METAMOR-PHOSIS	MOUTH PARTS	WINGS	DISTINCTIVE FEATURES	HABITAT	ECONOMIC IMPORTANCE
HYMENOPTERA	ants bees wasps sawflies	complete	chewing, or chewing lapping	2 pr	attachment between abdomen and thorax usually constricted, female has stinger or ovipositor, some species are social insects	terrestrial	some are very beneficial pollinators, some are very important biological control agents, and some are very destructive pests
ISOPTERA	termites	incomplete	chewing	2 pr	social insects, broad attachment between thorax and abdomen, short cerci, straight or waved antennae	wood	destructive to buildings and other structures constructed out of wood
LEPIDOPTERA	moths butterflies skippers	complete	adult-siphoning; larva-chewing	2 pr	large wings covered with scales, often brightly colored, larvae have fleshy abdominal prolegs, larvae called caterpillars	terrestrial	some are very destructive in larval stages
NEUROPTERA	lace wings aphid lions ant lions	complete	chewing	2 pr	wings held roof-like, much larger than body, equal size with many cross veins, long antennae	terrestrial	beneficial (predaceous on other insects)
ORTHOPTERA	grass-hoppers crickets	incomplete	chewing	2 pr	hind leg adapted for jumping, tympanum (sound makers) present, long ovipositor, large pronotum	varied, terrestrial, meadows on trees	very destructive to crops
THYSANOPTERA	thrips	incomplete	rasping-sucking	2 pr	wings with fringe, no claws on tarsi, blunt head tapering to posterior end, tiny insects	leaves and flowers, some predaceous on other insects	particularly damaging to floral crops, may spread disease

Another method of insect recognition involves the examination of damage done by the pest. Pest identification can often be made based on the nature of the feeding damage as indicated below:

Damage From Chewing Insects

Defoliators- Those pests which chew portions of leaves or stems, stripping or chewing the foliage of plants. Examples: leafbeetles, caterpillars, cutworms, grasshoppers, flea beetles.

Borers- Those pests with chewing mouthparts which bore into stems, tubers, fruit trees, etc. Examples: corn borer, white grub - potatoes, granary weevil - grains, codling moth - apple.

Leaf Miners- Pests which bore into and then tunnel beneath surface layers of the leaf. Examples: leaf miners.

Damage From Piercing and Sucking Insects

Distorting plant growth- Those pests that cause leaves, fruits or stems to wilt, curl or become distorted. Examples: aphid injury, cat facing of peaches from lygus bugs, cone gall on spruce.

Causing stippling effect to leaves- Pests which may cause small, discolored spots on the leaves which eventually turn yellow. Example: thrips

Causing burn on leaves- Pests which secrete toxic substance in the host tissue, causing foliage to appear burned. Examples: leafhopper injury, greenbug (aphid) injury.

INSECT STRUCTURE

There are a great variety of shapes and forms in the external structure of different insect species. For example, the mosquito which sucks blood has piercing-sucking mouthparts adapted for this purpose. The plum curculio has chewing mouthparts which enable it to chew its way into an apple. Through study it becomes apparent that structures have evolved which play an important role in the insect's development and survival. This chapter will provide an introduction to the variation and complexity of the external anatomy of insects, which is basic to further study.

■ The Body Wall or Cuticle

The cuticle makes up the major structural portion of the outer body wall (known as the exoskeleton) and is a protective covering which regulates the passage of liquids and gases. Chitin is soft and pliable but very strong. The exoskeleton has 3 major functions:

- ✔ Protection and support of delicate internal muscles, nerves and other tissues from weather, desiccation, enemies and disease.
- ✔ To enable communication between the outside and the inside of the insect. Some sites on the exoskeleton are modified for sensory purposes (seeing, hearing, feeling, etc.).
- ✔ Movement.

■ Structures of the Exoskeleton

Segmentation is a process by which the insect body becomes divided into a series of parts or segments. It allows greater flexibility for the insect. Numbers of segments will fuse together into body regions such as the head, thorax or abdomen.

The following characteristics distinguish insects from other animals:

- Three body regions - head, thorax and abdomen
- Three pair of jointed legs on the thorax
- One or two pair of wings (some have none)
- One pair of segmented antennae
- Compound eyes and/or
- Simple eyes

◆ The Head

General Structure: The insect head is a hard capsule whose form and position are generally dependent on the mouthparts and type of food ingested (eaten) by the particular insect. An understanding of the mouthparts and feeding habits of insects can be helpful in selecting control measures. Mouthparts are of two general types, *chewing* or *sucking*.

Insects with *chewing* type mouthparts move their mandibles or jaws in a sideways motion. These types of insects include adult beetles, ants, wasps, dragon and damsel flies, grasshoppers, and crickets. Immature insects such as caterpillars, maggots, and beetle larvae also have chewing mouthparts.

Sucking type mouthparts are highly modified. Insects with these mouthparts cannot chew their food. Sucking mouthparts are in the form of a somewhat elongated beak through which food is sucked. This type of structure may be further modified to be:

- Piercing-sucking as in the mosquitoes, true bugs, and aphids
- Lapping-sponging as in the housefly
- Rasping-sucking as in the thrips
- Tube-like as in the moths and butterflies

Insects with sucking mouthparts include the adult sucking lice, flies, mosquitoes, true bugs, aphids, scale insects, leafhoppers, moths and butterflies, fleas, and thrips.

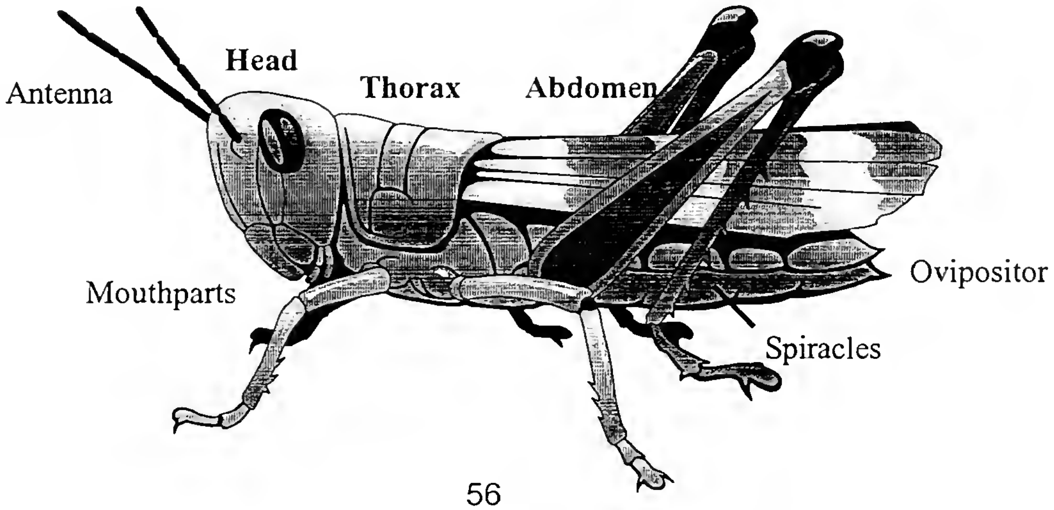
◆ The Thorax

The thorax controls the insects' locomotion. This is the middle region of the insect body and is divided into three segments. One pair of legs is attached to each of these segments. When present, paired wings are also attached to the thorax. Characteristics of the wings and legs are often useful in insect identification.

◆ The Abdomen

The abdomen, generally composed of 10 or 11 segments, is usually very flexible, facilitating such possible functions as copulation, oviposition, and stinging. On each of the first eight segments of many adult insects are found a pair of ***spiracles*** (small openings to breathing tubes) with the last several segments modified for various structures, the most important being reproductive in nature.

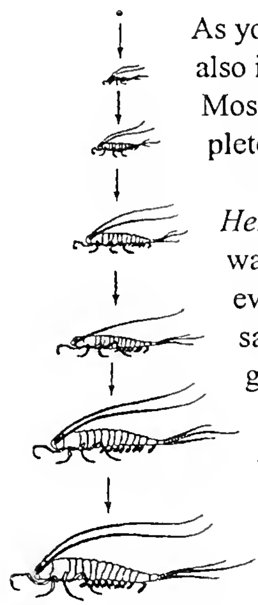
Stemming from the eighth and ninth abdominal segments is the female egg-laying mechanism, used to place eggs in protected sites. This is called the ***ovipositor*** and is most often an extended tube.



INSECT DEVELOPMENT

All insects develop from eggs, most after the eggs have been laid. A few insects develop from eggs within the body of the female and are born alive. Insect eggs vary widely in size and shape. They are usually laid in protected locations that afford the young good conditions for survival.

After hatching, insects develop by passing through a series of growth stages. The size of an insect is restricted by its hard outer exoskeleton. Each new growth stage involves shedding of the old exoskeleton and forming a new one. This shedding process is called ***molting***. The insect stage between molts is call the *instar.*

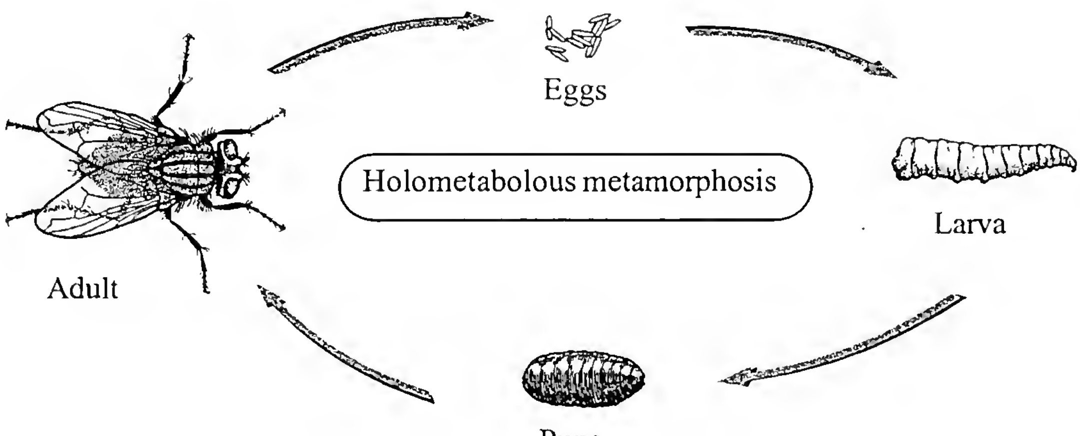


Hemimetabolous metamorphosis

As young insects progress toward adulthood, they may change not only in size, but also in form. **<u>Metamorphosis</u>** describes the process of changing from egg to adult. Most insects have either *hemimetabolous* (incomplete) or *holometabolous* (complete) metamorphosis.

Hemimetabolous insects resemble the adult form in the immature stages in many ways, but are not reproductively mature and do not have functional wings. However, these immature stages often live in the same environment and feed on the same food as the adults. The term "nymph" is given to the immature stage of this group.

Holometabolous development characteristically includes a pupal instar in which great changes in form and structure occur and larvae most often live in different environments and feed on different food than the adults. The immature is called a "larva" and never possesses wings and are sexually immature. Although there is much transformation occurring during the pupal stage, it is also a resting stage as far as eating, reproduction and locomotion are concerned. As a result, the pupa are immobile and in need of protection. Some insect types remain in a protective skin from their last molt called a puparium while others spin cocoons using silk glands. A third type find refuge in hard-to-reach places such as spaces underneath bark or debris.



Holometabolous metamorphosis

IMMATURE STAGES OF INSECTS

The immature stages of insects are of particular importance in pest management because these are the stages when insects do most of their feeding, and in most cases cause the most damage. These stages are highly variable. Immature insects are commonly classified into types based on their appearance and common characteristics. Insects are generally broken down into two major types, NYMPHS which have hemimetabolous metamorphosis, and LARVAE, those with holometabolous metamorphosis.

The NYMPH, aside from having hemimetabolous metamorphosis, looks like the adult. It has six legs on the thorax. The nymph does not have fully developed wings, but usually has wing pads.

The LARVA, which has holometabolous metamorphosis never look like the adult in appearance. Legs on the thorax may be absent or present. Wing pads are never present. Among larvae there are several distinct types as follows:

Vermiform (Figure III-1) larvae are cylindrical, elongate and wormlike without legs. These include bees and wasps (Hymenoptera), some beetles, (Coleoptera) and flies (Diptera). In the case of Diptera, the larva is called a maggot and is characterized by the absence of a distinct head, presence of mouth hooks, and spiracles on the anal end of the body.

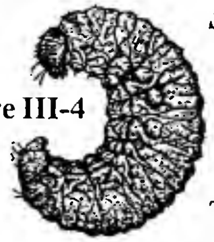
Figure III-1

The ***eruciform*** (Figure III-2) larva is cylindrical. It has six legs on the thorax and also fleshy prolegs on the abdomen. The head is distinct and well-formed. These larvae are commonly called caterpillars. Caterpillars may be found in two economic orders. Those that become moths or butterflies (Lepidoptera) have five or fewer pairs of prolegs on the abdomen. Those that become sawflies (Hymenoptera) have more than five pairs of abdominal prolegs.

Figure III-2

Figure III-3

The ***carabiform*** (Figure III-3) larva is the common form found among ground beetle larva and leaf beetle larvae.



igure III-4

Scarabaeiform (Figure III-4) larvae are commonly called grubs after the larvae of May and June Beetles. They are typically C-shaped with a well-developed head and usually have six thoracic legs, but no abdominal prolegs. This form is also found in several other groups of beetles.

The ***elateriform*** (Figure III-5) larva is cylindrical, smooth and "hard shelled" in appearance. It has short thoracic legs, but no abdominal prolegs. The destructive wireworm larva of the click beetle is elateriform.

Figure III-5

THE INSECT PEST

A *PEST* may be any organism which competes with mankind for a limited resource, or is threatening to human health or comfort and possessions. It has been estimated that there are a million species of insects which have been identified and named, of which ten thousand are considered economic pests. This number is only one percent, or one in each 100 species. This may seem low, but a single species can be devastating. Insects have been known to cause crop failures, induce plagues and spread epidemics producing enormous suffering from famine or disease, or both.

Ecologically, there are no pests, only consumers. However, when an organism begins to take what mankind wants, that organism becomes a pest. The insects categorized as pests are everywhere, they even attack us and our pets.

Variables such as temperature, moisture, soil fertility and natural controls interact to complicate the assessment of insect damage and the prediction of loss. An insect population is dynamic (constantly fluctuating), and influenced by its surrounding environment. Certain pests become problems when such factors as the lack of sanitation (in the case of house flies or stable flies), or the flooding of land (in the case of mosquitoes), create an optimal habitat for the insect. The impact of many crop pests may be intensified when the crop is affected by disease pathogens, or is in competition with weeds. These variables, or a combination thereof, along with other physical and biological factors predicate the loss that will occur. Thus, damage from an insect pest will vary from year to year, from area to area, and from crop to crop.

■ When Do Insects Become Pests?

Insects generally reach pest status in one of the following ways:

➢ By being *introduced* into, *invading* or otherwise *entering* an area previously uncolonized by the species. This movement may be *intracontinental* where an insect moves from one area to another. It may also be *intercontinental* (between continents). Either case often results in serious pest situations. In this movement from area to area, natural enemies are often left behind, climate may be more suitable for reproduction and development, and food sources more available.

➢ *A great and lasting increase in numbers of a species* takes place. Such numbers can generally be categorized as resulting from either:

◆ *A lasting or permanent increase in a favorable resource* (in contrast to year to year fluctuations) such as food, oviposition sites, or other requirement, <u>or</u>

◆ *A lasting decrease in a repressive factor* such as inclement weather, natural enemies or sanitation. In some cases, both of the above conditions may play a role in allowing an insect population to fully utilize resources.

➢ There may be a *change (usually genetic) in an insect population* which results in a characteristic which now causes insect-crop interactions which did not occur before the characteristic change. The European corn borer, which changed from one generation per year to two or three generations per year, is an example. This change brings the destructive larval stage in contact with many more crops than only a single generation.

➢ *Changes in the activities and habits of people* may occur in such a way that they become sensitive to insect activities to which they were previously indifferent. Prior to the time it was realized that apple maggots might be kept out of the orchard, the apple maggot was not considered a pest. Likewise, aphids dropping honeydew on an old 1967 Oldsmobile parked under a tree could be disregarded, but the same aphids in the same tree become pests when the same person's new Oldsmobile is involved.

Seldom can a pest situation be attributed to only one of these causes. Often, all may play a role to varying degrees. However, it is the great and lasting increases in number that we think about most often when we label an insect a "pest".

■ The Causes of Insect Outbreaks in Crops

The ways insects become pests and the causes of insect outbreaks are related. Some of the causes of crop-pest problems follow:

✔ *Large scale single crop culture* provides mass quantities of a specific food that may be desirable to a certain species of insect. This greatly reduces the constraints on the species, thus allowing large pest populations to build-up.

✔ *Indiscriminate use of pesticides reduce the species diversity.* The application of an insecticide not only reduces the population of a pest, but also its competitors. Should an insect pest acquire resistance to an insecticide through genetic selection, the lack of competition from other feeders for the food resource can lead to serious outbreaks of the insecticide resistant pest.

✔ *The sensitive balance of insects and their natural enemies* may be disrupted. This may be the result of cropping systems which establish breeding grounds for particular insect species while making conditions unfavorable for their parasites and predators. It may also result from attempted pest control procedures which destroys the pest's natural enemies without effectively controlling the pest itself.

✔ *Favorable weather conditions* may contribute to increased insect pest populations. Many aphids, such as the pea aphid, develop huge populations when there is a cool spring with temperatures of 15 to 18 degrees C (59 to 64 degrees F) predominating. The cool temperatures are favorable for the aphid, but unfavorable for the development of its natural enemies.

■ The Kinds of Damage Insects Cause

Insects that attack and damage agricultural commodities are classified as either **direct** or **indirect** pests.

Direct Pests are those organisms which attack the marketable part of the crop, such as the apple maggot which feeds on and destroys the fruit.

Indirect Pests are those which cause loss by attacking the non-marketable part of the crop, such as the western corn rootworm which attacks the corn root system and causes plants to lodge.

The damage insects cause can be broadly categorized as either **quantitative** or **qualitative**.

Quantitative Damage is the actual destruction of plant tissue, interruption of metabolism, or commodity injury which results in less yield or marketable product than would occur in the absence of harmful insects. This may occur when the leaf is consumed and there is a subsequent reduction in the photosynthetic capability of the plant. Product destruction by direct insect feeding, such as tomato hornworm on tomato fruit, or by secondary plant pathogens entering wounds caused by insects (soft rot of carrots or potato) is also quantitative in nature. Types of quantitative damage include:

- ➢ *Loss in yield*: The reduction in harvestable yield is usually the first consideration of loss from insect infestation. Thus, most economic thresholds are based on the population size of an insect pest that will reduce yield sufficiently to make control of the pest profitable.

- ➢ *Lower plant tolerance*: Stress from insect infestation may hinder recovery following harvest, reduce stand, and consequently reduce the yield of later harvests. It can be shown that an alfalfa weevil infestation on the first-cutting alfalfa crop, not only decreases the growth of the first cutting, but also the second or third cuttings. Yield, rate of recovery and stand can be reduced for the entire growing season.

- ➢ *Transmit disease to plant*: Insects which may not cause serious economic damage from feeding alone, may cause serious losses by transmitting disease pathogens. Viral diseases, many of which are transmitted by insects, generally reduce yield from 0 to 20%. The green peach aphid is known to feed on plants of 30 different families (transmitting, in course, more than 100 virus diseases) including such important crops as potatoes, beans, peppers, tomatoes, sugar beets and tobacco.

Qualitative Damage affects the physical shape, size, appearance, or nutritive composition of a product and is often difficult to evaluate. In addition, the presence of insects or insect fragments in a marketable commodity also affects the quality of the product. Although no health hazard may be involved, the public has come to believe that insect contamination is generally unacceptable in its food products.

- ✔ *Loss in marketability of commodities*: Qualitative losses which affect the marketability of a commodity may involve such things as aphids on lettuce or broccoli (for which there are federal standards specifying how many may be present), or flea beetle damage to potatoes. If a crop is graded and those items of lesser grade removed, this becomes actual quantitative loss. Often, however, lower prices may be available for those products of lesser grade. Cooking or juice apples may bring as little as one-sixth the price of dessert apples because of insect damage.

✔ *Alter nutritional components of the plant:* In some cases feeding by insects can influence the physiology of the plant to the extent that nutritional quality is affected. For example, a serious loss in protein occurs when the potato leafhopper feeds on alfalfa, causing the plant to produce less protein and more sugars. This loss, results in significant reduction in nutritional value of alfalfa as a livestock feed.

PRINCIPLES OF INTEGRATED PEST MANAGEMENT

To a large extent, the value of entomology is based on applied insect control. To an even greater extent, the support given to this branch of science by the public is in direct proportion to the efficiency of measures for insect control which have been developed by entomologists. While the lessening of insect damage or the control of insect outbreaks is far from the only aim of insect study, it is the most important. Insect control includes all those factors, natural and applied, which make life difficult for insects, that regulate their rates of increase, and that make it laborious for them to spread about the world. This chapter outlines the many ways in which insect control can be accomplished and establishes a framework in which these techniques can be organized into systems of applied ecology, that is integrated pest management (IPM) of insects.

Integrated pest management is simply the ecologic approach to insect control. It is a system in which all available techniques are evaluated and consolidated into a unified program to regulate insect populations so that economic damage is *avoided* and environmental disturbances are *minimized* (National Academy of Sciences, 1969). Rabb (1970) defined IPM as the intelligent selection and use of pest-control actions that will ensure favorable economic, ecological and sociological consequences. Thus, IPM is philosophically related to the more familiar concepts of fisheries, forest, and game management.

There are four basic principles of integrated pest management. IPM must:

❶ be a part of the total crop production program.

❷ be economical.

❸ recognize that pest control actions can result in undesirable effects such as water pollution and the destruction of non-target species.

❹ refer to all pests including weeds, pathogens, insects, nematodes and vertebrate animals, such as moles, ground squirrels, and pocket gophers.

■ Requirements for a Pest Management Decision

In order to make intelligent decisions regarding pest control, integrated pest management requires:

- Identification of the pest.
- An accurate measurement of the pest population. This is accomplished by scouting the field and sampling.
- An understanding of the pest's habits and seasonal development.
- The assessment of damage levels. The producer saves money by not taking action until action is required. Many times the economic threshold, or action threshold is not reached and it is not necessary to apply a control.

- An assessment of potential ecological or environmental hazards that may occur with a proposed control methodology.

■ Background for Integrated Pest Management

Following World War II, growers achieved crop production with unprecedented quality and yield by indiscriminately using many of the new "miracle" chemicals that became available. This is understandable because of the tremendous economic benefits realized from higher yields and the high premiums obtained because of the "cosmetic" effect of insect-free produce at the market. Pesticides were inexpensive when weighed against the consequences of non-use. Consequently, the grower became almost totally dependent upon chemical pest control for almost 30 years. The intensive use of these chemicals frequently violated basic ecological principles. Consequently, serious problems developed as follows:

- Pests developed strains which were resistant to chemicals.
- It became necessary to increase levels and frequency of pesticide applications to kill insects as they became more and more resistant. This in turn increased the cost of insect control.
- Certain pesticides tended to persist in the environment.
- Some pesticide residues became biomagnified in the environment.
- Non-target organisms were adversely affected.
- Finally, the public was disturbed by reports of extensive amounts of pesticides which were not biodegradable released into the environment.

These problems led to the reassessment of biological and ecological principles and the development of modern integrated pest management systems.

■ The Economics of Pest Management

The use of prophylactic or "insurance" treatments against possible infestation and loss of a crop is against fundamental pest management principles. However, in a practical sense, such treatments can not be avoided unless the consequences can be accurately predicted. To do this, it is necessary to understand the insect population level that will cause loss and how to sample to determine when there is a potentially damaging population infesting a crop.

■ Economic Injury Level

A basic concept underlying all pest management decisions is the economic injury level. It has been defined in various ways as...

> "the lowest pest population density that will cause economic damage" (Stern et al. 1959).
>
> "the loss caused by the pest equals in value the cost of available control measures" (National Academy of Science, 1969).
>
> "the pest population that produces incremental damage equal to the cost of preventing the damage" (Headley, 1972).

Regardless of how the economic injury level is defined, it essentially depends on whether or not treatment will make money for the producer. Thus, the term **economic injury level (EIL)**. For example, if the value of crop damage prevented by a pesticide application is $12 per acre and the cost associated with treatment (pesticide materials, application equipment costs and labor) is greater than $12, the pesticide application is not economical. In this instance, the pest population has not exceeded the economic injury level.

■ Economic Threshold (ET)

The economic threshold (ET) is the "pest density at which control measures should be applied to prevent an increasing pest population from reaching the economic injury level." Therefore, the ET generally represents a pest density lower than that of the EIL and is the guideline for the initiation of applied control measures. When the density of a pest population reaches the economic injury level, the crop has already sustained damage and loss in yield. In many cases, this is a "tolerable loss" and that control would be uneconomical. However, when the density of the pest population increases through time it becomes desirable to implement control procedures in those instances when pest populations will ultimately exceed the economic injury level.

The economic injury level is always tied, in some way, to the pest population. Pest population density, like the population density of all organisms on earth, fluctuates over time. When this fluctuation is averaged over a period of time it is termed the **equilibrium position**.

Changes in population numbers below the equilibrium position can be caused by environmental factors (i.e. rainfall, adverse temperatures), natural enemies (i.e. parasites, predators, diseases), or competition between members of the population for food or space. Those populations that remain close to their equilibrium position are termed *stable populations*, while those that fluctuate widely are termed *unstable populations*. Pest populations are frequently divided into groups according to the relationship of the equilibrium position and the economic injury level.

■ Economic Classes of Insects

Many insect species feed on crops, but never reach densities high enough to cause economic injury. These insects are *non-pests* and treatment is never required.

Some insect species have very unstable populations and under favorable environmental conditions, their numbers grow rapidly and exceed the economic injury level. These insects are termed *occasional pests*. Many insects fit into this category and include corn rootworm beetles, Diabrotica spp., that feed on corn silks; the green cloverworm, Plathypena scabra (Fab.), on soybeans or the fall webworm, Hyphantria cunea (Drury), on trees.

A number of insects have populations that nearly always exceed the economic injury level and are termed *perennial pests*. The Colorado potato beetle, Leptinotarsa decemlineata, is an example of a perennial insect pest.

The final group of insects are *severe pests*. Severe pests have an equilibrium position above the economic injury level and always require control intervention to prevent economic loss. Common examples are the corn earworm, Heliothis zea, on sweet corn; the codling moth, Laspeyresia pomonella, on apples; and the house fly, Musca domestica, in dairy barns.

■ Basis of the Economic Injury Level

The economic injury level is frequently based on a direct measure of the pest population. For example, insects per stem, or "grubs" per cow. However, many economic injury levels are based on indirect measures which are often easier to obtain than actual pest population counts. These indirect measures fall into two general categories:

- The damage that is of interest is measured and includes a sampling for the percentage of leaf defoliation, or the number of fruit with oviposition scars, etc.

- The measure of a factor that is not in itself damaging to the plant which indicates the presence of a pest population that will create damage later. Leaf feeding by early instar corn borer larvae, Ostrinia nubilalis, on corn leaves is such an indicator.

It is important to consider plant damage in association with an estimate of the insect population. It is possible that unfavorable environmental conditions might reduce the pest population below damage thresholds. This would eliminate the need for a control action even though early leaf feeding exceeded the economic threshold indicated by the damage index. Indirect indices of pest damage can be very useful for determination of economic injury levels. However, their limitations should be considered when making control decisions.

■ Factors Influencing the Economic Injury Level

Economic injury levels are dynamic values. The value for any pest is influenced by a number of factors including value of commodity, cost of control, host plant tolerance, interaction of pest species, and environmental stress on the crop. In general, as the cost of control measures and the tolerance of the crop to the pest increase the economic injury level also increases. This means that as the cost of an insecticide treatment increases from $10 to $15 per acre a producer would need a more damaging pest population before the yield savings would pay for the additional pesticide cost. Also, if tolerant varieties were used, larger pest populations would be required to justify treatment. Thus, the economic injury level goes up.

As the value of the commodity increases, the economic injury level goes down. Fewer soybean pests are needed to pay for the cost of treatment when soybeans sell for $8 per bushel than when they sell for $6 per bushel. In general, seed producers of any crop have lower economic injury levels than commercial growers. This is primarily because of the greater value of a unit of the crop. In addition, the plants used to produce seed might also be less tolerant than commercial varieties, thus reducing the economic injury level.

It is difficult to say that environmental stress and interaction of pests always affect the economic injury level in the same direction. As a general rule, however, increased stress on the plant, whether from the environment or other pests tends to decrease the economic injury level. Treatment may be economically justified at lower pest levels when the plant is under moisture stress than when adequate moisture is available. The important point is that many factors influence the economic injury level and it may change from area to area, year to year, and even from field to field.

■ Zero Damage Concept

A concept that is essential to a discussion of the economic injury level is what has been called the ***zero damage level***. For every pest there exists a population level that will not have an impact on the yield or quality of the plant. When the pest population is at or below this level, it no longer has pest status. Thus, considerations regarding changes in the economic injury level are no longer relevant. Unfortunately, many farmers have unnecessary production costs because they have become accustomed to killing pests, regardless of demonstrated need. Furthermore, there is increasing evidence that populations at or below the zero-damage level may produce a positive yield response as shown with alfalfa and the alfalfa weevil. Research at Laconia, Indiana show that low populations of alfalfa weevil larvae feeding on the plant stimulated alfalfa to produce more growth. This appears to continue until the weevil population gets so large the plant cannot tolerate it and loss occurs.

■ The Sporadic Nature of Certain Pests

Many pests are not only sporadic through time, but also occur sporadically throughout a field. The desirable approach would be to spot-treat those areas where the pest infestation exceeds the economic injury level. However, when spot treatment is not feasible the pest manager must decide whether the potential losses from areas of the field economically infested would pay for the cost of treating the entire field. Generally, in these situations a farmer must learn to tolerate some damage in small areas in order to make money.

In the same way, the sporadic nature of certain pests over years must also be considered. It doesn't make economic sense to treat in "insurance fashion" a field that faces a low level loss in 1 year of 6 when the cost of the treatment over the years exceeds the value of the crop saved. An alternative would be to attempt to control the pest in those years when it appears. However, in some situations a small probability of high crop damage from pests exists. Such damage could seriously impair the financial stability of a farm operation. In this instance the application of insecticides, even though the added cost is higher than the potential gain, is the safe approach in terms of the total farm operation. It is important to consider the relevance of the nature of the pest population over the years in making a pest control decision.

The economic injury level is the basis of most pest management decisions. Farmers are in business to make money and the use of unneeded pest control chemicals is a production cost that comes straight out of the profit column on the balance ledger.

■ Categories of Insect Control

There are two broad classifications of insect control ➠ **natural** and **applied.**

Natural control occurs when the forces of nature reduce insect populations and they include:

- ➢ Physical factors (i.e. temperature, moisture)
- ➢ Biological factors (i.e. natural enemies)
- ➢ Topographical factors (i.e. mountains and lakes)
  (The above may serve as barriers to insect migration or movement.)
- ➢ Climatic factors. Certain insects such as the potato leafhopper do not become pests early in the season in the north because they cannot survive the winter. Consequently, they have to migrate from the south each year and their arrival is later in the season.

Applied control involves any methods used by farmers to suppress insect populations to non-damaging levels. Applied methods may be:

✔ Legislative - The state or federal legislature may place a quarantine on a pest prohibiting the movement of commodities the pest infests from infested areas to non-infested areas. By law, the commodity cannot be shipped out of the infested area without inspection or treatment.

✔ Physical control involves the use of physical factors such as temperature, moisture, light and sound. People use physical control where they can, but in most cases utilization of physical factors is difficult or impossible, except in controlled environments.

✔ Mechanical control involves the use of a mechanical device such as a fly swatter or mechanical barrier. Flaming alfalfa with an LP gas burner to control the alfalfa weevil and shredding corn stalks to control the European corn borer were once used as mechanical methods. In modern day pest management other control methods are usually more economical or more effective.

✔ Cultural control utilizes agricultural practices to alter the environment so that it is unfavorable for a pest. Important cultural practices include: sanitation, tillage, crop rotation, fertilization, harvesting, trap crops, crop site, etc.

✔ Biological control technically includes any biological factor that suppresses insect populations. In insect pest management, biological control implies the manipulation of parasites, predators, and pathogens to manage the density of insect populations.

✔ Host resistance is categorized into three types:

◆ *Antibiosis* is an inherited characteristic in a plant which has an adverse effect on the biology of an insect which causes any or all of the following: mortality, reduced reproductive potential, reduced size or weight, inability to store food reserves or other physiological abnormalities. This may be caused by a chemical in the plant which interferes with normal physiological functions of the pest, or it may be from a characteristic, such as the presence of hairs, spines, etc. that make it unsuitable.

◆ *Antixenosis* is a term synonymous with "non-preference." It means that the insect finds the plant unattractive, or has inherited avoidance behavior towards it.

◆ *Tolerance* is the ability of a plant to sustain injury or recover through increased growth and produce a crop in spite of insect attack.

✔ Chemical control is presently the only practical pest management method when insect populations approach or are at the economic threshold. Chemicals must be used whenever other measures have failed and when emergency intervention is necessary. With some pests there is no alternative to the use of insecticides. Response to them is quick, producing curative action and preventing economic damage. Chemicals are usually classified according to their mode of action.

❒ Stomach poisons kill when ingested (eaten).

❒ Contact poisons kill by absorption through the body wall.

❒ Fumigants, which are in a gaseous state, kill by penetrating the insect through the trachea.

✔ Attractants comprise a relatively new and imaginative approach to insect pest management. This methodology utilizes the instinctive behavior of the pest insect itself to regulate the pest's population. Chemicals are used to attract insects at sites where they are destroyed; to divert insects in their search for mates; or to divert the insect's orientation.

◆ *Pheromones* are chemicals which insects emit and respond. Sex pheromones attract the opposite sex of the same species. In some cases pheromones trigger aggressive or flight responses and others may mark a path to a food source.

◆ *Allelochemicals*, unlike pheromones stimulate insects of another species rather than those of the species producing the chemical. Allomones are allelochemicals which are defense secretions (i.e. toxins in the larvae of the monarch butterfly make them unpalatable to birds; the irritant produced by bombardier beetles).

◆ *Kairomones* include plant substances that emit odors which warn insects of toxicity or attract them to the right source of food (e.g. coumarin in sweetclover attracts flying sweetclover weevils to their food plant).

✔ Repellents are chemicals that are applied to prevent damage by rendering the commodity, animal or person unattractive, unpalatable, or offensive.

✔ Growth regulators which have been used extensively against weeds are now available for insect control. An example is "Altosid" which is registered for use against mosquitoes.

Hormone chemicals which interrupt normal processes associated with growth have not been found to be toxic or hazardous to higher animals. However, the possible adverse effects on a wide variety of beneficial insects and non-target species is not yet fully understood.

Sterile release of males into the environment is another way of controlling insects. The sterile male mates with females, which produce inviable offspring. Examples: screworms and medflies.

THE ECOLOGICAL BASIS FOR INTEGRATED PEST MANAGEMENT

Integrated insect pest management must be based on an understanding of the ecological factors which regulate insect populations. ***Ecology is the study of the interrelationships between organisms and their environment***. There are many environmental factors (water, oxygen, predators, parasites, food, sound, reproduction, gravity, light, heat, etc.) in addition to the process of development and the physiological status of the insect that affect growth, reproduction, and behavior. It is in this setting that man's variety of management practices must fit to compliment those factors which naturally regulate the pest population. In the definition of ecology given above ***organisms*** are referred to as:

- Single individuals or one unit.
- A *population* which is comprised of a number of individuals of the same species.
- A *community* which is comprised of a number of individuals of more than one species living together in a habitat or environment.

The space and conditions surrounding an organism is termed the ***habitat***. The habitat can vary tremendously. It may be so small that it comprises only a thin layer of air around an individual, or it may be large enough to encompass a field, an island, a continent, or the entire world.

Interrelationships refer to the way organisms are affected by numerous physical and abiotic factors in the environment which is comprised of the species in question and all the factors of this habitat. The following brief summary of the ecological factors which affect insect populations will help to give a background for pest management concepts and the integration of various agricultural management practices.

■ Natural Abiotic Control

The *abiotic potential* of a species is its maximum possible growth rate if no regulating or control factors are acting against it.

If such a trouble-free environment did indeed exist, an insect would be able to produce an enormous number of offspring; and although the abiotic potential in reality is never realized, the concept is nonetheless useful in helping to identify the "effectiveness" of each regulating factor. Each species has its own abiotic potential owing to the particular growth and reproductive characteristics of that species, such as sex ratio, fecundity, fertility, number of generations per year, length of each life cycle, etc.

A *natural abiotic control* is any condition of the environment that inhibits the growth of insect populations and cannot be altered by human actions. Examples are as follows:

- ◆ **Weather**- temperature is the most important component of the weather. The insect's body temperature is dependent on the air or soil temperature, thus warmer weather conditions increase its metabolic rate, while cooler temperatures slow it. The insect's activity also generally parallels temperature levels, the result being that in many species the individual may consume greater amounts of food, reproduce more and may experience more generations in a given warm season. In addition, the insect's ability to fly may sometimes be diminished by lower temperatures; consequently, the distribution of the species is reduced, as are the opportunities to find both food sources and mates. Sometimes, extremely low temperatures may freeze and kill insects. However, most species have the ability to lower the freezing point of their bodies well below the freezing point of water.

Other weather conditions can also be controlling factors. One of these is *moisture*. Dry weather may desiccate an insect, reducing its metabolic activity or rendering it susceptible to disease or affect its behavior. On the other hand, excessive moisture may also act as an indirect controlling factor by providing conditions favorable to the increase of harmful microorganisms.

Another major weather factor is directive air movement. *Winds* may affect populations either by helping them to move to new food sources and breeding areas, or by driving them away. In addition, winds increase the evaporation rate and may be a significant contributor to insect desiccation.

◆ **Sunlight** intensity and duration constitute the next major controlling factor. For many species there exists a specific cutoff day length under which the insect may experience the onset of *diapause* (a slowdown of metabolism and development). Other light-related reactions include lower fecundity (or reproductive potential) and certain aspects of behavior such as egg laying.

■ Biotic Control Factors

The living components which affect the survival of insects in the environment are called *biotic*. These include food, competitors and natural enemies. Other areas of behavioral changes include some species' ability to regulate their oviposition as well as the percentages of each caste produced in the colony (i.e. honey bees and termites). Insects may also select favorable habitats such as protected burrows within trees. Examples of biotic factors include:

Food- Plant feeding insects in the community are called phytophagous, whereas those species that feed on other insects are called entomophagous. In general phytophagous insects are considered injurious and entomophagous insects, beneficial. Insects may be further classified by their feeding habits.

Competition is a major regulating biotic factor. It occurs between individuals of the same species as well as between species. Competition between individuals for food can become very intense as the available food supply diminishes. This adds stress to the community as a whole. For example, a given food supply may be sufficient to support a population of insects to complete their development. An increase in the population may exhaust the food supply and the population will be destroyed before any individuals reach maturity. However, the latter rarely occurs because of biological variability between individuals which allows some to feed faster, or develop faster and survive at the expense of the slower individuals. This *intraspecific competition* brings about the selection of better adapted individuals. There can also be competition for mates, space and habitat, all of which can limit the development of insect populations.

When different species compete (*interspecific competition*) with each other for food and space, a small species which needs less food to complete its development, usually has an advantage over a larger species. Likewise, a species which completes its development in a short time usually will have an advantage over a monophagous species because it may be able to move to a different food source.

Occasionally, even favorable environmental conditions may, in a sense, act as a regulating factor by allowing the vigor of the overall population to decrease. Such favorable conditions allow weaker individuals to survive, and if continued for several generations, may render the population too weak to reproduce. As a result, the population may suddenly be depleted by adverse conditions that normally would not be considered severe.

Natural enemies- Other insects, animals, and pathogens which are natural enemies of an insect species contribute to the regulation of its numbers. However, through natural selection a balance has usually been developed. Predators do not always get their prey, nor do parasites find the last host. It has been found that the reaction time of many predators and their prey is about the same, so that about half the time the predator gets its prey or the prey escapes. Likewise, a parasite population may kill most of its host in a short time, but as host numbers diminish, the parasite has difficulty locating the last few host individuals. It may itself be reduced to low numbers through starvation. Thus, host species are able to rebuild their populations. This preserves both predator and prey species, and is important if a biological control program is to have lasting effectiveness. Extreme efficiency on the part of predators and parasites, eliminating all prey and hosts would eventually cause the predators, parasites, and pathogens to perish, too.

■ The Pest and The Agroecosystem

Pest populations live in agricultural habitats which are man-made ecosystems or agroecosystems. In order to obtain economic production of a crop the farmer has disturbed the habitat by tilling the soil and resorting to many practices which increase production, but also change the ecological balance. A crop field is a habitat which supports a community of insects and other organisms in what may be called an agroecosystem. The crop grown creates an environment which either favorably, or unfavorably may affect the species in the community.

The crop produces a stand of vegetation which establishes the physical conditions of the habitat. First, light within the crop canopy is reduced since this vegetation prevents some light from reaching the ground. In turn, this shade limits the extent to which the soil temperature rises and is directly related to the density and height of plants, and to the size of the leaves. Vegetation can greatly moderate the soil temperature. When the canopy is open, or vegetation is removed, soil temperature can be raised to a level higher than soil insects can tolerate if living close to the surface.

Dense crop vegetation also reduces evaporation from both ground and plant surfaces because of a reduction in wind penetration. This results in greater retention of moisture in soil and vegetation and also tends to minimize the heat loss usually associated with evaporation. On the other hand, plants also use a great deal of moisture and can hasten the drying out of the soil, or deplete it of moisture under conditions of drought.

Tilling the soil may clear the soil surface and deprive insects of their food plants. Clean cultivation of weeds is effective in reducing stink bug and tarnished plant bug infestations in soybeans and flea beetles and billbugs in corn. Likewise, the application of both inorganic and organic fertilizers or irrigation can favor some insects and have adverse effects on others.

This section illustrates the importance of having an understanding of the crop ecosystem and the consequences either an agronomic or a pest management decision will have. The decisions the grower makes including the sequence of crops he grows, the cultural practices he uses, the timing of farm operations, and the application of chemicals largely determine the severity of pest problems he/she will encounter. The risk/benefit ratio of all farm operations has to be weighed for economic crop production.

BIOLOGICAL CONTROL OF INSECTS

Biological control involves the use of living organisms to destroy, suppress or regulate pest species. In the natural environment insect populations are regulated or kept in check by various environmental factors. Some of these are living organisms which are called *natural biological control agents* because they can not be readily manipulated to control a pest.

■ Natural Biological Control Agents

Natural biological controlling factors have a great effect in limiting insect populations. These include:

- ✓ predators,
- ✓ parasites,
- ✓ pathogens,
- ✓ natural resistance of plants or animals to attack by insects, and
- ✓ competition between the same or different species for a given food supply.

There are many vertebrates that feed on insects including birds, some mammals, amphibians, and some reptiles. Although vertebrates consume great quantities of insects, the most abundant predators of insects are other insects. Ladybird beetles are considered by some as the most valuable family of predacious insects, but there are many others.

■ Applied Biological Control Agents

One of the oldest and most successful methods of controlling insects and related pests is by using their natural enemies - parasites, parasitoids, predators, and disease organisms to attack and destroy them. The first noteworthy demonstration of biological control occurred in California in 1888. Entomologists discovered that many pests that became established in new environments often did so unaccompanied by their natural enemies that attacked and often controlled their populations at the place of origin.

At that time, the California citrus industry was seriously threatened by the cottony-cushion scale, which was introduced from Australia or New Zealand. The ladybird beetle known as Vedalia, was found to attack the scale. The beetles were imported and within a year the scale were no longer a serious threat. Vedalia beetles continue to this day as an important pest control for the citrus industry.

When serious pest situations are found to exist, the most appropriate strategies for controlling them must be determined. Biological controls usually are not effective alone, but are important as a part of a broader strategy that includes other controls.

The mode of life adopted by parasites or parasitoids has greatly limited their freedom of action; they have become highly adapted to certain niches. The host and parasite or parasitoid must be in an identical microhabitat when both are in the appropriate stages of development. The ability to find hosts varies widely among parasites and parasitoids. Some species often possess a high reproductive potential and are able to expand their numbers rapidly when there is an abundance of hosts. Such species are able to overcome and may suppress pest populations of outbreak proportions.

■ The Use of Parasites, Parasitoids and Predators

The introduction of exotic species is the primary procedure or technique involved in the use of parasites, parasitoids or predators as biological control agents. This requires the moving of the organism from a place where it has been established to a place not yet occupied by that particular species. In order for this procedure to be effective, there must be an unoccupied niche in the life cycle of the pest which can be filled by the introduced parasite or predator, or a niche must be inhabited by an inefficient regulating organism which could be displaced by a more aggressive and efficient species.

Some protective measures for conservation of natural enemies of a pest are:

- Protection against pesticides.
- Development of resistance against pesticides.
- Preservation of the inactive stages.
- Avoidance of harmful cultural practices.
- Maintenance of diversity.
- Use of alternate hosts.
- Use of artificial food and shelter.

By adding mass reared or collected individuals to an existing population, the total effectiveness of the regulating organism can be increased.

Insect Pathogens

Pathogens, or disease causing organisms, may be introduced into an insect pest population as a control factor. While repeated applications are often necessary for temporary control, a single application may be all that is needed to permanently introduce the microorganism into the population as a mortality factor. These pathogens include viruses, bacteria and fungi and are usually applied by means of spraying or dusting for ingestion by the insect.

Pathogens are not as popular as insecticides for a number of reasons. Compared to insecticides, pathogens require an incubation period before infection causes death to the insect. This may require anywhere from several hours up to two weeks, as opposed to insecticides which may take only minutes to cause death. Also, because of the relative host-specificity of pathogens, companies are reluctant to invest millions of dollars for their development. Another problem is the susceptibility of some pathogens to weather conditions unfavorable to their growth. Fungi, for example, seem to be sensitive to direct sunlight and dependent upon high humidity for their survival. Means of encapsulation with various products are being developed to deal with this weakness.

However, this is not to say that pathogens are of no use. In particular, bacteria have proved to be effective when introduced against specific hosts. The most well-known of these bacteria is the crystal forming Bacillus thuringiensis (Bt), which infects the larvae of many species of Lepidoptera.

Biological Control Information Needed For Pest Management Use

- Chronological life history of the pest and its natural enemies.
- Gross description of the physical environment.
- Factors regulating the pest (to determine the most vulnerable stage).

Advantages of Biological Control

- Persistence or permanence.
- Safety.
- Economy.

Disadvantages of Biological Control

- Length of time to become effective.
- Cannot prevent all damage.
- Effect of weather and other ecological factors on the controlling agent.
- Specifically may be a problem where more than one pest must be controlled on a single crop.
- Difficulty in producing some microorganisms in reasonably large quantity.

GENETIC APPROACHES TO INSECT PEST MANAGEMENT

The utilization of genetic principles in dealing with insect populations is a relatively recent occurrence, with the exception of host plant resistance. In a number of beneficial species, genetic manipulation through selective cross-breeding can yield favorable results. Hybridization of particular strains of honeybees has resulted in greater resistance to disease, greater cold-hardiness, and increased honey production. In addition, valuable parasitic and predacious species of insects may be made more resistant to normally lethal insecticides.

■ Genetic Manipulation

Increasing interest in genetic manipulation to control insect populations has produced a great number of studies. Studies on the Hessian fly have shown that the prevalent strain of fly from Kansas cannot survive on any of the resistant soft red winter wheats of the eastern United States. Furthermore, it was found that when crosses were made between the Kansas race and all other known races of Hessian fly, the inability to survive was genetically dominant to the ability to survive on resistant wheats.

One of the most successful utilizations of genetic control has been the *sterile insect release method* or SIRM for short. In this method, mass reared males are sterilized by irradiation, and then released into the population to mate, and so reduce the fertility of the entire population. This procedure can be utilized only when the females mate once or twice (i.e. Diptera and Lepidoptera); otherwise the sterile male will not limit the fertile female's mating activity. Although introduced in the 1950's, SIRM has already been shown to be effective; it has been responsible for the eradication of the destructive screwworm from Florida and Georgia.

An alternative method to the release of sterile, mass-cultured insects is the use of *chemosterilants*. Applied to bait, these chemicals cause sterilization in the wild population by interfering with cell division. Although less expensive to implement, this method has some serious drawbacks, including the chemosterilant's non-specificity, its harmful action on beneficial insects, wildlife and people, and their frequent carcinogenic activity.

■ Host-plant Resistance

Another effective method of pest control is the introduction of increased resistance in plants through selection and breeding. This inbred resistance can take the form of chemical changes within the plant, or actual changes in plant structure. Entomologists have demonstrated three mechanisms of resistance to insects in plants; antixenosis, antibiosis and tolerance.

Antixenosis is a condition in a plant which makes it unattractive to the insect for food, oviposition, shelter, or for combinations of all three. This type of resistance in a crop to insect attack is many times due to the condition of the crop at the time of infestation.

Antibiosis is a condition in a plant which is unfavorable for the development or survival of the insect. It may affect the insect by reducing fecundity, decreasing size, or causing mortality.

Tolerance is a condition in a plant which makes it possible to support a pest population and continue to grow, repair injury and reproduce itself under infestations that would destroy a susceptible plant.

INSECT CONTROL WITH CHEMICALS

Insecticides are pesticides used to control or manage pest insect populations. As a chemical group, pesticides are unique because they are designed to disrupt the physiology and/or behavior of target organisms. Insecticides have traditionally been classified according to their mode of entry into the insect as *stomach poisons* which kill when ingested, *contact poisons* which kill when absorbed through the body wall, and *fumigants* which kill when entering through the trachea.

The introduction of the synthetic organic compounds has made it difficult to classify modern day insecticides in the above categories since many of these materials may enter the insect's body in more than one way. Thus, insecticides are more commonly referred to as inorganic or organic compounds. In the discussion that follows, the organic compounds will include botanicals, synthetic organic compounds, microbial compounds and growth regulators.

■ How Pesticide Toxicity Is Determined

An understanding of the basic principles of toxicity is essential. In the early stages of developing a pesticide for further experiments and exploration, toxicity data are collected on the pure toxicant, as required by EPA. These tests are conducted on test animals that are easy to work with and whose physiology, in some instances, is like that of humans; for example, white mice, white rats, white rabbits, guinea pigs, and beagle dogs. For instance, intravenous tests are determined usually on mice and rats, whereas dermal tests are conducted on shaved rabbits and guinea pigs. Acute oral toxicity determinations are most commonly made in rats and dogs, with the test substance being introduced directly into the stomach by tube.

These procedures and others determine the overall toxic properties of the compound to various animals. From this information, toxicity to humans can generally be extrapolated, and eventually some micro-level portion of the pesticide may be permitted in food as residue, which is expressed in ppm (parts per million). Simple animal toxicity tests are used to rank pesticides according to their toxicity. Long before pesticides are registered with the EPA and eventually released for public use, the manufacturer must declare the toxicity of their pesticide to the white rat under laboratory conditions. This toxicity is defined by the "LD_{50}", expressed as milligrams (mg) of toxicant per kilogram (kg) of body weight, the dose that kills 50 percent of the test animals to which it is given under experimental conditions.

The LD_{50} is measured in terms of oral (fed or placed directly in the stomachs of rats), dermal (applied to the skin of rats and rabbits), and respiratory toxicity (inhaled). The size of the dose is the most important single item in determining the safety of a given chemical.

■ Inorganic Chemical Compounds

With the development of the synthetic organic compounds following World War II the inorganic insecticides have largely been replaced by more efficient toxicants. Most of the inorganic compounds are stomach poisons. Some that are occasionally used include:

Lead arsenate- used for foliage feeders in orchards and forests.
Sodium fluosilicate- used in baits for cockroaches, ants and grasshoppers.
Cryolite- used on truck crops which are generally sensitive to chemical injury.

■ Botanical Compounds

Plant derivatives have a long history of use in insect control. Although their major use has been as insect toxicants they have had other uses in insect control. For example, eugenol and geraniol as attractants, citronella and oil of cedar as repellents, and walnut shell flour and cottonseed oil as solvents or extenders have practical uses. Of the insect toxicants, pyrethrum, rotenone and nicotine are the most important.

Pyrethrum is produced from the ground flowers of the daisy, Chrysanthemum cinerariaefolium, by extracting the active materials with solvents and formulating the extracts into sprays and dusts. Pyrethrum acts almost entirely as a contact poison, working on the nerve axon causing a quick "knockdown". Many times it knocks down insects which recover later. Because it is relatively harmless to mammals and plants, it is advantageous for many uses. It has two major disadvantages, it lacks persistence because of breakdown by sunlight and is relatively expensive. Pyrethrum is commonly formulated with a synergist such as piperonyl butoxide to increase toxicity and reduce the amount of pyrethrum necessary for a satisfactory kill.

Rotenone is extracted from the roots of two species of Derris grown in the Amazon Valley of South America. Rotenone is a selective insecticide acting as both a stomach and contact poison. It is believed that it kills insects by inhibiting the utilization of oxygen by the body cells. Rotenone is harmless to plants and most mammals with the exception of swine which are highly susceptible to rotenone poisoning. It is highly toxic to fish and is used to clean trash fish from farm ponds. Rotenone is widely used, particularly in the home garden and on livestock because of its advantage of safety. However, its low toxicity, slow action, and tendency to breakdown in storage are major disadvantages.

Nicotine is extracted from the leaves of tobacco. It is not only highly toxic to many insects, but has a very high mammalian toxicity. It is toxic if ingested, absorbed through the body wall, or taken in through the tracheae. It acts on the nervous system and has very low phytotoxicity.

■ Synthetic Organic Chemical Compounds

Chlorinated hydrocarbon insecticides The rediscovery of DDT with its miraculous killing powers during World War II opened the door to the development of the synthetic organic insecticide industry and the chemical control era of the 40's, 50's and 60's. Never before had the world experienced such spectacular insect control. Although DDT has been largely banned or phased out (by world-wide authorities) because of undesirable characteristics, (primarily its persistence in the environment and its accumulation in the fat tissue of animals), it has been humans' most significant insecticide discovery. Even though it was found that organisms in the food chain accumulate DDT and pass it on through the food chain with increasing concentration (through a process called biomagnification), it has done more to relieve human suffering and death than any other chemical. It led to extensive research not only on the chemistry and biological activity of DDT, but in the development of newer materials which are less hazardous in their persistence.

To realize the impact of DDT one needs only to look at the tremendous human mortality in World War I caused by typhus. It was estimated that 25% of the Serbian army died and the Russians lost several million people. In 1944, during World War II, a typhus epidemic broke out in Naples. A mass delousing program was initiated with the new insecticide and within three weeks the outbreak was under control. This was the first time that an epidemic of typhus during wartime had been halted before it had taken its toll of thousands of lives. The results obtained in bringing malaria under control on a world-wide basis through the use of DDT are equally impressive.

Chlorinated hydrocarbon insecticides are made up of molecules composed of chlorine, hydrogen, carbon and occasionally oxygen or sulfur. Many of these materials, particularly the chemically related cyclodienes (aldrin, dieldrin, chlordane, heptachlor, endrin, and endosulfan) have been banned by the EPA or are being phased out of use because of their persistence and tendency to produce carcinogenicity and possible mutagenicity in test animals.

Methoxychlor is possibly the most widely used chlorinated hydrocarbon in the U.S. today. It is closely related to DDT without the latter's disadvantages. It accumulates less in fatty tissue and is secreted less into milk. It is not only effective against many of the same pests as DDT, but is of particular value where environmental contamination is concerned.

Organophosphorous insecticides: Organophosphorous compounds are made up of organic molecules containing phosphorous. All appear to have a common mode of action as irreversible inhibitors of enzymes of the nervous system.

Organophosphorous insecticides were first developed in Germany during World War II. Intensive research since then has led to the discovery of thousands of chemicals with various insecticidal properties. Some of these compounds are contact poisons; some are stomach poisons with limited contact activity. Others act systemically; they are absorbed by the plant either through the foliage of root system, making the plant sap toxic to insects, or they may be taken in by animals, rendering the blood toxic. Examples of insecticides which have been developed from this research and that have different insecticidal properties include:

- Tepp, parathion and mevinphos-short residual activity, broad-spectrum insecticides with very high mammalian toxicity.
- Diazinon and azinphosmethyl-prolonged activity, broad spectrum insecticides.
- Malathion-broad-spectrum insecticide with low mammalian toxicity and short residual activity.
- Demeton, dimethoate and phorate-systemic insecticides.

Carbamate Insecticides Carbamates resemble organophosphorus insecticides in use and activity. Some have low mammalian toxicity while others are very toxic. They have the advantage of being rapidly detoxified and eliminated from animal tissues and are not accumulative in fats or milk. Also, toxic effects to the nervous system are reversible. These compounds break down readily, leave no harmful residues and are unstable in alkaline solutions.

- Carbaryl is very well known and useful in commercial and home gardens because of its low mammalian toxicity and broad spectrum of activity.

- Carbofuran is an example of a highly toxic carbamate which has particularly effective agricultural use against the alfalfa weevil and has also been registered to control corn rootworms.

- Propoxpur is a moderately toxic carbamate with some agricultural use, but has been developed for the control of household insects and is used extensively by pest control operators.

- Aldicarb is an extremely toxic carbamate which is known for its wide spectrum of effectiveness against not only insects, but also mites and nematodes. It acts only systemically as an insecticide.

Synthetic Pyrethroids Synthetic pyrethroids are related to natural pyrethrins, but are synthesized from petroleum-based chemicals. In recent years, this class of insecticides has grown tremendously and new pyrethroids are being registered constantly. This class of compounds has a long and successful history. The newest types require only one-tenth of the active ingredient of the older pyrethroids. Among these are cypermethrin, fenpropathrin, flucythrinate, and fluvalinate. All of these are photostable and provide long residual effectiveness in the field.

- Allethrin has the characteristics of quick knockdown, high toxicity to insects and low toxicity to warm blooded animals that are similar to the pyrethrins. It is commonly used by pest control operators to flush cockroaches when determining the extent of an infestation.

- Resmethrin has greater residual activity then the pyrethrins and is more toxic to insects and less toxic to mammals. It does not need to be synergized. It is commonly used against insects in households, greenhouses and industrial buildings, and in mosquito control.

- Permethrin is a broad-spectrum insecticide with greatest activity against lepidopterous insects. Fenvelerate also has broad spectrum activity. It is registered on more than 20 crops. These materials are effective at very low rates, but also have been highly toxic to some insect parasites and predators.

Microbial Compounds Considerable research is underway to develop commercially produced insecticides from naturally occurring diseases of insects.

- *Bacillus thuringiensis* commonly called "*Bt*" is the most widely used microbial agent and a bacteria. It is most effective against lepidopterous leaf-eating caterpillars, but its toxicity varies tremendously among species. One disadvantage of *Bt* is that it has very little residual activity and must be present at the time the caterpillar is actively feeding.

- *Bacillus popilliae* is an obligate bacterial pathogen that causes a milky disease in the larvae of the Japanese beetle and other scarab beetles. It is often used in grub control in turf.

Several species of protozoans are effective insect pathogens. Nosema locustae is registered for the control of grasshoppers, and Nosema pyraustae for the European corn borer.

Immature insects are often attacked by naturally occurring viral pathogens which generally are remarkably host specific. Despite the large number of insect viruses, their use as microbial insecticides has been limited because they must be produced from live hosts. Viruses of the alfalfa caterpillar and the codling moth have been used commercially. Viral pathogens of the gypsy moth, tussock moth and the pine sawfly have been used by the U.S. Forest Service.

Insects are known to be attacked by a variety of disease-producing microorganisms, and more than 80 species of bacteria, 250 protozoans, 460 fungi, and 450 viruses have been identified as insect pathogens. Under favorable conditions, some of these pathogens may become epidemic and cause destructive epidemics in natural insect populations, but many others produce only chronic effects. Insect pathogens are used in pest management in three different ways by:

- Maximizing the extent of naturally occurring diseases.
- Introducing insect pathogens into insect pest populations as permanent mortality factors.
- The application of insect pathogens as microbial insecticides using suspensions of spores, toxins, or viruses.

Advantages of microbial insecticides:

- Their specificity of attack on insects and their safety to humans, domestic animals and wildlife.
- Their specificity is insect pest species so that beneficial insects are not affected.
- The safety of their application to crops just before harvest because they leave no toxic residues.
- Their compatibility with almost all other elements of insect suppression used in IPM.

Disadvantages of microbial insecticides:

- Their lack of persistence and their susceptibility to destruction by desiccation, sunlight and heat so that proper timing of applications is essential.
- The extreme specificity to insect pests, which limits general applications for pest control, resulting in high development costs of most products.

Growth Regulator Compounds

These are also known as insect growth regulators (IGRs). They are low in toxicity with acute, oral LD_{50}s that range from roughly 5,000 mg/kg to 35,000 mg/kg. They are non-irritating to the skin, low in odor, and represent one of the safest pesticide groups available. Most IGRs mimic insect juvenile hormones. If these hormones are present when they should not be, pupation or adult development becomes abnormal. The disruption of this development process results in long term control of the insect population.

- Kinoprene (sold under the trade name, Enstar) is an insect growth regulator that is registered for control of whiteflies and aphids on ornamental plants in greenhouses. It produces morphological, ovicidal and sterilizing effects which result in a gradual reduction of insect populations to below damaging levels.

- Methoprene (Altosid, Precor) is a relatively nonpersistent chemical which exhibits morphologically toxic activity. It is fed to cattle to control horn flies and is also used for mosquito control. The acute oral LD_{50} is greater than 34,600.

- Diflubenzuron (Dimilin) kills insects by preventing the formation of cuticle. It controls a wide range of leaf feeding and certain other insects in forests. It must be fed upon to be effective. Its use is restricted to uninhabited areas until its possible carcinogenic nature can be determined.

Factors Which Affect Insect Toxicity of an Insecticide

- Bioavailability - An insecticide must be in a form and applied in a manner that will get to the insect when it is used. It must be able to penetrate the cuticle, or be fed on by the insect.

- Residual life.

- Sunlight or photo-decomposition is a significant factor in the breakdown of a chemical.

- Rainfall soon after application may wash the pesticide off the leaves. It may also cause the pesticide to leach through the soil. On the other hand, it may bring the insecticide into contact with the insect.

- Humidity is not a significant factor unless it is very low when concentrate sprays are being applied. In this case, it may have an unfavorable drying effect on the fine mists being applied.

- Soil moisture is beneficial in moderate quantity for the efficacy of most pesticides. Wet soil is unfavorable since it may prevent the insecticide from reaching and contacting soil particles.

- Soil type plays an important role, especially in the control of soil insects. Sandy soils have course particles and consequently have less surface area. Lower rates of insecticide can usually be used on them to control soil insects. Silts and clays consist of fine particles which have the most surface area. Chemicals can be physically tied up in clays and may require higher rates of insecticide to accomplish control. Organic soils require higher rates of insecticides to control insects because these soils tend to bind, or absorb the chemicals, limiting pesticide activity.

- Sorption refers to the adsorption of a material on a surface. For example, some plants have waxy leaves from which spray materials tend to run off and drip to the ground. A wetting agent (spreader-sticker) may be necessary to prevent this from happening. The type of surface, whether slick or rough, has considerable effect on whether a pesticide adheres or doesn't.

- Temperature affects the rate at which an insecticide is absorbed into the insect cuticle and the rate at which the insecticide is detoxified by the insect. Thus, theoretically, the most successful control is usually obtained when temperatures are high at the time of application to get the insecticide into the insect's body, followed by low temperatures to slow the rate of detoxification. However, this may not always be true. A comparison of the effectiveness of malathion and methoxychlor, each applied at the rate of one pound of toxicant per acre at two temperatures to control the alfalfa weevil, is shown in Table 2. These data are part of a series of tests conducted at Vincennes, Indiana. Methoxychlor consistently gave better control at low temperatures, while malathion was consistently more effective at higher temperatures.

Table 2. Effect of Temperature on Insecticide Efficacy (Armbrust and Wilson, 1970).

	PERCENT FOLIAGE CONSUMED*	
TREATMENT	60^0	85^0
Methoxychlor	11.0	14.0
Malathion	19.0	10.3
Untreated Check	45.0	45.0

* *Alfalfa weevil damage measured 2 weeks after treatment. Differences between the insecticides were statistically significant.*

- High temperatures may also be unfavorable causing some soil pesticides to evaporate rapidly.

- Wind governs air currents which are particularly important since they may evaporate fine spray mists before they reach their target or carry spray and dust particles away from the target causing uneven distribution of the material or uneven deposits. Wind may also erode spray materials from the treated surface.

- Growth rate of the crop plant is significant. A rapidly growing plant such as corn may grow 6 to 10 inches in a few days. When this happens, new growth quickly generates plant surface area that has no toxicant, giving conditions for pest resurgence.

- Conversion by microorganisms cause insecticide residues to be converted to other materials and are detoxified in the process. This is an important environmental safety factor, but also reduces the length of the period of residual activity for the pesticide.

- Stability of the chemical is affected by its volatility or vapor pressure. Will it disappear as a gas? How long will it take before the pesticide will change degrades to something else? Some materials break down relatively quickly compared to those with greater residual lives.

- Resistance is playing an ever increasing role in insects evolving genetically through natural selection to the environmental stress of insecticides.

PESTICIDES AND POLLINATORS

Bees are used to pollinate many different crops, including fruit trees and seed crops. The honeybee is the most widely used pollinator although leafcutting bees are used in Montana exclusively for alfalfa seed production. For almost 100 years, the pollination industry has sustained serious losses from agricultural pesticide applications. Chemical pest control in forests, recreational and residential areas and on rangeland inflict even further damage to pollinators. It is believed that chemical poisoning overshadows all other bee problems, including bee diseases.

The most important factor in preventing bee poisoning is good communication between all parties involved: grower, applicator, dealer, field consultant, and beekeeper. In addition, there are a number of specific practices that can help prevent bee poisoning. Herbicides and fungicides do not greatly affect pollinating insects directly, however, they do affect them indirectly. The action of added carriers or surfactants may either cause harm to the insects themselves or render the food supply undesirable. Many wild pollinators rely heavily upon weedy plants, such as sweetclover, dandelion, knapweed, and mustard as a source of food. The use of herbicides in weed control may seriously reduce food supplies in some areas resulting in decline of pollinator numbers.

No insecticide is so species specific that nontarget insects are not at risk. Application of pesticides will always result in the killing of beneficial pollinators, both domestic and wild. However, the adverse effects of pesticide applications can be greatly minimized.

*What the **Grower** Can Do*

- ✓ Remove blooming weeds from the treatment and border area prior to the application. This may be accomplished by mowing, discing or applying an appropriate herbicide.

- ✓ Avoid pesticide applications when pollinators are present. If possible, use either a pre- or post-bloom spray.

- ✓ Notify nearby beekeepers if you must treat your crop during bloom, so they can attempt to minimize the impact on their bees.

*What the **Applicator** Can Do*

- ◆ Follow the pesticide label for ***bee protection***. Most labels prohibit application and/or drift onto blooming plants.

- ◆ If possible, use the pesticide formulations which are the least hazardous to bees. The formulations which are the most hazardous to bees are microencapsulated compounds, dusts, and wettable powders.

- ◆ If possible, use pesticides with a short residual hazard and apply them in late evening or early morning when bees are not actively foraging. Evening applications are generally the least hazardous to bees, but if a hazardous residue persists for a day or more this technique will not prevent poisoning.

- ◆ Let nearby beekeepers know when the application will be made, so they can attempt to minimize the impact on their bees.

*What the **Dealer and Field Consultant** Can Do*

- ➤ Recommend products that are low in hazard to pollinators when blooming plants are present adjacent to or in the treatment area. If bloom is present, pollinators will be present.

- ➤ Inform the applicator of label and rule restrictions for bee protection.

- ➤ Get to know who the beekeepers are in your area so you can help your growers know who to contact before their crop is treated.

*What the **Beekeeper** Can Do to Protect Colonies*

- ● Ensure that your hives are clearly marked and you have the landowner's permission prior to placing them in a location.

- ● If possible, place your hives in a location which is several miles from any pesticide application. If you cannot use an isolated location, then select a site which is normally upwind from the crop to be treated and try to have an untreated buffer between the hives and the crop.

- ● Get to know the landowners and pesticide use pattern in the area.

- ● Be prepared to move or protect your bees if necessary.

There are three basic ways to reduce pesticide damage to pollinators - the use of ***consideration***, ***common sense*** and ***cooperation.***

☞ *Consideration* involves realizing that the beekeeping industry is an important part of agriculture because of the vital pollination service it provides and that any pesticide damage to bee colonies may have a severe economic affect upon individual beekeepers who rely upon beekeeping for their livelihood. Realizing these two points, efforts should be taken to prevent any pesticide damages to honeybees and other pollinating insects.

☞ *Common sense* involves selecting and applying damage prevention methods to each pesticide application situation. For example, if two different insecticides are both effective in controlling a pest insect, select the one which is least toxic to bees.

☞ *Cooperation* between pesticide applicator and beekeeper is perhaps the most important point in reducing pesticide damage to bees. Discussion of tentative plans for pesticide application between the applicator and the beekeeper will prevent most pesticide damages to honeybees. If a pesticide applicator contacts these beekeepers in advance who may be affected by a certain application, the beekeeper can remove his bees from the area and prevent serious damage from occurring.

Agricultural Insect Pest Review Questions

1. All insects have three body parts which include the following:
   a. head, antennae, and legs
   b. head, thorax, and abdomen
   c. wings, antennae, and legs
   d. none of the above

2. Coleoptera is the order of ________ which have chewing mouth parts.
   a. flies
   b. beetles
   c. spiders
   d. grasshoppers

3. The female egg-laying mechanism is called the ovipositor.
   a. True
   b. False

4. Holometabolous metamorphosis is the development in which great changes in form and structure occur and larva most often live in different environments and feed on different food than the adults.
   a. True
   b. False

5. The nymph is a stage in the holometabolous metamorphosis.
   a. True
   b. False

6. Quantitative insect damage includes:
   a. Loss in yield
   b. Lower plant tolerance
   c. Transmit disease to plant
   d. All the above

7. To regulate insect populations so that economic damage is avoided and environmental disturbances are minimized is called:
   a. chemical control program
   b. integrated pest management
   c. integrated insecticide program
   d. biological control program

8. The zero damage level can be defined as the population level that has the greatest impact on the yield or quality of the plant.
   a. True
   b. False

9. Pheromones, allomones, and kairomones are all attractants.
   a. True
   b. False

10. Organophosphorus insecticides all appear to have a common mode of action as irreversible inhibitors of enzymes of the nervous system.
   a. True
   b. False

11. Termites have chewing mouth parts and are in which of the following order:
   a. Hymenoptera
   b. Orthoptera
   c. Isoptera
   d. Dermaptera

12. Pesticide applicators need to be aware of pollinators and can help protect bees in the following ways:
   a. use the pesticide formulations which are the least hazardous to bees.
   b. apply the pesticides in the day when bees are most active.
   c. let nearby beekeepers know when the pesticide application will be made.
   d. a and c

13. Most insect growth regulators (IGRs) mimic insect juvenile hormones.
   a. True
   b. False

NOTE to Commercial and Governmental Pesticide Applicators

The following appendices (A - C) are additional reference material. The test will **NOT** include information from these appendices. The information is only added for your benefit to identify pests in the field or for reference in the future.

The availability of registered pesticides for pest control in agricultural crops changes regularly as new pesticides are registered and older products are removed from use. There may be state registrations available for a special local need (24 (c) Registrations) or for a temporary use on a specific pest (Section 18 Emergency Registrations). To determine the registration status of a pesticide in Montana or the most current pesticide recommendations contact your local Montana State University extension office or the Montana Department of Agriculture at (406) 444-5400.

APPENDIX A

Pest Management in Major Montana Crops

Quick Reference

Crop/Pest Species	Page #
ALFALFA HAY	
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Alfalfa Hay

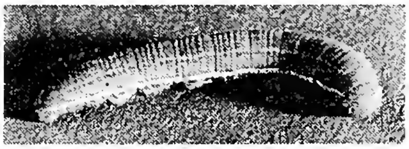
Alfalfa Caterpillar (*Colias eurytheme*)

Life cycle: Mature caterpillars are about 1.5 inches long, green, with a white stripe along each side of the body. Adult male butterflies are yellow with black wing margins and a wing span of 2 inches. Some females are white and lack the back margins. However, both have orange coloring to the upper side of the wings.

Damage: Larvae feed on the leaves of alfalfa plants. Infested fields show parts of the leaves eaten out or entirely consumed by the larvae.

Habitat: Adults can be seen in open sunny meadows, fields, and along road sides. The Larvae are found feeding on plant material (alfalfa).

Control: Treat only when 10 or more nonparasitized larvae are present per straight sweep (90 degrees) with a net. They are normally controlled by natural enemies, but heavy infestations may require an insecticide treatment.



Alfalfa caterpillar larva

Alfalfa Looper (*Autographa californica*)

Life cycle: Mature larvae are about 1 inch long, light to olive green with a palecolored head, and stripes along its' side. These larvae only have 3 prolegs giving them the characteristic "looping motion" like an inch worm. Adults have dark mottled gray forewings with a silvery white spot in the center of the wing that is elongated and angular and a wingspan of 1.5 inches. Alfalfa loopers overwinter as pupae in the soil or litter next to the base of the plant. Moths emerge in May. The female deposites her eggs singular on weed hosts. The eggs will hatch in 3 to 5 days. Moths appear early with 3 to 4 generations each year. Eggs are round, white to cream in color, and are laid on the underside of leaves.

Alfalfa looper larva

Damage: The larvae are general feeders that cause damage to leaves as they feed. Damage is most noticeable in June and July, then again in September and October.

Habitat: Alfalfa loopers are found in crop fields, waste lands, and open areas. The larvae will feed on alfalfa, cereals, vegetables, garden flowers, ornamentals shrubs, and orchard trees.

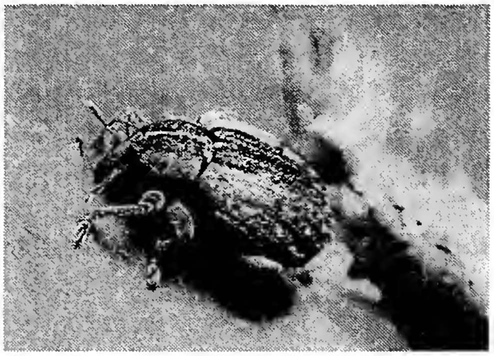
Control: The alfalfa looper is often reduced by a virus and several natural enemies. Heavy looper populations will require the use of insecticides. To determine if treatment is needed, sample the field using a standard sweep net. Take at least 100 sweeps in groups of 10 in different parts of the field and along the field margins. An average of 10 loopers without signs of disease can be used for a threshold. *Bacillus thuringiensis (Bt)* is also successful at reducing populations.

Alfalfa Weevil (*Hypera postica*)

Life cycle: Alfalfa weevil adults are 4 to 5 mm long and vary from light to dark brown. They have a broad, dark brown stripe extending from the front of the head along the middle of the back approximately two-thirds the length of the body. The stripe tapers to a triangular shape on the wing covers. The larvae are legless, 8 mm long, and green with a dark brown to black head and a white stripe down the middle of the back. The first instar larvae are white.

Damage: The larvae feed within the buds at the terminal and skeletonizing the leaves. Damaged leaves dry rapidly and the field appears gray or frosted. The larvae do the greatest damage to the first crop of hay. There is only one generation per year. Adults also feed on the foliage.

Adult alfalfa weevil



Habitat: The alfalfa weevil is the major pest on alfalfa in the United States. It also feeds on clover and other legumes

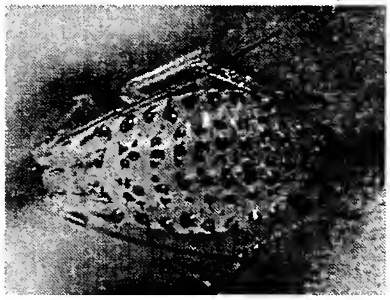
Alfalfa weevil larvae

Control: Early cutting of alfalfa may reduce the damage caused by the larvae and expose large numbers to the sun and natural enemies. The parasitic wasp, *Bathyplectes curculionis*, may reduce the population in some areas. Damage may justify treatment with insecticides when the larval population reaches about 10 per straight sweep. Severe damage may also be expected if 1.5 to 2.5 overwintering adults per square foot are found early in the spring (April-May).

Aphids - Pea aphid (*Acyrthosiphon pisum*) & Spotted alfalfa aphid (*Therioaphis maculata*)

Life cycle: *Adult pea aphids* are soft-bodied, about 4 mm long, and range in color from light green to yellow-green. Their legs and antennae are long and slender. The nymphs closely resemble the adults except in size and are produced at the rate of 1 - 14 per day asexually. During the fall, sexual forms are produced, which mate, and females lay overwintering eggs. The eggs are glued to alfalfa stems and leaves. There are 6-8 generations per year.

Adult spotted alfalfa aphid



Spotted alfalfa aphid are about 2 mm long, pale yellow and have 6 or more rows of black spots along the back. Under magnification, each spot will have a setae (bristle or hair) projecting from it.

Damage: Adult aphids and nymphs suck plant juices from alfalfa stems and leaves causing the leaves to curl, turn yellow, and drop off the plant. The pest injects a toxin while feeding, which may quickly kill seedlings and stunt growth of older plants. In Montana, these symptoms can easily be confused with drought in dryland fields. The aphid seems to affect dryland plants differently than irrigated plants. For example, in dryland, symptoms (yellow streaking and yellowing of leaves) occur when populations are as low as 5 to 10 individuals per straight sweep. In irrigated fields no symptoms may be evident at 50 or even 100 aphids per sweep.

Habitat: In Montana, these aphids affect alfalfa much differently than in other states west of the continental divide. The spotted alfalfa aphid feeds on clovers. The pea aphid also feeds on clover, peas, lentils, and vetch.

Control: Rapid growth of alfalfa in the spring helps reduce the possibility of pea aphid damage. High temperature reduces pea aphid reproduction and plants tend to outgrow the damage. Many natural enemies, such as lady beetles, lacewings, syrphid larvae, and parasites help reduce the aphid population. However, populations of natural enemies may not adequately reduce high populations of aphids. The use of insecticides may be necessary if the pea aphid population reaches about 300/sweep depending upon the number of predators present. Insecticides should be used only when necessary and according to directions on the label to protect natural enemies and pollinators.


Adult pea aphid

Armyworms - Includes Western yellow striped armyworm (*Spodoptera praefica*) and Bertha armyworm (*Mamestra configurata*)

Life cycle: *Western yellow striped armyworm:* Mature larvae are about 1.5 - 2.0 inches long and have velvety black stripes on top with two prominent and several narrow, bright yellow stripes on the sides. The key identification is an inverted, white "Y" on the top of the head. Adult moths are gray, mottled, and often referred to as "millers".

Bertha armyworms: Mature larvae are about 30 mm long, dark on the top, have a yellow-orange strip on each side and are mottled gray or green on the bottom. These differ from the western yellow striped armyworm by having no "Y" on the head. The adults are brown in color and are also known as "millers".

Damage: Typical damage includes irregular holes with edges eaten out that gives plants a ragged appearance. And at times the whole leaf may be striped. When the food supply is exhausted, armyworms will move in masses to adjacent fields. Larvae feed on foliage during the day and cause defoliation.

Habitat: *Western yellow striped armyworms* feed on peas, beans, lentils, alfalfa, sugarbeets, and potatoes. *Bertha armyworms* feed on rape, legumes, sugarbeets, hops, cabbage, corn, peas, and beans. Young larvae may be found feeding on the terminal leaves and buds during the day. Older larvae tend to be found in trash (leaf and plant matter) and on the soil surface.

Control: These pests rarely reach population levels that require chemical treatments.


Western yellow striped armyworm


Bertha armyworm

Blister Beetles (*Epicauta spp.*)

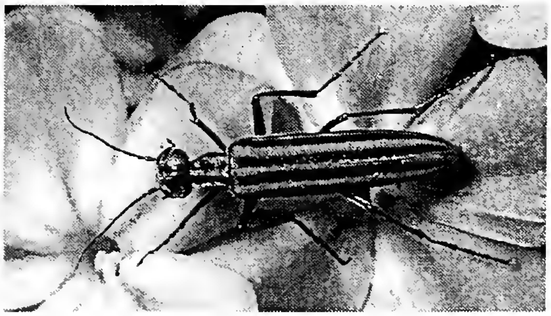
Life cycle: Adult blister beetles are 3/8 to 1 1/8 inches long. They have a broad head which is usually wider than the prothorax (bulbous) that is often neck-like. Adults emerge from the soil in early summer and the females lay their eggs in cluster of about 100 in the soil. These eggs hatch in 10 - 21 days. The larvae burrow into the soil looking for grasshopper eggs to feed on. The larvae pupae within 2 weeks and overwinter in the soil. There is one generation per year. All species of blister beetles contain a blistering substance called cantharadin. And when the adults are crushed, the will cause blistering on the skin.

Damage: Blister beetles usually become a problem where host crops are grown next to rangeland or where grasshoppers breed. The adults feed on plant foliage and flowers. Crops include alfalfa, corn, potatoes, beans, peas, onions, carrots, peppers, radishes, cereal, ornamentals and weeds. In alfalfa the adults will feed on new crown growth in late spring and summer. The larvae feed on grasshopper eggs deposited in the soil and are considered beneficial. One larva can destroy 30 or more eggs.

Habitat: Adult beetles tend to appear in years of grasshopper outbreaks since the larvae are parasitic on grasshopper eggs. Problems have occurred where numbers of beetles are contained in hay bales and fed to horses resulting in sickness and death. Blister beetles can be found in fields, pastures, and crop lands.

Control: Early cutting will avoid most problems with blister beetles. They usually do not build up until the alfalfa is in full bloom to feed on the flowers. If swarms are noted in the field and the hay crop is to be fed to horses, an insecticide treatment should be justified.

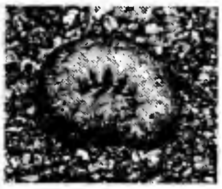
Adult blister beetle



Cutworms

Life cycle: Adults emerge in the spring after overwintering as larvae or pupae. The female moths deposit several hundred eggs in grassy areas and weedy fields. The eggs hatch in about one week. The larvae feed on young plants by cutting them just above or below the soil surface. Mature larvae also feed on the foliage of older plants. The mature larvae burrows into the soil and form a cell and pupates. Nearly all species of cutworms overwinter as larvae or pupae in the soil. There is usually one generation per year.

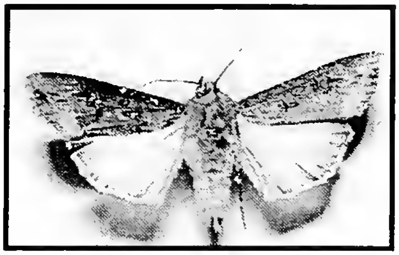
Cutworm larvae



Cutworm larvae are usually soft, fat, dull gray, brown, or black in color and may be striped or spotted. They will often curl up into a "C" shape when disturbed. The larvae are typically 38 - 58 mm long. The adults are usually silvery gray, with spots or bands. They are active at night and are often attracted to lights.

Damage: The larvae usually feed at night and cut off young plants or feed on the foliage of older plants. If alfalfa fields do not "green up" in the spring it may indicate the presence of cutworms.

Adult cutworm moth

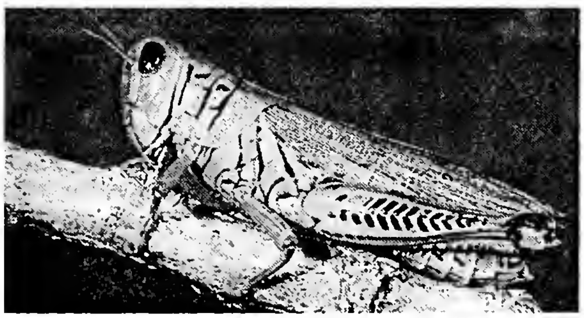


Habitat: Cutworms are primarily a pest of alfalfa and clover, but will attack other legumes.

Control: Examine the soil around plants to locate the larvae. They will spend the day "resting" just under the soil surface. Treat when 5 or more larvae per square foot are present. Irrigating the field before treating helps bring the larvae to the surface. Late evening applications are most effective when they are beginning to feed. Weed control is important along field edges. Cutworms move from edges to the field as weeds dry up.

Grasshoppers

Life cycle: There are over 100 species of grasshoppers in Montana, but only a few ever reach economically important levels. These include the *migratory grasshopper, twostriped grasshopper, redlegged grasshopper, clearwinged grasshopper* and the *bigheaded grasshopper.* These species overwinter in the egg stage in the soil. The eggs are laid in pods in the soil during late summer and fall and the nymphs begin emerging in April, May, and June. Nymphs feed on vegetation for 40 to 60 days before molting into the adult stage. Adults disperse to suitable hosts during the summer and lay the overwintering eggs. Some species have well defined breeding and egg laying areas. In most areas, eggs are laid in waste areas, along roadsides, and around field margins.



Adult grasshopper

Damage: Damage to crops occur when hoppers migrate from rangeland adjacent to fields as the vegetation drys. The green crops are a very appealing site to these hoppers. Grasshopper adults and nymphs cause defoliation as they feed. They will feed on all of the above ground parts of a plant. In large numbers grasshoppers can totally eat whole fields of crops.

Habitat: Grasshoppers are found in rangelands, roadsides, and croplands.

Control: Temperature and moisture are important factors in reducing grasshopper populations. Heavy mortality occurs in the spring when warm weather causes premature hatching of eggs. In late spring, short periods of hot weather increases the incidence of fungus (*Entomophaga grylli*, Figure 1) and bacterial diseases. Grasshopper control should be initiated when the population reaches about 10 per square yard and are in the nymphal stage (see Table 1).

Figure 1. Life cycle of *Entomophaga grylli* fungus

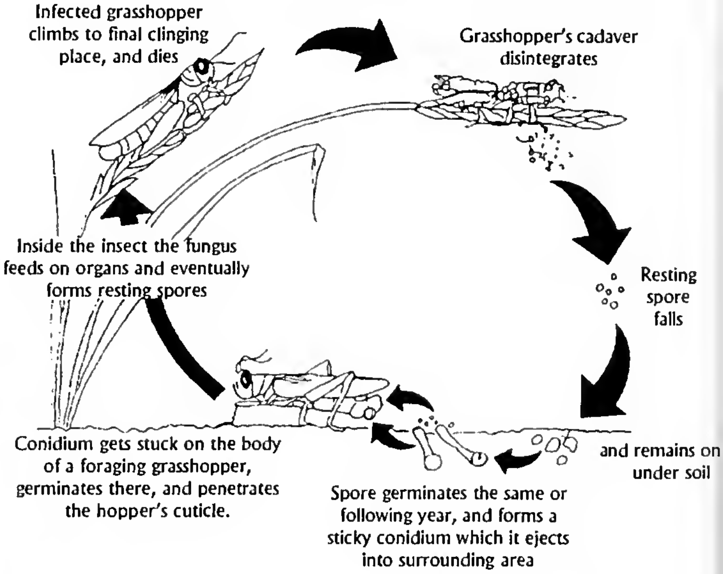


Table 1. Grasshopper nymph and adult infestation ratings based on numbers per square yard.

Rating	Nymphs Margin	Nymphs Field	Adults Margin	Adults Field
	- - - - - - per square yard - - - - - -			
Light	25-35	15-23	10-20	3-7
Threatening	50-75	30-45	21-40	8-14
Severe	100-150	60-90	41-80	15-28
Very severe	200+	120	80	28+

Spider Mites (*Tetranychus spp.*)

Life cycle: Spider mites are not insects. They belong to the arachnids (spiders). They differ from spiders in that their oval to elongated bodies are not divided into two parts.

Adult two spotted spider mite

Adult mites are 0.3 to 0.8 mm long. They are pale yellow to green in color with two very distinct black spots on the rear of their bodies (two spotted spider mite). They are also covered with black bristles on their bodies and legs. Spider mites overwinter as pregnant females beneath debris and in cracks in the soil. Female mites emerge in the spring, disperse, and begin laying eggs on the alfalfa leaves. The eggs hatch into larvae in four to five days. The newly hatched larvae have 6 legs and after the first molt gain 2 more legs and are called nymphs. A complete life cycle takes one to three weeks.

Damage: Spider mites cause leaf yellowing, and if abundant, defoliation of alfalfa from leaves dropping because of the sucking of plant juices (desiccation). Spider mites of this family often introduce diseases through feeding or by weakening the plants. Look for webbing on the underside of the leaves.

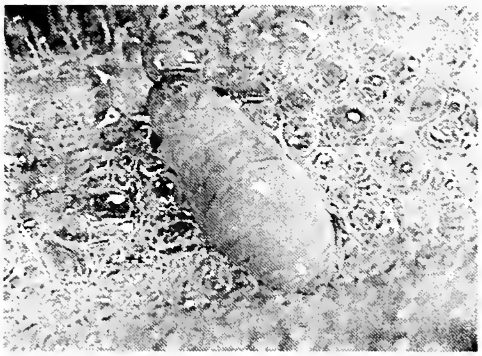
Habitat: Spider mites attack many crops including: alfalfa, beans, peas, sugarbeets, potatoes, ornamentals, fruit trees, cereal, and corn.

Control: Treatment may be justified when 25% of the leaves show damage in early summer and 50% in midsummer. However, control is questionable with 75-100% leaf damage after August 15.

Other Alfalfa Hay Pest

Meadow Spittlebug (*Philaenus spumarius*)

Contact your local Montana State University (MSU) Extension Agent or the Montana Department of Agriculture for more information.



Nymph meadow spittlebug

NOTES ✍

Alfalfa Seed

Most, if not all pesticides registered for use on alfalfa lack legal tolerances established for residues that may be present on the seed. Therefore, in the case of screenings or products of harvest, Montana seed producers have declared through an agreement with the Montana Department of Agriculture that alfalfa produced for seed is a non-food crop. This declaration means that none of the seed, screenings or products resulting from harvest will be available for human or animal consumption.

Alfalfa Weevil (*Hypera Postica*)

See previous section (alfalfa hay, pages 96-97) for description.

Aphids

See previous section (alfalfa hay, pages 97-98) for description.

Armyworms and Cutworms

See previous section (alfalfa hay, pages 98, 99 and100) for description.

Grasshoppers (*Melanoplus spp.*)

See previous section (alfalfa hay, page 100) for description.

Lygus Bugs (*Lygus spp.*)

Life cycle: Adults are 3/16 of an inch long and have a "V" on the back. The adults mate soon after emerging and immediately begin laying eggs in plant tissues. The eggs hatch in 1 - 4 weeks, depending on the temperature and the young pass through 5 nymphal instars requiring about 3 weeks. Adult females begin egg laying in about 10 days. Three or four generations per season may occur depending on climatic conditions.

Damage: Lygus bugs suck juices from the productive portions of the plant causing blossoms to drop and shriveled seed.

Habitat: They overwinter in plant debris and weeds, becoming active on the first warm days of spring.

Control: *First application* -- if lygus numbers approach 5 to 6 per 180 degree sweep prior to the introduction of pollinators, treatment can be made with a greater number of insecticide options. It is critical that a safe interval is maintained between the insecticide application and the introduction of pollinators.

Second application -- during bloom, usually when the lygus (adults plus nymphs) approaches 5 or 6 per sweep, but before the nymphs reach the third instar stage (1/2 grown), an economic threshold is reached. With certain new, "bee safe" pyrethroids, it is possible to apply an insecticide after bee flight has ceased in the evening. This enables the chemical to dry overnight with little if any noticeable effect on bees the following morning.

Adult lygus bug

Seed Chalcid (*Bruchophagus roddi*)

Life cycle: The adult is a small, shiny, black, wasp-like insect 2 mm long. The larvae are white and about 1 mm long when mature. All stages of development are completed in the seed. The chalcids overwinter as mature larvae within seeds on the ground, on unharvested plants, along field margins, and in stored seed. The adults generally emerge from the seed in July. There are 2 to 3 generations per season. The larvae from the last generation remain within the seed to overwinter, and a mature larva can remain in a seed for two or more years when conditions are excessively dry before pupating.

Seed chalcid damage

Damage: The larvae feed within the seed and destroy it.

Habitat: Infested alfalfa seed may be found in volunteer plants, along roadsides, in surrounding alfalfa fields, in chaff stacks, or scattered on the ground in alfalfa fields.

Control: Cultivating in the fall with a springtooth harrow to a depth of at least 1 inch to bury infested seed followed by irrigation, aids in reducing chalcid numbers. Cutting and removal of hay during May will delay and reduce populations. Destroy or burn chaff stacks and screenings by the first of April and remove volunteer and waste area alfalfa plants to also reduce populations.

There are several species of Chalcidoidea that are natural parasites of the alfalfa seed chalcid that attack the larvae and pupae.

Adult seed chalcid

Spider Mites - *Tetranchus spp.*

See previous section (alfalfa hay, page 101) for description.

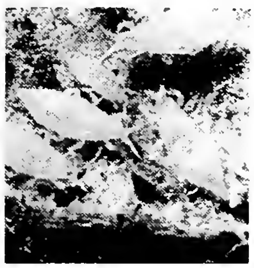
Thrips - *Frankliniella spp.*

Life cycle: Thrips are small, slender, quick-moving insects less than 2 mm long.

Damage: The adults and nymphs feed by rasping flower and leaf surfaces and sucking up the exuding juices. This injury can distort flower racemes and potentially damaging the seeds.

Habitat: Thrips are found in all crop environments including greenhouses.

Control: Almost all programs involving the use of insecticides to control other injurious insects will reduce thrip populations. Therefore, chemical control is not recommended when applied solely for thrips.



Adult thrips

Canola

From emergence, canola crops are subject to attack by a number of insect pests. Fields should be examined daily during the seedling stage and regularly thereafter. By recognizing which insects found in the crop are capable of causing major losses and which are of no economic importance, you will avoid unnecessary and costly treatments. If there is a suspected problem, consult with your county agent or production agronomist.

Aphids - Brevicoryne, Hyadphis, and Myzus spp.

See previous section (alfalfa hay, pages 97-98) for description.

Cutworms - (family Noctuidae)

See previous section (alfalfa hay, pages 99-100) for description.

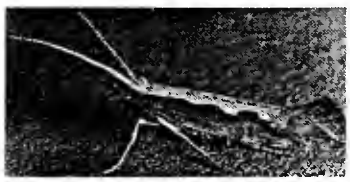
Diamondback moths - Plutella xylostella

Life cycle: The eggs are laid on the underside of lower leaves. The young larvae hatch and first mine the leaves, eventually eating holes in them. They may move up the plant to feed on the growing tip. The next generation lays eggs higher on the plant. These larvae, as they mature, move over to the buds, flowers and seedpods to feed.

Damage: The small (up to 1/3 inch long), greenish larvae make tiny irregular holes in the leaves. Larger larvae feed on buds, flowers, and developing seedpods. Seedpod damage can lead to the development of undersized, poor quality seed. Foliar damage by the larvae may look bad, but significant yield losses are not common. The damage is much worse when the plants are drought or heat stressed. Pod damage is likely to occur if lower foliage is damaged by drought or other insects.

Habitat: These small moths move to canola in late spring or early summer from volunteer canola, rapeseed, and other mustard hosts. The migration of the moth may be from local populations or populations that have developed in more southern areas.

Control: Cool, wet weather during and after egg laying will reduce populations below economic levels. Usually damage is considered severe enough to treat when populations reach 28 per square foot or 10 per plant, and the plants are under drought or other stress.



Adult diamondback moth

Diamondback moth larva

Flea Beetles - Phyllotreta spp.

Life cycle: The shiny, black beetles (1/10 inch) move into fields just as seedlings are emerging. Eggs are laid in the soil and hatch into larvae that feed on the roots of the canola plant. The larvae feed for 3 to 4 weeks, pupate, and emerge as adults during July or early August. Emerging adults feed on any green plant tissue and then move to protected areas surrounding the field to overwinter.

Damage: Adult feeding in the spring on the cotyledons, can lead to seedling death and significant stand loss. Cotyledons can withstand up to 50% defoliation without yield loss. Damage becomes more severe when plants are stressed, particularly during periods of drought.

Habitat: Flea beetles overwinter as adults and fly to volunteer rapeseed, canola, or wild mustards when the temperature reaches 68° F.

Control: Treat when 25% of the cotyledons show severe pitting or tissue loss. Normally, plants are not treated once past the first true leaf stage.

Adult flea beetle

Lygus and plant bugs - (family Miridae)

See previous section (seed alfalfa, page 102) for description.

NOTES

Corn

Aphids - (several species)

See previous section (alfalfa hay, pages 97-98) for description.

Corn earworm - *Heliothis zea*

Life cycle: The larvae are brownish to greenish, striped worms, which are about 2 inches long when fully grown.

Corn earworm larvae

Damage: This is the most destructive and hard-to-control pest of sweet corn in the United States. First generation larvae may feed as "budworms" damaging leaf whorls and newly forming ears. Corn attacked by the corn earworm will show the ears with masses of frass (insect feces) at the tip of the ear, and may be eaten down to the cob.

Habitat: The time of planting will have a marked effect on injury by this pest, but will not always be the same in different years; i.e., in some years early-planted corn will be injured, while in most years the latest corn suffers the worst damage. The moths prefer to lay their eggs on fresh corn silks, so corn which silks before or after the greatest abundance of moths will largely escape infestation. Fall plowing, to disturb the overwintering pupal stage, may be of importance. Resistant varieties of corn will greatly reduce damage from corn earworm.

Control: The corn earworm is best monitored with pheromone traps. Pheromone trapping is an easy method of monitoring male moth activity and gives an indication of the female egg-laying activity and of subsequent caterpillar damage. Spraying the silks when they first appear with a registered insecticide gives effective control in commercial plantings if pheromone traps indicate a need to do so. As a rough rule, a cumulative catch of 0 - 50 moths from first tassel to first silk indicates that no pesticide applications are needed; in processed corn, catches of 50 - 150 moths indicate a possible need for control, and catches of over 150 moths indicate a likely need for control.

Cutworms and Armyworms - Various spp.

See previous section (alfalfa hay, pages 98-99) for description of life cycle, damage, and habitat.

Control: One of the best methods of avoiding damage by *cutworms* is to rotate the crops in such a manner that corn is not planted on sod ground unless sod has been broken early in the fall or during late summer. Cutworms are parasitized by tachinid flies, by braconid and ichneumons wasps and are also readily fed on by many types of birds.

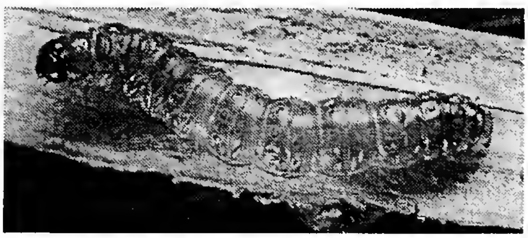
The *armyworm* is preyed on by a number of insects, especially the tachinid fly, *Winthemia quadripustulata*, which lays its eggs on the backs of armyworm larvae. They are also preyed on by several ground beetles and certain parasitic wasps. Perhaps the most efficient insect enemy of the armyworm is an extremely small, black wasp (scelionids) parasite which deposits its eggs inside the eggs of the armyworm. Braconid wasps attack the armyworm larvae when they are partly to nearly fully grown and they prevent an excessive increase in the next generation, but they do not kill the larvae until after most of their feeding has been done. The egg parasite, on the other hand, by preventing the eggs from hatching stops all damage by these insects.

European corn borer - *Ostrinia nubilalis*

Life cycle: The European corn borer overwinters as mature larvae in debris in the fields. These larvae pupate in the spring for about 2 weeks. The adults then emerge in late June. The female lays her eggs on the under side of corn leaves. There is usually an incomplete second generation in Montana. Ninety percent of corn in Montana is grown as silage (feed corn). Because of this most overwintering larvae are destroyed in the silage process. The larvae in sweet corn fields probably survive.

The adult female moths are yellowish-brownish in color with a distinguishing white zig-zag markings on the wings. The males are smaller and darker in color. The moths are nocturnal. The larvae at first are pale yellow with several rows of black to brown spots and a black head. They are about 1 inch when mature and gray to light brown or even pink in color, and faintly spotted.

Damage: The first generation larvae will greatly affect corn yields. They attack the early stages of corn where they begin feeding in the whorls on the leaf surface of the plants. Later they bore into the stalk. This boring causes damage by weakening the plant and causing the ears not to properly develop or not develop at all. The second generation larvae cause less damage, but can further weaken the plant and cause ears to drop. This also opens the plant up to infections of corn rot.



European corn borer larva

Habitat: European corn borers are found in fields of corn and weedy areas near these fields.

Control: Thresholds vary depending on crop stage. The earlier the stage of growth, the lower number of larvae percent to cause economic damage. Check at least 100 plants in 4 to 5 locations in the field. Count the number of plants with "shotholes". When more than 75% show whorl feeding, insecticide control would be warranted.

It is best to use a granular insecticide with distribution aimed at the whorls where larvae are feeding. One of the newest technologies being developed and used that show the best promise of control is genetically generated hybrid corn using *Bt*. The hybrid plants are used as a trap crop to attack the early flying moths by planting the *Bt* hybrids early. As the first generation larvae feed on the leaves they ingest the *Bt* which stops development to adulthood.

Grasshoppers - (many species)

See previous section (alfalfa hay, page 100) for description.

Seed corn maggot - *Delia platura*

Life cycle: The maggots pass the winter in the soil, and are found inside of dark-brown capsule-like manpupariums about 1/5 inch long. The adult flies are grayish brown in color and about 1/5 inch long. They deposit their eggs in the soil where there is an abundance of decaying vegetable matter, on the seed, or on small plants. The eggs will readily hatch at temperatures as low as 50° F and the larvae and pupae may develop at any temperature from 52° to 92° F. The maggots burrow in the seed, often destroying the germ. When full-grown, they are of a yellowish-white color, about 1/4 inch long, sharply pointed at the head end, legless, and very tough-skinned. They pupate inside the brown puparium in the soil and emerge as adults in 12 to 15 days. The insect can complete a life cycle in 3 weeks making 3 generations per year a possibility in Montana.

Seed corn maggot larvae

Damage: Seed attacked by the seed corn maggot usually fails to sprout, or if it does sprout, the plant is weak and sickly. The maggots will be found burrowing in the seed and injury is usually most severe in wet, cold seasons and on land rich in organic matter.

Habitat: Seed corn maggots are found in fields where corn is planted and volunteer corn grows. These insects can also be found where the fields contain a high amount of organic material.

Control: Shallow planting of corn in a well-prepared seedbed, sufficiently late to get a quick germination of the seed, is probably the best means of preventing injury. Land that is heavily manured, or where a cover crop is turned under, should be plowed early in the fall if possible, so it will be less attractive to the egg-laying females the following spring. Prompt resetting or replanting of the damaged crops will usually give a stand. This insect is particularly susceptible to control by insecticidal seed treatments.

Spider Mites - (*Tetranchus spp.*)

See previous section (alfalfa hay, page 101) for description.

Western corn rootworm - *Diabrotica*

Life cycle: There are 3 species of corn rootworms in the USA. Only the western corn rootworm is know to infest corn in Montana. The adult beetles are about 1/4 inch long, yellow or greenish-yellow in color with 3 dark stripes on its back. Corn rootworm larvae are thread-like, wrinkled, white worms about 1/2 inch long with yellowish-brown heads.

Corn rootworm adults emerge in late summer and are present until the first frost. The female beetles deposit eggs about 2 weeks after emerging. The eggs are laid in the soil around the base of the corn plant. The eggs overwinter there until the next spring when they hatch.

Damage: Infestations of corn rootworms cause slow growth of plants which is most noticeable about the time tassels appear. Plants will become undersized and frequently fall over (lodging) after heavy rains, making harvesting difficult. Adult beetles feed on newly formed corn silks and may be so numerous as to clip off the silks before pollination, producing ears with few kernels (scatter corn). The larvae causes the most sever damage to the corn.

Western corn rootworm larva (left) and adult

Habitat: Rootworms are found in fields of corn and where volunteer corn stands are found.

Control: Observance of an economic threshold based on the number of adult beetles per corn plant in the late summer prior to egg laying is a reliable way to determine the need for control. If the beetle population is averaging 5 or more per plant as silking begins, control may be necessary. If beetles average 3 or more per 4 ears on any one scouting day during July and August, then a soil insecticide application should be considered for the following season. Noticeable damage will occur when populations reach 2 adults per ear.

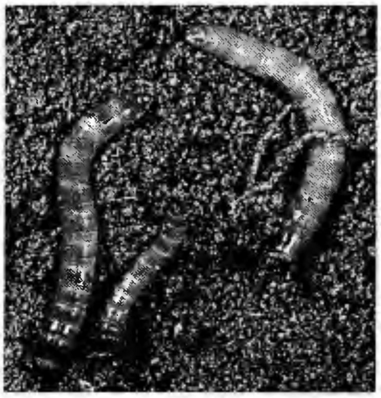
Wireworms - (*many species of the order Coleoptera, family Elateridae*)

Life cycle: The wireworm larvae are usually hard, dark brown, smooth, and wire-like. The larvae vary from 1/2 to 1 1/2 inches in length as mature larvae. The adults are know as click beetles. They have an elongated body and are light brown to black in color. They can arch their backs when up-side down and "click" themselves right-side up making a clicking noise.

Mature larvae pupate in the soil in the late summer, the adults overwinter. In the spring the adults emerge and the females lay eggs in the soil or plant roots. The larvae then hatch in a few weeks to begin feeding.

Damage: They are very destructive and widespread pests of corn. Crops often fail to germinate since the insects eat the germ of the seeds or hollow them out completely leaving only the seed coat. The crop may not come up well, or it may start well and become thin and patchy because the larvae bore into the underground part of the stem causing the small plant to wither and die, though they do not cut it off completely. Their injuries are usually most severe to crops planted on sod ground or the second year from sod.

Wireworm larvae

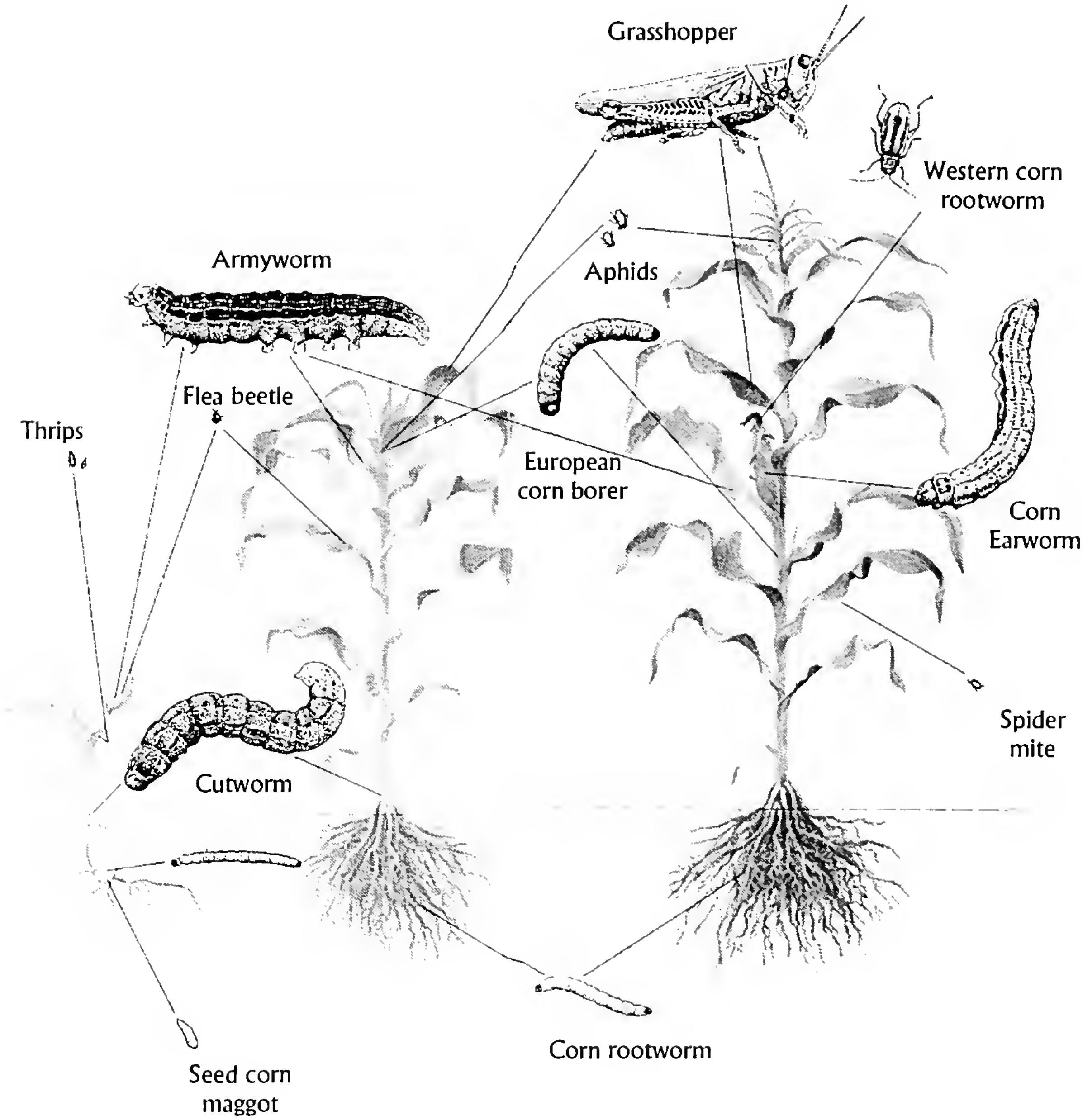


Habitat: Wireworms are common in gardens and fields. They are most common where the soil is high in organic material.

Control: Crop rotation is an important long-term control method for wireworms. A 2 to 3 year rotation of alfalfa significantly reduces wireworm populations in most infested fields in Montana.

NOTES ✍

The 3 best times to scout for corn insects



May & June June & July July & August

Cherries

Black cherry aphid - *Myzus cerasi*

See previous section (alfalfa hay, pages 97-98) for description.

Cutworms - (many species)

See previous section (alfalfa hay, pages 99-100) for description.

Fruittree leafroller - *Archips argyrospilus*

Life cycle: The adult moth has a wingspan of 3/4 to 1 inch in length and is brown with variable lighter markings on the fore wings. The slender, pale green larva reaches a length of 3/4 inch. It has a black head and a black spot on the thorax just behind of the head. Eggs are laid in gray, compact oval masses on the bark of twigs and branches, each mass contains up to 100 or more eggs. They are coated with a secretion from the moth which hardens and serves to protect the eggs.

This insect overwinters in the egg stage and hatching occurs when the buds begin to open. The larvae feed on the buds, blossoms, leaves, and fruit, becoming fully grown in June and pupate inside rolled or folded leaves. The larvae when disturbed will wriggle and drop from the leaf on a silk thread. In about 2 weeks the moths begin emerging and shortly afterwards lay their eggs and die. Only 1 generation develops annually.

Damage: Early larval feeding on blossom buds may prevent setting of fruits. Most damage from larvae is done in the spring. Serious damage results where the leaves are held against the cherries with silk, the larvae feed within. Foliar injury is of less consequence although it may also be severe. Damage to the fruit opens it up to decay organisms.

Fruittree leafroller larva

Habitat: Fruittree leaf rollers attack cherry, apple, and pear trees.

Control: Fruittree leaf rollers are rarely a major pest. There are several natural enemies that help to keep it below the economic threshold. Trichogramma a small parasitic wasp, lays its eggs in the leaf rollers eggs. There are also several predators that feed on leafroller larvae. They include lacewings and lady bird beetle larvae.

Pacific flatheaded borer - *Chrysobothris malis*

Life cycle: The beetles are flat, bronzy-black and nearly 1/2 inch in length. The larvae are white, legless, and about 1 inch long when fully grown, with the forepart of the body is broad and flattened. The adults are more prominent in sunny locations. Eggs are laid beneath scales of bark and hatching larvae burrow under the bark. Development is usually completed within 1 year although 2 years are sometimes required. Partly grown larvae winter in tunnels. In the spring before pupation they tunnel a cavity almost at a right angle to the bark surface. Adults may begin emerging in May and this continues until midsummer.

Pacific flatheaded borer larva

Damage: This borer is one of the worst enemies of deciduous trees and shrubs in western North America. They are especially destructive during the first 2 to 3 years after the trees are planted, in very dry seasons, or where parts of trees that have been shaded are exposed to the sun by pruning. Damage is caused by tunnelling under the bark in the larval stage and feeding on the foliage as adults. The feeding of the larvae may cause parts of the bark to die, or girdle and kill young trees.

Habitat: The Pacific flatheaded borer attack most deciduous trees. Among the fruittrees that it attacks in Montana are apple, cherry, peach, and pear.

Control: Maintenance of tree vigor is considered of utmost importance. Shading the trunks of newly set trees by wrapping with paper or burlap impregnated with a residual pesticide inhibits egg deposition and kills newly hatched larvae. Applying external white latex paint to the trunks of young trees before borer eggs are laid prevents sunburn and reduces borer attacks. Removing and destroying infested wood and prunning during winter are recommended practises.

Peach Tree Borer - *Sanninoidea exitiosa*

Life cycle: The adult is a clearwinged moth, steel blue with yellow or orange markings; both pairs of wings of the male are transparent, and there are several narrow yellow bands on the abdomen; the female's forewings are covered with metallic blue scales, and there is a broad orange band on the abdomen. The female is about 1 inch in length, the male is slightly smaller. The moths are day fliers and may easily be mistaken for wasps. Fully grown larvae may exceed a length of 1 inch and are white with brown heads. There is only 1 generation each year.

Various larval stages of the peach tree borer overwinter in burrows under the bark at or near ground level. The larvae resume their feeding and complete their development in the spring and early summer. They pupate within a cocoon that is constructed in an upright position just beneath the soil at or near the trunk. After 3 to 4 weeks the adults emerge leaving the empty pupal case protruding from the cocoon. The females mate and begin laying eggs on the day of emergence. Each female will average 400 eggs within a few days that are laid on the trunks of trees, weeds, and on the soil around the base of the tree. The eggs hatch in about 10 days and the larvae enter the tree through cracks or wounds in the bark near the soil. The larvae feed and develop in the cambium layer until winter.

Peach tree borer larva

Damage: The larvae are the damaging stage. They feed in the inner bark and cambium tissue of the trees within a few inches to below ground level. Feeding may also occur on large roots near the soil surface. Evidence of infestation is frass and fine wood borings mixed with gum at the base of the trees. Young trees may be completely girdled in a single season resulting in death. Older infested trees are less vigorous and productive and will often succumb to other insect diseases or winter injury before girdling kills them.

Habitat: The peach tree borer is found in cherries, plums, and related species.

Control: Control of the peach tree borer is like many orchard crops and is depended on a good monitoring program. Using pheromone traps to attract male moths at emergence is good for determining when egg laying is beginning. Experience has shown that populations seldom need treatment when trap catches peak at less than 10 moths/trap/week.

Also determine the average number of cocoons and empty pupal cases in the soil or near the base of trees. In trees up to 3 years of age, if any evidence is shown, treatment is warranted. In older orchards, an average of one cocoon and/or empty pupal case per tree would warrant treatment.

Maintaining healthy trees is very important. Only previously damaged trees will become infested. Pruning at the proper time of the season will help to lower populations. Chemical treatments targeted at the larval stage should be applied with a hand gun directed at all the wounds on the base of the trunk. Thoroughly wet the top few inches of the soil.

Pear Slug - *Caliroa cerasi*

Life cycle: The larvae of the pear slug appear as shinny, black, and slug-like. They reach 1/3 of an inch in length. When larvae first hatch, they are white with a brown head. They soon secrete a dark coat of slime which gives the larva its slug-like appearance. The head end is some what wider than the rest of the body. The larvae have 7 pairs of prolegs that separate them from lapidoptera larvae (caterpillars), but these are covered by the slime. The full grown larvae turn yellow-orange in color. The adults are black with 4 transparent wings about 1/5 of an inch long. The adults are known as sawflies (Hymenoptera) and are often mistaken for bees or wasps.

Pupae overwinter in the soil. The adults emerge in the spring and the females begin to oviposite (lay eggs) on the leaves. The females usually reproduce parthenogenetically (asexually). The eggs are inserted into small slits in the leaves and hatch shortly (1 week). The larvae complete their development in 2 to 3 weeks and drop to the soil and pupate within cocoons about 4 inches deep in the soil. There are usually 2 generations per year.

Pear slug larva

Damage: The pear slug is a widely distributed chewing insect which skeletonizes the upper surface of the leaves of cherry trees. Such injury may be extensive especially the second generation. If the injury is severe, tree growth may be reduced in the following year.

Habitat: Host trees include cherry, pear, apple, and plums. They also occur on shrubs, trees, and willows.

Control: Observe skeletonizing injury in mid to late summer. There are no thresholds and minor injury does not warrant treatment. Insecticidal soap may be effective in controlling the pear slug. Dislodging the larvae with a strong blast of water is usually all that is needed to control this insect.

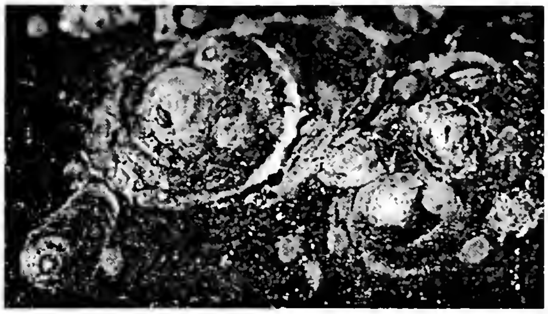
Pear thrips - *Taeniothrips inconsequens*

See previous section (alfalfa seed, page 103) for description.

San Jose Scale - *Quadraspidiotus perniciosus*

Life cycle: Winter is passed in the partly grown nymphal stage under the scale coverings on the host plants. Development continues in the spring, and maturity is reached usually in May or June when very small, 2-winged adult males appear, which mate with the females and die soon afterwards. The female produces young which crawl from under the edge of her covering. Newly born lemon-yellow nymphs resemble mites, but they can be distinguished by the presence of 3 pairs of legs and a pair of antennae. The nymphs are called "crawlers" and migrate over the host for a few hours before inserting their mouthparts into the bark, leaves, or fruit to feed. After the first molt the legs and antennae are shed; these are incorporated in the scalelike covering that increases in size as the nymphs continue to grow. Underneath these scale-like coverings may be found the yellow, nearly circular sack-like bodies of the insects. Growth is completed in about 6 weeks and 2 or more overlapping generations are produced each season.

Damage: Tree vigor is reduced and fruits are blemished by the nymphs and the adults remove sap and part of the plant, but especially the wood. Diagnosis can be easily made by the encrusted scales on the branches and the tiny red circles with white centers. Unchecked, heavy infestation may kill the trees.


Adult San Jose scale

Habitat: The San Jose scale attacks most cultivated fruits and a large number of ornamental shrubs and trees. Included are apple, pear, plum, cherry, peach, currant, and gooseberry.

Control: If twigs look unhealthy or are dead, examine them closely for the crusty scales. Also examine twigs for scale during pruning. Look for the scales or their feeding blemishes on the skin of the fruit at harvest; if they are found, be prepared to initiate control the following spring. The adult males can be monitored by using pheromone traps. The traps should be hung in the trees during the early pink bud stage. The males usually will begin to fly at bloom or petal-fall.

Once there is an infestation detected it is more than likely it will get worse and not better as time goes on if no action is taken. The first step in control is to apply a dormant oil in the spring before growth starts. This should be followed by a foliar insecticide directed at the crawler stage. If after 10 days there are still many crawlers, a second application should be applied.

Shothole borer - *Scolytus rugulosus*

Life cycle: The adult beetle is 1/4 inch or less in length, brown-black with brown legs, and a short, stubby snout. The larva is a small, white, footless grub, slightly larger at its anterior end and about 1/8 inch in length. The adults emerge in the spring and early summer. They burrow into the bark until they reach the sap wood. A long, narrow, longitudinal gallery about 1/2 inch is excavated and is called the "maternal gallery". This is where the female lays up to 50 eggs. The eggs soon hatch and the young larvae tunnel outwards from the maternal gallery between the bark and sap wood. When mature, the larvae dig a deeper cell in which they pupate. The new adults emerge and bore out through the bark and cause the familiar "shot-hole" like holes. There are 2 generations per year and the larvae of the second generation overwinters.

Damage: The shothole borer holes are about the diameter of small lead shot and are often filled with gummy exudates. They are not serious enemies of healthy trees, but occasionally they may be found infesting broken, dead or dying branches. A weakened tree with a serious infestation may die.

Habitat: These beetles are common and widely distributed. They attack apple, cherry, plum, and other fruit trees.

Control: Healthy, vigorous, well-cared-for trees are less subject to be attacked by shothole borers. Removal and burning of infested or diseased branches or trees during the winter period destroy the insects while still in their burrows. This helps prevent the increase of beetles to the point where they might attack healthy wood.

Spider mites - (McDaniel mite, Twospotted Spider mite, European Red mite, and others)

See previous section (alfalfa hay, page 101) for description.

Western Cherry Fruit Fly - *Rhagoletis indifferens*

Life cycle: The winter is passed in a brown, capsule-like puparia in the soil. The adult cherry fruit flies emerge from the soil about the middle of May to the middle of July and are active 3 to 4 weeks. They fly to cherry trees exuding juices where the females feed on the leaves and fruits. Mating then takes place and eggs will be deposited over a period of about 25 days during which she lays 50 to 200 eggs These are inserted through small slits cut with the ovipositor into the flesh of the fruit. The adult is a little smaller than the housefly and is a general black color with white bands on the abdomen. The wings are transparent with distinct dark bands. It can be distinguished from other fruit flies by this pattern. Eggs will hatch in 5 to 8 days after they are deposited. The young larvae burrow directly into the surface of the cherry seed. They pass through 3 instars over 10 to 12 days. The last instar, forms one or two breathing holes to the surface of the fruit and about 3 days later emerges and drops to the ground where it seeks a pupation site in the upper 3 inches of the soil. About 1% of the flies may emerge in August or September as a second generation, but the remainder overwinter as the pupa.

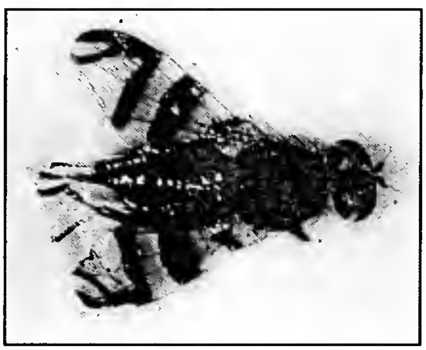
Damage: The maggots will cause cherries to become somewhat misshaped and undersized; they may turn red ahead of the main crop, often with one side of the fruit partly decayed and shrunken or wrinkled and closely attached to the pit.

Habitat: The cherry fruit fly attacks all varieties of cultivated and wild cherries.

Control: The western cherry fruit fly may be controlled by spraying the fruit at the time the first adults are captured in pheromone traps. A single adult catch is the threshold. Two or three applications of insecticide is usually required at 10-day intervals starting just after the blossom buds open. These applications protect the fruit by killing the adult flies. Cull cherries around canneries and picking stands should be destroyed by heat or buried.

The cherry fruit fly is attacked by several parasitic wasps. Parasitism may reach 50% of the flies breeding in the native wild cherries, but is less than 3% in cultivated cherries where the larvae are much better protected.

A post-harvest control should be considered for late emerging flies from the cherries left on the trees. These should be treated to prevent the flies from completing their life cycle and reduce problems for next season.



Adult western cherry fruit fly

NOTES

Garden symphylan - *Scutigerella immaculata*

Life cycle: Symphylans are not insects. Mature symphylan are 3 to 6 mm long, white, with prominent antennae, 12 pair of legs, and 15 body segments. This pest spends its entire life cycle in the soil. Symphylans can be distinguished from centipedes by their rapid movement, vibrating antennae, and a pair of spinnerets on the posterior end of its body. Symphylans are long lived and some have survived up to 5 years.

Symphylans reproduce from eggs which are deposited in clusters in the soil. The newly hatched nymphs have 6 pairs of legs. They shortly molt into a second instar with 7 pair of legs. An additional pair of legs is added with each new molt until all the legs are added (12 pair). Symphylans continue to molt their entire live (up to 52 times). Eggs, nymphs, and adults can be found at any time of the year. The majority of the eggs are found in early spring and fall. The nymphs and adults become active in the spring within the upper 6 inches of the soil. In the fall and winter they dig deeper into the soil. It takes 3 months to develop from egg to adult. There is at least one generation per year that overlaps with other generations.

Damage: Symphylans are general feeders that attack germinating seeds, plant roots, and the above ground plant parts in contact with the soil. Surviving plants are stunted and produce poorly in yield and quality.

Habitat: Symphylans are found in high organic soils. They attack all field crops and are found in home gardens.

Adult garden symphylan

Control: The best time of the year to sample for symphylans is from March through September. However, to properly control them with an insecticide, you must apply it prior to spring regrowth. Take a shovel full of soil to a depth of 10 inches from different sites in the field (one site per 1 1/2 acres). Count the number of symphylans per sample and calculate an average number per sample. If an average of 4 to 5 symphylans are found per sample, control may be required depending on the vigor of the stand.

If chemical treatment is justified, the material should be incorporated into the soil by irrigation. If possible, identify areas in the field where the population is concentrated and treat only those areas. Symphylans prefer heavier soils to sandy soils and often infest ridges or high areas avoiding low spots where water concentrates. Soil fumigation may be needed in extreme cases. Soil tillage helps to reduce numbers by disrupting symphlar activity.

Grassoppers

See previous section (alfalfa hay, page 100) for description.

Loopers - *Autographa californica*

See previous section (alfalfa hay, page 96) for description.

Mint flea beetle - *Longitarsus waterhousei*

See previous section (canola, pages 104-105) for description.

Mint root borer - *Fumibotys fumalis*

Life cycle: Mint root borers overwinter as a mature larvae in an earthen cell in the soil. In early spring, the mature larvae pupate and adults emerge in June and July. This emergence continues throughout the summer until early August. The female moths deposit their eggs that look like small scales on the leaf veins on both sides of the leaf. The female moths can lay from 100 to 200 eggs each. The eggs will hatch in 5 to 10 days when the newly hatched larvae feed on the leaf surface for 1 to 2 days. These larvae then drop to the soil and tunnel into the rhizomes at the bases of buds. The larvae will feed for 70 to 80 days until early October. The larvae then emerge from the rhizomes and construct an earthen cell where they overwinter. There is one generation per year.

Damage: Mint root borer larvae cause damage by feeding inside peppermint and spearmint rhizomes during the summer months. Feeding damage weakens mint stands which overwinter poorly and regrow slowly in the spring. Adults will be active in the summer. When disturbed, adults fly a few feet and land on the underside of a mint leaf.


Mint root borer larva

Habitat: The mint root borer is a pest of peppermint and spearmint fields.

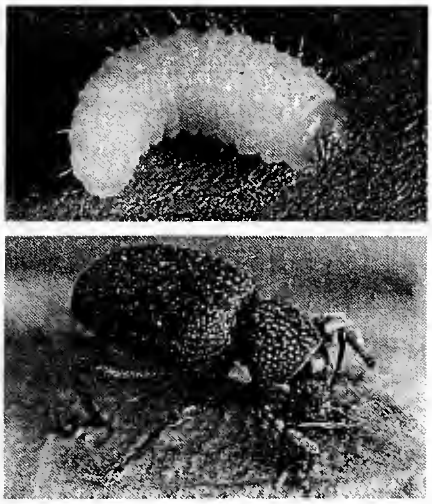
Control: To monitor for mint root borer adults, pheromone traps should be placed at 2 traps per field. For larvae sampling, one square foot per every 2 to 3 acres should be done. Collect moths by sweeping foliage, then shaking net contents to the bottom and slapping lightly against a hard surface. Empty net contents onto a light background. The presence of adults in a field should serve as a signal to take postharvest soil samples for larvae in the fall. Treatment is justified if an average of 2 to 3 larvae are found per square foot sample. Chemical control should be applied after harvest. Only soil treatments are effective and must be irrigated into the soil. This requires at least 1 inch of water. Treat only the acreage that can be irrigated immediately. Chemigation of an insecticide as a postharvest application is also effective. A minimum of 1/4 inch of water to pre-wet the soil surface prior to chemigation is recommended.

Tillage, after harvest, has been shown to significantly reduce mint root borer populations. In sprinkler-irrigated fields, plowing and double discing mint fields in late October, early November or in the spring may provide 80% or more control. Tillage may spread verticillium wilt; growers should use this practice only in fields with a low incidence of verticillium wilt.

A parasitic nematode, *Steinernema carpocapsae*, is also approved for use on mint to control mint root borer larvae.

Strawberry root weevil - *Otiorhynchus ovatus*

Life cycle: The larvae are white with tan colored heads and have no legs. The adults are black weevils about 1/4 to 1/2 inch in length and have a long snout with its mouth parts at the end. The strawberry root weevil mainly overwinters in the soil as larvae, but a few adults will also overwinter in protected areas along the field margins. These overwintering adult females will start depositing eggs soon after emerging in the fields. The overwintering larvae will pupate in the spring (April/May) in the soil. The new adults emerge in mid-May to early June. All of these adults are



Strawberry root weevil larva (top) and adult

female. They begin to depost their eggs in about 2 weeks around the bases of the plants. There is one generation per year.

Damage: The larval stage of this insect causes damage to mint by feeding on the roots.

Habitat: The strawberry root weevil feeds on many different crop roots including mint, strawberry, blueberry, and others.

Control: Sampling for this pest is generally done in late August and September or the following spring in March, April, or early May. Take at least 25 soil samples from different areas of the field (one site per 2 1/2 acres), screen the soil, count the number of larvae and calculate the average number per sample. If the average number of root weevil larvae exceeds 2 per sample, treatment of adults is recommended.

When sampling for adults, one should use a sweep net in the evening a couple of hours after sunset. Still, warm and dry evenings are the best. Windy, cool and/or rainy periods produce fewer weevils per sweep, giving the impression of a smaller field population than is actually present. Take 10 sweep samples in at least 5 different sites in fields up to 30 acres. Add one additional sample site for each additional 10 acres.

There is not a treatment threshold for adult weevils, but once an infestation becomes established in a field, it can be difficult to control. An evening insecticide application against adults may be justified even if the population is at a relatively low level. Ideally, this measure is timed after 90 to 100 percent of the adults have emerged and prior to egg laying in June or early July. Weevils will not have mature eggs in their bodies until about 2 weeks after emergence. If one sprays too late, egg laying will have already occurred. Two applications may be necessary in some cases.

A parasitic nematode is labeled for control of strawberry root weevil larvae in mint. For best results, applications should be injected through sprinkler irrigation after harvest in the evening or at night at a rate of 3.0 billion juvenile nematodes per acre. This application can control both strawberry root weevil larvae and mint root borer larvae.

Two-spotted spider mite - *Tetranchus urticae*

Life cycle: *See previous section (alfalfa hay, page 101) for description.*

Damage: Feeding from these mites may cause a speckled appearance on the mint leaves. The leaves may turn brown or bronze and drop from the plant mid to late season. The undersurface of such leaves look as though they had been very lightly dusted with fine white powder. When examined under a lens, the fine white specks are empty wrinkled skins and minute spherical eggs and are suspended on almost invisible strands of silk. On the strands of silk, and beneath it on the surface of the leaf, mites of several sizes, up to about 0.4 mm long can be found. These mites live on the sap of the plant, which is drawn by piercing the leaf with two sharp slender lances attached to the mouth. Feeding injury caused by densities greater than five mites per leaf increases water stress, reduces photosynthesis, and alters plant metabolism to negatively influence mint oil quality. Spider mite populations can increase rapidly during hot, dry weather and even after an insecticide application. Fields should be inspected twice weekly during these times.

Habitat: *See previous section (alfalfa hay, page 101) for description.*

Control: Correct sampling procedures for spider mites involve close observation of leaf samples taken from different areas in a field. The use of a 15 power hand lens will enable growers to distinguish between spider mites and predator mites. By walking in a "Z" or "M" pattern in the field, randomly collect stems and inspect the leaves from the bottom, middle, and top of the stems for mites (count adults, nymphs, and eggs). Classify the leaves as "infested" if the mites (adults and nymphs) number five or more.

For each 30 acres, 15 individual field sites should be monitored for mites by examining a total of 45 leaves (15 leaves each from the bottom, middle, and top) from 15 randomly selected mint stems per site. It also is important to count the number of predator mites on each leaf. These natural predator mites help reduce spider mite populations below economic levels through harvest. If predator mites are present, the field may not require immediate treatment and should be rechecked at a later date. Treatment of spider mites is justified if there are no predator mites and if 18 or more of the leaves in the 45-leaf sample taken at each site are infested with 5 or more spider mites. It is also important to estimate the number of spider mite eggs on the leaves, because their numbers will help predict an emerging infestation.

Variegated cutworm - *Peridroma saucia*

See previous section (alfalfa hay, pages 99-100) for description.

Wireworms - *Limonius spp.*

See previous section (corn, page 109) for descrpition.

NOTES

Potatoes

Blister beetles - *Epicauta spp.*

See previous section (alfalfa hay, pages 98-99) for description.

Colorado potato beetle - *Leptinotarsa decemlineata*

Life cycle: Adult Colorado potato beetles are oval, strongly convex beetles with hard wing covers marked with black and yellow stripes running lengthwise along their back. They are about 12 mm long and 6 mm wide. The larvae are dark red when young, but become orange as they near maturity. They have two conspicuous rows of black spots along the sides of the body and are about the same size as the adults. The Colorado potato beetle overwinters as an adult in the soil (25 to 30 cm deep) and emerges in late April and May to lay eggs. Adults lay orange-yellow eggs in masses of 10 to 30 on the underside of the leaves. Eggs hatch in 7 to 10 days and the larvae begin feeding on the underside of the leaves. Larvae mature in 2 to 3 weeks, drop to the soil and enter cracks to pupate. Adults emerge in 5 to 10 days, mate, and deposit eggs as before. In Montana, the beetle usually has one generation per year. On some occasions, especially if the first generation develops on volunteer potatoes, two generations may occur.

Adult Colorado potato beetle with eggs

Damage: The Colorado potato beetle is one of the most widespread and destructive potato insects in the United States. Adults and larvae feed on the foliage and will consume nearly all the leaves in heavy infestations. This pest also spreads several potato diseases, including brown rot, spindle tuber, and bacterial ring rot.

Colorado potato beetle larvae

Habitat: Colorado potato beetles are found in and around potato fields and where volunteer potatoes are found. The Colorado potato beetle can also be found feeding on tomatoes and egg plants. They can also be found in mountain meadows feeding on wild members of the night shade family.

Control: Most insecticides used to control other potato pests feeding on the foliage may also control the Colorado potato beetle. Insecticides applied early in the spring will reduce damage caused by larvae of the first generation. If properly timed, treatment will substantially reduce the likelihood of a heavy infestation during a second generation. Observations of other solanaceous plants, such as black nightshade may be useful to detect larvae and adults in the field or around the field margins.

Infestations should be treated at about 10% defoliation. Potatoes can tolerate about 20 - 25% defoliation before yields will be affected. The pest has developed resistance to all classes of insecticides and control may be difficult. There is one native species of tachinid fly and at least 3 kinds of predacious bugs that attack adults or prey on the larvae.

Cutworms, armyworms, and loopers

See previous sections (alfalfa hay, pages 96, 98, 99, and 100) for description.

Flea beetles - (including tuber flea beetle *Epitrix tuberis* and western potato flea beetle *Expitrix subcriniita*)

See previous section (canola, pages 104-105) for description.

Green peach aphid - *Myzus persicae*, Foxglove aphid - *Acyrthosiphon solani*, Potato aphid - *Macrosiphum euphorbiae*

See previous section (alfalfa hay, pages 97-98) for description. The green peach aphid is the major vector of potato leafroll virus (PLRV).

Potato leafhoppers - *Empoasca filamenta*

Life cycle: The potato leafhopper is not commonly reported in Montana, but is found annually in North Dakota. Certain weather conditions could conceivably blow it into Montana. The adults and nymphs are both green in color. There are a series of 6 white spots on the pronotum. Potato leafhoppers are very active. The nymphs will quickly run sideways to the other side of the leaf if disturbed.

Adult potato leafhopper

Damage: Both the adults and the numphs feed on the underside of the potato leaves causing a stippling or speckling of the leaf surface called "hopper burn". The edges of the leaves curl down ward, first turning lighter green, then yellow, and finally brown and necrotic.

Habitat: Host plants for the potato leafhopper include potatoes, tomatoes, apple, and members of the night shade family.

Control: The economic threshold for potato leafhoppers is 1 or more adults per sweep and 10 or more nymphs per 100 leaves.

Western spotted cucumber beetle - *Diabrotica undecimpunctata*

Life cycle: Adult western spotted cucumber beetles are 6 mm long, yellowish-green and have 12 distinct black spots on 1/4 inch long wing covers. This is a subspecies of the southern corn rootworm which is a serious pest of corn in the central United States. Mature larvae of the beetle are 14 to 17 mm long. They are yellowish, except the head and last abdominal segment, which are brown. This beetle overwinters as a fertilized female. Adults are active during mild periods in the winter, but do not lay eggs until early spring. Eggs are deposited in the soil around the bases of potato plants. The eggs hatch in 7 to 10 days and larvae feed in roots for about three weeks before pupating in the soil. Adults emerge in two weeks and begin feeding on pollen. There is one generation per year in Montana.

Adult western spotted cucumber bettle

Damage: The larvae of this pest feed on the roots of corn, beans, potatoes, immature cole crops, and some other vegetable crops. Adults feed on corn silk, pollen, bean blossoms, and pollen of cucurbits.

Habitat: The spotted cucumber beetle is found in meadows, wastelands, field crops, and gardens. They feed on a wide variety of crops including cucumbers, melons, corn, potatoes, and beans.

Control: Elimination of weedy areas around the field can help reduce the number of overwintering sites for adults, although adults can readily disperse into adjoining fields in the spring. Insecticides are the most common method of preventing damage by this pest.

Wireworms - including *Limonius* spp.

See previous section (corn, page 109) for description.

NOTES ✍

Small Grains

Cereal leaf beetle - *Oulema milanopus*

Life cycle: The adult cereal leaf beetle overwinters in small grain stubble and becomes active by April to mid-May. The females oviposit singly, 12 to 50 very small (1 mm) eggs near the midrib on the inner side of winter wheat and late spring grains. The eggs will hatch in 10 to 13 days to form wrinkled, hairy, humped back, yellowish larvae with dark brown legs and head that are usually covered with a glob of excrement (fecal matter). In about 2 weeks, larvae pupate in earthen cells in the top 2 inches of soil and emerge after 17 to 25 days as metallic, blue-black beetles about 1/6 inch long with a red thorax and red legs. This entire life cycle takes 45 to 47 days and the newly emerged beetles feed on grasses for a few days and enter summer diapause until fall when they hibernate under crop refuse in September and October. There is one generation per year.

Cereal leaf beetle adult (left) and larva

Damage: Adults and larvae feed on young leaves of grain crops, the adults feed primarily on shoots causing small slits and the larvae feed on tissue between the leaf veins causing a windowing affect. Barley, oats, wheat, rye, corn, timothy, and other grasses are preferred in that order. In severe infestations, 20 to 50% of the crop is destroyed.

Habitat: The cereal leaf beetle can be found in small grain fields or grassy field margins.

Control: Monitor the eggs and larvae to determine the thresholds. Examine 10 plants per location with one location for every 10 acres. Count the number of eggs and larvae per plant and determine the average. There are different thresholds based on the growth stage of the plant. For smaller plants (pre-boot) 3 eggs and/or larvae is the threshold. One larva per flag leaf in larger plants is the threshold.

There are several biocontrol agents currently used to help reduce the cereal leaf beetle population. *Anaphes flavipes* is a small wasp which is an egg parasite and lays its eggs in the cereal leaf beetle eggs. *Tetrastichus julis* attacks the larvae of the cereal leaf beetle by laying its eggs directly into the cereal leaf beetle larvae. Both these parasites are available in Montana.

Grasshoppers

See previous section (alfalfa hay, page 100) for description.

Cutworms and armyworms

See previous section (alfalfa hay, pages 98, 99, and 100) for description.

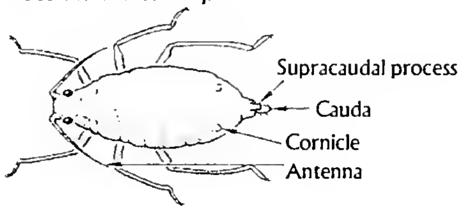
Russian wheat aphid - *Diuraphis noxice*

Life cycle: The Russian wheat aphid is light green, elongated and spindle-shaped and the antennae are very short. It has a wart-like projection above the tail that gives it a two-tailed appearance (see Figure A-1, page 121). The dorsal tubes (cornicles) are present, but they are very short and not obvious. The aphids appear on plants in the spring in colonies. As the crops mature aphid populations increase. In June, colonies consist of adult parthenogenetic, wingless females that live from 12 to 16 days. There are several generations per year.

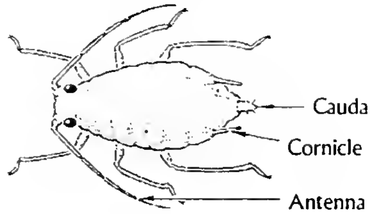
Damage: Russian wheat aphid damage to grain is easy to recognize. The aphids secrete a toxin that causes leaf rolling and white (warm weather) or purple (cool weather) streaking on the leaves. Heavily infested plants are severely stunted and sometimes flattened. Heads of infested plants may become twisted and distorted and sometimes fail to emerge properly. Sometimes a large colony inside the flat leaf sheath can kill the head while leaving the rest of the tiller green. Damage in the field will first appear as patches of stunted or discolored plants which resemble drought-stressed areas. Whole fields can be lost if infestations are not detected and controlled early. The Russian wheat aphid is a vector of barley yellow dwarf virous.

Figure A-1

Russian Wheat Aphid



Other Grain Aphid



Habitat: Barley and wheat are the most important host of the Russian wheat aphid. It is also found on oats, rice, corn, sorghum, brome, wheat grass and other native grasses.

Control: Early detection is difficult because the pest tends to hide in the plant. Colonies are most often found in tightly rolled leaves near the base of the leaf, in leaf whorls or concealed on the stem inside the flag leaf sheath. The easiest way to detect Russian wheat aphids is to look for the characteristic damage. Plants from several areas of the field should be thoroughly inspected for symptoms of aphid infestation. Mixed colonies of Russian wheat aphids and other species are common. The presence of detectable infestations varies from year to year and at different times. There are several natural enemies that are reared for release including lady bird beetles, predacious flies and parasitic wasps.

Adult Russian wheat aphid

Thrips - (including *Limothrips denticornis*)

See previous section (alfalfa seed, page 103) for description.

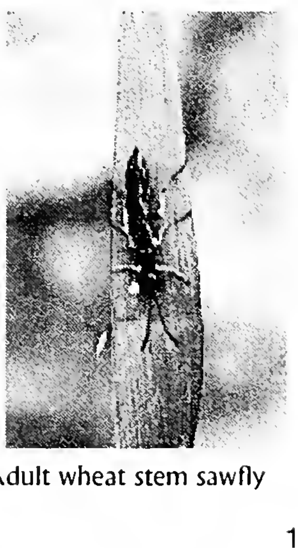
Wheat stem maggot - *Meromyza americana*

This insect is not a major pest in small grains in Montana. In most years a very small percentage of stems will be infested. Heads of the infested plants turn white "white top" and are easily pulled out of the tems. Crop rotation and removal of volunteer grain is helpful in lowering the population of the wheat stem maggot.

Wheat stem maggot larva

Wheat stem sawfly - *Cephus cinctus*

Life cycle: The adult insect is a small, slender-bodied sawfly of black and yellow color. The larva is a slender, yellowish, almost legless caterpillar-like worm that tunnels up and down inside the stems. This weakens the stem enough to reduce the yield of grain or cause loss by stalk breakage. Fully grown larvae attain a length of 10 mm. By late July, the larvae move to the base of the stems and gnaw a ring around each from the inside, weakening the straw which easily breaks off at ground level. Each infested stub is then plugged at the top with frass (insect feces) and lined with silk-like material forming a chamber in which the larvae overwinter. Late in May of the following year, pupation occurs, and adults begin emerging about June 10 and are present until about July 15. Egg-laying in the stems begin during this period with hatching taking place a few days after. This insect spends most of the year in the larval stage. Only one generation occurs annually.



Adult wheat stem sawfly

Damage: The damage most distinct is the cutting of the wheat stem by the adult sawfly laying her eggs. This causes the lodging and loss of grain in the wheat fields. The feeding of the larvae also causes damage to the conductive tissues of the plant by their feeding inside the stem.

Habitat: The wheat stem sawfly is found in wheat fields and where volunteer wheat is found. They are also found in grasses that serve as alternative hosts.

Control: Control may be obtained by plowing under the stubble in the fall and working the soil to prevent escape of the adults. Grasses that serve as alternate hosts should be destroyed where feasible. These include *Elymus condensatus*, *Elymus canadensis*, species of *Agropyron*, *Bromus inermis*, and timothy. Rotation of crops should also be of some value in checking the insect. Parasites that reduce the sawfly populations are *Bracon cephi*, *Bracon lissogaster*, and *Eupelmus allynii*. Planting the resistant spring wheat varieties Rescue and Chinook has resulted in economical production in spite of this pest. Other resistant varieties are Golden Ball and Stewart.

Wireworms

See previous section (corn, page 109) for description.

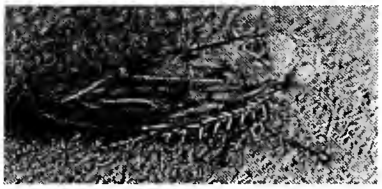
Sugarbeets

Beet leafhopper - *Circulifer tenellus*

Life cycle: The beet leafhopper is gray-green in color and about 3 mm long. They are also know by the common name of "white fly". This leafhopper will travel several hundred miles in the winds.

Damage: The direct feeding of the beet leafhopper is not of economic importance, but it is the vector of curly top virus in beans and sugarbeets. A single highly infected leafhopper can transmit the disease.

Habitat: The beet leafhopper overwinters on Russian thistle and other plants in weedy areas and rangeland. Host plants include, in addition to Russian thistle, tomato, lambsquarter, beans, melons, mustards, nightshade, and squash.



Adult beet leafhopper

Control: The best control for the beet leafhopper is cultural. There are several resistant varieties and planting as early as possible will help to withstand curly top virus. During hot, dry weather, frequent irrigation will help to keep high humidity in the plant canopy which repels the leafhoppers. Since the leafhoppers prefer the edges of the field, a perimeter application of an insecticide may work best. When scouting the field, the threshold to determine if an application is needed is 5 hoppers/10 sweeps. The beet leafhopper can become a problem in Montana after a prolonged period of hot, dry weather. Most years it is not a problem pest.

Cutworms - *Peridroma saucia* and *Euxoa ochrogaster*

See previous section (alfalfa hay, page 99) for description of life cycle, damage, and habitat.

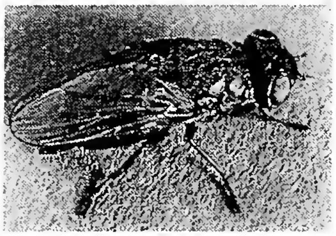
Control: Control of cutworms is advised when there is a 4 to 5% cutting of seedling beets.

Flea beetles

See previous section (canola, pages 104-105) for description.

Sugarbeet root maggot - *Tetanops myopaeformis*

Life cycle: The adult fly is about 6 mm long. It has a glossy, black body with clear wings that have a smoky color to the margins. The adult female has a very distinct ovipositor. The adults emerge from the soil in early June to early July and start laying eggs shortly thereafter. The female lays her eggs singly or in clusters of up to 40 eggs just below the soil surface in cracks close to the beet seedlings. The eggs hatch within 3 days and the larvae move down into the soil to feed on the taproot. The mature larvae (or maggots) are yellow-white and about 12 mm long. The body of the larvae tapper towards the head end. After feeding for about 2 months the mature larvae begin to burrow deeper into the soil where they overwinter. Then in the spring when temperatures increase the larvae move up towards the surface (about 7 cm below) and pupate. There is usually one generation per year, but two are not uncommon.



Adult sugarbeet root maggot

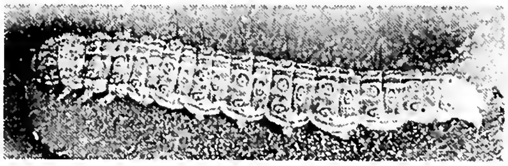
Damage: Wilted plants in June and July are a sign of root maggot damage. The sugarbeet root maggot may cause severe injury in some parts of individual fields, particularly in dry sandy soils. The maggots feed on the taproot of sugarbeets, sometimes cutting it off, resulting in death of the plant. Plants that survive produce small stubby roots with low sugar content.

Habitat: Where ever sugarbeets are grown throughout western United States and Canada.

Control: Where possible, irrigation may be used to keep the soil-moisture content up in order to force maggots to feed high enough to prevent injury to the taproot. The number of insects which justifies treatment is poorly defined. Seeding beets early in the spring when the danger of frost is over to obtain a strong stand, helps to combat this pest.

Sugarbeet webworm - *Loxostege sticticalis*

Life cycle: The sugarbeet webworm overwinters as larvae in the soil and then pupates in the spring. The adults first appear in late May and early June. These adults are smoky colored, about 12 mm long, and are nocturnal. During the day these moths hide in the beet foliage and are readily observed when the foliage is disturbed. The larvae are olive green, 25 mm long, with a black strip down the middle of its back and wavy white lines on each side and black and white tubercles. There are two generations per year. The first is in June and the second generation is in August.



Sugarbeet webworm larva

Damage: The webworm larvae feed on the beet foliage, skeletonizing the leaves and are protected by the webbing that they spin. In heavy infestations total sugarbeet defoliation can occur. Hot weather will increase the larvae's food intake and can contribute to a rapid rise in webworm populations.

Habitat: Host plants include sugarbeets, carrots, cabbage, beans, and potatoes.

Control: If 50% of the leaves have eggs on them or if 1 or 2 larvae are found, an insecticide application is warranted. This insect is not usually a major pest in Montana.

Other Sugarbeet Pests

Sugarbeet root aphid

Contact your local Montana State University (MSU) Extension Agent or the Montana Department of Agriculture for more information.

Wireworms

See previous section (corn, page 109) for description.

APPENDIX B

Noxious Weeds in Montana

Control of perennial noxious weeds should be of concern to every landowner and land manager in Montana. An integrated weed management approach of good farming and ranch management practices; cultivation, mechanical, and cultural methods; biological control when available; and herbicides will continue to aid the control of noxious weeds. The pages that follow give a brief description of the most serious noxious weeds threatening Montana agriculture. For specific control information on all weeds refer to current Cooperative Extension publications. For color plates and a more complete description of these weeds refer to publications found in the References section of this manual. Noxious weeds are defined by rule in the County Noxious Control Act. The three categories in weed classification are defined as follows:

Montana County Noxious Weed Classification

Category 1

Category 1 noxious weeds are weeds that are currently established and generally widespread in many counties of the state. Management criteria includes awareness and education, containment and suppression of existing infestations and prevention of new infestations. These weeds are capable of rapid spread and render land unfit or greatly limit beneficial uses.

Category 2

Category 2 noxious weeds have recently been introduced into the state or are rapidly spreading from their current infestation sites. These weeds are capable of rapid spread and invasion of lands, rendering lands unfit for beneficial uses. Management criteria includes awareness and education, monitoring and containment of known infestations and eradication where possible.

Category 3

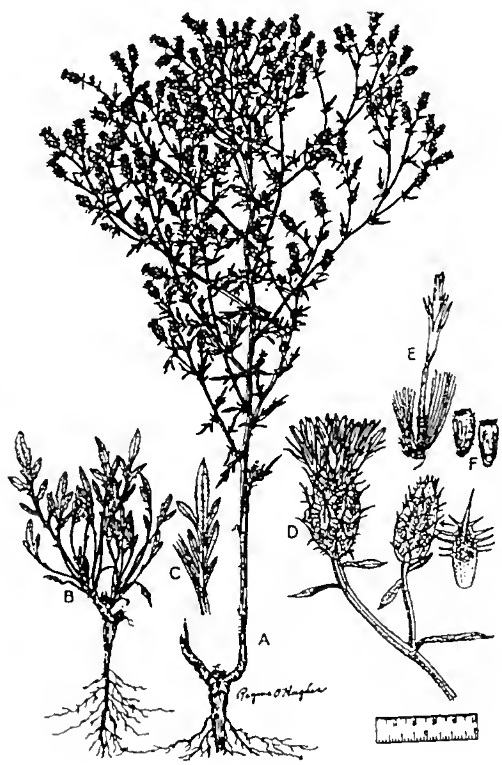
Category 3 noxious weeds have not been detected in the state or may be found only in small, scattered, localized infestations. Management criteria includes awareness and education, early detection and immediate action to eradicate infestations. These weeds are know pests in nearby states and are capable of rapid spread and render land unfit for beneficial uses.

SUNFLOWER FAMILY (*Asteraceae*)

Diffuse Knapweed (*Centaurea diffusa*) - **Category 1 Noxious Weed**

Diffuse knapweed is a biennial or short-lived perennial forb that grows to a height of 1 to 3 feet. It has a taproot and only one or very few stalks. The tip of each branch has a single flower head. The flowers are most commonly white with the upper portion of the bract narrowing to a distinct spine. Often the outer most flowers are sterile. The bracts are yellowish green with a light brown margin. Seeds are achenes, dark brown, 1 inch long, with faint pale brown or ivory lines.

Diffuse knapweed grows well in dry sites and is found on waste grounds, fields, and along roadways in many areas of western Montana. The most serious infestation is located near East Helena.



Diffuse Knapweed

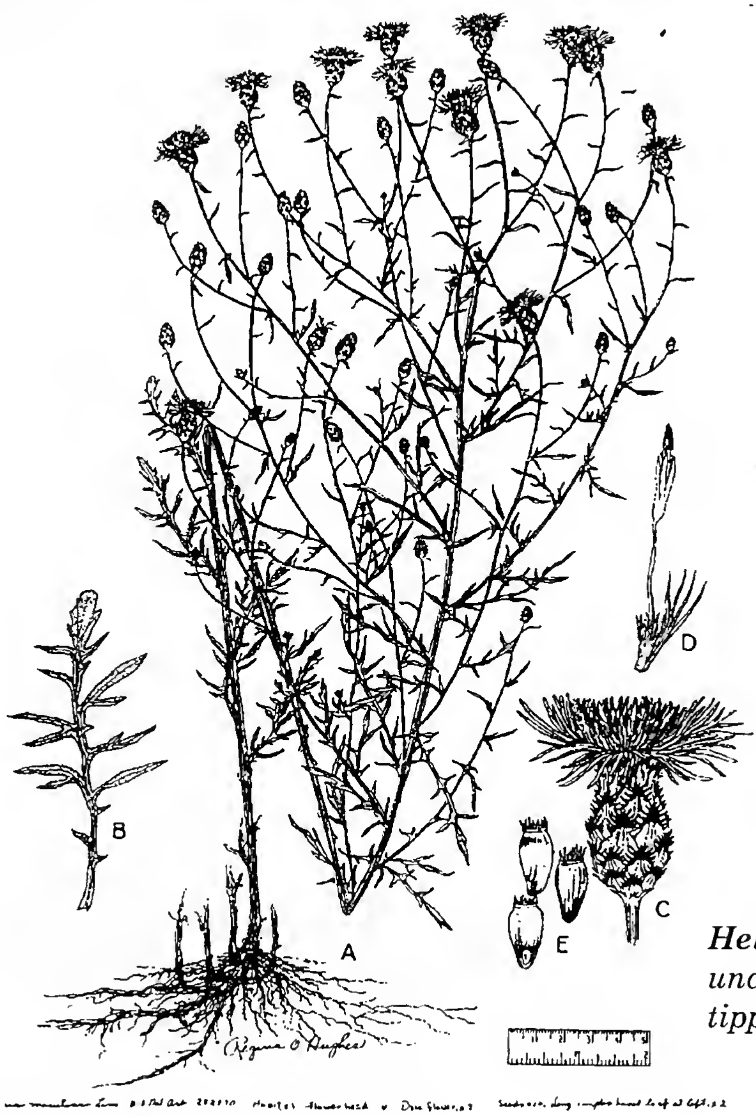
A. Plant Habit
B. Young Rosette
C. Leaf
D. Flower Head
E. Flower
F. Achenes

Helpful identification tip: *Bracts under the flower have yellow spines with teeth appearing as a comb along the spine margins.*

Spotted Knapweed (Centaurea maculosa) - **Category 1 Noxious Weed**

Spotted knapweed is a short-lived perennial reproducing primarily by seed. The stems are erect with slender, wiry branches, rough and hairy, and approximately 1 to 3 feet tall. Leaves are alternate with deep, narrow divisions and a rough, hairy surface. Flower heads are clustered and numerous at the top of the stems. Flowers range from pink to purple and the outer bracts are tipped with black, comb-like margins. Heads are 1/2 to 1 inch in diameter. The seed is an achene, brownish with one side notched near the base. There is a short tuft of bristles at the tip end and the seeds are approximately 2 mm long.

Spotted knapweed is introduced and naturalized from Europe. It is often found in dry gravelly or sandy pastures, old fields, and along roadsides. It readily invades pastures and can take over nearby range and pasture. Spotted knapweed is found in every county in Montana but the heaviest infestations are in the western part of the state.



Spotted Knapweed

A. Plant Habit
B. Enlarged Leaf
C. Flower Head
D. Disk Flower
E. Achenes

Helpful identification tip: *Bracts under the flowers have dark spots tipped with fringe.*

Russian Knapweed (Centaurea repens) - Category 1 Noxious Weed

Russian knapweed is a bushy, branched perennial plant reproducing by seed and underground rhizomes. The roots are characteristically black in color and have a scaly appearance. The stems are erect, 2 to 3 feet tall, branched at the base, ridged and have a dense gray hair-like covering. The basal leaves are hairy and the upper leaves are small and linear with smooth edges. The intermediate leaves have slightly toothed margins. The flowers are 1/2 inch wide, rose to purple composite heads and solitary on the ends of leafy branches. The seeds are grayish to yellow, smooth, flattened, oval, and about 1/8 of an inch long. The flowers generally bloom from June to August.

Russian knapweed was introduced from southern Russia and Asia. It grows in pastures, grain fields, cultivated fields, meadows, waste places, roadsides, and irrigation ditches. It is found throughout Montana. Once established it will completely crowd out other vegetation.

Russian Knapweed

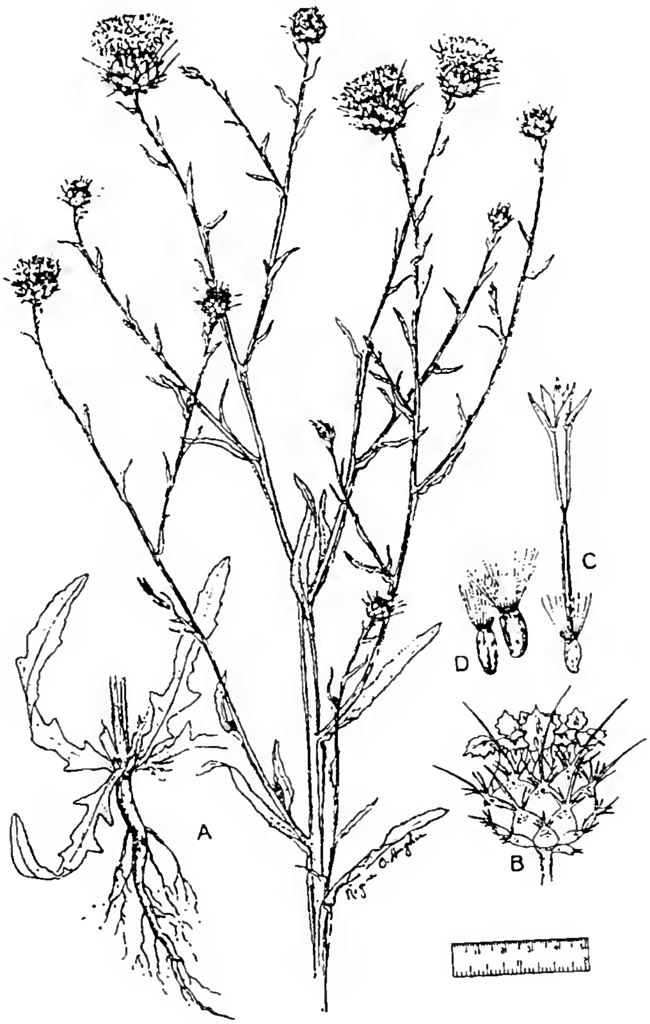
A. Plant Habit
B. Head
C. Bracts
D. Flower
E. Achene

Helpful identification tip: *Bracts under the flower are rounded with pointed papery tips.*

Yellow Starthistle (<u>Centaurea</u> <u>solstitialis</u>) - **Category 3 Noxious Weed**

Yellow starthistle is commonly a winter annual but it can germinate and grow to maturity in one season. The plant is gray green in color with cottony hair on the leaves and stems. It reaches a height of 1 to 3 feet, is branched, and has a yellow flower on the end of each branch. The leaves are narrow with the base of the leaf extending along the stem, giving them a winged or ridged appearance. The flower is bright yellow and has long sharp rigid spines as bracts below each flower. Two types of seeds are produced; light colored with bristly awns and dark with no bristles.

Yellow starthistle is found in cultivated and fallow fields, pastures, rangelands and waste places. It can invade range and pasture and competes well with existing vegetation. It crowds out existing grasses where moisture is limited and grasses are weakened from overgrazing. It produces a toxic chemical that can cause death in horses and the spines can cause serious injury to grazing animals. It has been reported in Montana in Ravalli, Lake, Gallatin, and Liberty counties. It is a serious problem in Idaho and Washington. It should be eradicated when found in Montana.



Yellow Starthistle

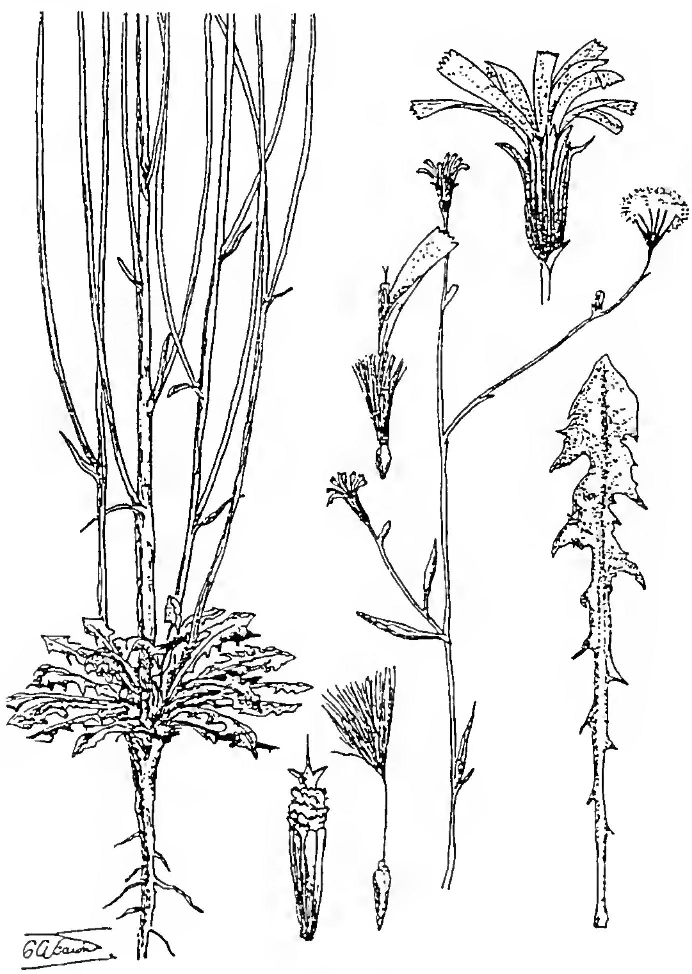
A. Plant Habit
B. Involucre
C. Flower
D. Achenes

Helpful identification tip:
Yellow spines up to 3/4 inch long extend from the involucre or seed case.

Rush Skeletonweed (Chondrilla juncea) - **Category 3 Noxious Weed**

Rush skeletonweed is a taprooted herbaceous perennial plant that overwinters as a compact rosette resembling an immature dandelion. The plant bolts in early spring and the flower stalk is 1 to 4 feet, nearly leafless with spreading side branches. Stem leaves are narrow and linear. The flowers are yellow, 3/4 of an inch in diameter, and composed of 7 to 15 individual florets. An individual plant may produce up to 20,000 seeds. Each seed is attached to a light pappus, similar to the dandelion. Seeds have no dormancy and remain viable for only 18 months under normal environmental conditions. Taproots may extend to soil depths of 7 feet and produce lateral roots which give rise to satellite plants. Cut plant surfaces exude a milky white latex sap.

Rush skeletonweed generally inhabits well-drained, light soils along roadsides, in rangelands, grain fields and pastures. Soil disturbance aids establishment. It presently infests several million acres of rangeland in Idaho, Oregon, Washington, and California. It can potentially become a problem in cropland areas with light textured soils. It has caused an estimated $30 million loss in Australian wheat producing areas. It is not currently found in Montana and detection and eradication programs should be initiated for the state. Cooperative detection programs have been developed for the Pacific Northwest.

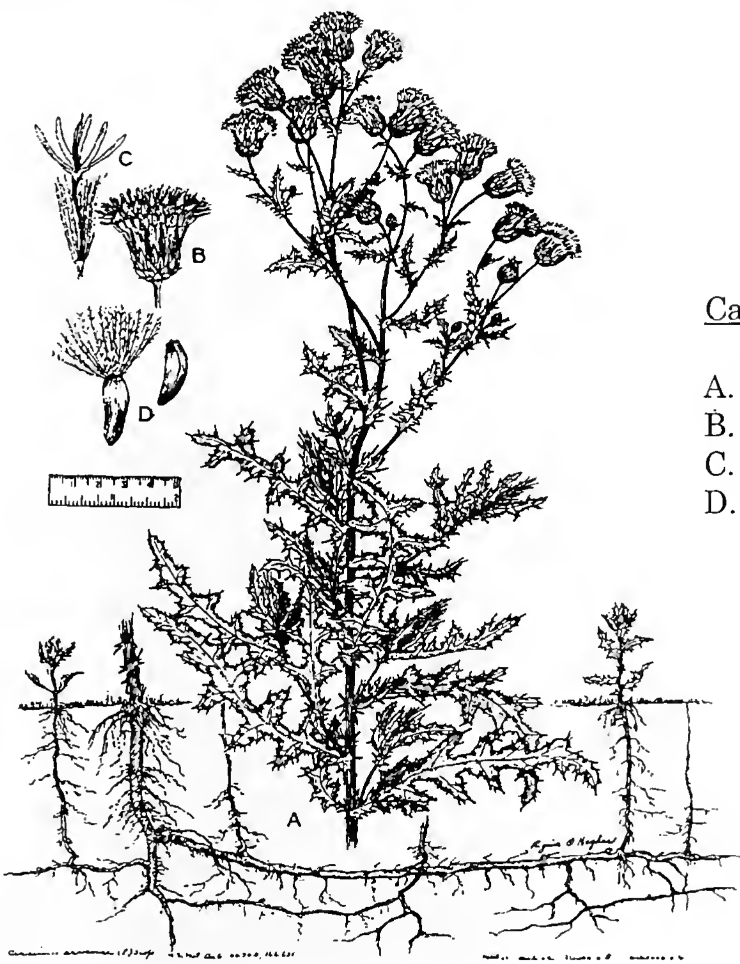


Helpful identification tip: *Yellow flowerheads, less than one inch wide, have strap-shaped petals that are flat across the end with distinct lobes or teeth.*

Canada Thistle (*Cirsium arvense*) - **Category 1 Noxious Weed**

Canada thistle is a perennial plant reproducing by creeping horizontal roots and by seed. The extensive roots are fleshy and send up frequent new shoots. The stems are erect, hollow, smooth or slightly hairy, up to 4 feet high and branched at the top. The plants are leafy but no wings or spines occur on the stem. The wavy leaves are oblong to lance shaped and vary from irregular and deeply cut, to spiny toothed on the margins, to almost smooth with few or no spines. The color is usually bright green but the upper surface varies from dark to light and the leaves are sometimes very light green and slightly hairy on the underside. The flowers are numerous, small, compact, and vary from light lavender or white to rose-purple. There are many flower heads clustered together on the ends of branches. Canada thistle flower heads often appear much smaller than most other thistles. The bract on the heads are not spiny. The plant is dioecious, with male and female flowers produced on separate plants. Seeds are oblong, flattened, curved, smooth, dark brown, and approximately 1/8 inch long.

Canada thistle is an introduced species from Eurasia and grows throughout the northern half of the United States and north into Canada from British Columbia to Quebec. It grows in all crops, pastures, meadows, and waste places in rich, heavy soils. Canada thistle is a serious threat to grain crops in Montana. Wheat yields have been reduced from 15 to 60% in infested areas.



Canada Thistle

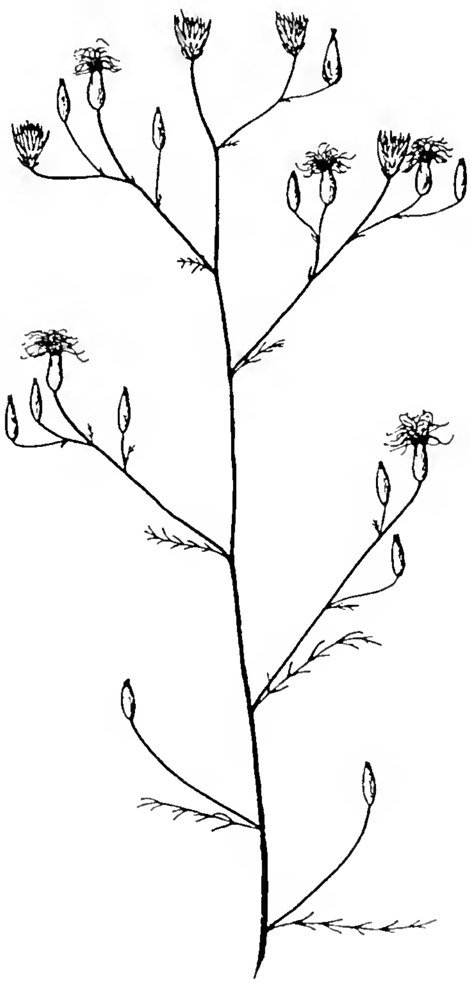
A. Plant Habit
B. Head
C. Flower
D. Achenes

Helpful identification tip:
Bracts under the flowers are spineless.

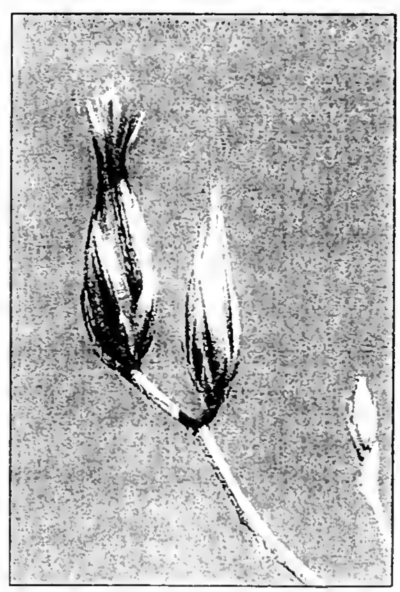
Common Crupina (Crupina vulgaris) - **Category 3 Noxious Weed**

Common crupina is a winter annual that reproduces by seed. It is closely related to the knapweed species. The cotyledon leaves are large, thick and dark green. They generally germinate in the fall when moisture is adequate and from a basal rosette. The true leaves are finely divided. A dense, fibrous root system develops quickly once the seedling is established. The plants overwinter as compact rosettes. In the spring the plant bolts and has a main flower stem from 1 to 4 feet tall. Leaves are alternate the length of the stem and are finely divided, lace-like leaflets. Stiff hairs on the leaf surface give them a sticky feel. Flowers are lavender to purple and are 1/2 inch long. Plants produce 5 to more than 100 flower heads. Each head produces 1 to 5 seeds. Seeds (achenes) are large, cylindrical, tapering slightly to a blunt end. They have a dark, stiff pappus at the basal end. Dense, fine hairs cover the seed, giving it a black to silver color.

Common crupina is generally found on well-drained, rocky to silt loam soil in pasture or rangeland. Infestations start in disturbed areas or sites with sparse vegetation. It is a recent introduction and is currently found on the federal noxious weed list. Current infestations are found only in Idaho and Washington. An effort must be made to keep this weed out of Montana.



Helpful identification tip: *Flower heads are narrow, cylindric and topped with pink, lavender or purple flowers.*

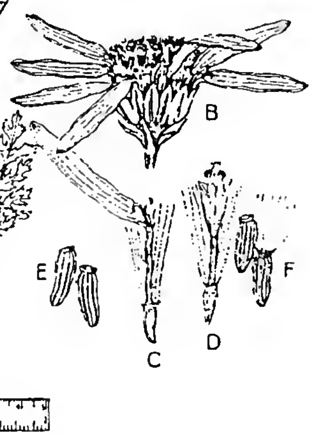


Tansy Ragwort (<u>Senecio jacobaea</u>) - **Category 2 Noxious Weed**

Tansy ragwort is a biennial or short-lived perennial plant. Most seeds germinate in the fall, form a rosette the following year and flower and set seed the next year. If the plant is cut, pulled or broken the second year this damage results in regrowth and blossoming during the third year. Tansy ragwort has daisy-like golden flowers with a long blossoming period. The rosettes have irregular, lobed leaves with a visible blade region near the tip. The stems are 1 to 6 feet high. The leaves, 5 to 9 inches long, are attached directly to the main stalk. Leaf color may vary from light to dark green. The plant spreads principally by seeds, and individual plants may have as many as 150,000 seeds.

Tansy ragwort is a native of Europe. It grows well in pastures and disturbed areas on a wide range of soil types. It can survive under most soil moisture conditions and does well through the Northwest area. Hot dry summer and very low (-20 degrees) winter temperatures do not adversely affect this plant. The plant is toxic to both cattle and horses, and to some extent sheep. Alkaloids found in all parts of the plant cause irreversible liver damage. This plant is currently one of the most serious weed problems in Oregon and is also found in Northern California, western Washington and British Columbia. It is found in limited areas of western Montana and detection and eradication programs are important to keep it from spreading.

Helpful identification tip: *Rosettes have leaves that are deeply lobed and the compound leaflets are also lobed.*



<u>Tansy Ragwort</u>

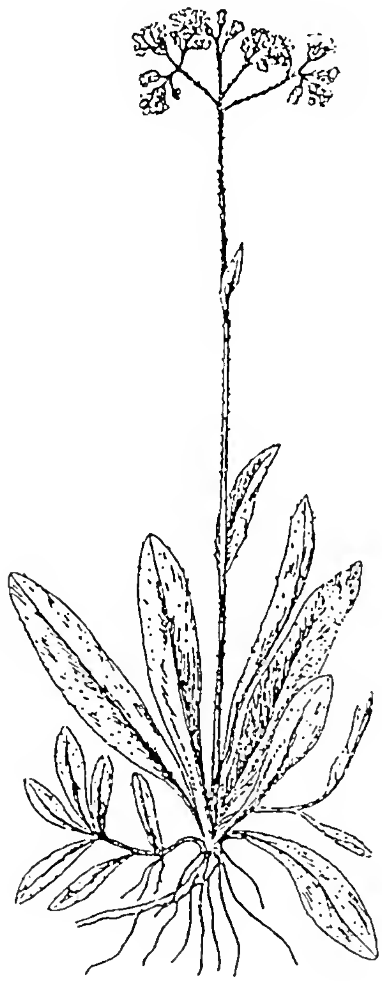
A. Plant Habit
B. Flower Head
C. Ray Flower
D. Disk Flower
E. Achenes (ray flower)
F. Achenes (disk flower)

Meadow Hawkweed Complex (<u>Hieracium pratense</u>, <u>H. floribundum</u>, <u>H. piloselloides</u>)
Category 2 Noxious Weed

Meadow hawkweeds are perennial weeds with shallow, fibrous roots. Leaves are hairy, up to 6 inches long, spatula shaped, and almost exclusively basal. Stolons are extensive, creating a dense mat of hawkweed plants that practically eliminates other vegetation. Stems are bristly and usually leafless, although occasionally a small leaf appears near the midpoint. Stems can reach a height of 3 feet and bear up to thirty, 1/2 inch, flower heads near the top. Flowers are yellow and appear in late May or June. Stems and leaves exude milky juice when broken. Seeds are black, tiny, and plumed.

Meadow hawkweed was introduced into the United States from Europe. Spread is aided by contaminated grass seed. It is an extremely agressive weed that invades and dominates hay fields, meadows, pastures, riparian areas, rights-of-way and similar sites. It is found widely in northwestern Montana.

Native hawkweeds differ from introduced hawkweeds because they lack stolons and have numerous upper stem leaves and a branched, open, flower arrangement.



Helpful identification tip:
Narrow, spatula-shaped leaves are 4 to 6 inches long, dark green above, and light green beneath.

Orange Hawkweed (<u>Hieracium aurantiacum</u>) - **Category 2 Noxious Weed**

Orange hawkweed is a perennial weed with shallow, fibrous roots. Leaves are hairy, spatula shaped, up to 5 inches long, and almost exclusively basal. Extensive stolons create a dense mat of hawkweed plants that practically eliminates other vegetation. Stems are usually leafless, although occasionally a small leaf appears near the midpoint. Stems may reach a height of 1 foot and bear up to thirty, 1/2 inch, flower heads near the top. Flowers are red to orange and appear in late May or June. Stems and leaves exude a milky latex when cut or broken. Seeds are tiny and plumed.

Orange hawkweed is native to Europe. It is common in the eastern United States, where it has become a troublesome weed. It invades meadows, pastures, roadsides, tree plantations, riparian areas, and urban sites. Orange hawkweed is widely distributed in northwestern Montana.

Native hawkweeds differ from introduced hawkweeds because they lack stolons and have numerous upper stem leaves and a branched, open, flower arrangement.

Helpful identification tip: *Shorter than meadow hawkweed, red to orange flowers, and spreads less rapidly than meadow hawkweed.*

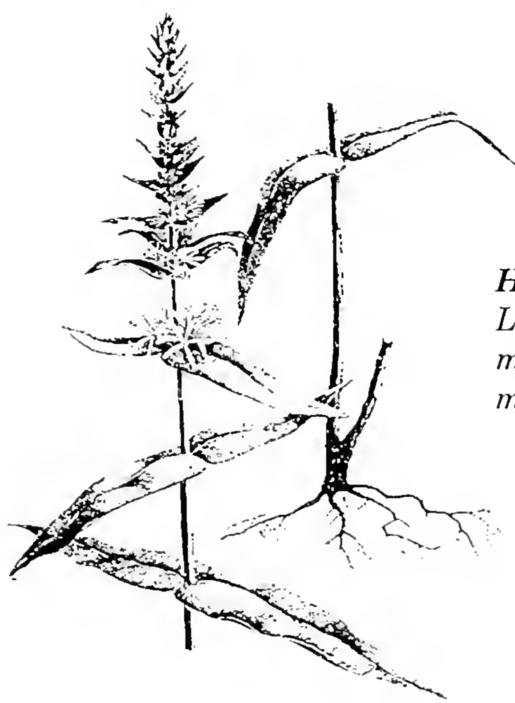
LOOSESTRIFE FAMILY (*Lythraceae*)

Purple Loosestrife (Lythrum salicaria, L. virgatum, and any hibrid crosses there of)

Category 2 Noxious Weed

Purple loosestrife is an exotic perennial plant that infests wetlands. The seed germinates in the spring and summer, although seedlings do not typically flower in their first season. In autumn, the stems die back and the plant remains dormant through the winter. The following spring, new stems form from root buds. Flowering starts in late June and continues into September. Rose-purple flowers with spike-like panicles are borne on upright 3- to 5-inch stalks. Single plants continue increasing in size with each subsequent year of growth. New shoots form at the base of the plant, resulting in dense stands. These dense clumps of semi-woody stalks resist decay, and overtime, debris becomes trapped between roots and stems, resulting in the elevation of the ground level. This eliminates water-dependent species such as cattail, rushes and sedges. The tall stalks create shade that is detrimental to the growth of wildlife foods such as pond weeds. In addition, the vigorous growth and extensive seed dispersal give purple loosestrife a significant competitive advantage over most native species.

Purple loosestrife, a native of Europe and Asia, was introduced into North America in the early 1800s. It has been found in flood plains, along drainage ditches and on marsh edges in several places in Montana. The most severe infestations are often found in areas where the natural vegetation has been disturbed or eliminated. This plant is a serious threat to wetlands.



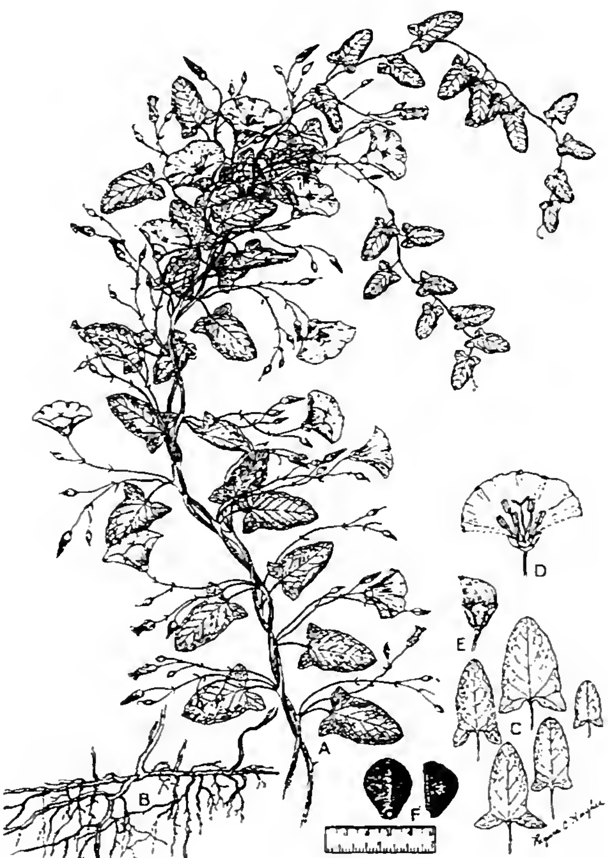
Helpful identification tip:
Lance-shaped leaves with smooth margins are arranged in whorls or may be opposite on the stem.

MORNINGGLORY FAMILY (Convolvulaceae)

Field Bindweed (Convolvulus arvensis) - **Category 1 Noxious Weed**

Field bindweed is a veiny, weak-stemmed, persistent perennial weed. It reproduces from an extensive root stock, rhizomes, and abundantly produced seeds. The plant forms a mat on the soil surface with prostrate stems 2 to 7 feet long that can climb short distances. The roots may extend 20 to 30 feet into the soil. The leaves are dull green and vary in size and shape, depending on soil fertility and moisture. Characteristically, they are ovate oblong with acute spreading basal lobes. The leaves have short leaf stalks that alternate on the stem. The plants flower from May to August and the flowers are white to light pink in color, funnel-shaped and borne on slender 1 to 2 inch stalks in the leaf axis. A pair of narrow, pointed leaflike structures (bracts) are found on the flower stalks 1/2 to 1 inch below the flower. The seed pod is round, pointed, light brown, and contains four seeds. The seeds are dark-brown with a roughened surface, three-angled, and 1/8 to 1/5 inch long.

This plant was introduced from Eurasia and is now found throughout the United States except in the extreme Southeast and a few areas in the Southwest. It grows well under most cultivated conditions as well as in all uncultivated and waste places. It is extremely difficult to eradicate due to it's low growth and widespread, deeply penetrating root system. It is a serious problem in cropland in Montana.



Field Bindweed

A. Plant Habit
B. Rootstock
C. Leaf Variation
D. Flower
E. Capsule
F. Seeds

Helpful identification tip: *Leaves of field bindweed are shaped like arrowheads.*

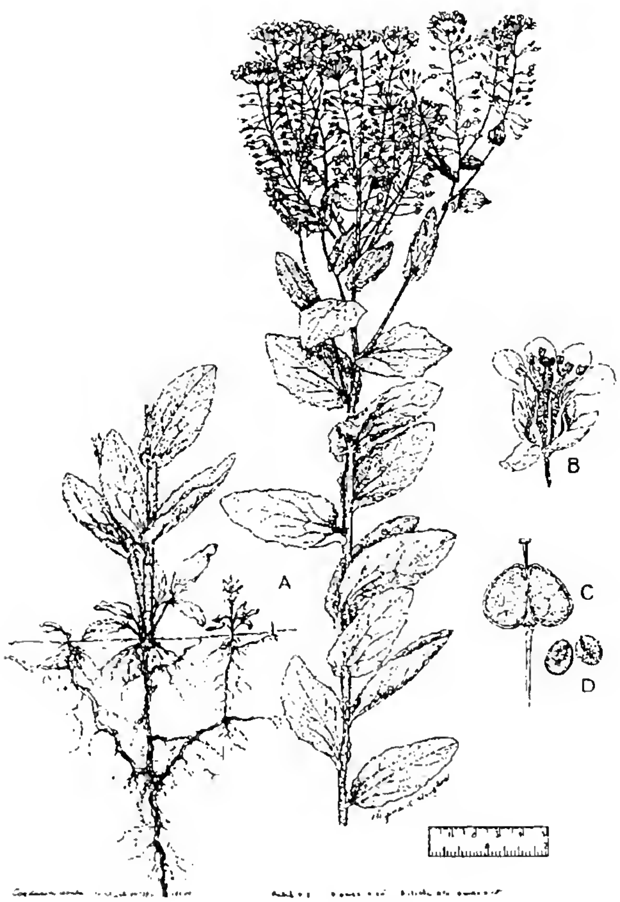
MUSTARD FAMILY (*Brassicaceae*)

Whitetop (*Cardaria draba*) - **Category 1 Noxious Weed**

Whitetop (hoary cress) is a perennial reproducing by seed and rhizomes. It has numerous erect stems 1 to 2 feet high that are branched at the top. An extensive root system spreads both horizontally and vertically with frequent shoots arising from the root stock. The plant seems to be gray green due to many fine hairs on the leaves. The leaves are simple, alternate, oblong, toothed and the upper leaves have a broad clasping base. The flowers are white, four parted, about 1/8 inch wide and borne in flat-topped clusters. Seed pods are slightly flattened, two-valved, heart-shaped with a prominent persisting style. The seeds are oval, slightly flattened, granular with reddish-brown seed coats.

Whitetop is naturalized from Europe and found throughout the United States except in the Southcentral area. It is found in pastures, cultivated fields, hay fields, meadows, waste places, and roadsides. It is most common in western and central Montana.

Helpful identificaiton tip:
Many white flowers with four petals develop into bladder-like seed capsules in mid-summer.



Whitetop

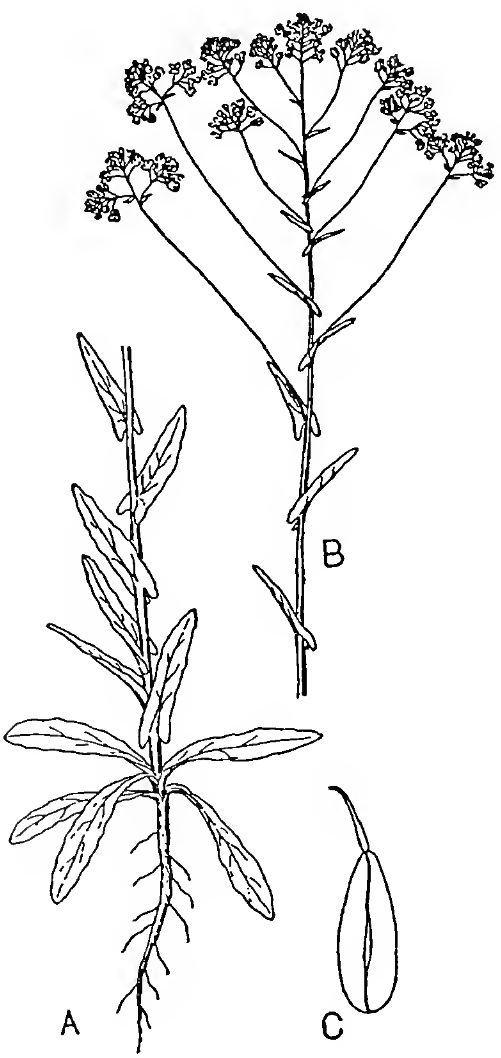
A. Plant Habit
B. Flower
C. Silicle
D. Seeds

Dyers Woad (*Isatis tinctoria*) - **Category 2 Noxious Weed**

Dyers woad is a perennial, biennial or annual forb reproducing by seeds and from roots. The plants may grow from 1 to 3 feet tall and have a smooth, bluish-green color. The lower leaves clasp the stem with ear-like projections. The yellow flowers are very small and form a flat-topped inflorescence. The seed pods are about 1/2 inch long, winged like a maple seed and turn black when mature.

Dyers woad is native to Europe. It's name comes from Germany where dye was extracted from the purplish black seed pods. It is a serious weed problem in both Utah and Idaho and can be found in several locations in Montana. It spreads readily by seed from roadsides to rangeland and crops. Detection and eradication is imperative for Montana.

Helpful identification tip:
Purplish-brown seed pods containing a single seed appear near mid-summer, giving this weed a totoally differnt appearance.



Dyers Woad

A. Plant Habit
B. Flower Head
C. Fruit

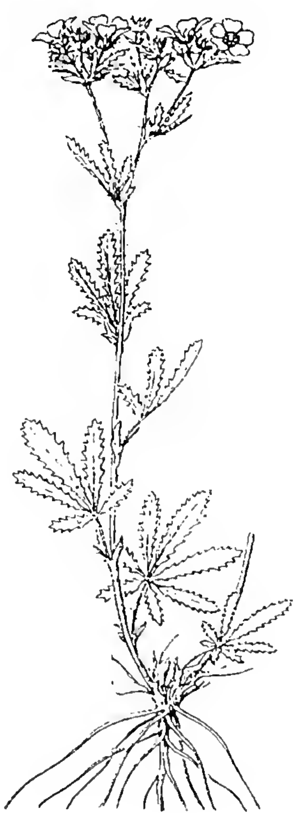
ROSE FAMILY (*Rosaceae*)

Sulfur Cinquefoil (*Potentilla recta*) - **Category 2 Noxious Weed**

Sulfur cinquefoil is a long-lived perennial forb that begins growth early in the spring. It reproduces by seed and can produce 1,650 seeds per year. Although it does not reproduce vegetatively, as old roots die in the center, new shoots grow from the edges and can form a ring-shaped clump of individual plants. Plants 20 to 30 years old have been reported in Michigan.

Sulfur cinquefoil produces one to several erect stems which vary from 12 to 28 inches in height. The compound leaves have five to seven leaflets arranged in a palmate pattern. Numerous leaves are attached along the length of the stem, but few of them grow from the base of the plant. The leaflets decrease in size, and the length of the leafstalks get shorter near the top of the stem. Uppermost leaves are attached directly to the stem. Stems and leafstalks are hairy.

This noxious weed is adapted to a wide range of environmental conditions. It grows in open grasslands, shrubby areas and open forest and logged areas, often in association with spotted knapweed. Disturbed sites such as roadsides, waste areas, logged areas and abandoned fields are easily invaded by sulfur cinquefoil. It is widely distributed in Montana.



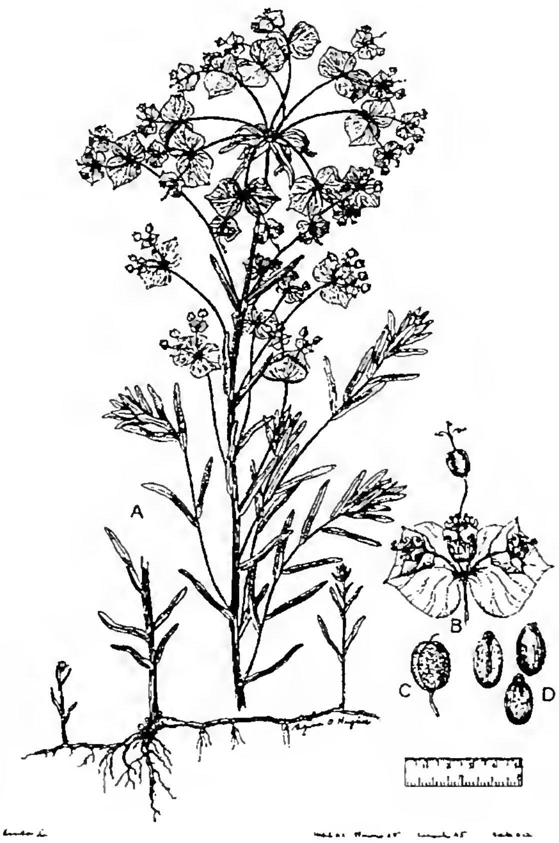
Helpful identification tips: *Long, right angled hairs on stem; many stem leaves, few basal leaves; net-like (reticulated) seed coat; and pale yellow flowers.*

SPURGE FAMILY (*Euphorbiaceae*)

Leafy Spurge (*Euphorbia esula*) - **Category 1 Noxious Weed**

Leafy spurge is a perennial, reproducing by seed as well as an extensive underground rhizome system. The heavy running roots are woody, persistent and widespread and give rise to dense colonies of the plant. Pink buds on creeping rhizomes give rise to roots and shoots every few inches. The stems are erect, smooth, and branched at the top. The entire plant is a dull green color with milky juice and grows about 2 feet tall. The leaves are alternate and irregularly spaced along the stem. There is a whorl of lance-shaped leaves at the base of the umbel. The flowers are inconspicuous and are formed above pairs of rounded floral bracts on repeated forking stems arranged in a flat-topped umbel. When in full bloom the entire umbel, including the bract, turns a bright greenish yellow. The seed pods are on a short stalk from the cup-like base and are three angled. There are three ovoid, smooth, light gray to brownish seeds in each pod.

Leafy spurge is an introduced plant from Europe. It is found in most of the northern United States and Canada. It grows readily in waste areas, pastures, roadsides, cultivated fields and sandy banks. It can be toxic to cattle, but sheep do well eating it. Leafy spurge is one of the most persistent noxious weeds in Montana. It is found throughout the state and has a wide habitat suitability, prolific reproduction capabilities, strong competitive ability and is difficult to control.



Leafy Spurge

A. Plant Habit
B. Flower Cluster
C. Capsule
D. Seeds

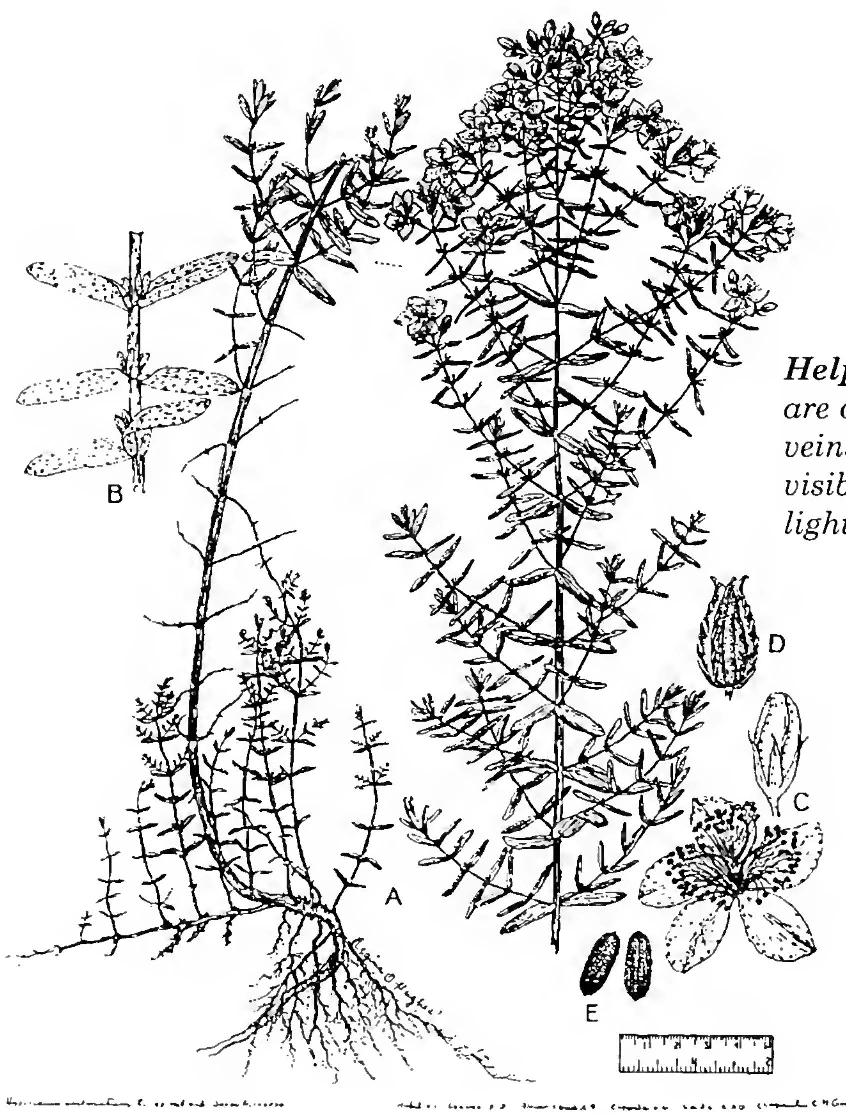
Helpful identification tip: *Heart-shaped yellow bracts surround the 3-celled seed capsule, each cell containing a single seed.*

ST. JOHNSWORT FAMILY (*Hypericaceae*)

St. Johnswort (<u>*Hypericum perforatum*</u>) - **Category 1 Noxious Weed**

St. Johnswort (goatweed) is a perennial forb reproducing by seed and from rootstock. Stems are smooth, branched, about 3 feet tall and woody at the base. The opposite leaves are elliptic to oblong and have small, glandular dots. The orange-yellow flowers are about 3/4 inch in diameter and five-petaled. The three-parted seed pods are round, pointed, and contain many seeds.

St. Johnswort is common in dry pastures, rangelands, and neglected fields and along roadsides in western Montana. It is not readily grazed by livestock and causes photosensitization in light skinned animals. It should be regarded as a poisonous plant. It is difficult to control.



Helpful identification tip: *Leaves are oval in shape with prominent veins. Tiny transparent dots are visible when leaves are held up to a light source.*

<u>St. Johnswort</u>

A. Plant Habit
B. Enlarged Leaves
C. Flower and Bud
D. Capsule
E. Seeds

SNAPDRAGON FAMILY (*Scrophulariaceae*)

Dalmatian Toadflax (Linaria dalmatica) - **Category 1 Noxious Weed**

Dalmatian toadflax is a perennial, reproducing by seeds and creeping rootstocks. The plants are erect, about 2 feet tall, pale green and have showy, yellow flowers. The spurred flowers are tinged with orange and are about 1 inch long. The leaves are broad, heart-shaped, and clasp the stem.

Dalmatian toadflax is a native of the Mediterranean region. It is found scattered throughout the northern and western United States. It is an escaped ornamental found along roadsides and near dwellings, spreading to valleys and sagebrush flats. Large infe

Helpful identification tip: *Early spring growth of this prolific perennial has waxy leaves with a blue-green color.*

Dalmation Toadflax

A. Plant Habit
B. Flower
C. Capsule
D. Seeds

APPENDIX C

Classification of Herbicides by Chemical Families and Mode of Action

Chemical Family	Common Name	Trade Name	Mode of Action
acetanilides	alachlor bensulide diphenamid pronamide propachlor prynachlor	Lasso Betasan, Prefar Dymid, Enide Kerb Ramrod Basamaize	Growth Inhibitors
alphatic carboxylic acids	dalapon TCA	Dowpon, Basfapon various	Metabolic Inhibitors
benzoic acids	chloramben dicamba 2,3,6-TBA	Amiben Banvel Trysben, Benzac	Growth Regulators
benzonitriles	dichlobenil bromoxynil	Casoron Brominil, Buctril	Photosynthetic Inhb.
bipyridiliums	diquat paraquat	Ortho Diquat Ortho Paraquat	Contact Herbicides
carbanilates	chloropropham barban phenmedipham	Chloro-IPC, Furloe Carbyne Betanal	Growth Inhibitors
dinitroanilines	benefin dinitramine fluchloralin nitralin proflurain trifuralin	Balan Cobex Basalin Planavin Tolban Treflan	Mitotic Poisons
diphenyl ethers	bifenox	Modown	Contact Herbicides

Chemical Family	Common Name	Trade Name	Mode of Action
imidazolinones	imazapyr imazathapyr	Arsenal Pursuit	Acetolactate synthase (ALS) Inhibitors
inorganic compounds	AMS boron coppersulfate sodium chlorate	Ammate Borax, Borascue Bluestone, Cutrine Atlacide, others	Contact Herbicides
organic arsenicals	DSMA MAA MSMA	various various various	Unclear
phenols	dinoseb	Premerge, Sinox	Contact Herbicides
phenoxy compunds acetic butyric propionic	 2,4-D MCPA 2,4,5-T 2,4-DB MCPB 2(2,4-DP) 2(MCPP) silvex (2,4,5-TP)	 various Methoxone, Weedar, Weedone various Butoxone, Butyrac Thistrol, Can-Trol Weedone several Kuron	Growth Regulators
phthalic acids	DCPA endothall naptalam	Dacthal Aquathol, Hydrathol Alanap	Metabolic Inhibitors
pyridines	picloram	Tordon	Growth Regulators
pyridazinones	pyrazon	Pyramin	Photosynthetic Inhibitors
substituted amino acids	glyphosate	Roundup Rodeo	Metabolic Inhibitors
sulfonylureas	chlorsulfuron metasulfuron methyl	Glean, Telar Ally, Escort	Acetolactate synthase (ALS) Inhibitors

Chemical Name	Common Name	Trade Name	Mode of Action
thiocarbamates	butylate CDEC cycloate diallate EPTC EPTC + antidote pebulate triallate vernolate	Sutan Vegedex Ro-Neet Avadex Eptam Eradicane Tillam Fargo Vernam	Growth Inhibitors
s-triazines	ametryn atrazine cyanazine cyprazine prometon simazine terbutryn	Evik AAtrex Bladex Outfox Pramitol Princep Igran	Photosynthetic Inhibitors
as-triazines (asymmetrical)	metribuzin	Sencor, Lexone	Photosynthetic Inhibitors
triazoles	amitrole	Weedazol, Amino-triazole, Prob	Chlorphyll Inhibitors
uracils	bromacil terbacil	Hyvar Sinbar	Photosynthetic Inhibitors
ureas	chloroxuron diuron fenuron linuron monuron siduron	Tenoran, Norex Karmex Dybar Lorox Telvar Tupersan	Photosynthetic Inhibitors

GLOSSARY

Abdomen - the third major division of the insect body, consisting primitively of eleven segments, but normally with 9 or 10 apparent segments and bearing no functional legs in the adult stage.

Abiotic - non-living; devoid of life.

Allelopathy - the release into the environment by an organism of a chemical substance that acts as a germination or growth inhibitor to another organism (see antibiosis).

Annual weed - a weed that completes its life cycle from seed to mature plant in less than one year. Examples: cheat grass, kochia, field pennycress.

Antibiosis - the release of a chemical substance by an organism which is unfavorable for the development or survival of another organism. Examples: plants inhibiting insect development; fungi inhibiting bacteria (see allelopathy).

Antixenosis - a condition in a plant which makes it unattractive to the insect for food, oviposition, shelter, or for combinations of all three.

Axil - the angle between a leaf and stem.

Bacilliform - the shape or form of a bacteria.

Bacteria - one-celled microorganisms found in all types of air, soil, and water and are common on or in all plants, animals, and humans. Examples - potato ring rot, bacterial wilt in alfalfa, bacterial canker.

Bacteriostat - prevents the growth of bacteria without killing them.

Basidium (basidia) - a club-shaped fungal structure or stalk bearing the sporidia.

Biennial weed - a weed that completes its life cycle from seed to mature plant in two growing seasons. Examples: burdock, common mullein, musk thistle.

Biotic - relating to living organisms.

Bt - *Bacillus thuringiensis*, a bacteria used as a microbial insect control agent.

Cambium layer - a layer of plant cells lying between the xylem and phloem.

Catalyst - used to accelerate a chemical or biochemical reaction. The catalyst is not affected by the overall reaction. Enzymes are naturally occurring catalysts.

Cell membrane - the sheet-like membrane that encloses and delimits the contents of a cell. A living structure that is selectively permeable, allowing free water passage but controlling other molecules.

Cell wall - a strong, rigid extra protoplasmic layer in plants whose growth is directed from within the cell.

Chemosterilants - chemicals that cause sterilization in the wild population of organisms by interfering with cell division.

Chitin - cuticle being insoluble in water, alcohol, ether and other solvents and resistant to acids and alkalis.

Chitinous - composed of chitin or like it in structure.

Chlorophyll - the green photosynthetic substance in plants which allows them to capture solar energy.

Chromosome - a DNA - protein thread usually associated with RNA, occurring in the nucleus of the cell; best seen during cell division.

Cotyledons - the first leaf (or pair of leaves) of seed plants.

Cucurbit - a plant of the gourd family.

Cuticle - superficial non-cellular layer covering a plant or animal; secreted by the epidermis. In plants it retards the movement of water and gases into and out of the leaf.

Desiccate - to dry; to dry up.

Diapause - in insects, a period of suspended development or growth, accompanied by greatly decreased metabolism; often correlated with seasons (i.e. hibernation).

Dicot - a flowering plant with two seed leaves or cotyledons.

Diploid - having a double set of chromosomes per cell.

Disease triangle - the right combination of susceptible host plants, a virulent pathogen, and suitable climatic conditions experienced during the growing season.

Disintegration - to break or decompose into constituent elements, parts, or small particles.

DNA - deoxyribonucleic acid; nucleic acid providing the genetic template of chromosomes.

Economic Threshold - the pest density at which control measures should be applied to prevent an increasing pest population from reaching the economic injury level.

Economic Injury Level - the lowest pest density that will cause economic damage; or the pest density that causes damage equal to the cost of preventing the damage.

Elytra - the leathery forewings of beetles, serving as a covering for the hind wings.

Entomophagous - consuming chiefly insects or their parts.

Enzymes - naturally occurring organic catalyst, being usually a protein.

Epidermis - outermost layer of cells of a plant or animal. In plants one cell-layer thick, covered in aerial parts by a non-cellular protective cuticle.

Equilibrium position - the population density of insects when fluctuation is averaged over a period of time.

Eradication - the elimination of a disease-causing agent, pathogen, weed, or insect pest ***after*** it has become established.

Exclusion - the prevention of disease-causing organisms from entering and becoming established where susceptible plants are growing.

Excretion - the act of getting rid of products of metabolism by storing them in an insoluble form or by removing them from the body.

Exoskeleton - the external skeleton consisting of hard cuticle, to the inner side of which muscles are attached.

Exuding - to cause to ooze or spread out in all directions.

Foliage - the aggregate of leaves of a plant.

Frass - plant fragments made by wood-boring insects, usually mixed with excrement.

Fungi - simple microorganisms that lack chlorophyll and are unable to manufacture their own food. Examples - stem rust, leaf rust, smut diseases, potato late and early blight, alfalfa leaf spot, powdery mildew.

Girdle - in insects, a silk band used to support the pupa. In plants, cutting transversely across the phloem in a stem so that downward transport of substances is stopped.

Grafting - to transfer part of an organism from its normal position to another on the same or a similar organism.

Halteres - modified hind wings, which are sense organs concerned with the maintenance of stability in flight.

Haploid - having a single complete set of chromosomes.

Head - the first region of the insect body, articulated at its base to the thorax, bearing the mouth structures and antennae.

Hemelytra - anterior wing, the basal portion of which is thickened.

Hemimetabolous insects - insect that resemble the adult form in the immature stages in many ways, but are not reproductively mature and do not have functional wings.

Holometabolous insects - insects which have 4 general stages in metamorphosis - egg, larva, pupa, and adult - each entirely different from the others.

Hypha - a thread-like filament that is the structural unit of a fungus mycelium.

Inoculation - the introduction of a pathogen into a living organism to stimulate the production of antibodies.

Inoculum - that portion of a pathogen which is transferred to a host; usually consists of spores, bacteria, mycelial fragments, nematode cysts, or virus particles.

Instal - the stage between molts in the nymph or larva, numbered to designate the various stages.

Kairomones - plant substances that emit odors which warn insects of toxicity or attracts them to the right source of food.

Larva - a young insect which quits the egg in an early stage of morphological development and differs fundamentally in form from the adult.

Mandibles - the first pair of jaws in insects, being stout and jawlike in chewing insects, or needle - or sward-shaped in piercing-sucking insects.

MDA - Montana Department of Agriculture.

Mesosomes - a complex infolding of the plasma membrane in prokaryotic cells. Contains respiratory enzymes and appears to play a role in cell division.

Metamorphosis - the series of changes through which an insect passes in its growth from the egg to the adult stage.

Molting - the shedding of the old exoskeleton.

Monocot - a plant having a single cotyledon or seed leaf. Monocots, which include grasses, usually have parallel leaf veins and fibrous roots.

Monophagous - feeding upon only one kind of food, e.g., one species of plant.

Morphology - the study of form and structure (anatomy).

MSU - Montana State University.

Mycelium - the mass of interwoven threads (hyphae) making up the vegetative body of fungus.

Mycoplasma-Like Organisms (MLOs) - microorganisms of an intermediate size between viruses and bacteria, generally without cell walls. Examples - witches broom, hay wire, aster yellow disease.

Necrosis - the death of a circumscribed piece of tissue.

Nematodes - microscopic, unsegmented roundworms. Examples - root-knot nematode and sugar beet nematode.

Nocturnal - active at night.

Nucleoid - one of a number of names given to the area of a prokaryotic cell that contains the chromosomal DNA.

Nymph - an immature stage of hemimetabolous insects.

Ovipositor - in female insects, the organ by which the eggs are deposited.

Parasite - an organism that lives in or on another (the host), from which it obtains food, shelter, or other requirements.

Parthenogenesis - egg development without fertilization.

Pathogen - an entity capable of producing disease.

Perennial weed - a weed that produces vegetative structures, allowing it to live for more than two years. Examples: leafy spurge, Canada thistle, quackgrass.

Pheromone - a chemical substance, usually a glandular secretion, which is used in communication within a species, such that one individual releases the material as a signal and another responds after sensing it.

Phloem - vascular tissue, composed of living cells, which conducts food from the plant leaf to the stem and roots.

Phyla - one of the major divisions of the animal kingdom.

Phytophagous - feeding in or on plants.

Plasma membrane - see cell membrane.

Pleomorphic - the ability of an organism to exist in different forms or shapes.

Predaceous - living by preying upon other organisms.

Prokaryote - a type of organism which is mainly unicellular and in which the cells lack a true nucleus; now synonymous with bacteria.

Prolegs - any process or appendage that serves the purpose of a leg.

Pronotum - the upper and dorsal part of the prothorax.

Propagation - to increase in numbers by sexual or asexual reproduction.

Protein - a polymer that has a high relative molecular mass of L-amino acids. Occupy a central position in the architecture and functioning of living matter.

Prothorax - the first thoracic ring or segment, bearing the anterior legs but no wings.

Pupa - the inactive stage in all holometabolous insects, being the intermediate stage between the larva and the adult.

Puparium - the nymphal skin enveloping the adult.

Rhizome - an underground, horizontal, creeping stem which bears roots and leaves and usually persists from season to season.

Ribosomes - a sub-cellular granule composed of RNA and protein, which is found in cell types if cells and in some sub-cellular organelles: The site of protein synthesis.

RNA - ribonucleic acid, any of various nucleic acids that contain ribose and uracil as structural components and are associated with the control of cellular chemical activities.

Sclerotia - fungal resting bodies which are resistant to unfavorable environmental conditions and can remain dormant for long periods of time.

Secreting - to release product by an animal or plant.

Solanaceous - relating to the nightshade family of plants.

Spinneret - small tubular appendage from which silk threads are exuded by spiders and by many larval insects.

Spiracles - external opening of the tracheal system.

Spiroplasmas - a genus of bacteria in which the cells are variable in shape, but can form helical filaments. The cells lack cell walls.

Spore - a microscopic structure which functions in reproduction and dispersal. A spore does not contain an embryo and is thus distinct from a seed.

Sporidium (sporidia) - a small spore produced by basidia.

Stolon - an aboveground, horizontal stem.

Stomates - the small openings on the plant epidermis which allow transpiration to take place.

Stylet - slender, tubular mouthparts in plant-parasitic nematodes or aphids.

Tarsi - the leg segment attached to the apex of the tibia, fourth segment of the leg.

Telispore - a thick-walled resting or overwintering spore, produced by rust and smut fungi.

Terrestrial - living on the land.

Thoracic leg - the jointed appendage attached to the thorax.

Thorax - the middle portion of the body between the head and abdomen, consisting of 3 segments, each of which usually bear a pair of legs.

Translocation - the movement of food, water, or mineral solutions from one part of a plant to another.

Transpiration - the loss of water from plant tissues in the form of vapor.

Tubercle - a small knoblike or rounded body structure.

Tympanal organ - an organ sensitive to vibrations, consisting of a thin area of cuticle and an inner air sac.

Tympanum - tympanal organ.

Vector - an agent, such as an insect, nematode, or fungus, that may transmit a pathogen.

Viruses - complex macro-molecules composed of ribonucleic acid with a protective protein "overcoat". Examples - wheat and barley streak mosaic, potato leaf roll, alfalfa mosaic virus, little cherry, curly top virus.

Whorl - a ring of hairs, pestles, leaves etc. set about in a joint or center like the spokes of a wheel.

Xylem - vascular tissue, made up of non-living cells, which conducts water and mineral nutrients from the roots to the stem and leaves.

Zero Damage Level - when the pest population is at or below the level that will not have an impact on the yield or quality of the plant, the insect no longer has pest status.

Zoophagous - feeding on animals.

Zygote - a diploid cell resulting from the union of two haploid cells.

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ANSWERS

Plant Diseases - Part I

1. d.
2. d.
3. b.
4. b.
5. a.
6. c.
7. b.
8. a.
9. d.
10. c.

Weeds - Part II

1. d.
2. c.
3. d.
4. b.
5. a.
6. d.
7. b.
8. a.
9. a.
10. b.
11. b.
12. a.

Ag. Insect Pest - Part III

1. b.
2. b.
3. a.
4. a.
5. b.
6. d.
7. b.
8. b.
9. a.
10. a.
11. c.
12. d.
13. a.

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