Section II

New Mexico Pesticide Applicator Training
Agricultural Pests and Agricultural Weeds

Control of Insects, Mites and Other Invertebrates

Adapted with permission from the
Arizona Study Guide for Agricultural Pest Control Advisors (1991)

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I. INTRODUCTION TO INVERTEBRATES

A. CLASSIFICATION

All living organisms are described by a hierarchial classification system. Each level of the hierarchy designates a set of physical characteristics, becoming more specific as the classification progresses. There are seven major levels:

Classification	Example
Kingdom	Animalia
Phylum	Arthropoda
Class	Insecta
Order	Homoptera
Family	Aleyrodidae
Genus	*Bemisia*
Species	*tabaci*

B. CHARACTERISTICS OF INVERTEBRATES

The animal kingdom is divided into major taxa (divisions) called phyla (e.g. Chordata, Nematoda). One very large phylum is Arthropoda, which includes insects, mites and other economically important groups of invertebrates. Arthropods are the most abundant of all animals with almost 90 percent of all described animal species included in this taxon. To date, more than a million species have been described as arthropods. These animals are well adapted to a wide range of habitats.

While no single feature separates members of arthropoda from other animals, the distinction is made possible by the recognition of certain characteristics. All members of the phylum Arthropoda have the following features in common:

- Segmented bodies with two or three distinct regions
- Jointed and paired appendages
- Bilaterally symmetrical bodies
- Hard body covering, composed of chitin, known as exoskeleton
- Central nerve cord
- Open circulatory system with a dorsal vessel (heart)

Within the phylum Arthropoda are five major groups (classes) that include many of the most important pests of man and his crops. These groups are Crustacea (crabs, barnacles etc.), Chilopoda (centipedes), Diplopoda (millipede), Arachnoidea (spiders, ticks etc.) and Insecta (beetles, flies etc).

DIPLOPODA: Millipedes live in damp areas, such as under rocks, leaf mold and rotten logs. A few species are known to feed on living plants and have been reported to be pests in greenhouses. The body is cylindrical with two body regions: a head and a merged thorax and abdomen. Body segments have fused into pairs so that each apparent segment has two pairs of legs; usually more than 10 pairs are present.

ARACHNOIDEA: This class of Arthropods include spiders, ticks, mites and scorpions. The most common species are in the subclass Arachnida. Arachnoidea have two major body parts: the cephalothorax (includes head and thorax) and the abdomen. All species have eight legs. Antennae and wings are absent.

INSECTA: These are the insects, the only invertebrates to bear wings. Their bodies are composed of three distinct regions: head, thorax and abdomen. The thorax has three pairs of legs and a single pair of antennae. The number of insect species currently approaches a million, but only 200-300 species are considered persistent economic pests of man.

C. CLASSIFICATION OF INSECT ORDERS

The insects have evolved into many different kinds of organisms. The exact number of insect orders vary, but is usually between 25 and 30. Following are the subclasses and orders in the class Insecta. Orders of economic importance in agriculture are denoted by an asterisk (*).

Subclass/Order	**Common Name**
Subclass: Apterygota	
Order:	
Diplura	campodeans and japygids
Protura	proturans
Collembola	springtails
Thysanura	silverfish, firebrats
Subclass: Pterygota	
Order: Ephemeroptera	mayflies
Odonata	dragonflies, damselflies
Orthoptera*	grasshoppers, crickets, cockroaches

Subclass/Order	**Common Name**
Order: Isoptera	termites
Dermaptera*	earwigs
Grylloblattodea	grylloblattids
Embioptera	embiids
Plecoptera	stoneflies
Zoraptera	zorapterans
Psoscoptera	psocids, booklice

Anoplura	sucking lice
Thysanoptera*	thrips
Homoptera*	aphids, leafhoppers, scale insects
Hemiptera*	true bugs
Hymenoptera*	bees, ants, wasps
Coleoptera*	beetles
Megaloptera	dobsonflies
Neuroptera*	lacewings
Raphidiodea	snakeflies
Mecoptera	scorpionflies
Siphonoptera	fleas
Diptera*	true flies
Trichoptera	caddisflies
Strepsiptera	twisted-wing flies
Lepidoptera*	moths, butterflies

D. IDENTIFICATION OF ECONOMIC INSECT ORDERS

Order	Common Name	Wings	Metamorphosis	Mouthparts	Economic Importance
Orthoptera	Grasshoppers, Crickets, Katydids, Mantids, Cockroaches	Two Pair (some species are wingless); the front pair is long and slender; hind pair is fan like	Gradual	Chewing	Injurious to crops. Mantids feed on other insects.
Dermaptera	Earwigs	Usually two pair; the front pair are short leaving the abdomen exposed, the hind pair are folded under front pair.	Gradual	Chewing	Feed on plant materials, decaying vegetable matter and other insects. Can be an important greenhouse pest.
Thysanoptera	Thrips	Two pairs of fringed slender wings with few veins.	Gradual	Rasping sucking	Injurious to citrus, cotton and field crops. Some species feed on other insects.

Hemiptera	True Bugs	Two pair with the front pair thickened with membranous tips (hemelytra).	Incomplete	Piercing sucking	Found in water, on plants and animals. Feeding causes considerable damage.
Homoptera	Aphids. Leafhoppers, Cicadas, Whiteflies, Mealybugs and Scales	When present, wings are held roof-like over body	Ametabolous	Sucking	Reduce plant vigor, transmit plant pathogens, cause phytotoxicity and secrete honeydew which attracts sooty mold
Neuroptera	Lacewings, Antlions	Two pairs of about equal size. Multi-veined.	Incomplete	Chewing	Beneficial as they feed on other insects
Coleoptera	Beetles	Two pair. Thick front pair forms a hard shell (elytra) and meets in a straight line down the middle of back. Hindwings are membranous and are folded under front wings when at rest.	Complete	Chewing	Food habits vary: some feed on living plants, some are predaceous, some are scavengers and some bore into wood.
Lepidoptera	Butterflies and moths	Usually two pair. Covered with overlapping scales.	Complete	Immatures have chewing; adults have siphoning	

E. INTERNAL ANATOMY OF INSECTS

DIGESTIVE SYSTEM: Most insects are generalists or polyphagous, meaning that they feed on a wide variety of plants and animals. The alimentary canal in these insects extends directly through the center of the body from the mouth to the anus. If an insect is oligophagous (restricted to a few species of plants) or monophagous (feeding on a single plant species), they may have specialized systems with filter chambers to remove water from nutritional materials.

CIRCULATORY SYSTEM: In many animals, blood is pumped by the heart through the body in specialized vessels such as arteries, capillaries and veins; this type of circulatory system is known as a closed system. Insects have an open circulatory system where the hemolymph (blood) flows or percolates throughout the body with the aid of the insect heart, or the dorsal vessel.

NERVOUS SYSTEM: The nervous systems in insects is considered to be highly developed. It coordinates activities such as flight and evasive behaviors. The insect nervous system consists of ganglia (the brain) and sub-ganglia. These are connected throughout the body by nerves and can function independently. In mammals, signals are sent from the body to the brain, the brain interprets the message and then sends instructions to the body to react. In insects, the sub-ganglia can receive a message and determine a reaction without interpreting the message. The main "brain" (ganglia) interprets the message later. This allows very short reaction times and accounts for the insects' ability to escape quickly from predators.

RESPIRATORY SYSTEM: Insects breathe by obtaining oxygen absorbed either directly through the exoskeleton or through a series of spiracles located along the sides of the abdomen. The spiracles are the external openings of the tracheal tubes, which are channels that deliver oxygen to and remove carbon dioxide from individual cells in an insect.

EXCRETORY SYSTEM: The insect excretory system serves to eliminate both solid waste and metabolic products from the body. Solid waste, which consists of undigested foods, is passed from the alimentary tract to the rectum. Once in the rectum, specialized cells extract the remaining water before the fecal pellet is voided. Metabolic waste, which results from cellular activity, is absorbed by the blood; the waste from the blood is then extracted by the malpighian tubules (in most insects) and discharged into the intestine near the junction of the midgut and hindgut.

REPRODUCTIVE SYSTEM: The female insect always exists, but in some species the male is unknown. Most reproduction takes place by fertilization of the eggs, although the mechanism may vary. In most insects, the female has an ovary, vagina and ovipositor. The male has testis, accessory glands and an adeagous. Asexual reproduction may occur as part of the life cycle of some insects such as aphids.

F. EXTERNAL ANATOMY OF INSECTS

Insects, unlike most animals, have an exterior skeleton, called the exoskeleton, rather than an interior skeleton. The exoskeleton functions to support the muscles and protects internal organs. It is composed of a protienaceous material known as chitin with a waxy cuticle. The exoskeleton is very important in preventing water loss. If the outside cuticle is damaged, the insect may die of desiccation.

G. INSECT GROWTH AND DEVELOPMENT (METAMORPHOSIS)

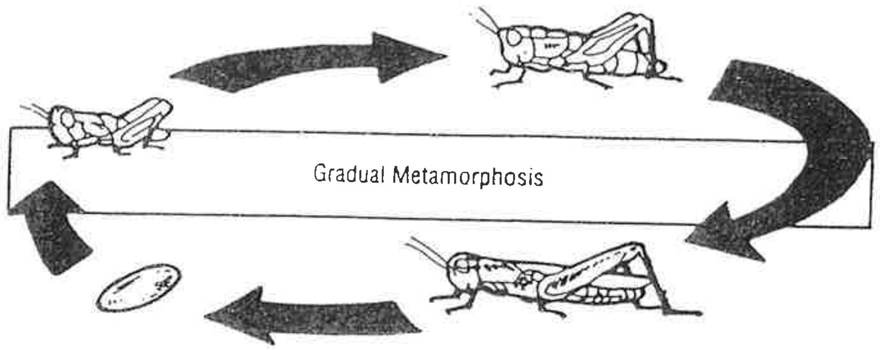
Metamorphosis is defined as *a change in form*. As insects mature, they go through a series of stages. There are five definable stages: egg, larvae (caterpillar, grub, maggot), pupae (a"resting" form), nymph and adult although not all insects exhibit each stage. The type of metamorphosis is determined by the changes made by the insect. These changes take place from the time the eggs hatch until the insects reach maturity. Maturity is indicated by the presence of wings (in the winged forms) and evidence of reproductive activities, i.e., mating and egg laying.

Because their body size increases over time, insects must shed their chitinous exoskeleton. This molting process occurs from three to seven times depending on the particular species and environmental conditions. The period of time between two molts is called stadium, and the actual insect during a stadium is termed an instar.

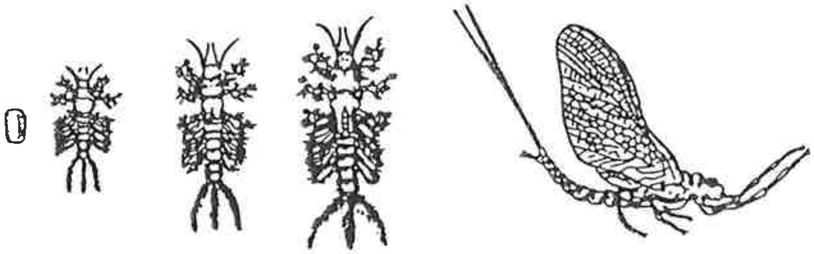
The types of metamorphosis are described below:

NO METAMORPHOSIS (ametabolous): The insects who exhibit this type of development only change in size between the hatching and adult stage. The insect grows larger with each successive instar until it reaches maturity. Examples are silverfish, firebrats and springtails. The food and habitats of the young (called nymphs) are similar to those of the adult.

GRADUAL METAMORPHOSIS: Insects in this group pass through three stages of development before reaching maturity: egg, nymph and adult. The nymphs resemble the adult in form, eat the same food and live in the same environment. The change in the body is gradual and the wings become fully developed only in the adult stage. Examples are grasshoppers, lygus, lice, termites, aphids and scales.



INCOMPLETE METAMORPHOSIS: The insects with this type of metamorphosis also pass through three stages of development: egg, naiad and adult. The adult is similar to the young, but the naiads are aquatic. Examples: dragonflies, mayflies and stoneflies.



COMPLETE METAMORPHOSIS: There are four stages in complete metamorphosis: egg, larvae, pupae and adult. The young, which may be called larvae, caterpillars, maggots or grubs, are entirely different than the adults. They usually live in different situations and in many cases, feed on different foods than adults. The pupal stage may be erroneously termed a resting stage, because of the apparent quiescence. Actually, many of the major changes in morphology and physiology take place during this pupal stage, after which the adult emerges. Examples are the beetles, butterflies, flies, fleas, bees and ants.

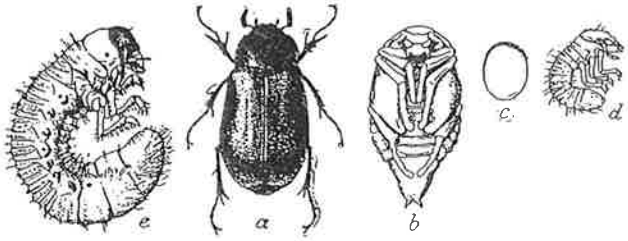


Fig. 10. Complete metamorphosis of a May beetle, *Phyllophaga fervida* (Fabr.), family Scarabaeidae: *a*, adult; *b*, pupa; *c*, egg; *d*, newly hatched larva; *e*, fully grown larva;

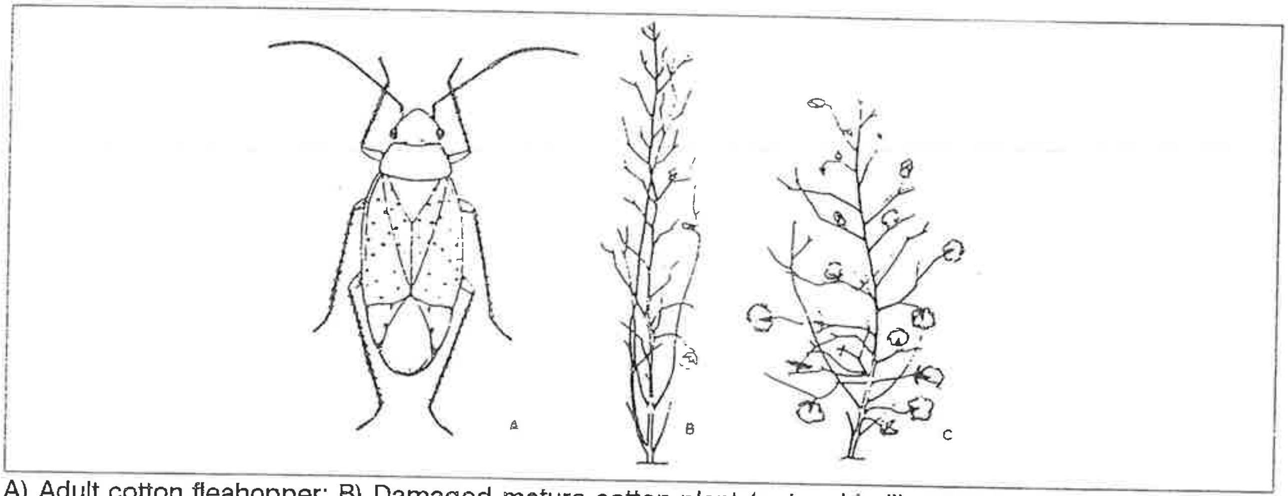
H. ECONOMIC IMPORTANCE OF INSECTS AND OTHER INVERTEBRATES

Of the many animals on earth, arthropods (particularly insects), are the greatest competitors for man's food and fiber. The losses incurred to buildings, fresh agricultural produce, stored foods, forest trees, animals and fabrics by insects would no doubt total billions of dollars annually. It has been estimated that perhaps 20-25 percent of the world's agricultural products harvested by man are destroyed or made unusable by insects or their relatives. These invertebrate pests destroy man's food and fiber in many ways, including direct contamination of food stuffs with feces or body parts. Some insects are also harmful in that they are carriers of disease organisms. These insect vectors are known to carry both plant and animal pathogens. Overall, however, relatively few species (perhaps one to two percent) are consistently economically important pests. These few species must be controlled in ways that permit the remaining nontarget species to persist.

II. Invertebrates Important to New Mexico Agriculture

A. Deleterious Insects and Mites

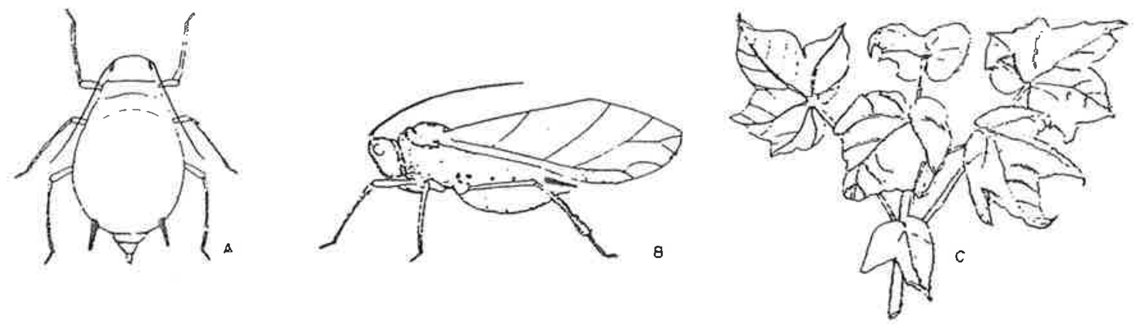
Fleahoppers (Hemiptera): These one-eighth inch long insects are quite active in cotton, particularly during May and June. While they frequently attack seedling cotton, the major impact is in cotton around the time of squaring. Cool weather is of importance in determining the level of damage attributable to fleahoppers in cotton. Heavy populations of five or more fleahoppers per seedling on cotton has been known to kill the plants. Black fleahoppers are most active on cotton plants late in the morning.



A) Adult cotton fleahopper; B) Damaged mature cotton plant (note whip-like stems and suppression of bolls); C) Normal mature cotton plant

Aphids (Homoptera): Probably no other single group of insects is responsible for more of the world's agricultural problems than aphids. Not only do enormous populations of aphids frequently extract enough phloem sap to affect plant vitality, but these insects also transmit pathogenic plant organisms. Many species secrete "honeydew" from the rear of their abdomen. This sticky substance, consisting largely of various sugars, may be deposited in enormous quantities. Honeydew, in turn, may be attacked by sooty mold fungi. Sooty molds stain plant parts, inhibit photosynthesis and interfere with harvesting and ginning operations. The life cycle of aphids may be very complex, involving sexual and asexual (parthenogenic) modes, winged (alate) and wingless (apterous) stages and egg laying (oviparous) and live-bearing females. Once aphids are introduced in New Mexico, most generations are parthenogenic. Nymphs of some species may have different coloration from the winged adults of the same species. Every crop in New Mexico is attacked by one or more species of aphids. The following is a partial list:

Crop	Aphid
Cotton	cotton and cowpea aphid
Alfalfa	spotted alfalfa, pea, green peach and blue alfalfa aphid
Corn, wheat, barley	green bug, rusty plum and corn leaf aphid
Lettuce, cole crops	green peach and cabbage aphid
Sorghum	green bug, corn leaf aphid
Melons	melon and green peach aphid
Pecans	black, black margin and yellow Aphid



A) Wingless adult, cotton aphid; B) Winged adult, cotton aphid C) Damaged cotton leaves, typically deformed and curled down on the edges.

Whiteflies (Homoptera): Sweet potato whiteflies, *Bermisia tabaci*, resemble aphids both in appearance and habits, but they are an order of magnitude smaller. Eggs hatch first into first instar nymphs known as crawlers, capable of moving a short distance over the leaf surface. They quickly settle over a minor vein, inserting their mouthparts into the phloem tissue to extract sap. They are sessile for the remainder of their immature life until they emerge from the "pupal" case as winged adults. Sweet potato whiteflies have an extremely wide host range, attacking cotton and a number of vegetable crop hosts. They can damage plants in a number of ways. Populations often build to such high numbers that they remove enough phloem sap to reduce plant vigor and yield. Sweet potato whiteflies also serve as vectors for a number of important viral pathogens such as lettuce infectious yellows virus and squash leaf curl virus. Finally, during feeding they can extract large enough amounts of sap to filter out rare salts, vitamins and amino acids. Estimates are that they can extract as much as 500 pounds of sugar from an acre of cotton. Whiteflies also excrete excess materials through the anus (as aphids do).

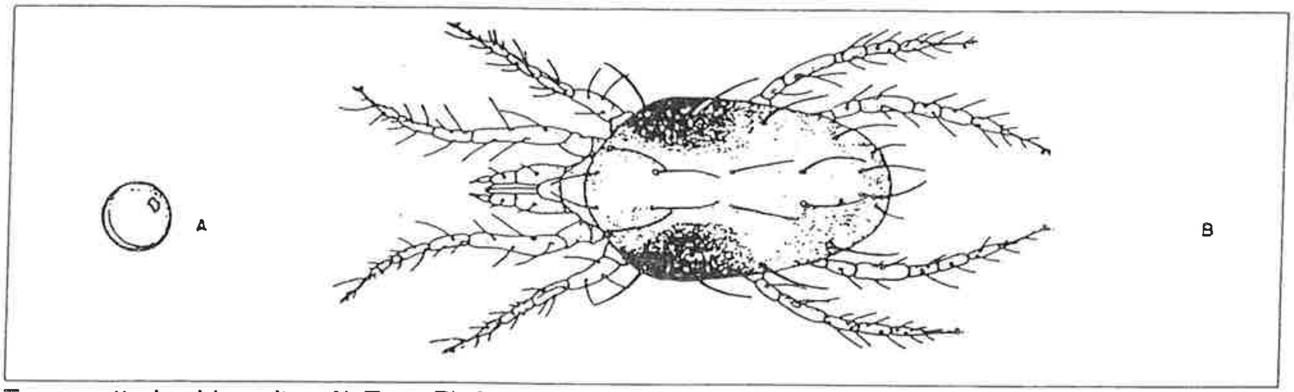
Alfalfa Weevil (Coleoptera): The adult of the alfalfa weevil, *Hypera postica*, is one eighth to one quarter of an inch long, grayish brown or nearly black in color, with short grayish hairs which gives them a spotted appearance. There is one full generation a year and sometimes a partial generation. The adults emerge in the spring and lay eggs in the stems. The larvae emerge and soon become inactive during the summer months, summer hibernating (aestivating) in weeds and trash, or under tree bark. Eggs are laid in stems of the alfalfa.

Thrips (Thysanoptera): Thrips are very small insects, frequently 1 mm or less in length. Their rasping-sucking mouthparts produce extensive scarring in leaves of cotton, onion and citrus as they search for food. In some plants, a decided inward curling of the leaves is a positive indication that large numbers of thrips are present. Some important thrips species and their hosts are listed below:

Crop	Thrips
Cotton	Western flower thrips
Onion	Onion thrips
Citrus	Citrus thrips
Chile	Western flower thrips

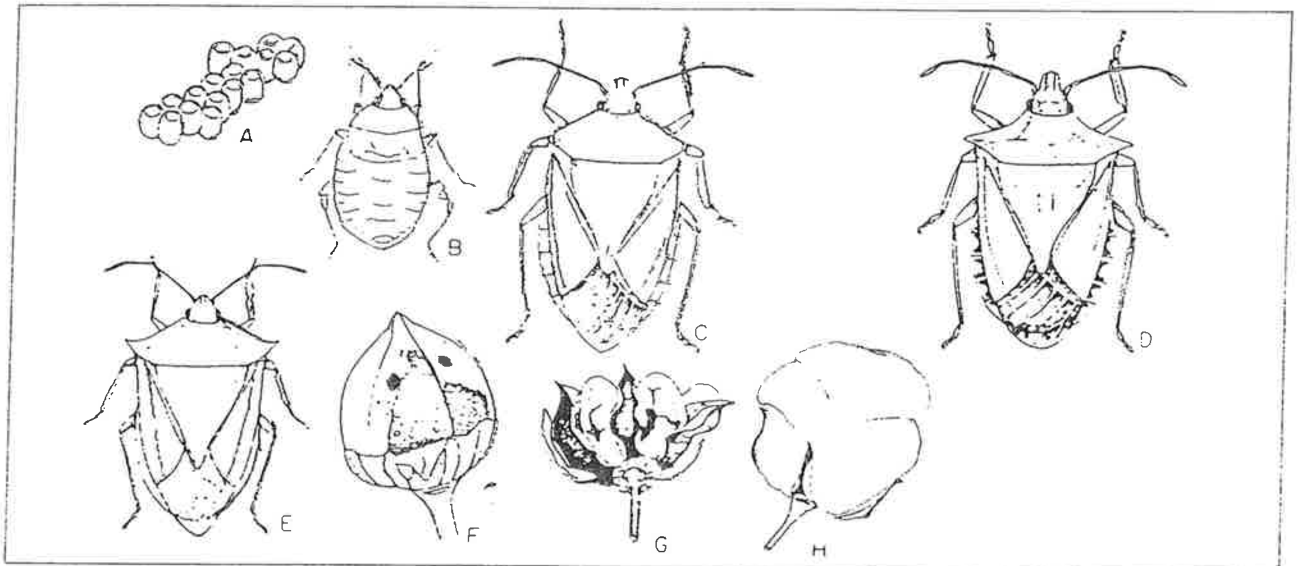
Mites (Acarina): Mites are minute animals, closely related to insects. Since a crop may be attacked by a complex of insect species, often only an individual with experience in mite taxonomy can positively identify the species involved. Injury by mites may vary from crop to crop. Cotton leaves may develop reddish spots on the top surface from the mites feeding on the under surface of the leaves; severe infestations can result in defoliation of the cotton plant. Mites can often be detected by webbing of silk on the leaf surface. Adults and nymphs may be seen on the leaf surface or scurrying about the webbing. Round green or red eggs may be seen deposited on the leaf. Mites attacking some New Mexico crops are listed below:

Crop	Mite
Cotton	two-spotted mite, strawberry spider mite, carmine mite
Citrus	citrus red mite, citrus flat mite, Yuma mite
Sorghum	Banks grass mite
Bermudagrass	Banks grass mite



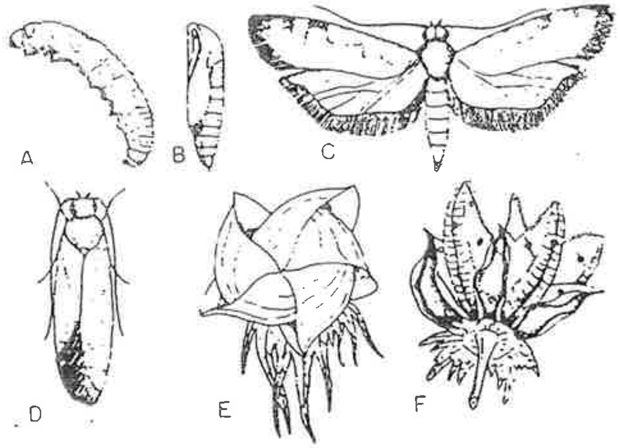
Two-spotted spider mite. A) Egg; B) Adult.

Stink Bugs (Hemiptera): Stink bugs are serious pests of cotton, sorghum, safflower and alfalfa seed crops. These bugs, which can range from approximately one-half inch or longer secrete a distinctive odor. Four species are commonly found on New Mexico crops. The barrel-shaped eggs are about 1/16 inch long, and laid in masses. Feeding of both nymphs and adults on cotton bolls produces staining of the lint and withdrawal of the seed juices. A small "wart" on the inside of the boll carpel wall, plus stained lint and shriveled seeds, is a sure sign that stink bugs were active. Use of the insect sweep net in cotton is a good means of detecting stink bug infestations; even if the net doesn't catch the bugs, their offensive odor will provide proof that the bug was present in the field.



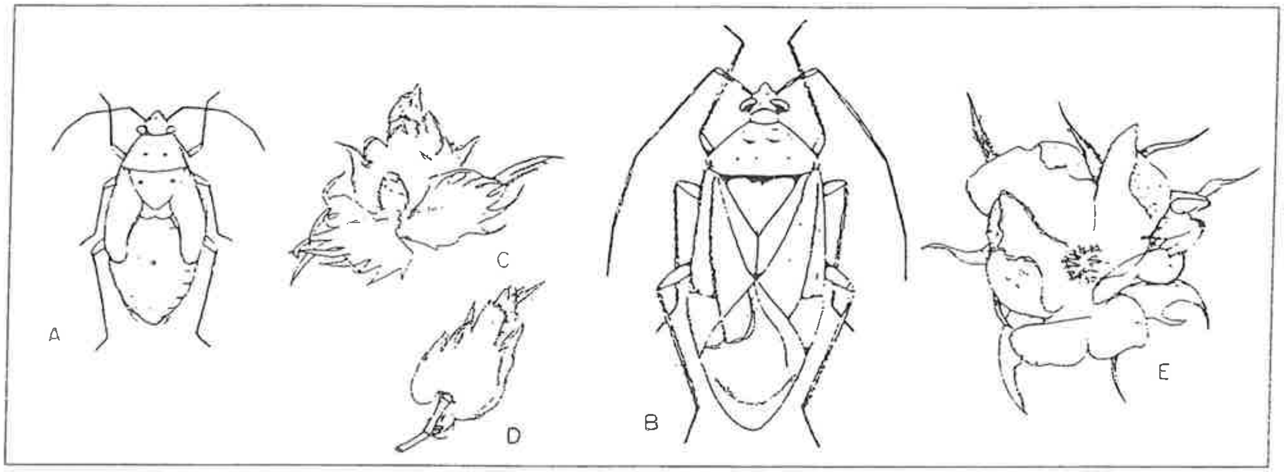
A) Say stink bug egg cluster; B) Say stink bug nymph; C) Say stink bug adult; D) The brown cotton bug; E) The red-shouldered plant bug; F) A maturing boll infected with boll rot facilitated by feeding stink bugs; G) An abnormal open boll with hardened dry locks caused by stink bug feeding during boll development; H) A normal open boll.

Pink Bollworm (Lepidoptera): The pink bollworm, *Pectinophora gossypiella*, has been observed in New Mexico. If left unchecked, this insect can ruin a cotton crop completely. Eggs are laid at the base of bolls or under flower bracts. The first instar larvae mine into the cotton boll, sometimes feeding on the squares or flowers. The mature larvae is about 1 inch long with a definite pink cast. Its activities stain the cotton lint and its feeding does irreversible damage to the seeds. Pupation occurs in the soil; moths emerge soon after. During the summer, the total time from egg to egg may be as little as three to four weeks. At the onset of fall, the larvae enter diapause and pass the winter in the soil or in crop residue. "Rosetted" blooms and exit holes on bolls are very visible signs of pink bollworm larvae activity. Useful tools in assessing population levels are the trapping of male adults with sex lure (pheromone) traps and the inspection ("cracking") of representative boll samples.



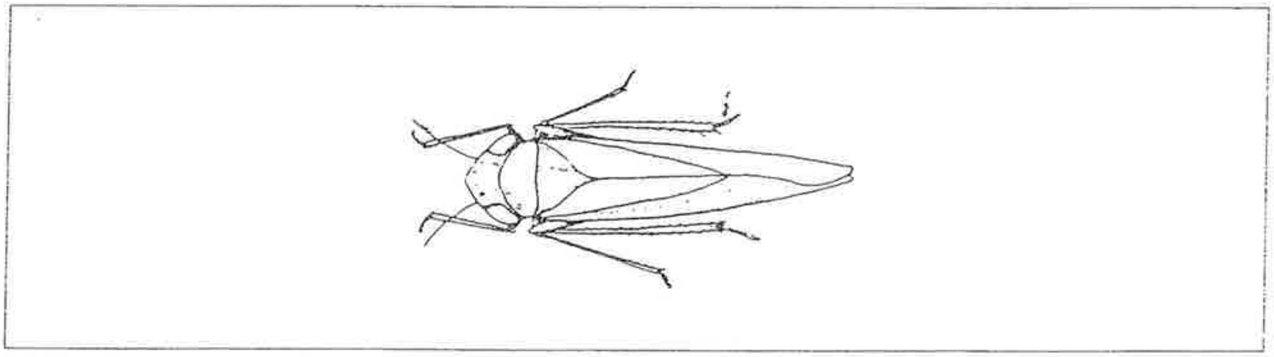
A) Pink bollworm mature larvae; B) Pink bollworm pupa; C and D) Pink bollworm adult; E) Rosetted cotton blossom; F) An open boll showing tight locks and damaged lint.

Lygus Bugs (Hemiptera): Lygus bugs, *Lygus spp.*, are a serious economic pest in the Southwest. This insect can be distinguished by a yellow, heart-shaped V on its back. Lygus are pests in cotton, seed alfalfa, safflower and occasionally lettuce. Lygus feed on the cotton squares, causing severe shedding even in moderate infestations. Their activities can also cause premature fruit drop. Lygus attack the midrib of lettuce leaves, causing brown staining and rupturing of the epidermis. Five molts are required to pass through the nymphal stages to the fully winged adult. Both nymphs and adults are very active. They overwinter as adults on alternate hosts such as London Rocket.



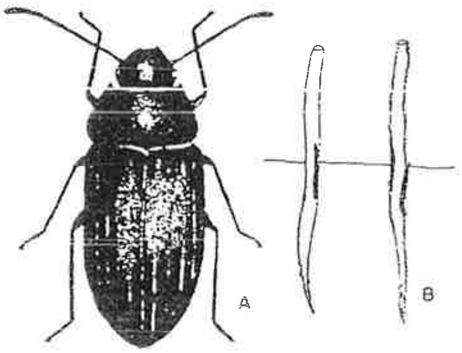
A) Lygus nymph;B) Adult lygus; C) Punctured and flared square; D) Normal square; E) Damaged blossom showing typical warty and deformed petals.

Leafhoppers (Homoptera): Leafhoppers are important pests of grapes, melons and potatoes; they are found in varying degrees on many New Mexico crops. They damage crops through direct feeding. Elsewhere they are known to transmit pathogenic organisms like the one responsible for Pierce's disease. The hind legs are well developed, enabling them to move rapidly about the plant. Eggs are deposited within the plant tissues. The nymphs molt five times before attaining adulthood and wings.



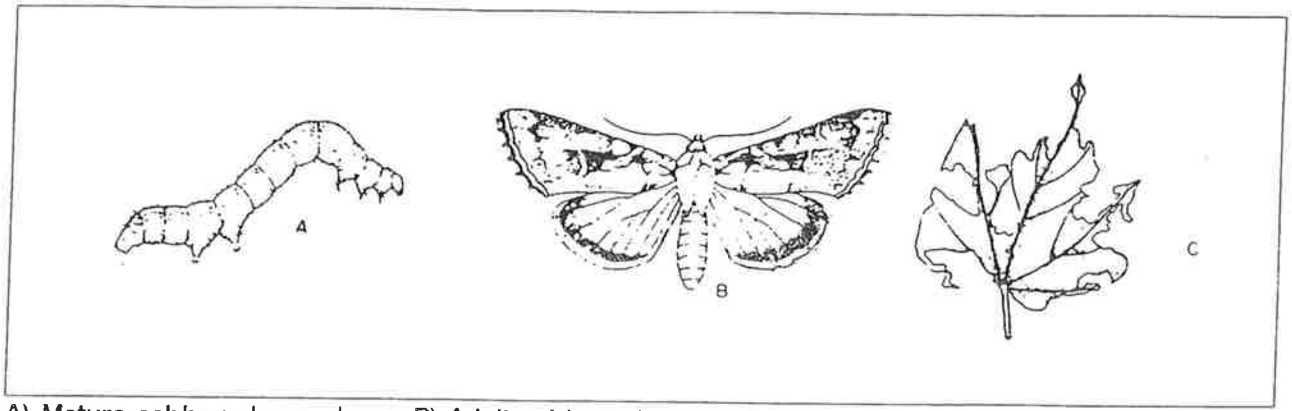
Adult leafhopper.

Darkling Beetles (Coleoptera): Darkling beetles are frequently destructive to seedling cotton; they also attack melons and grapes. Most infestations result from previous population increases in other host crops attractive to the beetles. Infestations build up in such crops as alfalfa and sandy soil pastures. When these crops are plowed under, both the immature and adult beetles feed on the organic matter. If cotton follows in rotation, the adult darkling beetles feed on succulent seedlings. These beetles are dark brown to nearly black in color. They range from one-fourth to one-third of an inch in length and are approximately a third as broad as they are long. In cotton fields, beetles can be found by digging approximately an inch and half deep around injured seedlings. They are nocturnal and can only be found in the soil during the day.



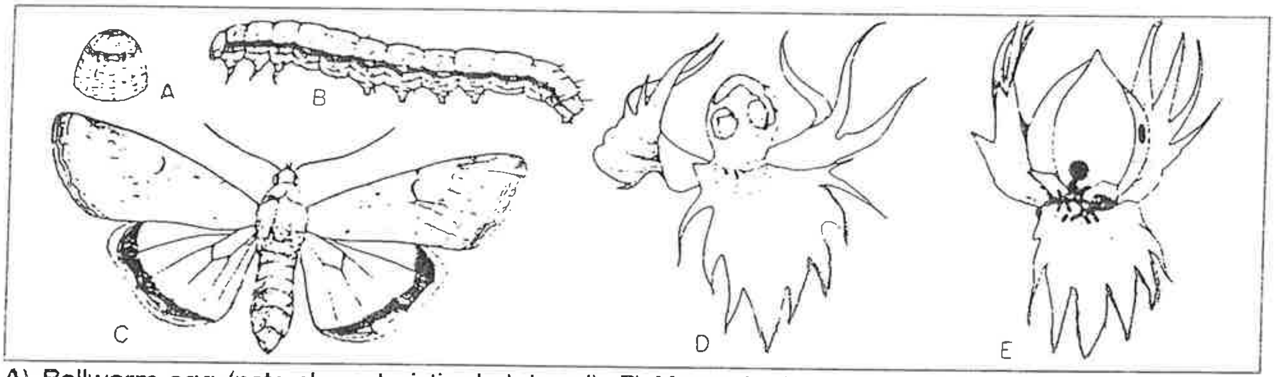
A) Typical darkling beetle; B) Seedling stalks with cotyledons removed, showing darkling beetle injury at ground level.

Cabbage Loopers (Lepidoptera): The cabbage looper, *Tricoplusia ni.*, attacks lettuce, cole crops, cotton, alfalfa and melons. A characteristic "ragging" of cotton leaves with large blotchy holes and clean, sharp, non-necrotic margins mark this pest's feeding. Irregular holes with an abundance of dark green frass are characteristic of cabbage looper feeding on lettuce. The larvae travel in a "looping" motion because of the three pairs of true legs at the front of the body and two pairs of false legs (proleg) near the rear. The adults are medium size moths with a wing span of about 1-3/4 inches; a small, silvery "hangman's knot" marks each of the forewings. A formless black appearance or quiescent yellow larvae indicate the presence of a viral disease that frequently eliminates entire populations of cabbage looper on cotton.



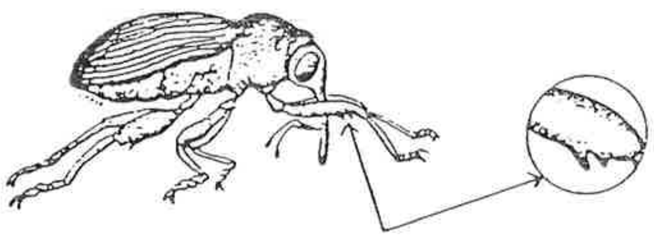
A) Mature cabbage looper larva; B) Adult cabbage looper (note 'Y' shaped markings on fore wings); C) Typical leaf injury on cotton.

Bollworm (Lepidoptera): Corn earworm, tomato fruitworm and bollworm are all the same insect, *Helicoverpa zea (*Formerly *Heliothis).* This insect is a major pest of a number of agricultural crops and attacks crops such as lettuce, cotton, sorghum, chile and corn. The bollworm feeds on the fruiting parts of cotton, corn and sorghum. When it moves to the interior of the lettuce head to feed, it cannot be reached with conventional chemical controls. Mature bollworm larva are 1-1/2 inches long, varying in color from pale green to dark brown. Under optimal conditions, six larval instars are completed in 17-21 days. The pupal period is spent in the ground. The entire lifecycle takes from 25-30 days in mid-summer. Tobacco budworm, *H. virescens,* which is a related species, can be distinguished from the bollworm in the larval stages through hand lens examination of the mandible (together in *H. verescens*) and setal differences. Adult differences between the two moths may be detected without visual aids; the tobacco budworm adult has well defined stripes on the wings and an overall yellowish-green color.

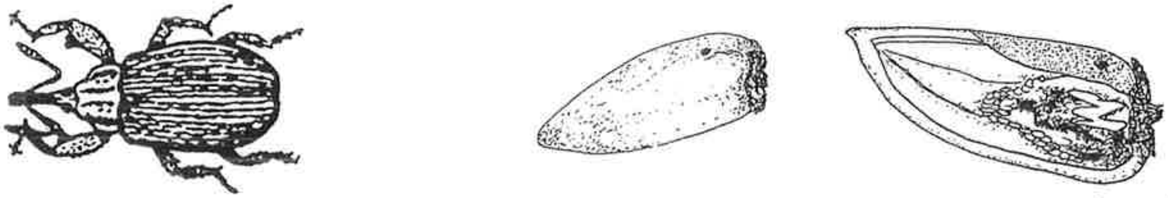


A) Bollworm egg (note characteristic dark band); B) Mature bollworm larva; C) Adult bollworm; D) Damaged square; E) Damaged boll.

Boll Weevil (Coleoptera): The boll weevil, *Anthomonous grandis*, is perhaps one of the most destructive of the cotton pests; it has become widespread throughout the cotton belt from western Texas to the eastern United States since its introduction in 1934. It has recently become a concern in New Mexico. The characteristic elongated, white eggs are inserted into squares and bolls. Larvae are c-shaped grubs with a light brown head. The spurs on the femur of the front legs of the boll weevil are easily seen with the unaided eye.



Pepper Weevil (Coleoptera): The pepper weevil *Anthomonus eugenii*, Cano, is a severe pest of sweet and hot peppers. The adult snout beetle is about 1/8 of an inch long and has a single stout spine at the middle of the front femur. The white, brown-headed grubs feed on the inside of buds and fruit and cause fruit and bud drop. There may be five to eight generations per year. Management of this pest includes intensive scouting for early detection, carefully timed insecticide applications and good sanitation (i.e. plow downs and crop residue shredding).

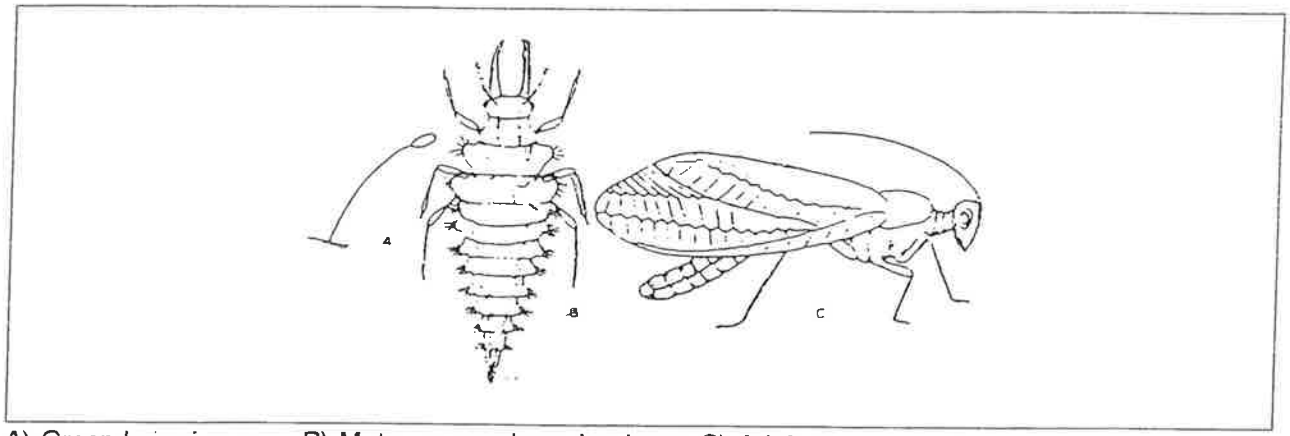


A) Pepper weevil adult; B) Pepper damage by pepper weevil larvae.

III. Beneficial Insects

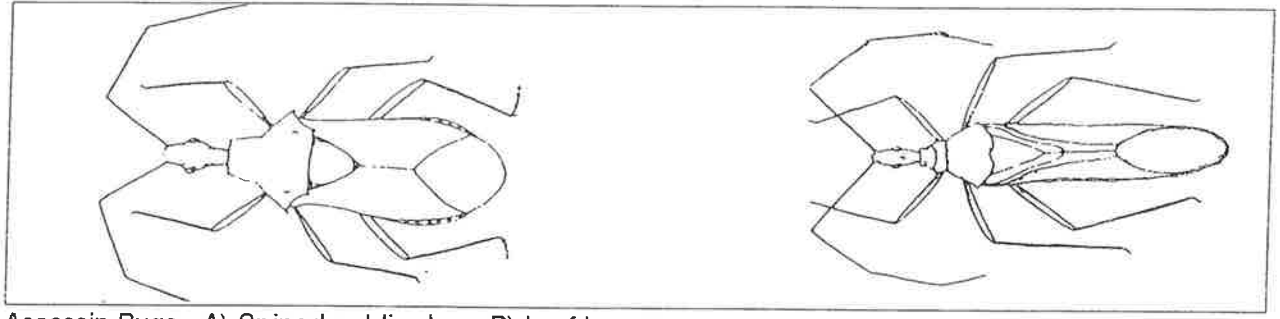
Many predatory and parasitic insects are directly helpful to New Mexico growers. These beneficial insects can frequently hold or reduce populations of harmful insects to levels that do not require control.

Lacewings (Neuroptera): The larvae of green lacewings, *Chrysoperla carnea* (formerly *Chrysopera*) are frequently described as resembling alligators. Lacewing larvae have well developed piercing-sucking mandibles. The adults, named for the delicate wings held roof-like over their body, have chewing mouthparts and may frequently be observed extracting the juices from the nectaries on cotton plants. The eggs are deposited singly on stalks that rise about one-half inch from the leaf surface.



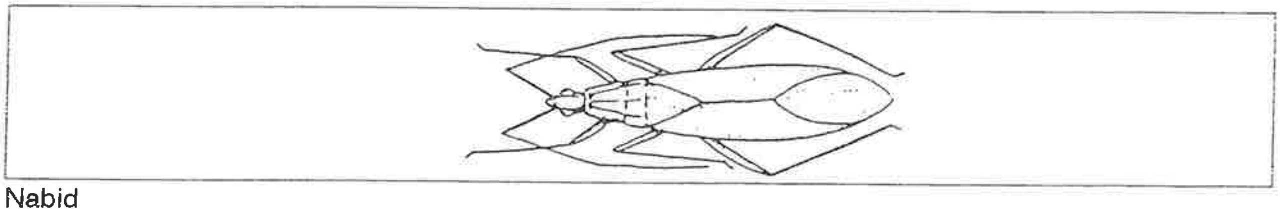
A) Green lacewing egg; B) Mature green lacewing larva; C) Adult green lacewing.

Assassin Bugs (Hemiptera): Generally, the assassin bugs (e.g. *Zelus renardii*), which are valued predators in New Mexico are small, about three quarters to one inch. Both nymphs and adults have piercing sucking mouthparts. In general, assassin bugs do not restrict their prey to a few species, but will feed on most prey species they encounter.



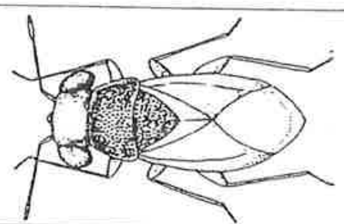
Assassin Bugs. A) Spined soldier bug; B) Leaf-hopper.

Nabids (Hemiptera): Nabids (e.g. *Nabis alternatus*) resemble miniturized assassin bugs, slightly under one-half inch long. They are effective predators of aphids, leafhoppers, lygus bugs and small caterpillars. Their forelegs are raptorial or well adapted for grabbing prey.



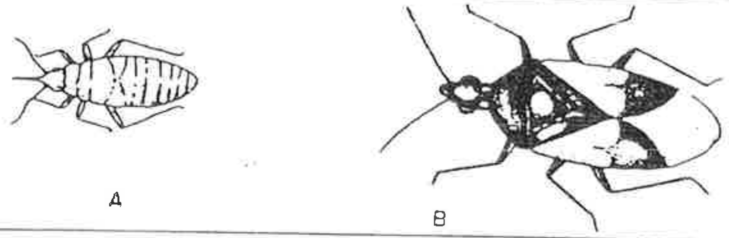
Nabid

Big-Eyed Bugs (Hemiptera): Big-eyed bugs (e.g., *Geocoris pallens*) are sometimes extremely abundant in cotton fields and alfalfa and may be confused with immature stink bugs. They are efficient predators of leafhoppers, spider mites, and eggs and small larvae of Lepidoptera. They also feed on many species.



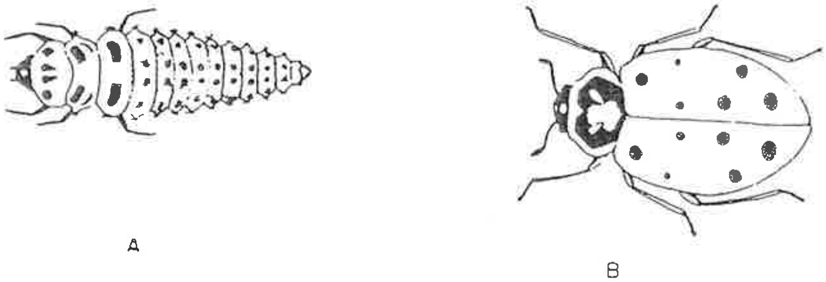
Adult big-eyed bug.

Minute Pirate Bugs (Hemiptera): Minute pirate bugs (e.g., *Orius insidiosus*) are about one sixteenth inch long, with black and white markings. The nymphs are orange in color and very active. These little bugs move swiftly through a spider mite colony and can very efficiently find and feed on bollworm eggs and first instar larvae.



A) Minute pirate bug nymph; B) Adult minute pirate bug.

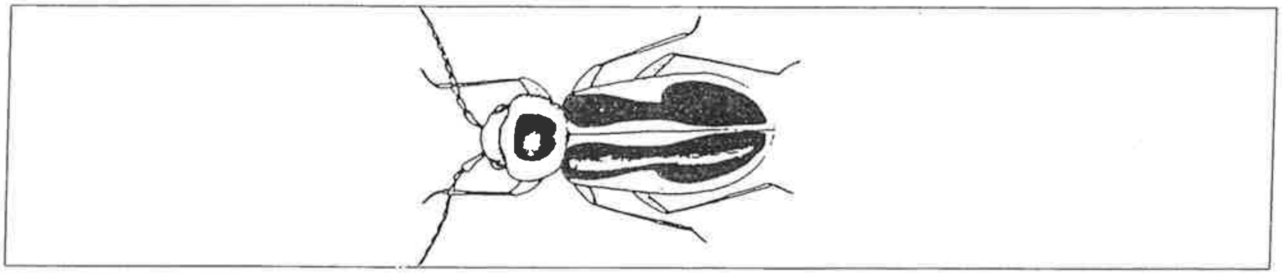
Lady Beetles (Coleoptera): The small orange and black "dragons" moving somewhat ponderously through an aphid colony are the larvae of the lady beetles. The pupae are "cemented" to the plant, rather resembling a bird dropping. Some species of adult lady beetles are migratory and in the fall will congregate in dense clusters in mountain foothills. Theses insects are among the most efficient known predators of aphids and mites. Their actual impact on pest populations is difficult to assess because they feed on so many different prey species.



A) Convergent lady beetle larva; B) Adult convergent lady beetle.

Six Spotted Thrips (Thysanoptera): Occasionally small thrips with six darkish areas on the wings are seen darting around spider mite colonies. These six spotted thrips, *Scolothrips* *sexmaculatus*, may be locally important in reducing spider mite colonies.

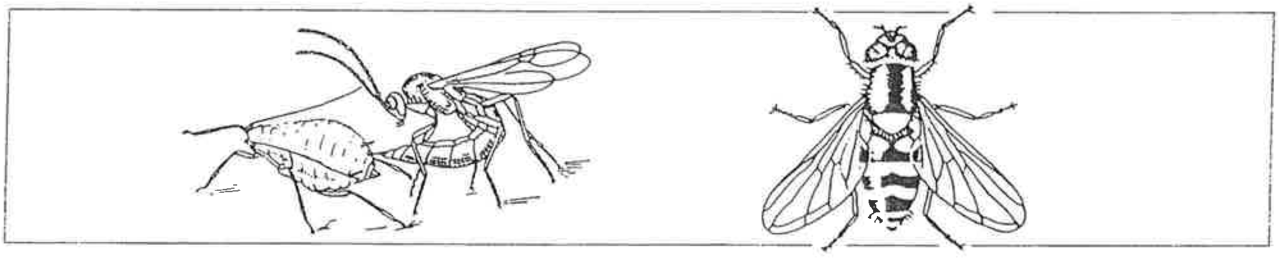
Striped Collops (Coleoptera): This striking orange and metallic blue beetle is a general predator, feeding on salt marsh caterpillar and stinkbug egg masses, as well as caterpillars, fleahoppers, leafhoppers and aphids. The larvae are thought to live in the soil and to be predaceous.



Adult striped collops.

Syrphid Flies (Diptera): The larvae of syrphid flies are legless, one quarter to one half inch long maggots which are exceedingly efficient aphid predators. Adult syrphid flies, generally black and orange in color, are very fast fliers that feed on nectar, honeydew and sweet plant secretions.

Parasitic Flies and Wasps (Diptera, Hymenoptera): Insect parasitism is one of the factors that keeps populations of injurious insects below the destructive level. Many flies and wasps are parasitic on the eggs, young and adults of harmful insects. They range from minute insects that destroy bollworm eggs to flies whose maggots internally devour large caterpillars. Because most parasitoids are small and may not congregate about plants, field observers seldom see them. The nature and habits of many of these important insects are now under investigation.



IV. Control of Invertebrates

A. Principles of Integrated Pest Management

The effective control of invertebrate pests demands not only knowledge of the particular species involved and the various methods available, but also an awareness of the environmental impacts of pesticide use. These factors are key elements in integrated pest management (IPM). IPM brings the best combination of all insect control methods together for a given situation. It is the practical manipulation of insect populations, using sound ecological principles applied in a systems approach.

The basic elements of a pest management system include good sampling, use of sound economic thresholds, knowledge of the biology and ecology of target insects, a recognition of natural mortality within a given area resulting from naturally occurring biotic and abiotic factors and selection of the most appropriate control strategy.

Once a good base of information is established, as many components can be added to the system as are available and practical. Methods such as cultural, biological, chemical and mechanical controls and host plant resistance are components that can be used. In order to develop the most effective and efficient system possible, however, pest management must be practiced on a year round basis. Emphasis needs to be placed on the implementation of control measures at the appropriate time.

B. Control Methods

1. Biological Control

Biological control involves the use of insect parasitoids, predators, pathogenic organisms and other agents that reduce the reproductive potential of pest species.

a. Insect Parasitoids and Predators

Entomologists have used propagation and have distributed natural enemies to control destructive invertebrate pests for many years. One classic example of a biological control effort in 1888 involved the introduction of the vedelia beetle (*Rodolia cardinalis*) from Australia to control the cottony cushiony scale on citrus in California. The success of this particular program spurred the development of many of the biological control programs still in existence today.

It is well documented that many of the important economic pests have been introduced to the United States. Without the natural resistance applied to them by predators and parasites in their native habitats, these insects established themeselves rapidly.

To offset this, programs have been initiated to preserve and increase the number of native (endemic) predators and parasites. A complementary strategy is to search the pest species' native home for control agents that can be imported. Once located, these beneficial control agents are propagated and released in the hope that natural control mechanisms can be established.

b. Pathogenic Organisms

Natural outbreaks of fungal, bacterial, viral or protozoan diseases of various insects have led many entomologists to develop methods to propagate and disseminate these pathogens for the control of insect pests. It is currently believed that these agents are safe and effective in the control of insects pests if applied at the proper time. Another advantage these agents have is their specificity.

Among the better known of the current pathogenic agents currently used and investigated are the polyhedrosis viruses that attack loopers and other noctuid moths. Presently, only one virus is registered for agricultural use, Elcar. There has been considerable success with various strains of *Bacillus thuringiensis* (a bacteria), which have also been shown to be pathogenic through several methods, including the production of a naturally occurring toxin. There have been several other successful demonstrations of pest control with various fungi and protozoans.

The most prevalent limitations to using these control agents are cost and rapid deterioration. The agents often lose their infectivity or toxicity when subject to adverse environmental conditions including sunlight, low relative humidity and extreme temperatures. In some cases, these agents may take from one to several days to achieve control. The technology surrounding these pathogenic control agents continues to improve.

c. Reproductivity Control (Sterile Male Technique)

Another attempt to control pest populations with biological methods has been through manipulation of pest reproductive potential. Several techniques have been developed to accomplish this including radiation treatments or the application of sterilizing chemicals in the field. Other efforts have been made to manipulate the genetics of pest species by elaborate cross-breeding to insects that produce few, if any, females.

The most successful use of the sterilizing techniques has been for the control of screwworm flies. Male flies were mass-reared, sterilized with gamma radiation and then released. These sterilized males mated with naturally-occurring fertile females. After these matings, the females could not produce viable eggs. The success of this program relied on two factors: 1) the sterilized males had to be of equal vigor and have the same mating behavior as the field males and 2) the sterilized males had to be released in greater abundance than the naturally occurring males. The greatest disadvantage in this type of program was the cost of mass producing and releasing the sterile males. However, the costs in this situation were offset by the successful control of the flies.

2. Plant Resistance

People who produce agricultural commodities recognize that certain biotypes or varieties of plants are less affected by insects and their damage than others. These plants that inherently sustain less damage or infestation by pest species have been termed "resistant". Plants exhibit resistance through nonpreference, i.e., the pest insect simply prefers other biotypes than the one that is planted. Another type of resistance in plants is antibiosis. Antibiosis is an ability of the plant to reduce the longevity and survivability of the feeding individuals. In some cases, the natural products of the plants have been shown to be toxic or repellent to invading insects.

Certain plants show resistance through tolerance. Certain tolerant plants may outgrow the damaging effects of a pest infestation. Other tolerant plants can support large populations of insects because they can repair the damages caused by the infestation or compensate through increased vigor or rapid growth during periods where insect populations are reduced by environmental factors such as extreme heat or cold.

The advantages in using resistant or tolerant plant varieties is that the control obtained may often be permanent with no toxic residues or hazards associated with chemicals. The limitation is the possibility that the resistant varieties may be susceptible to pathogens or may be less productive. Because the resistant varieties are built on a similar genetic base, care must be taken to insure resistance to a number of factors in addition to insects such as plant pathogens, nematodes and climatic conditions.

3. Cultural Control

Some insect pests of agricultural importance may be kept below the economic threshold by various cultural or management practices that successfully manipulate the environment to make it less favorable for the development of damaging population levels. These practices are intended to prevent pest damage through source reduction rather than through the destruction of an existing pest population. Important general practices include keeping the plants healthy with proper and timely fertilization, drainage, irrigation and cultivation. Some common cultural controls include crop rotation, time of planting and harvest, tillage, animal and plant waste disposal, crop spacing, pruning and thinning, water management, weed management and use of proper plant species or varieties.

4. Legal Control

Legal (quarantine) control uses procedures that resist the introduction or spread of a pest into an area. Examples would be trapping, inspection stations and cooperative efforts of federal and state agencies to abate potentially threatening pests.

5. Use of Pheromones

Many behavioral traits of insects are controlled by communication chemicals or "pheromones". These chemicals are secreted by one or more insects and are usually received by other insects of the same species. The pheromones ellicit certain responses such as aggregation or dissemination. The chemicals also control such behaviors as mating and defense. An example of pheromone use as a pest control method has involved sex pheromones.

Female insects typically produce minute amounts of a pheromone that attracts males. The chemical composition of some insect pheromones have been identified and reproduced in the laboratory. The pheromones have been used in traps to assess the presence of foreign insects in new areas. They have also been used as a direct means of control in mass trapping programs or to confuse the males, which prevents mating.

The first U.S. registration of a sex pheromone for protection of a field crop was granted for the use of gossyplure to suppress pink bollworm infestations in desert cotton. Development efforts continue for pheromone products for pests in other field crops, forests, stored products, fruit and vegetable crops and for various household pests.

6. Use of Hormones

Hormones are products of living cells that circulate in body fluids to produce a specific effect on the activity of cells remote from their point of origin. Various types of hormones control molting, metamorphosis and sexual maturation in insects. One of these is the brain hormone, secreted by special cells in the brain to activate gland's in the prothorax, which in turn secretes a hormone called ecdysone. One or several of these ecdysones cause the insect to molt. The juvenile hormone determines the form that the insect will take upon molting. When the juvenile hormone is active, the larvae remains in the larval stage. But when the hormone is active or inactive, the larvae molt into pupae or adults. In simple terms, the presence of the juvenile hormone delays the development into the adult stage. Insects prevented from reaching the adult stage could not reproduce and populations would decline. Recent research has indicated that synthetic hormones (analogs) mimic the action of the juvenile hormones and these may be used in insect control efforts. Methoprene (Altosid) is a synthetic juvenile hormone and diflubenzuron (Dimilin) is a chitin inhibitor, which interferes with molting.

7. Chemical Control

a. Insecticides

1) Classification by Mode of Action

Chemical control is achieved through the use of various pesticides. Insecticides are the largest group of pesticides and they may be classified in several different ways. Insecticides vary not only in the way they enter the bodies of insects, but also in the way they kill. The manner in which a particular insecticide accomplishes this goal is called its mode of action.

Stomach Poison: Some insecticides enter an insect only orally and kill by absorption through the digestive tract; such materials are called stomach poisons. Until recent years, the stomach poisons applied to plants remained on the foliage or fruit surfaces and affected chewing insects that fed on those plant parts. During the last ten years, an increasing number of systemic insecticides have come into use. These substances enter plant or animal tissues and kill chewing as well as piercing-sucking insects.

Contact: Substances that kill insects by contact are derived from many sources and act in different ways. Generally, contact poisons enter the body or respiratory system and thereby affect the nervous or respiratory system. Contact poisons may be applied for controlling insects with any type of mouthparts. Many contact poisons will also result in stomach poison action if taken orally, but most of them affect the normal functioning of the insect before ingestion takes place.

Fumigants: Fumigants are chemicals that enter the insect in gaseous or vapor form through the respiratory system. Although fumigants are adapted primarily for use in enclosed spaces, a similar effect may occur outdoors from the use of certain very volatile insecticides.

2) Classification by Chemistry

Insecticides can be classified by mode of action or by chemistry. Given the uncertainties associated with classifying them according to the mode of action, this method is gaining in popularity.

a) Naturally Occurring Compounds

(1) Inorganic Insecticides

Inorganic insecticides, many of which have been in use for many years, are of mineral origin. These are mainly compounds of antimony, arsenic, barium, boron, copper, fluorine, mercury, selenium, sulfur, thallium, zinc, and elemental phosphorous and sulfur.

Sulfur Compounds: The use of sulfur as an insecticide dates back thousands of years. It has been found that the finer the particles, the greater the effectiveness of sulfur as a pesticide. Sulfur is usually applied either as a dust or as a spray made from a wettable powder. In dust form, sulfur is often conditioned by adding a small amount of gypsum, bentonite clay, talc or other material to make it flow more freely. Pure sulfur does not readily wet with water, so an organic wetting agent is added to make it a wettable powder.

(2) Organic Insecticides

An "organic" chemical is one that is formed with carbon atoms as part of the molecule. Certain of these, derived from plants of various kinds, logically called the botanicals. In years past, commercial botanical insecticides have been developed including nicotine, rotenone, sabadilla, ryania and pyrethrum. These botanical products have been used less frequently of late, primarily because of the greater efficacy of the newer synthetic insecticides. The insecticidal properties of the pyrethrum powder extract form the flower heads of *Chrysanthemum cinerariaeolium* have been well known for over 100 years. Although the six natural insecticidal constituents known as pyrethrins have been used against a wide range of garden and household pests, their instability in light has severely restricted their use in agriculture.

Allethrin was the first compound to be synthesized and is a derivative of cinerin. This compound was more stable and uniform then the pyrethrins and made a standardized formulation possible.

b) Synthetic Organic Insecticides

A whole new era in the development of insecticides and insect control began after World War II. The successful use of DDT by the U.S. Army during the war, as well as the successful civilian use of this and similar materials immediately after, firmly established the value of the synthetic organic insecticides (i.e. materials produced first in the laboratory and later in manufacturing plants).

(1) Chlorinated Hydrocarbons (Organochlorine Compounds)

At least two important chemicals in this group were known to chemists for many years before their insecticidal properties were discovered. DDT was first synthesized in Germany in 1874, although samples and factual knowledge of its insecticidal properties were not received in the United States until 1942. BHC (benzenehexachloride) required even longer to be recognized as an insecticide. This chemical was first synthesized by Michela Faraday in 1825 and its structure was determined in 1836; yet it was not until 1941 or 1942 that its insecticidal value was discovered. Because of the persistence of these chemicals, their use sometimes resulted in excessive residues. Contaminated soil may have been washed or blown into streams, lakes and other bodies of water where fish and other life forms were affected. Since then, these materials have been found in living organisms in various body tissues, especially fat, at sublethal levels. Primarily for this reason, most chlorinated hydrocarbons have been taken out of production.

A few chlorinated hydrocarbons, including dicofol and endosulfan, are still in use and can be very effective. Dicofol is mite specific. It has a low mammalian toxicity and is very selective in killing a wide range of mite species with minimum effects on natural enemies. Endosulfan has been particularly useful in controlling the green peach aphid, which has become resistant to several organophosphorous compounds. Endosulfan is an exception as most hydrocarbons are most effective against chewing insects. Endosulfan is also effective against various caterpillars, whiteflies, woodboring insects and cyclamen mites.

(2) Sulfone and Sulfite Compounds

The chemicals in this group are primarily nonsystemic contact miticides (acaricides) with low mammalian toxicities. Aramite, one of the oldest representatives of the sulfite group, is an extremely effective contact miticide. Few, if any, cases of resistance to this compound have been reported. Aramite was once registered and used extensively on a wide range of crops. Unfortunately, a few years ago, it was found to have carcinogenic (cancer-causing) properties. Its use is now restricted to post-harvest applications to nonbearing vines and fruit trees or ornamentals.

Propargite is the newest compound in the sulfite group. It is a very effective miticide of low toxicity to warm-blooded animals. It also has a low toxicity to honey bees and other beneficial insects. It is presently used on strawberries, cotton and several fruit trees.

(3) Organophosphorous Compounds

Some of these compounds were developed near the end of World War II for use as insecticides after Nazi Germany lost its foriegn supply of compounds such as nicotine. In general, organophosphorous compounds (OPs) are highly toxic to insects, mites and other animals. The mode of action against insects and mites varies with the compound, but contact and stomach poison actions are common. Some with high vapor pressures kill by fumigation. Several are systemic in plants or animals.

The mammalian toxicities of the various compounds in this group vary widely. While some are very safe to use, others are extremely toxic and must be handled with special care, protective clothing and respiratory devices. These pesticides attach themselves to the cholinesterase enzyme, which is necessary for normal nerve function.

Since organophosphates "tie-up" cholinesterase, they are referred to as "cholinesterase inhibitors" or anticholinesterase compounds.

When cholinesterase is tied up and unable to perform its normal function, the nerves in the body continue to send messages to certain muscles, making them move constantly. These constant muscle twitchings and weaknesses are referred to as tremors or fibrillations. If this muscle action becomes intense, fits or convulsions (uncontrolled, violent muscle actions) will follow. Signs and symptoms of this type of pesticide poisoning in humans may be small or pinpoint pupils, watery eyes, excessive salivation, dizziness, excessive sweating, rapid heartbeat, vomiting, stomach cramps, diarrhea, difficult breathing, loss of ability to use muscles, loss of ability to control bowels and unconsciousness. These last four signs are seen only in advanced or severe cases of poisoning. The patient, even though near death at this point, may be saved if proper medical treatment is obtained quickly and continued for sufficient time.

The OPs are generally less stable than the organochlorines. They break down in the presence of water and sunlight through a chemical reaction called hydrolysis. Some hydrolyze very rapidly, becoming non-toxic in a few hours, while others may take several days. Upon hydrolysis, some OPs become more toxic before they breakdown into non-toxic compounds.

Organophosphorous compounds also tend to have relatively high vapor pressures (readily vaporize) and thus are often rapidly lost into the atmosphere. These materials are not stored in the body fat of animals, but are readily broken down and excreted through the kidneys. Although many of these materials have a very high acute toxicity and can cause immediate harm to man, wildlife, honey bees and other beneficial species, they are thought to have little long-term effect on the environment.

OPs can be generally grouped according to major characteristics of residual activity, mode of action and use. Exceptions do exist, however, and some could be placed in more than one category. A general knowledge of the characteristics of the materials can be useful in selecting one that is suitable for a particular pest control problem.

Trichlorfon has a low mammalian toxicity and two general areas of use as an insecticide. Often formulated as Dylox, it is used primarily on crops for control of various beetles, plant bugs and caterpillars. It has been very useful in integrated control or pest management programs in alfalfa, cotton and other crops because it is selective and does not harm certain natural enemies. Trichlorfon hydrolyzes rapidly to dichlorvos in warm, alkaline water and should be used immediately upon mixing. Buffering agents may be added to the spray tank to slow the rate of breakdown.

Naled is a moderately toxic insecticide that is useful against a wide range of pests. Because of its short residual action, it is useful close to harvest time on many fruit and leafy crops.

With increasing concern about contaminating the environment with persistent materials, the OPs, which were once used widely for soil insects, are being replaced by other insecticides. For instance, the usefulness of parathion, one of the earliest OPs, is diminishing.

Mevinphos (Phosdrin), phosphamidon (Dimecron) and monocrotophos (Azodrin) are all considered short residual, systemic insecticides and all are highly toxic to warm-blooded animals. However, Mevinphos is very useful in controlling aphids and other pests on fruit, nut, vegetable and forage crops close to harvest time.

Phosphamidon is less toxic than Mevinphos, but still in the highly toxic range. It has a short waiting period of one to three days on various vegetable crops.

Monocrotophos is reported to have short systemic action against certain insects, but its primary usefulness is for contact action against plant bugs and caterpillars on cotton and a wide range of insect pest on ornamentals.

Demeton, oxydemeton-methyl, dimethoate, phorate, disulfoton and dicrotophos can all be considered systemic insecticides with a relatively long residual action in plants. Again, the particular compound, the dosage, the use and other factors govern residual activity. Systemic insecticides have several advantages. When applied as sprays, some are absorbed very quickly into the leafy tissue and leave little toxic residue on the surface. This causes a minimum of harm to beneficial insects, while killing such sucking plant pests as aphids and leafhoppers. Systemics applied to the soil as granules or liquid drenches or by injection may also be taken into the plant through the roots, thus acting selectively and leaving no residual on the foliage to affect beneficial species.

(4) Carbamate Compounds

The carbamates, like the organophosphorous compounds, are cholinesterase inhibitors. Enzyme inhibition from these materials, however, is rapidly reversed in the mammalian body. These compounds range from very low to very high in mammalian toxicity. Some are strictly contact insecticides, while others are systemics.

The first of this group to be widely used commercially was carbaryl. This contact insecticide has a low mammalian toxicity, is affective against a wide range of chewing and sucking insects, and has a short residual action. It can be used close to harvest on many vegetable, fruit, field and forage crops. It is damaging, however, to many parasitic and predaceous forms and to honey bees.

Methomyl is a fast-acting contact insecticide with about three to five days residual. It has a high mammalian toxicity but breaks down quickly, allowing use fairly close to harvest. It is effective against various caterpillars, aphids, thrips and beetles on vegetables and ornamental plants.

Carbofuran is a systemic carbamate of fairly high mammalian toxicity. It acts as a systemic when applied to the soil or a contact insecticide when applied to plant foliage. It controls mites and chewing and sucking insects.

Aldicarb is also a systemic carbamate. The acute oral toxicity of this material in the technical form is one of the highest of all available insecticides. Aldicarb has been shown to be affective systemically on a wide range of chewing and sucking insects, as well as mites and nematodes. It is used on cotton and ornamental plants.

(5) Pyrethroids

The development of light-stable compounds with a high order of toxicity to insects created a whole new class of insecticides called pyrethroids, which are derived from the naturally occurring insecticide pyrethrum. Many of these compounds are efficacious on insects with field dosages as low as 1/50 of a pound per acre. They are not particularly toxic to mites, birds and mammals (including man), although they are very toxic to fish. The first two pyrethroids registered were permethrin and fenvalerate.

b. Fumigants

Fumigants are another type of pesticide used in several forms. They may be solid (crystal, flakes, pellets, powder, briquettes), liquid, or gas (vapor). Regardless of the form in which they are applied, they must have the ability to volatilize (vaporize) readily and to form a toxic concentration of vapor in an enclosed space or within a short distance from the point of application.

All fumigants that are effective against insects are also toxic to warm-blooded animals. Like other pesticides, they vary widely in toxicity: some are extremely toxic and should be handled only by an experienced operator with proper protective equipment.

Fumigants may be applied in enclosed spaces, such as tight fumigation chambers, in buildings and greenhouses, under tents covering trees or other plants, under gas-tight tarpaulins, in the fumigation of grains, fruits, and food products, in burrows of animals pests, or with soil injection equipment for soil fumigation.

Methyl bromide is a colorless, usually odorless, gas. It is one of the most widely used fumigants for stored grains, fruits, vegetables, food and feed products, seeds, bulbs, nursery stock, and drywood termites in buildings. It must be applied to gas-tight enclosures, such as sealed box cars, ship holds, metal bins and tanks, fumigation chambers, or beneath gas-proof tarpaulins. Methyl bromide is heavier than air and will settle to the lowest part of the space being fumigated. For this reason, electric fans must often be used throughout the recommended period of exposure to assure circulation of the gas to the upper portions of the materials being fumigated.

Since methyl bromide is colorless and usually odorless, a person may be exposed to an injurious or lethal concentration without knowing it. A warning chemical, such as chloropicrin, is often included in the formulation of methyl bromide. While chloropicrin adds some insecticidal value to the combination, its chief purpose is to supply an intense odor and severe irritation to the sensory system and respiratory passages to prevent long-term exposure to the chemical and possible poisoning.

c. Synergists

Synergists are materials that may not be toxic but are used to increase insecticidal effectiveness of other materials. One of the first materials discovered to have synergistic properties was sesame oil, which increases the effectiveness of pyrethrins when used in combination with them. Common synergists used today, particularly in fly sprays and sprays for household use, are piperonyl sulfoxide.

d. Formulations

Insecticides are rarely used in their pure form but are usually combined with other materials in a formulation. Common formulations are powders or dusts, wettable or soluble powders, emulsifiable concentrates, granules, and aerosols. In addition to the insecticide, these may contain one or more of the following: a carrier or diluent, a solvent, an emulsifier, or a spreading and sticking agent. Those ingredients considered inert have little or no effect on the pest but provide volume for more even distribution of the insecticide.

Each type of formulation has its own peculiar characteristics that should be considered in making a choice. Some factors to take into account are the type of pest to be controlled, available equipment, location of treatment (indoors and outdoors), susceptibility of plants to chemical injury, importance of unsightly residue, difficulty of obtaining good plant coverage and hazard of drift to adjoining areas.

Dusts (D): Insecticide dusts or powders are composed of an insecticide (toxicant) and carrier (diluent). These diluents are usually talcs, clays, pyrophylite, diatomaceous earth, walnut shell flour, or others. Some materials are light, with a low bulk density; others are considered heavy. Often one mixture of two or more of these types is used to obtain a bulk density value that will give the best dusting qualities and prevent caking or clumping in storage. Dusts are often prepared by mixing a solution of the insecticidal chemical in a volatile organic solvent, such as acetone or benzene, along with the dust diluent. The solvent is then allowed to evaporate, and the mixture is ground in a hammer mill. Another method is to dissolve the insecticide in the organic solvent and spray it into the dust diluent during the mixing and grinding process.

Advantages:

Dusts often penetrate dense plant foliage better than sprays and provide better coverage. They are less likely to cause plant injury than some other formulations because usually they contain no solvents, oils, emulsifiers or other agents of this type. Dusts are applied just as they come from the container; no water supply is necessary, eliminating the need for a nurse rig when the area to be treated is some distance from a water source. Actual dusting equipment usually costs less than conventional spray equipment because it does not require expensive pumps, nozzles, and valves.

Disadvantages:
One of the serious disadvantages of dusts is the drift problem. Drift may be a hazard to people living in nearby homes, livestock and pets. Undesirable residues on nearby feed or food crops can also result from drift. Since dusts deposit less material than sprays, these treatments usually provide shorter residual pest control. Residues from dusts are easily washed from plants by rain, dew or sprinkler irrigation, or blown off by wind; the insecticide is therefore lost. Dusts are usually visible on plant foliage, a disadvantage when unsightly residues are undesirable.

Wettable Powders (WP or W): Wettable powders are made in much the same manner as dusts except that, in addition to the toxicant and diluent, a wetting agent and sometimes a spreader-sticker are added. The wetting agent makes it possible to disperse or suspend the wettable powder in water for use as a spray. The spreader-sticker aids in spreading the spray over the plant and causes the insecticide residue to adhere to its surface.

Advantages:
Although wettable powders have wetting agents or spreader-stickers, they contain no solvents; they are therefore less likely to cause plant injury than emulsifiable sprays containing solvents. Wettable powder deposits adhere well to surfaces, providing a relatively long residual effect according to the toxicant involved. Wettable powder sprays do not drift as readily as dusts.

Disadvantages:
Since wettable powder sprays are merely minute particles dispersed or suspended in the water, they will settle out unless they are constantly agitated. For this reason, equipment used in applying wettable powder sprays must be provided with some means of constant mechanical agitation. This is usually a series of paddles mounted on a shaft, which runs through the lower part of the spray tank and is turned by the engine that powers the power spray pump. Despite the lack of adequate mechanical agitation, some formulations of wettable powders tend to lump and plug screens and nozzles. Since the diluents in wettable powders are clays or other materials of mineral origin, they are quite abrasive and tend to cause wear to spray equipment parts such as pumps, valves and nozzle orifices. Like dusts, wettable powders also tend to leave a visible residue on plant foliage.

Emulsifiable Concentrates (EC or E):
Emulsifiable concentrates are made by dissolving the insecticide (toxicant) and an emulsifying agent in organic solvent. Two general types of solvents have been used: 1) solvents that evaporate along with the water after spraying and leave a deposit of the toxicant on the plant; 2) nonvolatile solvents that leave the treated leaf surface coated with a solution of the toxicant in oil after the water has evaporated.

Advantages:
Once mixed with water, emulsifiable concentrates usually form a rather stable emulsion that requires minimal agitation. Usually, the flow from the pump bypass in most spray tanks is sufficient to prevent breakdown of the emulsion during the spraying operation. Emulsifiable concentrates are easy to measure because

recommended dosages are usually given in terms of volume rather than weight, as with wettable powders. Since no clay or other mineral carrier is used, results are less abrasion to spray equipment parts, a minimum of clogging of screens and nozzles orifices, and no unsightly residue on plant foliage. When sprays using emulsifiable concentrates have been applied, and the water and solvents have evaporated, an insecticide residue adheres closely to the treated surface and is not easily washed or blown away (as are dust residues).

Disadvantages:
Because they contain organic solvents and emulsifying agents, emulsifiable concentrate sprays have more of a tendency to cause plant injury than either dusts or wettable powders.

Soluble Powders (SP): Soluble powders are similar to wettable powders, except that the particles are completely dissolved in the water rather than in suspension. Also, as with wettable powders, these materials contain no solvent that might add to the hazard of plant injury. They also have some of the advantages of the emulsifiable concentrates: once the powder is dissolved, the particles do not settle out, and screens and orifices do not clog; usually no unsightly residue is left (as with wettable powders); and the toxicant deposit on the plant is not readily lost (as with dusts).

Encapsulated Pesticides: Encapsulated pesticides are enclosed in tiny capsules or beads of thin polyvinyl, nylon or other plastic material to control release of the chemical and extend the period of diffusion, thus providing increased safety to applicators as well as to the environment.

Granules (G): Granular formulations of insecticides contain a toxicant and a diluent or carrier, such as clay, vermiculite, ground walnut shells, or other inert materials. These ingredients are formed mechanically into very small pellets or granules. Often a "binder" may be added to the ingredients to prevent the granules from breaking up into powder during storage or handling.

Advantages:
Granular formulations of highly toxic chemicals are usually less hazardous to handle than liquid formulations. When accidentally spilled on clothing or shoes, granules do not penetrate the skin, whereas liquids often do. Far less danger of drift occurs with granules than with dusts and many sprays. Granules are relatively easy to apply to the surface of the soil around individual plants by hand, side dressed along plant rows, or broadcast over fields by power equipment. Certain kinds of fertilizer spreading equipment can by adapted for applying granules; or relatively inexpensive equipment, made specifically for applying granules, can be purchased. Granular formulations of several contact insecticides have been effective in controlling certain pests that live in or on the surface of the soil, while granular formulations of some of the newer systemic insecticides are effective in controlling aphids, mites, thrips and others.

Baits: Various types of bait formulations are available. Wheat bran, with an insecticide, water and molasses added, was a common homemade bait for many years. It was used for grasshoppers, crickets, earwigs, cutworms, snails and slugs. Occasionally, sawdust was substituted for half of the bran. Commercial bran baits (either meal or pellets) containing metaldehyde and calcium arsenate are used for snails and slugs.

Baits using apple pomace with metaldehyde or carbaryl as the active ingredient are commercially available for control of snails, slugs, cutworms and other pests.

e. Phytotoxicity

Several factors may be responsible for the phytotoxicity of pesticides.

Nature of the Chemical: The nature of the toxicant or so-called "active ingredient" in a pesticide formulation may directly react with living tissue and result in injury. Often where the toxicant is ordinarily harmless to the plant, injury may be caused by a solvent, wetting agent or emulsifier, which increases the penetration of the toxicant into the living tissue.

Plant Tolerance: Plants vary in their susceptibility to injury by different chemicals. This cannot be predicted without extensive testing, carried on during the development of an insecticide.

Plant Age: The susceptibility of a plant to chemical injury is often determined by its age. Chemical treatment may often injure young seedling plants, while older plants of the same species and variety are not affected. The same is often true of new plant growth. Young, tender, new leaves or fruits may be more susceptible to injury than older, more mature leaves or fruit on the same plant.

Application Method: The manner in which a pesticide chemical is applied may be determined by whether or not injury will occur. For example, use of excessive pressure while spraying may cause physical injury to plant tissues or drive the chemical into the stomata (openings in leaves through which oxygen, carbon dioxide and water vapors pass).

Chemical Concentration: The concentration of chemicals used is highly important in relation to plant injury. Certain concentrations of chemicals may be harmful to plants, while higher concentrations may cause slight or very severe damage or even kill the plant. The concentration should be high enough to give control of the pest involved, yet low enough to avoid plant injury. Directions for use of a chemical must be followed closely and measurements be made accurately.

Compatibility: Certain pest problems may require the combination of two or more chemicals. Certain substances, however, are not chemically compatible with others; undesirable reactions occur, such as the break down of one or more chemicals, foaming, flocculation or lumping of ingredients. These reactions may result in plant injury, difficulty in mixing, clogging of spray nozzles and screens, and failure to control the pest. Compatibility charts of spray chemicals are available from chemical manufacturers as well as from other sources. The charts should be consulted before combining chemicals, if the compatibilities are not already known.

f. Environmental Impact of Pesticides

Pesticides are effective, safe tools when used in the proper manner. While the major problems of famine and pestilence have not been completely conquered, for the first time in history technology now exists to produce an adequate food supply and maintain a lifestyle relatively free of insect pests. These advances in the quality of life have been made possible through the use of various chemical products, including pesticides.

The events of recent years have made it obvious that no chemical panaceas will solve all pest problems. Pesticides are designed and formulated to kill and restrict pests; and because of their nature, they can become a two-edged sword. They can be used in a safe and effective manner, or they can cause externalities in the form of environmental hazards. Because of the externalities that may result from the misuse of pesticides, stricter standards and environmental impact studies are now required from governmental agencies, such as the Environmental Protection Agency (EPA), Food and Drug Administration (FDA) and Occupational Health and Safety Administration (OSHA). These governmental activities reflect both the greater public awareness of the undesirable effects of misuse of pesticides and the increasing use of chemicals.

The term "environment" includes the sum total of all of the conditions and influences that affect the development of an individual; i.e., our surroundings. Scientists now have instrumentation to detect minute quantities of pesticides in nearly all parts of the environment. While chemicals may be present in extremely small quantities (ppms-parts per million), the important fact is that the chemicals are in places where they are not intended such as soil, water and air.

Soil may be contaminated with insecticides or their residues as a result of treatment or application of pesticides for pest control. This can result from incorporation of plant residues into the soil or direct soil treatment. Just how long the pesticides remain in the soil depends on the types of materials applied, the chemical stability and biodegradability of the particular formulation, and the soil type, temperature and availability of moisture. In general, chlorinated hydrocarbons are more persistent in soils than organophosphates or carbamates.

Waterways can be contaminated with pesticides through surface runoff from treatment areas or by direct application of chemicals to control specific pest control problems. In the complex habitat of an aquatic environment, slight amounts of chemicals can have devastating effects such as fish kills and death of beneficial insects. Because of closely knit food chains, biological magnification of pesticides applied even in small amounts may eventually affect man directly.

Pesticides move in the air as a result of drift from application areas, or on contaminated dusts carried from crop lands has been well documented. Air transportation of minute amounts of pesticides is a reality; it is not surprising then that pesticides have been recovered from remote islands or from the polar regions of the earth, far removed from known application sites. Industry and research corporations search continuously for techniques to reduce drift and other forms of chemical movement. New formulations, equipment and timing procedures with particular regard to wind and other climatic factors will eventually solve the drift problem. As a further incentive, stricter federal and state laws designed to enforce air standards are now in place.

g. Non-target Organisms

Chemical applications are directed at specific plant or animal target species. For the treatment to be effective, the target species must be contacted and the chemical must persist long enough to accomplish its purpose. Many pesticides presently used are non-specific, and may kill non-target organisms.

Improper use of insecticides can easily upset the balance of insect pest/parasite and predator relationships in the agriculture ecosystem. An insecticide application to control one or more economic pests may result in high populations of secondary pests. Outbreaks of secondary pest have been noted, for example, when applications were made for pink bollworm. Spider mites increase after such an application because predaceous mites, the natural control agents, are destroyed.

Since many of the parasitic hymenoptera and diptera are highly susceptible to pesticides, untimely applications may free the pest populations from natural biological control. Even when pesticides do not directly kill a pest's natural enemies, they may adversely affect parasites or predators by removing almost all of the pests and other species on which they depend on for food. In addition, reducing natural enemies may also permit the pest itself to multiply more rapidly and recover from the effects of the treatment.

The present day approach to answering the problem of insecticidal effects involves a search for selective chemical action, along with conservation of beneficial insects through a) choice of toxicant, b) timing of treatment, c) selective placement of chemicals and avoidance of drift, and d) use of insecticides only when the pest species is above the economic threshold.

h. Pesticide Effect on Pollinators

Honeybees and other insect pollinators are extremely important in modern agriculture, and the value and cost of culturing these beneficial insects is increasing because of their sensitivity to insecticides. Insect pollination of crops has also become more important, because wild bee populations have been reduced to ineffective levels through pesticide use. Growers of commercial crops often require honeybee colonies for pollination of crops in order to obtain good yields.

Generally, dust applications are more hazardous to honeybees than sprays. If pesticide applications must be made when honeybees are active, formulations not toxic to pollinators should be used whenever possible. If this is not feasible, all beekeepers in the treatment area should be notified to facilitate removal or protection of hives. Often application of short residual chemicals can be made between sundown and sunrise, when bees are not foraging. Covering hives with plastic sheeting or burlap may also serve to keep the bees in the hive and prevent contact with the insecticide. Bees and other pollinators will continue to be a concern for pest control advisors and applicators. However, with reasonable care for their protection, this problem can be alleviated.

i. Insecticide Resistance

What is resistance and how does it develop? Several mechanisms allow an insect to resist the toxic effects of pesticides. The most important mechanism involves the detoxification of the chemicals by means of specific enzymes. Some insects may be resistant because of special behavior patterns or physical adaptations, such as hairs on the tarsal pads, that allow them to avoid exposure to the chemical.

A second type of chemical resistance is co-selection. This phenomenon involves an additional increase in resistance to an earlier compound if a switch is made to a chemical of the same group. An example of this is the continued resistance of houseflies to malathion; although this chemical was abandoned in 1962, a chemical in the same group was used as a substitute. Co-selection often makes it impossible to return to an abandoned chemical and expect adequate results.

Research has demonstrated that resistance does not develop by "adaptation" of individual insects to the pesticide during their life span, rather a matter of selective breeding from resistant survivors of insecticide treatments is involved. Each succeeding generation of the pest following pesticide applications tends to contain larger and larger proportions of resistant individuals. Since the mechanisms that confer resistance are genetically controlled, the offspring of resistant parents tend to also be resistant.

The development of a resistant pest population is a function of the intensity, persistence, and extent of pesticide application coupled with the genetic adaptability of the pest. To avoid or delay development of resistance, the following measures should be emphasized: restriction of applications to the target area; optimum timing of application for the pest involved, based on sound economic thresholds; avoidance of unnecessary persistent pesticides; and chemical measures integrated with alternate means of pest suppression, such as the use of resistant seed varieties, crop rotation, and observance of host-free periods when possible.

Glossary

abdomen - the third or posterior body region of insects; bears no functional legs in the adult stage.

acaricide (miticide) - an agent that destroys mites and ticks.

aestivate - to become dormant in summer periods, during continued high temperatures or in dry periods.

antennae (sing., antenna) - the horns or feelers located on the heads of insects; paired, segmented sensory organs.

biota the animals and plants of a given habitat.

cerci (sing., cercus) - the thread-like or forcep-like appendages (usually paired) near the tip of the abdomen; usually slender, filamentous, and segmented.

chelicerae - feeding appendages on spiders.

chitin - a colorless, nitrogenous polysaccharide, a chemical compound intermediate between proteins and carbohydrates, applied to the hard parts of the insect body, the modern term for which is sclerotin.

choline esterase - an enzyme in the blood normally present and necessary for proper nerve function.

cornicles (siphunculli) - short, blunt horns or tubes (sometimes button-like) on the top and near the end of the aphid abdomen; give off a waxy liquid which helps protect against enemies.

cuticle - the outer covering of an insect.

diapause - a period of arrested development or suspended animation.

economic injury level - the lowest population density that will cause economic damage.

economic threshold - the density at which control measures should be initiated to prevent an increasing pest population from reaching the economic injury level.

ecosystem - the interacting system of all the living organisms of an area and their nonliving environment.

elytra - the leathery or hard front wings of beetles; usually cover the hindwings when at rest and are sometimes called "wing covers."

halteres - small knob-like organs (sometimes shaped like a baseball bat or bowling pin) located on the thorax of Diptera.

hormone - a product of living cells that circulates in body fluids and produces a specific effect on the activity of cells remote from its point of origin.

hydrolysis - a chemical process of decomposition involving splitting of a bond and addition of the elements of water.

larvae (sing., larva) - immature stages of insects with complete metamorphosis.

larvicide - a material that will kill larvae.

mandibles - the first pair of jaws in insects; stout and toothlike in chewing insects; needle or sword-shaped in sucking insects; the lateral upper jaws of biting insects.

maturation - that part of the life cycle of an insect between the commencement of sexual maturity and normal death.

mesothorax - the second or middle thoracic ring that bears the middle pair of legs and the first pair of wings.

metamorphosis - the series of changes through which an insect passes in growth from the egg through the larva and pupa to the adult; incomplete when there is no pupa or when the pupa is active and feeds.

metathorax - the third or last thoracic segment; bears the hind pair of legs and the second pair of wings or rudiments of these wings, such as the halteres found on flies.

molt - to throw off the old cuticle periodically.

ovicide - an agent that destroys an organism's eggs.

palpi (sing., palpus) - small "feelers" near the mouths of insects, probably used to help select food when eating.

parasitoid - any animal that lives in or on another at its expense and ultimate death.

parthenogenic - asexual, referring to reproduction by direct growth of germs for egg cells, without fertilization by the male element, as in plant lice and gall wasps, etc.

pathogen - an organism that causes disease.

pheromones - naturally occurring chemicals in animals that elicit a specific behavioral response in a receiving individual.

phytophagous - feeding upon plants.

phytotoxic - poisonous to plants.

predator - an animal that preys on others.

pronotum - the top or upper side of the prothorax.

prothorax - the first thoracic ring or segment; bears the first pair of legs, but has no wings.

scales - the powder-like covering that gives color to the wings of most butterflies and moths; actually, very small scales that overlap like shingles on a roof.

segmented - jointed or divided into sections

segments - joints or divisions of the insect body leg or antenna

spiracle - a breathing pore; a lateral opening on the segments of the insect body through which air enters the trachea.

stylet - tubular, sucking mouthparts of sucking lice or other sucking insects.

synthesize - to produce a substance by the union of elements or simpler chemical compounds.

tarsi (sing., tarsus) - the "feet" of insects; the last small segments or joints near the end of the insect leg; may vary from one to five in number.

thorax - the second or intermediate region of the insect body, found between the head and the abdomen; bears the legs and wings when present; made up of three regions or segments: first, prothorax; second, mesothorax; third, metathorax

trachea - a spirally ringed, internal air tube in insects; an element of the respiratory system.

tracheole - a very small, slender trachea.

vector - an organism (as an insect) that transmits a pathogen.

volatilize (vaporize) - to cause to pass off in vapor.

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