GCSAA Integrated Pest Management Study Manual

GCSAA INTEGRATED PEST MANAGEMENT (IPM) STUDY MANUAL

Table of Contents

Chapter 1. Introduction and General Overview

1. Background. The membership of GCSAA established an ongoing requirement that all golf course superintendent members should demonstrate a level of competency regarding knowledge of integrated pest management (IPM). This may be demonstrated by having a valid state or federal pesticide license or by passing the GCSAA IPM exam.

   1.1. Scope. This manual contains basic information related to integrated pest management procedures for golf courses. It is designed to be generic in nature and does not address specific state or territorial unique requirements. It does address federal issues, however, for exam purposes non-United States citizen members will not be tested on U.S. law or federal regulations.

   1.2. References. The majority of the content in this manual was adapted from governmental and open sources. All other sources are endnoted. The reference section contains a detailed list of references and sources used to prepare this manual.

2. Technical information. The most important but often overlooked element of pest management on golf courses is ensuring that knowledge exists at all levels of the program. This is especially true today as golf courses are under scrutiny by many organizations and special interests. The use of pesticides is one of the few activities where we deliberately place toxic agents into the environment with the purpose of killing a living organism. No profession can afford to have uneducated or misinformed people responsible for the distribution and use of such toxicants. This is why the GCSAA membership places such a strong emphasis on educating and training, not only its members, but also all people involved in control programs on the golf course.

3. Human safety. Human safety is the most important concern in any pest management effort. Because golf courses have the potential of exposing non-workers to pesticides, the GCSAA membership emphasized an expanded human safety section of this manual.

4. Environmental concern. The environment refers to everything that surrounds us indoors and outdoors including natural elements, manmade objects, people, and other living organisms. Second only to human health in importance and visibility are the environmental concerns that must be addressed before golf course pest management procedures begin. Over a number of

years, indiscriminate use of pest management chemicals caused adverse conditions that highlighted the dangers of pesticide misuse. GCSAA is involved in efforts to ensure misuse on golf courses and other areas is prevented. GCSAA is a major program participant among the nation's many agencies and organizations in establishing strong environmental protection programs.

5. The golf course integrated pest management (IPM) concept. What exactly is IPM? The definition of IPM from the National IPM Network is the following:

   "IPM is a sustainable approach to managing pests by combining biological, cultural, physical and chemical tools in a way that minimizes economic, health, and environmental risks."

   IPM entails multiple pest control tactics combined into a single plan to reduce pests and their damage. When an IPM program is being designed or evaluated, consider each of the following areas and use only those portions that apply to IPM needs.

   5.1. Inspection. Inspection is an important and often overlooked element of any successful pest management effort on the golf course. Inspections may be formal or informal and should include pre- and post-treatment surveys. Periodically inspect every aspect of the program to determine if the techniques used are effective and achieve desired results. If chemicals are used, make sure pest management actions don't compromise human safety and environmental concerns. Use inspections to identify and help correct potential problems, as well as educate and evaluate worker performance.

   5.2. Non-chemical measures.

      5.2.1. Cultural measures. These measures include techniques such as sanitation, vegetation management and water management. Some golf course superintendents are responsible for facilities and have a responsibility to understand facility sanitation requirements. Building occupants, members and workers need to recognize these conditions for the potential problem they present and correct them as one of the first steps in achieving good management. In addition to sanitation, two other common cultural techniques used are water management and vegetation management. Water management is essential to control water and moisture-breeding pests such as mosquitoes, aquatic weeds, molds and fungus. Techniques include irrigation auditing and timing, improved drainage, reducing areas of standing water, periodically flooding slow moving streams, and adjusting water levels in ponds and lakes. Vegetation management may include plant or tree selection (to prevent species attractive to problem pests), mowing, verticutting, aerating, weed control and brush removal.

      5.2.2. Biological controls. Biological controls are those that involve the regulation of pest organisms using their natural enemies. When these actions occur in nature with no human assistance, its called natural controls. With insects, there is a growing number of parasites, pathogens, and predators available to control a given pest population. While many biological control techniques are not a total answer, and may be of limited success alone, they are good methods for consideration in a true pest management effort. They are considered to be environmentally safe because the control organisms are very “species-specific.” This means they attack only the organisms that require control without causing damage to desirable animals or vegetation. Examples of biological controls include the use of predatory fish and insects, parasites, fungi, bacteria, nematodes, and sterile males of a pest species. There is much research to be done with regard to actual effectiveness of each biological control but it is worth exploring as an option for your IPM program.

5.2.3. Mechanical/physical controls. These are direct or indirect non-chemical measures used to destroy pests outright or to make the environment unsuitable for their entry, dispersal, survival, or reproduction. For golf course superintendents with facility pest management responsibilities, these controls are mostly corrective in nature because golf course superintendents often use equipment that makes a direct physical impact on the pest involved. Because of this equipment, and the time spent maintaining it, mechanical/physical controls are often more expensive than other categories of IPM. Examples include traps, removing and destroying wasp nests from building eaves, temperature manipulation to reduce an insect’s ability to reproduce and survive, and controlling moisture under buildings to prevent the growth of wood-destroying fungi. In new construction, mechanical techniques are the best ways to exclude pests. Although they work best if done during initial construction, they are still a necessary element that should be accomplished even through structural additions or modifications. On the golf course, the use of traps can be effective but consideration of the visibility of a dead or trapped animal needs to be weighed into the option. Although these methods may be more expensive initially, they are more economical over time. Also, these methods can reduce or eliminate hazards to people and the environment other methods may cause.

5.3. Regulatory/legislative actions. Lawmakers at all levels of government have a direct impact on pest management. Regulatory/legislative pest management methods include pesticide laws, sanitation laws, requirements for disposal of garbage and trash, food service sanitation ordinances, noxious weed laws, water use restrictions, establishment and maintenance of mosquito abatement districts, and licensing requirements.

5.4. Chemical measures. In the past, chemical pesticides have been the largest and most widely used pest management technique. But as previously indicated, to conduct a true integrated pest management effort, a number of appropriate methods should be combined to achieve pest reduction with the least potential hazard to people and the environment. Golf course superintendents can apply this “combined approach” idea to chemical control efforts. It’s easy to think of chemical control as using pesticides to kill pests, but there are also chemicals available, such as pheromones, which serve to trap insects, confuse them, or regulate their growth. Nevertheless, golf course superintendents will regularly need to include pesticides in most comprehensive pest management efforts.

6. Operations. The key to the success or failure of any golf course IPM program is often determined by how well it’s designed and planned. A complete IPM effort includes four elements: designing, planning, executing and evaluating. By considering all these factors,

golf course superintendents will develop economical and effective management programs. The benefits come by way of healthy personnel, better playing conditions, a healthy environment and pleased golfers.

7. Program design. To design an IPM program there must first be verified pest problems. There are several sources that can help make the determination, including the golf courses' history of pest problems treated, scientific literature, local extension services, adjacent or local golf courses, and by conducting actual scouting surveys.

8. Planning. The planning phase involves the identification of golf course facilities; personnel and equipment needed to meet program goals. By comparison, identifying pest problems and control methods are part of the design phase. In the planning phase, be prepared to modify the design if conditions warrant. There are many factors that affect pest management. Some key factors affecting golf course pest management are:

    8.1. Personnel roles and responsibilities. Personnel needs are normally the first consideration in this phase. Personnel should be associated with the various tasks required to execute the IPM program. If sufficient personnel are already on hand, no further action is needed in this area. But if more people are needed, this phase of the program may have to occur over time, forcing a delay or adjustment to various aspects of the IPM program.

    8.2. Shop organization and operation. Once roles and responsibilities are established for the IPM program, a supervisor or manager should be identified. In many cases this will be the golf course superintendent but it may also be one of the assistants or a specialized position. The IPM supervisor should be a certified pesticide applicator and familiar with the functions as a supervisor or golf course superintendent. Their responsibilities may include survey and scouting, training, applying non-chemical and chemical pest management methods, formulating and mixing pesticides, and cleaning and maintaining equipment and facilities. In addition to the normal responsibilities of any supervisor, the pest management supervisor may also be responsible for activities such as:

        8.2.1. Maintaining all required pesticide use records. This helps reduce repeated mistakes, maintains proof of proper application and can save money by improving efficiency.

        8.2.2. Conducting pesticide inventories.

        8.2.3. Prioritizing shop activities daily based upon ever-changing pest populations.

        8.2.4. Drafting revisions of the IPM plan as needed.

        8.2.5. Maintaining the program's spill and fire prevention/control plans.

        8.2.6. Maintaining a close liaison with the golf course's medical, fire, security support organizations.

    8.3. Certification. If a controlled or regulated pesticide is being used, most states and U.S. territories require that it be applied by a trained and licensed, or certified pesticide applicator. Any pesticides classified as restricted-use or state-limited-use must be applied by a certified applicator. Improved efficiency, reduced hazard risks and general program savings often offset certification costs over time. Certification of all applicators lets the supervisor use individual operators for all types of pesticide applications in their areas of certification, thus increasing flexibility and efficiency.

8.4. Shop facilities. In all long-term golf course pest management programs, planning must include facilities to house the pest management equipment and materials. In the United States all pest management facilities must meet certain requirements of the Environmental Protection Agency (EPA), the Occupational Safety and Health Administration (OSHA), as well as state and local regulations.

8.5. Proper equipment and material. The next step is to obtain the equipment and supplies needed to do the job. Always check the label of any chemicals being used for equipment specifications and requirements.

8.6. Specialized training. In addition to normal on-the-job needs, some operations require individuals to have additional specialized training, as with fumigation operations. Anytime a new type of operation is called for, workers will need specialized training. Such training is usually available from associations, state and local extension services, industry representatives and local vocational schools.

8.7. Scheduling. Scheduling pest management activities is needed to properly utilize pest management personnel, equipment and material; this rule applies for both normal and special requirements. Work to answer these questions when developing a schedule:

8.7.1. What are the pest population trends (as indicated by scouting and survey results), and the biological habits of the pest to be managed (to determine when the pest is vulnerable)? This is referred to as monitoring the pest population.

8.7.2. What is the relative importance of target pest(s)?

8.7.3. Do pests hold potential for devastation or only nuisance pests?

8.7.4. When will IPM operations cause the least interruption to other activities at the course, or when would they be most effective against the target pest (for example, white grub control)?

8.7.5. Will long- or short-term environmental conditions interfere with accomplishing recurring work schedules?

8.7.6. Are all materials and equipment available?

8.7.7. Are there enough trained personnel?

8.7.8. Is any specialized training required?

9. Scouting. Once a program starts, scouting helps:

9.1. Measure the relative population levels of known pests to determine when to begin specific management techniques.

9.2. Detect presence of new and potentially important pests.

9.3. Detect pest-breeding sites that can be eliminated.

9.4. Measure the effectiveness of previous management efforts.

9.5. Check with other local golf courses to find out what pest problems they are having.

10. Scouting techniques: there are many golf course scouting techniques used to determine relative pest populations. Besides simple visual observation, some of the most common are:

10.1. Habitat sampling - collecting specimen samples such as by dipping for mosquito larvae, or soil sampling for grubs.

10.2. Light traps and carbon dioxide traps for mosquitoes or agricultural/forest pests.

10.3. Bait traps.

10.4. Damage counts.

10.5. Probing to detect damage by pests such as termites.

10.6. Drag cloths and carbon dioxide for ticks.

10.7. Animal traps for small wild animals.

10.8. Floating for chinchbugs.

10.9. Pheromone traps for mole crickets.

10.10. Infrared imaging for diseases and plant stress.

10.10.1. In some cases, golf course superintendents may need to seek out the target pest's normal habitat; in others; they may only need an intercepting device, such as a light trap.

Chapter 2. Entomology

1. Introduction. This chapter describes basic entomological principles of pest management that apply in golf course settings but may differ depending on climatic region.

2. Introduction to applied entomology. Many species of insects, plants, vertebrate and related pests seriously affect golf course operations destroying vegetation, reducing the efficiency of the golf course, or destroying property. To better understand methods of reducing the potential for such adverse results, golf course superintendents must have some basic knowledge of the pests they may encounter. Golf courses should use the terms applied biology or entomology to describe pest management efforts. Operations are much broader than just the field of entomology. They involve other pests such as bats, birds, rodents, snails, snakes, and miscellaneous small animals. The term "applied biology" more correctly describes the range of pests encountered in pest management work. But since insects and related arthropods make up most of the pest problems encountered on golf courses, this chapter emphasizes that group of pests.

3. Classification. This ability to associate objects or ideas that are alike and to differentiate the unlike is a valuable attribute used to advance science and knowledge. In simple terms, classification is a means used to sort and arrange things into related groups according to some logical system. Every species of plant and animal has its own unique set of habits, capabilities and forms. To accurately determine whether or not a specimen belongs to a significant pest species, we mainly refer to its external characteristics.

   3.1. To begin a discussion of insect classification, golf course superintendents first need to understand the differences between the two major categories of living matter: the animal and plant kingdoms. The animal kingdom characteristically consists of free-moving organisms that generally assimilate organic foods, very rarely possess chlorophyll, have cell membranes and lack cell walls. The plant kingdom includes organisms that are characteristically immobile, generally take in organic foods, usually possess chlorophyll and have cell walls in addition to cell membranes. The last characteristic (cell walls) in these two descriptions appears to be the most universal difference between animals and plants.

3.2. Either kingdom may be further divided into seven subordinate categories. Each of these categories includes distinguishing characteristics peculiar to the members of the group at that level of classification. Table 2-1 shows the classificatory breakdown for three different organisms: a human, an insect and a plant.

Table 2-1. Classification system for a human, an insect, and a plant.

Classification	Humans	House fly	Dandelion
Kingdom	Animal	Animal	Plant
Phylum	Chordata	Arthropoda	Spermatophyta
Class	Mammalia	Insecta	Dicotyledoneae
Order	Primate	Diptera	Campanulades
Family	Hominidae	Muscidae	Compositae
Genus	*Homo*	*Musca*	*Taraxacum*
Species	*Sapiens*	*Domestica*	*Officinale*

In addition to formal and scientifically recognized names, there are common or local names for living organisms. A few, like human, housefly and dandelion, are so common we have come to recognize them as the same organisms throughout the world. But many common names are not universally recognized and the same name may characterize entirely different organisms in different parts of the world. A universal classification system like the one in table 2-1 eliminates that problem and lets people worldwide verify that they are dealing with the same organism. Although this manual uses accepted common names, there are organisms that do not have a universally accepted common name. Therefore, golf course superintendents should be familiar with basic classification and the use of scientific names. The following identifies the basic characteristics of five classes of arthropods. Arthropods are invertebrates that include insects, spiders, crustaceans, scorpions, and centipedes.

3.3.

Insects: superclass - hexapoda, class - insecta

Legs in 3 pairs

3 body regions, called head, thorax, and abdomen

1 or 2 pairs of wings (sometimes absent)

1 pair of antennae

4. Morphology. To select efficient pest management methods, it is necessary to know something about the pest's structure or morphology. Morphology is the biological science that deals with the form and structure of living organisms. To cover the morphology of all pests encountered would take a number of volumes, so only a short presentation of basic insect morphology is provided here.

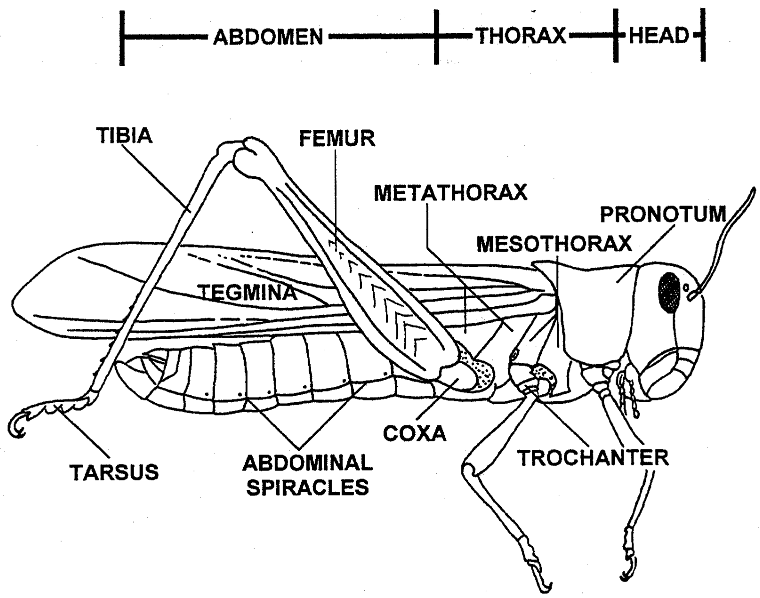
4.1.1. Morphology is used to describe the appearance of an organism so we can accurately and consistently understand and describe how it lives. Morphology also helps us consistently identify insect pests so we can select appropriate pest management strategies.

4.1.2. Insects may be as small as a grain of sand or as large as a doorknob. Size, shape and color all afford good characters for identification. For example, the wasp-like waist (petiole) of an ant distinguishes it from a termite.

4.1.3. The external covering of an insect is quite different from the skin of higher animals. In fact, it isn't skin, but a hard outer skeleton or exoskeleton. This exoskeleton serves as a supporting and protective sheath for the insect and is impervious to most elements in its natural environment. It also protects the insect's internal systems and organs from injury and serves as a framework for the attachment of muscles. Since a hardened exoskeleton restricts further growth, the insect must molt or shed its skin to grow larger. Those animals with similar outer protective coverings are generally known as invertebrates because they lack an internal framework. Higher animals like humans have an internal skeleton (endoskeleton) and are generally referred to as vertebrates.

4.1.4. Some insects have various body parts that are hardened or sclerotized. This hardened cuticle is usually in the form of plates or sclerites, which are not flexible. Movement of the insect's body is possible because the sclerites are joined together by flexible portions of the cuticle called intersegmental membranes. For example, a mosquito's abdomen becomes greatly distended (swollen) during feeding because of the flexibility of these membranous tissues. This is not true growth, since the other parts of the exoskeleton are inflexible.

4.1.5. Insect morphology. An insect's body is divided into three main regions - the head, thorax and abdomen (see figure 2-1). In the related class arachnida (arachnids) the body is composed of only one or two regions. The arachnids are familiar to us as ticks, mites, scorpions and spiders.



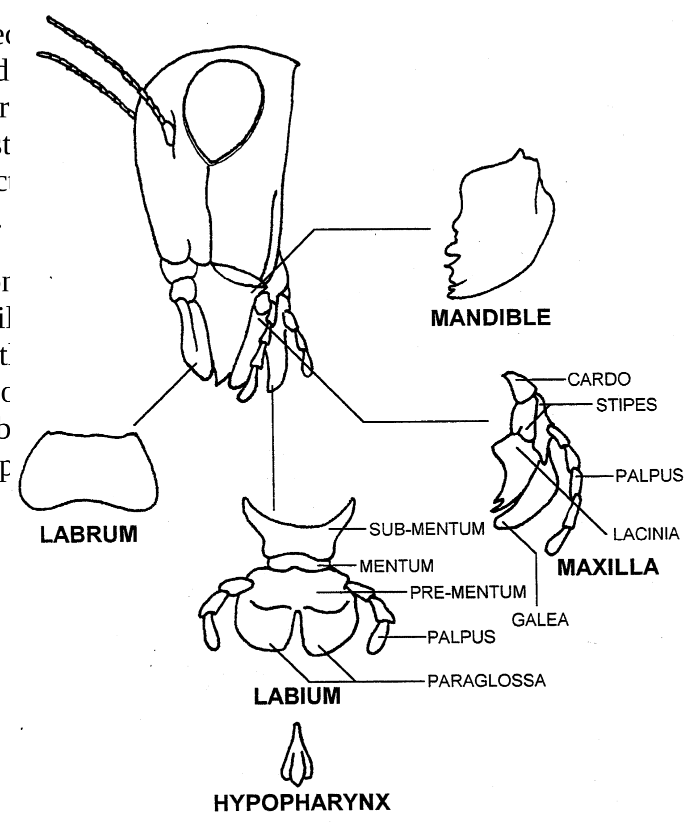
4.1.5.1.Figure 2-1. The three main regions of an insect body.

4.1.5.2.Head. The anterior region of the insect is the head. Its principal appendages are the mouthparts, antennae, compound eyes and simple eyes (ocelli). Adult insects have only one pair of antennae, but crustaceans, a closely related group, have two pairs and arachnids have none.

4.1.5.3.Mouthparts. Insects have an upper lip or labrum, a pair of mandibles, two maxillae, and a lower lip or labium. There are many forms of these parts, but three basic types of mouthparts are chewing, sponging, and piercing-sucking. Some insects have one mouthparts type in their immature stages and another type as adults.

4.1.5.4.Inse ... ndibles do the grind ... andle the food befor ... lpi and labial palpi assist ... l feel food. Some insec ... harynx (see figure 2-2).

4.1.5.5.Spor ... ing up liquid or readil ... h sponging mout ... ing tube called a probc ... m. To help dissolve solub ... onto the food. It then pump ... a liquid.



4.1.5.6. Piercing-sucking. Other insects use piercing-sucking mouthparts to penetrate the outer covering of a host (plant or animal) and suck out internal fluids. As with the sponging-type mouthparts, this feeding tube is also called a proboscis. Examples of insects with this type of mouthparts are mosquitoes, stable flies, fleas, kissing bugs and aphids. Some insects have mouthparts similar to the piercing-sucking type, but they are usually unable to pierce.

4.1.5.7. Antennae. Insects, millipedes and centipedes have one pair of antennae, or feelers, on the front of the head. Most crustaceans have two pairs of antennae, while the arachnids have none. In many insects, antennae are greatly modified and have a variety of shapes that are useful for identification.

4.1.5.8. Eyes. Two types of eyes occur in insects--simple and compound. The simple eyes or ocelli consist of single eye units or facets. Ocelli may be arranged in the form of a triangle between the large compound eyes. The compound eyes are usually round, oval or kidney-shaped. The outer face of each compound eye is composed of many small six-sided lenses, which are called facets. The size of the eyes apparently is related to demands for motion detection in the normal life of the insect.

4.1.5.9. Thorax. The insect thorax is the second body region. It's connected to the head by a membranous region, the neck, or cervix. The thorax comprises three segments that, in turn, are made up of varying numbers of plates, called sclerites. Each segment has one pair of legs and may also have a pair of spiracles. The segments are designated prothorax, mesothorax, and metathorax to indicate their position of first, second and third from the head. Wings, when present, are attached to one or both of the last two thoracic segments.

4.1.5.10. Wings. Insect wings are membranous extensions of the body wall with an upper and lower layer supported by reinforcing structures called veins. Wing veins that run from the base of the wing to its apex are called longitudinal veins. The crossveins cross the wing transversely and connect the longitudinal veins. The arrangement and number of wing veins are important characteristics for identifying insects. Insects typically have two pairs of wings, but some groups, such as flies, have lost the second pair, which remains in rudimentary form as small knobs called halteres, or balancers. Insects having two pairs of flying wings may use them independently or may have them coupled together as in many moths. Some insects, such as beetles, have forewings adapted as wing covers.

4.1.5.11. Legs. Referring back to figure 2-1, insect legs may be short and strong for digging or lengthened for jumping and walking, but they usually have the same number of main parts. The leg is divided into a coxa, trochanter, femur, tibia, tarsus, and pretarsus. The femur and tibia correspond to the human thigh and shin and the tarsus has a function similar to the human foot. Some tarsal segments may bear pads, or pulvilli, which help the insect walk on smooth surfaces like glass.

4.1.5.12. The abdomen, or third body region, has segments, or joints, bearing the spiracles and external reproductive organs. Spiracles are external openings for the respiratory system and some insects have a pair on each abdominal segment. In most insects, the terminal eighth and ninth segments bear the external sex organs used for copulation and the egg-laying device, or ovipositor, of the female. Some insects, such as silverfish, have a pair of tail-like appendages, called cerci.

5. Physiology. Physiology is the branch of biology dealing with the functions and vital processes of living organisms. Understanding a pest's physiology helps us determine effective management procedures even as we work to minimize adverse effects on nontarget plants and animals.

5.1. Digestive system. The digestive system basically consists of a tube running from the mouth to the anus, called the alimentary canal. This canal is divided into a foregut, midgut and hindgut. As an insect eats, the food passes through the esophagus, or throat, to the crop, an enlarged portion of the foregut that is used for food storage. Some insects also have a proventriculus, or gizzard, where food is ground into finer particles. The food then passes into the stomach, or midgut, where digestion takes place. Undigested food then passes out through the intestine and anus.

5.1.1. Insects in a dry environment need to conserve water. Because of this, all possible water is extracted from the liquid mass in the intestines and the feces are discharged as relatively dry pellets.

5.1.2. Insects may have salivary glands and gastric caeca to provide enzymes for food digestion. These glands are sometimes modified to secrete silk, as in many caterpillars, or to prevent blood from clotting, as in the mosquito.

5.2. Circulatory system.

5.2.1. An insect's body cavity is filled with a colorless or greenish-yellow blood that bathes the body tissues, nourishes them, and removes waste products. This blood doesn't bear oxygen and carry off carbon dioxide as in the higher animals, nor is it enclosed in blood vessels. Instead, it circulates through cavities, seeps into the heart through openings (ostia), and is pumped into the head region through the aorta. An insect's heartbeat is regulated by its rate of metabolism and is therefore accelerated by a rise in temperature or by muscular activity. The blood is circulated in the legs and antennae by small pulsating organs. Protective insect blood cells, called phagocytes, destroy foreign matter and plug wounds in the body wall.

5.2.2. Waste excretion from an insect's body is accomplished by the blood and the malpighian tubules. The blood also absorbs unwanted chemicals from the body cells. Then the malpighian tubules extract these wastes from the blood and discharge them into the intestine. These tubes vary in number from 2 to 150 or more.

5.3. Nervous system. Insects have a nervous system much like that found in higher animals. The brain is in the head above the esophagus and is connected to a sub-brain by two nerve cords encircling the esophagus. The double cord extends backward along the ventral surface of the body cavity. Each segment of the thorax has a nerve center or thoracic ganglion from which many nerves arise to serve the thoracic region. The more primitive insects have ganglia in each abdominal segment, but these have been reduced in most of the higher insects.

5.4. Respiratory system. Insects don't have lungs but use a simple system of tubes (tracheae) that diffuse oxygen to all body parts. This system also carries waste carbon dioxide from body tissues. Water loss through this system would be considerable were it not for valves in the spiracles. These valves are regulated by the presence of carbon dioxide; too much of this gas causes them to open. Air then passes through the spiracles into large tracheal trunks that usually run the length of the body. Many tracheae branch off these main trunks and carry air to the tissues through their finely branched tracheoles.

5.5. Reproductive system. Most insects have two sexes that must mate before viable eggs are produced. Some insects, such as the honeybee, can deposit infertile eggs to produce males (drones) and fertile eggs to produce females, such as the workers and queens. Some female insects (e.g. Aphids) may reproduce without fertilization through a process called parthenogenesis. Aphid populations can quickly increase their numbers by this type of reproduction.

5.5.1. Female insects usually produce large numbers of eggs, though some species produce very few and others may deposit living larvae. Insects that lay eggs are oviparous, while species that deposit living larvae are viviparous. The tsetse fly gives birth to larvae that are full grown and ready to pupate.

5.5.2. Female reproductive organs include a pair of ovaries, which produce eggs (ova) that pass through the oviduct into the vagina, where they may be fertilized by male sperm cells stored in the spermatheca. Some species have accessory glands that secrete an adhesive coating or case for the eggs. A single copulation will supply the female with sperm to fertilize a large number of eggs, whether she lays them at one time or at intervals over a long period.

5.5.3. The male reproductive system includes a pair of testes, where sperm cells are developed, and ducts leading to the penis or ejaculatory organ. The seminal vesicle serves as a reservoir for storing spermatozoa until mating occurs. The accessory glands secrete a liquid substance to serve as a vehicle for the sperm cells.

5.6. Senses. Insects have the same senses that are associated with humans, though some are more developed than in people. The five primary senses are touch, taste, smell, sight, and hearing. Auxiliary senses include balance and orientation.

5.6.1. Touch. The hardened cuticle is not sensitive to contact. The sense of touch is therefore served by sensory hairs (setae) covering most of the body. The antennae, or feelers, are also important organs of touch. Additionally, the tarsi and cerci are sensitive to contact, and insects react very quickly to pressure on these organs.

5.6.2. Taste and smell. Insects usually perceive chemical stimuli from odors and substances with a taste by small rod-like organs projecting from the body surface. The mouth, mouthparts, or front feet perceive taste, while the sense of smell is located mainly in the antennae. Palps also bear olfactory organs. Insects have a highly developed sense of smell that they use to locate food, mates, and suitable places for depositing eggs.

5.6.3. Sight. The main organs of sight, compound eyes and ocelli, have nerves that transmit stimuli to the brain. Insects can perceive movements readily, and visual powers usually according to the demand made on them by their habits. Laboratory tests have proved that insects are able to distinguish colors, whereas some of the higher animals, such as rats, are colorblind. Insects cannot move or focus their eyes.

5.6.4. Hearing. Insect groups differ in their ability to hear. Some pick up sound waves by fine sensory setae or special organs such as the auditory drum on the abdomen or lower part of the front legs. Flies and mosquitoes are believed to hear through a cup-like organ on the second antennal segment. This segment responds to sound waves picked up by the rest of the antennae.

6. Metamorphosis. This term refers to the changes in form or structure that occur during insect development (see figure 2-3). Some primitive insects develop without metamorphosis. The young possess all the obvious structures of the adult and differ from them only in size, color, and sexual maturity.

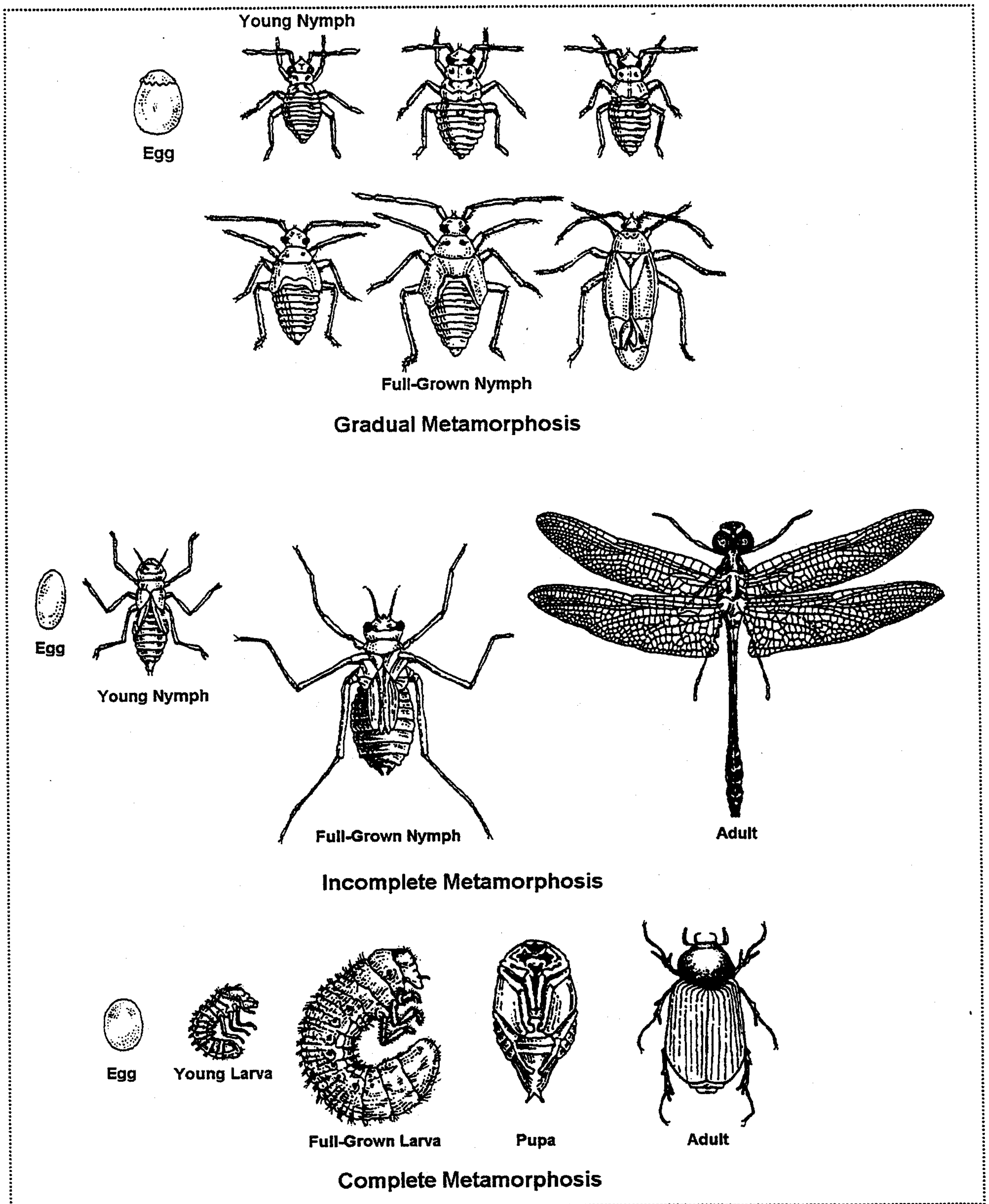


Figure 2-3. Metamorphosis

6.1. Insects with gradual or incomplete metamorphosis have three stages in their life history (figure 2-3): egg, nymph, and adult. Insects in this group change gradually while they go through a number of molts to become adults. The young, or nymphs, resemble adults except for their smaller size and the absence of wings in wing-bearing species. Nymphs are sexually immature and may bear wing pads in later stages of their development. All stages of these insects are found in the same environment, feed on the same foods, and cause the same type of damage

6.2. Insects with complete metamorphosis have four stages in their life history (figure 2-3): egg, larva, pupa, and adult. Insects with this type of life history experience great differences between the immature stages and the adults. Typical larvae are the maggots of flies or the caterpillars of butterflies and moths. During the pupal stage, the simple larva undergoes major structural and physiological alterations to become a mature adult. Most insects with complete metamorphosis have wings as adults, but some species, such as fleas, are wingless. The wing buds normally appear first in the pupal stage. When the young adult emerges from the pupal shell, the wings are crumpled and useless. Hydrostatic pressure of the blood within the insect body forces the sac-like wings outward and the two membranes collapse against each other to form a single structure.

6.3. As mentioned earlier, all insect growth occurs in the immature (larval, nymphal) stage. Insects grow by shedding, or molting, the old exoskeleton and forming a new one. Molting allows an immature insect to shed its protective skeleton, the linings of the respiratory system, and its foregut and hindgut. It then produces a molting fluid between the old exoskeleton and the new soft cuticle. It swallows air or water until its body swells, bursting the old cuticle on the dorsal surface of the thorax in most cases. The insect gradually extricates itself and a new cuticle hardens on its expanded body, thus accomplishing a stage of growth. The number of molts is small and constant in most species, such as three molts for the housefly, or it may be large and variable as with the 12 or more molts of an American cockroach. For a few hours to a day after molting, the insect's body may be soft and pale colored, leading some laymen to refer to it as an albino. During the first day after molting, there is a progressive hardening and coloring of the integument.

7. Ecology. Ecology is the branch of biology that deals with the relations between living organisms, their environment and each other. This discussion is limited to the subject of insects, but keep in mind that vertebrates and plants have an equally complex ecology.

7.1. The existence of an insect species depends upon its biotic potential and the environmental factors opposing it. Each opposing factor includes many subfactors. While there may be only a single target species, there will always be an association of many species in the struggle for survival.

7.2. Collectively, the insect, its environment and the other organisms in that environment make up an ecosystem. The golf course ecosystem is the area golf course superintendents must analyze, treat and protect in the process of managing target pest(s).

8. Biotic potential. An organism's ability to reproduce and build up a population in the absence of all checks is called its biotic potential. In the purest sense, this situation is never found in nature. But since the potential is always present, remember that if any of the natural checks are removed, the insect population gains an immediate advantage and an outbreak or population explosion usually occurs.

   8.1. The reproductive capacity and adaptability of insects are truly amazing. A single termite queen in her life span of approximately 10 years has the capacity to lay approximately 52,560,000 eggs or one every 6 seconds. Aphids possess an adaptation for increased reproduction called parthenogenesis. This form of reproduction doesn't require males to be present in the population. Thus, all the insects present can be females, each capable of producing new individuals. The reproductive advantage of this adaptation is enormous. Another type of reproductive adaptation found among some parasitic insects is known as polyembryony, wherein eggs divide many times into daughter cells before embryos develop. Each embryo can then develop into an individual insect. These examples demonstrate that insect reproductive capacity--biotic potential--can be enormous and, coupled with the short time required per generation (life cycle from egg to egg), can produce an overwhelming population if natural checks are removed.

   8.2. Insects have evolved many behavioral and structural adaptations to ensure populations survive long enough to reproduce. These devices include various means for protection from enemies, inherited behavior patterns that increase survival, diapause (reduced development and metabolism), and food selection.

   8.3. How insects protect themselves from enemies is important. Two protective methods involve coloration and body form. Some beetles have a very heavily sclerotized cuticle which, like armor, is practically impregnable. Other insects can blend in with their background, like the walkingstick, or resemble some unpalatable or poisonous object.

   8.4. An insect's behavior patterns are key to its survival. For the most part, these patterns are inherited and the instinctive reactions they produce are called tropisms. A tropism may be either positive, if the reaction is toward the stimulus, or negative, if the reaction is away from the stimulus. Tropisms are named by using the names of the stimuli as prefixes, which produce the reaction. The following are examples of tropisms which affect insects:

      8.4.1. Phototropism -- response to light.

      8.4.2. Geotropism -- response to earth contact or gravity.

      8.4.3. Heliotropism -- response to direct sunlight.

      8.4.4. Chemotropism -- response to chemical stimuli.

      8.4.5. Thermotropism -- response to heat.

      8.4.6. Hydrotropism -- response to moisture.

      8.4.7. Anemotropism -- response to air current.

8.4.8. Chromotropism -- response to colors.

8.4.9. Thigmotropism -- response to touch.

8.5. One or more of the above tropisms affects virtually all-living organisms. These stimuli largely determine the range or environment where the organism can best survive and thus govern its geographic distribution.

8.6. During the life cycle of most insects, there are periods when environmental conditions aren't suitable for normal activity. To survive these conditions, insects have acquired a mechanism called diapause that enables them to bypass adversity in a state of suspended animation without further development. Diapause may occur in any stage of an insect's development and may be controlled environmentally or genetically. Examples of environmental conditions that can produce diapause are freezing or high temperatures and dryness or highly humid conditions. In the wintertime, dispause is called hibernation; its summertime equivalent is aestivation.

9. Environmental impact. This is a combination of all factors that may affect an organism's population. It's divided into two major categories: physical factors, which include such conditions as moisture, light and temperature, and biotic factors, such as competition, food, host vigor, parasites and predators.

9.1. Moisture and temperature are the two most influential physical factors affecting insects.

9.1.1. On the whole, temperature requirements in insects vary a great deal. Some insects can continue normal activities even at winter temperatures, while others require very high temperatures to function. This is an important point affecting control efforts since each insect species normally can tolerate only a narrow range of temperatures. Temperature limits an insect's ability to spread and also determines when it will appear in the spring.

9.1.2. Water is an essential element in the habitat of all organisms. This makes it a potent force in controlling the lives and activities of insects. The interaction of temperature and moisture is typically more important than either factor alone and, in the range between the extremes, their combined effects are very difficult to separate from each other. Each insect has an optimum temperature and an optimum humidity; when these optima occur simultaneously, the insect's development is enhanced, other biotic elements notwithstanding.

9.2. Food availability, another biotic factor, directly affects the size of the insect population. A serious situation occurs when an insect population increases to the degree that competition within one species, or between different species, becomes very keen for what food there is in a habitat. Competition is greatest between members of the same species since they have identical needs. Food quality also limits development. For example, food may be too moist or may not contain enough of the essential elements for optimal development.

9.3. Apart from the organisms competing within a habitat, another group is always present for which the insects themselves are a food source. This group includes predators, parasites and diseases. Within this group, many species have a variety of characteristics that tend to reduce or hold insect populations in check.

9.3.1. Predators may be classified according to the stage of the host insect they attack. Thus egg, larval (nymphal) and adult predators are associated with a number of insect orders. Predators aren't limited to insects and include such vertebrates as rodents and birds.

9.3.2. From the human point of view, parasites are superior to predators because they tend to be more host specific; that is, they limit their actions to a single species or species complex. While each individual parasite may destroy only one host insect, this is offset by the high rate of reproduction characteristic of parasites. The great majority of parasitic insects are found in two orders, diptera and hymenoptera.

9.3.3. Disease is another natural phenomenon involved in maintaining the balance of nature. There are three types of diseases that attack insects: fungal, bacterial and viral. Often, these are the principal factors involved in reducing large populations of insects.

9.3.4. Host vigor and resistance are two extremely variable factors and depend upon a variety of conditions. A vigorous host may be able to throw off insect attack; but as the host's vigor decreases, so does its ability to protect itself. If the host can maintain vigor and resistance, an insect infestation of epidemic proportions seldom occurs.

9.3.5. The net result of the interaction of all these factors, including biotic potential and environmental resistance, is usually a balance, which causes a population to remain at a relatively stable level. When some member of this interacting group becomes extremely prominent or is seriously curtailed, the balance is broken and a population outbreak or collapse may result.

10. General identification techniques.

10.1. Laboratory identification. To effectively manage any pest, golf course superintendents must know what it is. In some cases, identification is rather simple and can be accomplished by firsthand experience or at the nearest extension office. However, extension offices normally lack the necessary microscopic equipment, preparation material, scientific keys or taxonomic expertise to identify the many species of arthropods encountered. Although a number of arthropods may appear to be the same species, even to a very careful and cautious individual, examination by an experienced professional taxonomist may reveal several different species. Golf course superintendents are encouraged to develop individual identification skills and use aids like pictorial keys. When uncertain, they should always get their identifications confirmed by a qualified professional.

10.2. Preparing specimens for shipment. In most situations, it's necessary to prepare specimens for shipping and identification. This process starts in the field when the specimen is first collected. In some cases it may be possible to immediately place a specimen in the medium used to ship it to the laboratory. At other times, the specimen must be placed in a temporary container to return it to the shop for further preparation before shipment. Regardless of the collection method, make sure to send field collection data with each specimen. At minimum, these must include the date of the collection, location where collected (be specific so additional specimens can be collected or localized management procedures taken, if necessary; and the name of the collector with contact information.

10.2.1. The method of specimen preparation varies with the type and life stage of the pest. Many specimens can be dispatched using a killing jar or killing tube. Most immature arthropod specimens, and those that are very small and don't have scaled wings, should be prepared for shipping by placing them directly in a 75% ethyl alcohol solution. It is best to check with the destination laboratory for shipping and packing instructions.

10.2.2. Field or local identification is usually sufficient for pests like rodents, most small wild mammals, birds, and snakes. In these cases, preservation isn't normally needed or desired; dead specimens should be disposed of appropriately.

11. Resistance to pesticides. In a world where natural and manmade chemicals have had a major impact on almost all aspects of the environment, we are constantly reminded that biological organisms react differently when exposed to the same chemicals over time. This is true for microorganisms, like those that cause staphylococcus infections and gonorrhea, as well as the drugs people take to combat these diseases. It is also true of the pests we seek to manage with chemicals. Today, almost 500 arthropod and arachnid species have demonstrated chemical resistance to one or more pesticides.

11.1. Types of resistance. Pesticide resistance is defined as the ability of a pest population to withstand pesticide treatments that were generally lethal to earlier populations. Its occurrence is most widely documented in the three groups of pests we most frequently target for pesticide applications - arthropods, rodents and weeds. After DDT was developed in the 1940s and the expansion of pesticide use began throughout the world, the potential for pesticide resistance grew along with the huge number of chemicals introduced into the marketplace. However, the impetus to develop more and different types of pesticides started to diminish in the 1970s due to legislative restraints, environmental concerns, and chemical resistance. Today we're seeing the development of fewer, but more target-specific, pesticides, which are less toxic to non-target organisms. For older pesticides still in use, we continue to see new cases of resistance develop. There are two types of chemical resistance we may observe.

11.1.1. Physiological resistance. Physiological resistance is the ability of an organism to physically negate the effects of a pesticide. We've discovered that physiological resistance is a result of both ecology and genetics. Scientists generally consider physiological resistance to be the result of a natural selection process that occurs within a pest population. Exposed pests that survive a pesticide application become the source for future resistant generations, and the ability to survive an application of the same pesticide is passed along to increasing numbers of offspring. Many cases of resistance are caused by excessive use of a certain chemical. But we also know that indiscriminate use or misuse of pesticides largely propels resistance.

11.1.2. Behavioral resistance. The second type of chemical resistance is behavioral and occurs when a pest learns (or acts out of instinct) to avoid a surface, bait, or trap where a chemical has been applied. Regardless of the relative importance of behavioral resistance, most scientists agree that it does occur and, like physiological resistance, can make a pesticide or trap ineffective.

11.1.3. Resistance testing. In some arthropods, such as mosquitoes and cockroaches, resistance now occurs on a worldwide basis. Therefor, it is possible for many insects to develop resistance. If any pests at a golf course appear to be resistant, the golf course superintendent should contact the appropriate pest management consultant, usually state extension, to have the suspect pest population tested.

12. Avoiding resistance. The following is a copy of an article that appeared in the January 2000 issue of Golf Course Management Magazine.

Pesticide Failure or Operator Error?

Rick L. Brandenberg, Ph.D.

Golf course superintendents often rely on pesticides in conjunction with good cultural practices to minimize the negative effects of pests on turfgrass. When we resort to the use of insecticides, nematicides, herbicides and fungicides, we do so with a great deal of confidence that our efforts will provide expected results.

Unfortunately, at times we don't get the results we expect after investing significant time and money in the use of a product. A common assumption is that the product of choice failed.

But 19 years' experience with follow-up visits to sites of pesticide failures indicates that pesticides rarely fail without being weakened or rendered ineffective by some mistake in their use.

The manufactured products we use are channeled through quality-control programs that ensure consistency of the product. Testing at major universities and by private consultants ensures information on local product efficacy.

Despite these assurances, however, pesticides fail. In laboratory and greenhouse work at North Carolina State University, for example, new insecticides often present very promising results without producing similar results in the field.

Several explanations are possible when pesticides don't perform up to expectations. Armed with this information, superintendents can take precautions to reduce the likelihood of pesticide failure. Of course, environmental factors can still enhance or restrict pesticide performance. That only increases the importance of knowing and manipulating other factors, which are under the control of the superintendent, to achieve success with pesticides.

Factors affecting pesticide performance can fit under three broad categories: biological, chemical and physical.

Biological factors

Improper identification of the pest problem unfortunately turns out to be a rather frequent cause of pesticide failure. This often occurs when someone relies only upon interpreting turfgrass injury when making a control decision. Damage can be very misleading. Not only can the damage from different insects look quite similar, but fertility problems, nematodes and other problems can be mistaken for insect injury.

Finding the pest, properly identifying it and monitoring to determine whether it is abundant enough to cause damage should always be first steps.

Poor timing is another biological factor in pesticide performance. Proper timing considers both:

Time of the day when the insect is most susceptible to the pesticide

Periods of the pest's life when the organism is most vulnerable.

Some caterpillars are more active in the evening and are therefore more likely to encounter a recently applied pesticide if it is applied late in the day. Mole cricket nymphs, commonly seen in June and July, are the most susceptible of the insect's stages to pesticides.

Another biological factor, *microbial degradation*, is a rare phenomenon in which soil microorganisms break down compounds. Basically the activity of these microbes is beneficial, for without them we would eventually have intolerable levels of toxins in our environment.

Under unusual circumstances, however, these organisms can break down a pesticide too quickly, before it controls the targeted pest. The pesticide may lose its residual activity or not work at all.

For example, repeated use of Oftanol (isofenphos) has resulted in an unusual increase in the microbes that can consume it and thus degrade it in the soil, and eventually the product has lost effectiveness in some soils.

Although microbial degradation is not widespread or common in most pesticides, its occurrence certainly cautions us not to rely solely on one product year after year and not to use products unless absolutely necessary.

Resistance is a similar biological cause of failure that occurs when the targeted pest becomes resistant to a pesticide. It has not been a significant problem with insect pests on golf courses, but unwise use of pesticides could cause future problems. Lawn care companies and homeowners in the Southeast have battled insecticide resistance in the southern chinch bug (*Blissus leucopterus*) on St. Augustinegrass (*Stenotaphrum secundatum*). The chinch bug has several generations each year and may be targeted repeatedly with insecticide during the year. Resistant individuals survive the treatments and multiply.

Most insect pests on golf courses have only a few generations per year -- although cutworms (*Agrotis ipsilon*) and sod webworms (*Crambus teterrellus*) may have several generations in southern locations -- so the development of resistance is not a big concern, nor is it a good explanation for insecticide failure. Many turf managers have suggested that mole crickets (*Scapteriscus vicinus*) may be resistant to a given insecticide, but work at North Carolina State University does not verify this theory.

Physical and chemical factors
Physical and chemical properties affect the application of the pesticide and its activity once it is applied. These properties include calibration of application equipment and the use of the equipment. Improper calibration -- or wear of nozzles and pumps that have altered sprayer output since the last calibration -- often results in the application of incorrect amounts of pesticide. Label directions may call for specific application directions with required gallonage amounts, so read them carefully.

Some products may be applied using subsurface application equipment that may improve the level of control of soil insect pests. Treating young, immature insect pests will generally permit the use of a lower rate, whereas "rescue treatments" targeted against the larger, more developed individuals, may require a higher rate.

Applying an insecticide under adverse weather conditions can also affect the efficacy of the product. Hot and dry conditions may seriously limit the effectiveness of an insecticide directed toward soil insects. Hot, dry conditions may force the insects deep into the soil, and those same conditions may bind some of the insecticide fast to the soil and organic matter, and some volatilization of the product may also occur. Bright, intense, midsummer sunlight may also break down some insecticides and render them less effective.

Beyond pesticides
Good turf management practices help reduce pest problems and the effects of pest injury by improving turfgrass tolerance. Well-maintained turfgrass does not have much thatch, which can act as a "sponge" for pesticides. Pesticides bound to thatch are essentially unavailable to do their jobs. Many "failures" for white grub and mole cricket control are the result of a thick thatch layer preventing the pesticide from reaching its target.

Irrigation and rainfall also play an important role in insecticide performance. Many insecticide labels call for immediate irrigation after application. This irrigation may reduce surface residues, and it also may initiate movement of the product into the soil where it can be effective and reduce the amount of product left on the surface where it is subject to microbial degradation. Moist soil generally will reduce pesticide binding and encourage soil insects to reside closer to the soil surface where they're more susceptible to control. Hot conditions and dry soils are generally a recipe for insecticide failure.

Mowing is linked closely with biological factors. It is best to treat fall armyworms (*Spodoptera frugiperda*) in the early evening when the small worms are active. It is also wise to avoid mowing the turfgrass for several days. If you mow shortly after treatment, much of the pesticide will be lost on the clippings, which may reduce effectiveness, particularly if clippings are removed.

A final factor that can influence the effectiveness of pesticides is the pH of the spray tank water. Some pesticides are sensitive to higher pH (alkaline) spray tank water. One of the most common sources of alkaline water is municipal supplies. Pesticides may be rapidly broken down or hydrolyzed at a pH greater than 7. The higher the pH, the faster the pesticide is broken down.

Some products are very sensitive to alkaline hydrolysis, but many are not. Dylox or Proxol (trichlorfon) are susceptible to this reaction. If you're using alkaline water in a spray tank, acidifiers or buffers may boost the performance of some products. These additives are cheap and effective, even though some pesticide formulations contain their own buffers. If you are unsure, check with the products' sales representative.

Proper identification of the pest is a critical step in obtaining good pesticide performance.

Read the label

By getting the most out of a pesticide, the superintendent has the opportunity to use less pesticide, avoid additional treatments, save valuable dollars in maintenance, get better-quality turf and work for a happier clientele.

Remember that the pesticide label is the most useful source of information on maximum performance and success from a particular pesticide. Manufacturers want their products to work because they want to sell them again and again. Any useful information that can help their products beat the competition is going to be on the label. Information on vulnerable pest stages, application techniques, timing, soil types and other factors may all be found there.

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Chapter 3. Nutrition and Disease Prevention

1. Introduction. Management of pests affecting turfgrass and other plants on the golf course requires more than a basic knowledge of pesticides. From the time when water is absorbed by the seed and germination begins thus initiating biochemical and morphological activities that result in the development of a plant, it has basic needs and vulnerabilities that must be understood for healthy life. The key to reducing pest damage is plant health care, which means keeping plants healthy enough to resist most pest infestations. One of the most important parts of plant health care is knowledge of nutrient requirements and a sound fertilization program. This section discusses the nutrients needed for plant growth and considers some of the plant growth requirements supplied by the soil. Also discussed are basic-types of fertilizer now available and some of the terminology used in the fertilizer industry.

2. Macronutrients. The macronutrients generally are Nitrogen, Phosphorus, and Potassium (NPK), plus Calcium, Magnesium and Sulfur.

2.1.Nitrogen (N). One of the elements necessary for plant growth is nitrogen. Plants contain about one to five percent nitrogen by weight and it is an integral part of chlorophyll. Historically, animal manures were applied to the soil to put nitrogen back into the soil. The production of low-cost synthetic nitrogen fertilizers caused the use of manure to be less important but still needed in agronomy and horticulture.

2.1.1. The nitrogen cycle. Green plants, animals, and several kinds of bacteria are involved in the nitrogen cycle. The roots of plants absorb compounds of nitrogen combined with oxygen, sodium, and potassium. In green plants, during photosynthesis, nitrogen combines with carbon, hydrogen, and oxygen. Sulfur and phosphorus are added. All these elements combine in the plants to form proteins. Animals need protein, which they get by eating plants and other animals. The animals' digestive systems separate this protein into amino acids. The amino acids combine to form another protein. The animals' energy comes from the protein in the plants. When that energy is released, the animal excretes nitrogen wastes, which go into the soil. Bacteria in the soil or water break down the excreted waste even more. Bacteria also break down dead organisms. Nitrogen from the decaying organism's protein combines with hydrogen to form ammonia. Bacteria in the soil then combine with the ammonia to form nitrites, which cannot be absorbed by plants. Other types of bacteria in the soil combine with nitrites to form nitrates. These can be absorbed by plant roots and, once again, nitrogen enters plants through their root systems. Plants may also utilize the nitrogen from ammonia. Plants growing in acid soil may use ammonium in preference to nitrate. Other plants grow faster with nitrate nitrogen.

2.1.2. Symptoms of nitrogen deficiency. Plants may be stunted and yellow in appearance. Plant leaves, which are severely deficient in nitrogen will turn brown and die. This deficiency will first occur in older leaves while young leaves remain green. In grass, leaves die from the tip back. The lower leaves turn brown starting at the tip of the leaf and extending along its midrib. Finally, the entire leaf is dead.

2.2.Phosphorus (P). Phosphorus is essential for the growth of healthy plants. Phosphorus has many functions in plant life, but storing and releasing energy are its most important functions. Plants produce energy through the photosynthetic process and through metabolizing carbohydrates. This energy is stored in the phosphate compounds adenosine diphosphate and adenosine triphosphate. Subsequently, plants use the stored energy for growth and reproductive processes. Adequate amounts of phosphorus are also necessary for seed formation associated with increased root growth. Adequate amounts of phosphorus are very beneficial to plant growth. Positive results include increased root growth, increased tolerance of plants to root-rot diseases, and decreased risk of winter damage.

2.2.1. Symptoms of phosphorus deficiency include overall growth reduction in plants, leaves may appear dull green and/or purplish. (There is no striking color change.)

2.3.Potassium (K). Potassium is another element that is essential to healthy plant growth. It is usually found in plants in concentrations of one to four or five percent. Although potassium exists in the soil in several forms, only a small portion of that potassium is available to plants. Plants require a large amount of potassium. The functions of potassium in plants can be divided into these six areas:

2.3.1. Enzyme activation. Potassium is necessary for the activation of over 60 enzymes, enzymes that are part of plant physiological processes.

2.3.2. Water relations. Potassium provides some of the osmotic pull, which draws water into the roots of plants.

2.3.3. Energy relation. Potassium is necessary in the process of photosynthesis and the formation of phosphate compounds.

2.3.4. Translocation of assimilates. Potassium is necessary for transportation of plant sugars to the parts of the plants where the sugars will be stored or used for growth.

2.3.5. Nitrogen uptake and protein synthesis. Nitrogen uptake and plant synthesis in plants require the presence of potassium.

2.3.6. Starch synthesis. For starch synthesis to occur, potassium in adequate supply must be present.

2.3.7. Symptoms of potassium deficiency. The first symptom appears in leaf development. The leaves may be yellow and streaked. Decreased resistance to certain fungal plant diseases such as powdery mildew is possible.

2.4. Calcium (Ca). All higher plants require the element calcium. Calcium, usually abundant in leaves, has a normal concentration of from 0.2 to 1.0 percent in plants. This element is essential for cell elongation and division and for the growth and development of cell membranes.

2.4.1. Symptoms of Calcium Deficiency. Growth reduction. Reddish-brown leaf discoloration, fading to red, withered leaf tips.

2.5. Magnesium (Mg). Magnesium, located at the center of the chlorophyll molecule, is usually found in plants in a concentration of 0.1 to 0.4 percent. Magnesium's importance is that it is the only mineral in the chlorophyll molecule, chlorophyll being necessary for photosynthesis in green plants. Magnesium is needed for maximum activity of many enzyme systems and protein production. Magnesium can move from one part of a plant to another part if needed to correct a deficiency.

2.5.1. Symptoms of Magnesium Deficiency. The leaves turn yellow with the veins remaining green. Lower leaves in some plants, such as cotton, turn reddish-purple, then brown and finally necrotic. Symptoms may first occur in young leaves.

NOTE: The balance of calcium, magnesium, and potassium in the soil may affect plant growth if there is a gross imbalance. The level of exchangeable magnesium should be between 15 and 50 percent of the level of calcium. Potassium should make up two to five percent of the exchangeable cations.

2.6. Sulfur (S). Primarily plant roots absorb sulfur, found in a concentration ranging from 0.1 to 0.4 percent by weight. Low levels of sulfur are absorbed through plant leaves. This element is necessary for plant synthesis of other essential compounds such as vitamins, enzymes, and proteins. Symptoms of sulfur deficiency include pronounced reduction of plant growth and uniform yellowing of the leaves.

3. Micronutrients.

3.1. Manganese (Mn). Manganese, a transition metal required for plant growth and development, is normally found in plants in the range of 20 to 500 ppm. Manganese is involved in the process of photosynthesis. This element is required for maximum activity of many enzyme systems and may be absorbed by plants from foliar sprays. Excessive amounts of manganese are toxic to plants.

3.1.1. Symptoms of manganese deficiency include interveinal yellowing with the leaf veins staying green and/or necrotic leaf spots with symptoms occurring first in young leaves.

3.2. Iron (Fe). Iron is involved in the photosynthesis and respiration process of plants and is a co-factor in enzymatic reactions. Seventy-five percent of the total iron in plants is in chloroplasts. Normal iron concentrations range from 50 to 250 ppm. Iron is associated with a dark green color in plants. Iron deficient plants will regain this green color within hours after a liquid iron fertilizer is applied.

3.2.1. Symptoms of iron deficiency include interveinal chlorosis in young leaves. Leaves may turn white.

3.3.Copper (Cu). Copper is an essential part of plant enzyme systems with normal concentrations in the range from 5 to 20ppm. This element cannot be replaced by any other metal ion.

3.3.1. Symptoms of copper deficiency. Deficiencies are most common in soils with high levels of organic material (because the highly organic soils do not retain sufficient copper). The symptoms vary with the turf. The youngest leaves become stunted and yellow. Leaves may also have an initial bluish cast. The leaves then yellow or bleach out and curl along the edges.

3.4.Boron (B). Adequate amounts of boron are essential for new cell development in plants. The adequate range of boron concentration is from 6 to 18 ppm. This element plays a role in the translocation of sugars, starches, nitrogen, and phosphorus in plants. Boron also aids in the synthesis of amino acids and proteins as well as regulating the metabolism of carbohydrates in plants.

3.4.1. Symptoms of boron deficiency include thickened, wilted, or curled leaves. Thickened, cracked, or water-soaked petioles and stems. Stunted growth point. Young leaves appear pale green or may blacken and shrivel.

3.5.Chlorine (Cl). Chlorine is essential for plant growth. The concentration range in plants is normally from 0.2 to 2.0 percent but may be as high as 10 percent. Chlorine seems to be a biochemically inert element that does not enter into metabolic reactions. Chloride ions may neutralize positively charged ions (cations) in the cells, increasing osmotic potential within cells. Essential functions include osmotic potential and disease control.

3.5.1. Symptoms of chlorine deficiency include the following: Chlorosis in younger leaves, overall wilting, necrosis and leaf bronzing.

3.6.Molybdenum (Mb). Plants absorb molybdenum in relatively large amounts without any apparent toxicity. The normal concentration of molybdenum in dry plant matter is less than 1 ppm. Molybdenum is mostly found in the enzyme nitrate reductase in legumes. This element is a component of nitrogenase, the enzyme involved in nitrogen fixation.

3.6.1. Symptoms of molybdenum deficiency. Deficiencies of this element are often found in the acidic, sandy soils along the Atlantic and Gulf coasts. Signs of deficiency include interveinal chlorosis on older, lower leaves, stunting, withering, and leaf necrosis.

3.7.Zinc (Z). Zinc, an element absorbed in various forms through roots and leaves, is usually found in plant dry matter in a concentration range of 25 to 150 ppm. Zinc is toxic in concentrations above 400 ppm. Zinc's availability to plants is affected by many soil and environmental factors, for example, absorption on clay surfaces, organic matter, carbonates and oxide materials, interactions with other nutrients, and climatic conditions.

3.7.1. Symptoms of zinc deficiency include, light green, yellow, or white mottling between the veins of leaves, stunted growth, shriveled and desiccated leaves.

4. Soil Structure and Composition of Soil.

4.1.The roots and the top growth of turfgrass and other plants are influenced by the structure of the soil in which they exist. If the soil is compact, pore space and soil oxygen are reduced. Adequate pore space is necessary for root growth; adequate soil oxygen is required for root respiration. If neither pore space or soil oxygen is adequate, the result is reduced growth and eventual death of plants.

4.2.Measurement of Soil Reaction. Soil reaction (soil acidity) is measured by pH. The pH scale measures the relative concentration of hydrogen ions (H) and hydroxyl ions (OH). In pure water the concentration of hydrogen and hydroxyl ions are equal. So in one liter of water, $1 \text{ X } 10^{7}$ molecules have split into hydrogen and hydroxyl ions. The pH of pure water is written as the reciprocal of the logarithm of the hydrogen ion concentration, so $1 \text{ X } 10^{-7}$ becomes pH 7. If the concentration of hydrogen ions increases to $1 \text{ X } 10^{-6}$, the pH is written as 6. Since pH 7 is neutral, values below 7 are acid (higher relative concentration of hydrogen ions), and values above 7 are alkaline (smaller relative concentration of hydrogen ions).

4.3.Plant Growth and Soil pH Level. Soil acidity doesn't directly affect plant growth. The pH does affect the availability of plant nutrients. A pH level of 6.5 is generally optimum for plant growth. Nutrients are available in adequate quantity at this pH, but not at toxic levels. Beneficial soil microorganisms thrive in slightly acid soils. Examples of the effect of pH include low availability of phosphorus in acid soils. In acid soils, phosphates may precipitate or bind to other substances in an unusable form. Manganese is unavailable in high pH soils. The micronutrient molybdenum becomes unavailable in low pH soils. Plants may be poisoned in low pH soils. Manganese can be released into soil water in toxic amounts (if sufficient manganese is present), and toxic levels, of aluminum may be released as the pH continues to drop. Adding calcium to soil raises the pH level. Adding sulfur to soil lowers the pH level.

4.4.Mineral Nutrient Elements. Mineral nutrients compose about 5 to 10 percent of the dry weight of plants. These nutrients (nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, boron, chlorine, copper, iron, manganese, molybdenum, and zinc) are absolutely essential to plant growth and development. Each of these nutrients is obtained from the soil.

4.4.1. Colloidal Fractions. Soil nutrient levels are affected by the amount of clay and organic matter in the soil. These soil fractions are called the colloidal fractions. The term "C "colloid" refers to the ability of clay or organic matter to stay suspended in pure water.

4.4.2. Colloidal materials have a huge surface area because of the tiny (less than O.OO2mm diameter) particle size.

4.4.3. Colloid particles also carry a negative charge, which attracts and holds positively charged ions (or cations).

4.4.4. The main cations affecting plant nutrition are H+, AI3+, Ca2+, Mg2+, K+, NH4+ and Na+.

4.4.5. Soils with high levels of organic material and clay are said to have high cation exchange capacity (because the cations often swap places with cations in the soil water).

4.4.6. Most soil particles carry a positive charge, so the negatively charged colloids are crucial to plant nutrition.

5. Plant Growth and Soil Water. Plant growth is often in direct proportion to the amounts of available soil water. Plant growth is restricted at very low and very high levels. Water is necessary for a variety of metabolic activities in plants, such as the manufacture of carbohydrates. Water is the main component of protoplasm. Water is a medium for the translocation of foods and mineral nutrients. Insufficient water reduces plant cell division and cell elongation, so plant growth is reduced under moisture stress.

6. Plants and Moisture Stress. Plants constantly lose water through transpiration and replace the losses by extracting soil water. Moisture stress results when the rate of transpiration exceeds the available moisture in the plant root zone. Plant growth (and thus the yield of agricultural crops) is affected by moisture stress, but the quality of crops is also affected. For example, the protein content of grain is influenced by the quantity of available water.

7. Plants and Soil Nutrients. Plants cannot effectively take up nutrients from the soil unless soil moisture levels are adequate. Because plants can take up nutrients more readily as soil moisture levels increase, the efficiency of water use (related to crop yield) is increased in moist soils.

8. Slow-Release Fertilizer. Fertilizers designed to control and prolong the release of nutrients over a period of time. These fertilizers are formulated by coating fertilizer granules with resin or plastic; coating granules with sulfur and binding agents; or using fertilizer materials which are naturally slow to dissolve, such as organic materials, urea formaldehyde, or IBDU (Isobutylidene diurea).

9. Soil Testing. Soil testing is a chemical (as opposed to the visual methods of early agriculture) method for estimating the fertility of soil. A soil test measures part of the total nutrient content of a particular soil and soil reaction. These values are meaningless alone. Extensive field and greenhouse testing have established the relation between soil nutrient values and plant growth. Soil scientists can now predict plant growth based on soil test results. Soil testing laboratories use this information to determine “low”, “medium,” or “high” nutrient levels in soil.

9.1. Objectives of Soil Testing.

9.1.1. To build up the fertility of a given area of land, or to maintain the fertility of an already productive area of land.

9.1.2. To predict the response of plants to a given application of a treatment.

9.1.3. To determine the proper amount of fertilizer or other treatment to apply.

9.1.4. To evaluate the fertility of soils over a large land area (such as a golf course).

9.1.5. Basic Purpose. In simple terms, the objective of soil testing is to obtain a value, which may be used to predict the amount of fertilizer to apply.

9.1.6. Sampling Technique For Soil Testing. Soil tests are useless unless the soil sample is representative of the land area being tested. Follow these guidelines to sample soil:

9.1.7. Take 12 to 15 samples from each uniform area.

9.1.8. Keep samples approximately 1-inch in diameter and 2 to 4 inches deep.

9.1.9. Remove thatch and turf from the sample.

9.1.10. Be sure the sample is thoroughly mixed.

9.2.Test the soils regularly with frequency depending on the soil type and the intensity of the culture. Intensively managed soils (such as golf courses) should be sampled at least once and probably twice a year.

10. Turfgrass Disease Prevention. "A disease may be defined as an abnormal condition of plants resulting from alterations in their physiological processes and morphological development and caused by some adverse environmental factor." (J.C. Walker as presented by Turgeon, 1991). "Within this definition, a disease could result from many causes, including such abiotic factors as nutritional deficiencies, poor drainage, and traffic." (Turgeon, 1991)

10.1. Conditions Which Promote Disease. For plants to become diseased, several conditions must be present, all at the same time:

10.1.1. A susceptible host.

10.1.2. Environmental conditions conducive to pathogen development.

10.1.3. Aggressive pathogens. If any one of these conditions is missing, disease in plants will not develop.

10.2. Some precautions to take. Sterilizing seedbeds and using high-quality seed, sod, or sprigs is helpful. Obtaining disease-resistant species and cultivars through local recommendations can inhibit diseases.

10.3. Cultural Practices to Prevent Disease. Cultural controls are aimed at changing the environmental conditions necessary for diseases to develop. A further aim is the production of healthy, rapidly growing turf, which can resist or "grow through" a disease infection.

10.4. Temperature. Temperature affects the growth of pathogens and turfgrasses. Most disease problems occur when the grass growth is slowed and fungi are growing rapidly. For example, fungi, which thrive in cool temperatures, cause disease in the fall when grass growth is slowed. The manager has very few opportunities to control temperature. Awareness of the effects of temperature is the best weapon.

10.5. Humidity. Leaf wetness is essential for the germination of fungal spores. The spores require about 12 hours of moisture. This period of leaf wetness is controlled by watering in early morning, improving air circulation (removing obstructions to air movement), mowing at the suggested height, sowing seeds at the recommended rate, knocking dew off the grass in early morning, and using powerful fans during humid weather.

10.6. Water. Soil moisture is important to turfgrass growth and the growth of pathogens. Turfgrasses grow most successfully in well-drained soils. Turfgrass should be watered in early morning to avoid long periods of leaf wetness. Irrigation should be applied as infrequently as possible, but enough water should be applied to wet the entire root zone. Irrigation should be applied to prevent wilt.

10.7. Light. Certain diseases are associated with low light intensity. Powdery mildew, rusts, and some leaf spot diseases are most severe in shady locations. Light intensity can be controlled by tree removal or pruning, although this is often impractical or undesirable.

10.8. Fertilizers and Soil Reaction. Balanced nutrition is necessary for rapid, healthy turf growth and disease resistance; however, overly high nutrition levels (especially high nitrogen) are undesirable and contribute to the risk of diseases such as pythium, brown patch, and typhula blight. Soil pH should ideally be maintained between six and seven, since the activity of beneficial microbes is maximized at this level. Decomposition of thatch is most rapid at this pH.

10.9. Pesticides. Unfortunately, pesticides do not kill target pests alone. Overuse of pesticides can disrupt the entire ecology of the soil by killing beneficial soil insects, earthworms, nematodes, and fungi. Since many soil organisms compete with pathogens, decay thatch, or actually feed on pathogens, pesticide overuse can end up contributing to future disease problems.

10.10. Mowing Practices. Turfgrass is obviously well adapted to mowing in that after defoliation leaf formation continues. However, mowing turfgrass contributes to turfgrass diseases. Mowing opens wounds for microbes to colonize, spreads fungal spores, and removes the leaf area needed for turf growth. The most highly managed turf is the most susceptible to disease. Many diseases can be controlled by slightly raising the mowing height (when this is practical).

10.11. Thatch Control. Thatch accumulation is a symptom of an imbalance between turf growth and tissue decomposition. Heavy thatch contributes to several turf diseases. Thatch can be controlled by proper fertilization and irrigation, maintaining pH between six and seven, and by mechanical removal, aeration, and topdressing. Repeated pesticide application may lead to thatch buildup.

10.12. Chemical Controls. Fumigants, fungicides, and nematicides are all pesticides that help control turfgrass diseases.

10.13. Fumigants. These toxic gases kill everything in their path: weeds, insects, and nematodes. This type of control should be used only in areas where other types of control have been ineffective. Fumigants are most often used on high-value golf greens.

10.14. Contact Fungicides. Fungicides are made with two purposes: (1) to kill certain groups of fungi or (2) to render certain groups of fungi temporarily incapable of growth. Contact fungicides kill mycelium or fungi spores when the fungicide is applied to the infected turf.

10.15. Systemic Fungicides. Most systemic fungicides are not toxic enough to kill fungi, or the plant would also be killed. These pesticides are actually fungistats. The fungi are not killed, but fungal growth is restricted. Most systemic fungicides move only upward in plants, so the chemical must be applied to the right part of the plant. Root or stem diseases cannot be controlled with a foliar application of systemic fungicide.

10.16. Benzimidazole Derivatives. Examples of this fungicide include benomyl and methyl thiophanate. Characteristics are as follows: The fungicide only moves upward in plants. It must be drenched into the soil to control root or stem pathogens. Overuse may lead to resistance. It is not toxic to pythium or several other fungal species.

10.17. Sterol Inhibitors. Examples include cyproconazole, fenarimol, and prochloraz. Look at these characteristics: The fungicide is mobile in plants. It prevents ergosterol production in sensitive fungi.

Note: More information on fungicides is found in Chapter 4.

Chapter 4. Pesticides

Pesticide statutes
Pesticide labels
Pesticide formulations
Insecticides
Herbicides
Fungicides
Plant Growth Regulators
Fertilizer
Fumigants
Rodenticides
Repellents
Mixing pesticides
Pesticide droplet size

1. Pesticide statutes. The first federal pesticide laws were enacted in 1910, but it was 1947 when federal legislation began to regulate the pesticide industry. During this time, governments at all levels began to develop more statutes and regulations to control pesticide content, safety, and use. Federal laws are not the only area of concern to the golf course since many states or local statutes are being developed to address regionally specific issues that can place extreme restrictions on the golf course IPM program. Because of this, golf course superintendents should know about state or local pesticide statutes and cooperate with local or state governments whenever possible. This is especially true when the state has laws more stringent than those set by the federal government regarding storage and disposal of many types of hazardous materials.

1.1.Federal. The federal insecticide act of 1910 was the first federal pesticide legislation enacted. Its purpose was to regulate insecticides and fungicides moving in interstate commerce. The second, and far more significant, piece of federal legislation was the federal insecticide, fungicide and rodenticide act (FIFRA) of 1947. This was the federal government's first major effort to regulate pesticides in general and was aimed mainly at pesticide production and registration. Then in 1972, public law 92-516, entitled the federal environmental pesticide control act (FEPCA) of 1972 was passed. This law made major changes to FIFRA and pesticide regulation rules. Additionally, FEPCA resulted in some restrictions of pesticide use and added a requirement for applicator training. This modification of FIFRA was further amended in 1974 and 1978. This act remains the major legislation that governs the use of pesticides in the U.S. and on golf courses today. Major provisions of the law are as follows:

1.1.1. Pesticides must be used according to label directions. The label is the law and is always correct. This means that no matter where golf course superintendents are in the United States, they must not apply any pesticide in a manner inconsistent with the label. The restriction applies to both the label and any other labeling. The term label refers to the pasted-on paper or printed-on labels on the container, labeling refers to any adjunct written, printed or graphic material the manufacturer provides with the product or refers to on the label. Both have a legal bearing on how a product may and may not be used.

1.1.2. The EPA classifies all pesticides as general use or restricted use. The term restricted use is the classification given to a pesticide's use when the EPA determines that it may cause adverse effects on the environment, even when it is applied exactly according to label instructions. This damage may include injury to the golf course personnel or other people unless additional precautions are taken. If the EPA determines a pesticide use doesn't pose such problems, they classify it as a general use pesticide. Notice it is a use, not a pesticide that is restricted. For one product, certain uses may be restricted, but another product with the same active ingredient may be classified as a general use pesticide.

1.1.3. When using restricted-use pesticides, golf course superintendents and/or their applicators must be certified as competent or be directly supervised by a certified applicator. Also, applications of restricted use pesticides must be recorded to include the specific site and conditions.

1.1.4. The EPA has established severe penalties (fines and jail terms) for violations of the FIFRA. All pest applicators will receive information as to what constitutes a violation of the law by participating in their state's certification or recertification process.

1.2.State. The EPA has delegated each state as an authority to help enforce FIFRA. States may also regulate the sale or use of any pesticide or device in the state, as long as it does not violate FIFRA. We generally refer to such products as state limited-use pesticides. States may and generally do establish, with EPA approval, training and certification programs for pesticide applicators.

1.3.Local. Special local needs for EPA 24c registration of a pesticide or its use may be granted by EPA to the state in accordance with FIFRA.

1.4.Foreign. In foreign countries and areas outside the continental United States, golf course superintendents must abide by the national laws and regulations.

2. Pesticide labels. The pesticide label contains the most important information needed regarding safety, mixing and use. This is why this manual repeatedly states, "the label is law." The only exception to this rule is, if the pesticide is banned or further restricted by a cognizant authority, such as the EPA. Appendix 1 of this manual includes a partial copy of a restricted use pesticide label as an example.

2.1.Use classifications. One of the most important parts of the label is the use classification. Under FIFRA, there are two categories established for the use of all pesticides: general use and restricted use. The general use category applies to most pesticides commonly used in golf course IPM programs.

2.2.Hazard warnings. Golf course superintendents should read and understand all parts of a pesticide label before a container is ever opened. This basic safety rule is particularly true of the hazard warnings or signal words that appear on every pesticide label. Based upon the toxicity of a pesticide to humans and animals, the EPA classifies a pesticide as highly toxic, moderately toxic, slightly toxic or relatively non-toxic. Each of these categories has a corresponding signal word that must appear on the label. All pesticide labels contain a warning statement to "keep out of reach of children" enclosed in a box along with the signal word. Additionally, most pesticides labels have a box called "precautionary statement" with the signal word and a warning statement as to actions to avoid, any specific dangers to people or animals, and medical information needed to administer first aid. Signal words include:

2.2.1. DANGER-POISON (Skull and Crossbones). Appears in red letters on highly toxic pesticides.

2.2.2. DANGER/PELIGRO. These products can cause severe eye damage or skin irritation.

2.2.3. WARNING/AVISO. The product is moderately toxic orally, dermal, through inhalation or causes moderate eye or skin damage.

2.2.4. CAUTION. Signals that the product is slightly toxic orally, dermal, or causes slight eye or skin damage.

2.3. Other label parts. Other parts of the label include:

2.3.1. Trade name. Each company has trade names for its products and this is the most identifiable name. It's also the name used in the producer's advertisements.

2.3.2. Common name. Many pesticides have complex chemical names. Some have been given another name to make them easier to identify. These are called common names. For instance, carbaryl is the common name of 1-naphthyl n-methylcarbamate. A chemical made by more than one company will be sold under several trade names, but the same common name or chemical name will apply to all of them. Glyphosate, isopropylamine salt E251 is another example of a chemical name.

2.3.3. Ingredient statement. Every pesticide label must list exactly what active ingredients are in the product. The amount of each active ingredient is given as a percentage by weight or as pounds per gallon of concentrate. It can be listed by either the chemical name or the common name. The inert ingredients need not be named, but the label must show what percent of the contents they make up.

2.3.4. Net contents. The net contents number tells how much product is in the container. This amount may be expressed in gallons, pints, pounds, quarts, or other units of measure.

2.3.5. Name and address of manufacturer. The law requires the producer or distributor of a product to put the company name and address on the label. This is so golf course superintendents will know who made or sold the product.

2.3.6. Registration and establishment number. A registration number must be on every pesticide label. It shows that the product has been registered with the federal government. This number is usually on the front panel of the label and will be written as “EPA registration no. 000.” The establishment number tells what factory made the chemical. This number doesn't have to be on the label, but will be somewhere on each container.

2.3.7. Directions for use. The use instructions are the single best way to find out the right way to apply the product. They will identify:

2.3.7.1. The pests the product is registered to control. (Labels use common names for pests. Knowing these names will help the golf course superintendent choose the proper pesticide and find control information.)

2.3.7.2. Areas where the product can be legally used.

2.3.7.3. Whether the product is for general or restricted use.

2.3.7.4. In what form the product should be applied.

2.3.7.5. How much to use.

2.3.7.6. Where the material should be applied.

2.3.7.7. When the material should be applied.

2.3.8. Misuse statement. The misuse statement is a reminder that it's a violation of federal law to use a product in a manner inconsistent with its labeling. Don't use it at more than the recommended rate. Before the product could be registered, the EPA made the manufacturer conduct many tests to ensure label directions were correct. Follow those directions exactly to get the best results the product can give, and avoid breaking the law.

2.3.9. Reentry statement. Most pesticides have a period of time when it is not safe to enter the area sprayed. A reentry statement, if needed, tells how much time must pass before a treated area is safe for reentry by people without protective clothing. This statement is most commonly found on fumigant labels. The category of applicator, if required for the product, will limit its use to certain categories of commercial applicators.

2.3.10. Storage and disposal directions. These directions must be on each pesticide container label to tell how to store and dispose of the product and/or empty containers.

2.3.11. Type of formulation. The same pesticide may be available in more than one formulation. Likewise, different formulations (such as liquids, wettable powders, and dusts) require different handling. The label will tell what type of formulation the package contains.

2.3.12. Precautionary statement. The hazards to humans and domestic animals statement will tell how the product may be poisonous to humans and animals. It also will describe any special steps needed to avoid poisoning, such as the kind of protective equipment required. If the product is highly toxic, this section will inform physicians of the proper treatment for poisoning.

2.3.13. Environmental hazards. This statement is included on pesticide labels to help golf course superintendents avoid wrong or careless use of the product that may cause environmental damage. Examples of this type of information are as follows:

2.3.13.1. "This product is highly toxic to bees exposed to direct treatment or to residues on crops."

2.3.13.2. "Do not contaminate water when cleaning equipment or when disposing of wastes."

2.3.13.3. "Do not apply where runoff is likely to occur."

2.3.13.4. Labels may contain broader warnings against harming birds, fish, and wildlife.

2.3.14. Physical and chemical hazards. The physical and chemical hazards statement will give a warning of any special fire, explosion, or chemical hazards that may be presented by the product.

2.3.15. Statement of practical treatment. This statement gives first aid procedures if it would be harmful to swallow or inhale the product or get it in eyes or on skin. It will also describe the types of exposure that require medical attention. Note: the pesticide label is the most important item to take to the physician if someone has been poisoned.

2.3.16. Statement of classification. The EPA is classifying pesticides into categories on the basis of the hazard of poisoning, how the pesticide is used, and its effect on the environment. The general use category is for pesticides that present very little or no hazard to the applicator or the environment when used exactly as identified by the information on the label. The label on the general use pesticides will read "general classification." The restricted use category is for pesticides that could cause human injury or environmental damage even when used as directed on the label. The label on these products will state: "restricted use pesticide for retail sale to and application only by certified applicators or persons under their direct supervision." The restricted use statement must be at the top of the front panel of the label.

3. Pesticide formulations. Many types of chemicals and formulations are used in pest management operations. The insecticides, rodenticides and other supplies standardized for golf course use have been carefully selected to provide a minimum number of items with maximum golf course applications and safety. With few exceptions, these items, used according to label directions, will provide effective pest management.

3.1.Pesticide ingredients. There are a number of ingredients that may be included in any pesticide.

3.1.1. Toxicant. This is the basic ingredient that has a toxic action and kills or repels the pest. It's normally shown on the label as the active ingredient or technical material. Many pesticides, especially those labeled for general use, will contain more than one active ingredient. If so, all active ingredients are listed on the label.

3.1.2. Carrier. The pesticide carrier is mixed with the toxicant to make a finished or semi-finished pesticide product. It normally has no pesticidal action itself and will be listed under inert ingredients on the label. However, there are some carriers, such as most petroleum products, that have some pesticidal action of their own and will be listed under the active ingredients on the label. For liquid pesticides the carrier is normally water or a petroleum-based product, while for most dry pesticides, the carrier is normally talc or diatomaceous earth. However, there are a few dusts, such as powdered sulfur and 91% Malathion, which are low in toxicity and may have little or no carrier added.

3.1.3. Solvent. A solvent may be used to dissolve a toxicant that is not readily soluble in a common carrier, thus enabling the toxicant to be added to the carrier and remain in solution. If the pesticide has a product added to change or cover the odor of a pesticide, it has had a masking agent added to the formulation.

3.1.4. Synergist. A synergist is a chemical product added to a pesticide to increase or enhance the effectiveness of the pesticide's active ingredient. Often the synergist has active ingredient qualities itself and will be listed on the label as a secondary active ingredient. When the main active ingredient and synergist are combined, the enhanced effectiveness of the combined product is greater than the accumulative effect that would be achieved if the products were applied separately. An example of a synergist is piperonyl butoxide, which is commonly added to natural pyrethrins.

3.1.5. Surfactant. This product increases the emulsifying, dispersing and spreading characteristics of a pesticidal formulation. One of the most common surfactants is called a wetting agent. A wetting agent causes a liquid to cover treated surfaces more thoroughly, and is most commonly used in pesticides applied to vegetation. Another common surfactant is the emulsifier. This material is used in liquid pesticides to help suspend one type of liquid (such as an oil-based toxicant) in another (such as water carrier).

3.1.6. Adjuvants. Added to a pesticide principally to increase it effectiveness, although some adjuvants are added to reduce phytotoxicity or drift.

3.2.Types of formulations. Manufacturers combine pesticides with other materials to make usable concentrations called formulations. These formulations are designed to kill insects readily without causing undue hazards to nontarget organisms when diluted and applied correctly. Some toxicants are applied as technical grade pesticides, such as Malathion in ultralow volume (ULV) applications. Most manufacturers market dry formulations such as dusts as ready-to-use products. Wettable powders are mixed with water to form suspensions of desired concentration. Liquid formulations, such as ULV insecticides, may be labeled “ready to use”, indicating no dilution is required, but most liquid formulations do require dilution before they are applied. For example, golf course superintendents may purchase a liquid pesticide as a concentrated solution or emulsifyable concentrate. They then dilute the concentrate solution with solvent oils to prepare a field-strength solution, or an emulsifyable concentrate with water, to prepare an emulsion. The following paragraphs describe the types of materials that are combined to make different pesticide formulations:

3.2.1. Technical grade pesticide. This is the basic toxic agent in its purest commercial form. It is rarely chemically pure. Some technical grade pesticides are liquids; others occur in solid form. Technical grade Malathion is a clear, amber liquid, whereas chlorpyrifos (dursban) is a white, granular, crystalline material. Some undiluted technical grade pesticides are used in ultralow volume space applications. But usually, technical grade pesticides are mixed with a carrier before use, forming a dust, granule, suspension, solution, or emulsion.

3.2.2. Microencapsulated pesticides. These have the active ingredient surrounded by or encapsulated by inert synthetic substances. These usually very small, encapsulated pesticides are suspended in a liquid carrier and applied with conventional equipment. This creates a slow release effect of the pesticide and enhances performance.

3.2.3. Dusts. Dusts are normally ready-to-use formulations with a low percentage of active ingredient (usually 1 - 10%) plus a very fine inert carrier such as talc, chalk, diatomaceous earth, clay or volcanic ash. These materials are usually low in cost, easy to apply, nonstaining, and nontoxic to vegetation. Dusts are always used dry and can easily drift into non-target areas if they are not applied carefully. For this reason, only make outdoor applications when the wind is calm. A common use for dusts is in crack and crevice or spot treatments indoors in out-of-sight areas (behind equipment, in wall voids, and so on), which remain dry. The residual pesticide activity of dust is normally fairly long, provided the dust stays dry, but quickly loses it toxicity in the presence of moisture. They don't adhere well to vertical surfaces. Dusts are also used on people during mass delousing operations to control outbreaks of lice. This use is normally restricted to large-scale contingency operations when people may become exposed to poor hygienic conditions for prolonged periods of time. Pesticide dusts aren't generally absorbed through the skin, but may be dangerous if inhaled into the respiratory tract.

3.2.4. Pesticide granules. These are basically the same as dust formulations except the carrier particles are larger. In most granular formulations, vermiculite is used as the inert carrier instead of talc or diatomaceous earth. A fine granular pesticide pours like table salt or sugar, while larger granules may be as large as buckshot. Since granules are heavier than dusts, they don't stick to leaves; therefore, they will penetrate dense foliage. This is a real advantage when the pesticide must reach the water surface for mosquito control in vegetated swamps, or if it must get to the ground surface through trees and shrubs for chigger or fire ant control. Granules are also available in timed-release formulations that release a dosage of the pesticide over an extended period of time. Other advantages of using granules are that they provide longer lasting effects and their use results in less drift than generally occurs with liquids or dusts.

3.2.5. Wettable powder. This formulation consists of the technical grade pesticide, an inert carrier, and a wetting agent (usually a synthetic detergent) that helps it mix with water. They also have an anticaking agent to prevent lumping while in storage, and a dispersant that helps keep the suspended particles from settling out too quickly. Wettable powders may have a technical grade chemical content of 15% to 90%. Once diluted, the amount of pesticide in the suspension may vary from 0.5 % to 15%. These formulations usually have sticking agents that help them adhere to plant material.

3.2.6. Suspensions. When water is added to a wettable powder, it makes a suspension. A great advantage of a suspension is the pesticide's tendency to stay on porous surfaces like concrete, plaster, adobe, or unpainted wood. Water penetrates these surfaces, leaving the carrier and the maximum amount of the pesticide on the surface available to kill pests. By contrast, when solutions or emulsions are used, the pesticide penetrates porous materials so less of it remains on the surface. Suspensions have other advantages, too. They don't need added solvents, which can injure plants, they have no solvent odor, and they don't tend to irritate or penetrate skin. However, they generally need agitation to keep pesticide particles from settling out. Also, they tend to clog sprayer nozzles and strainers, especially when the wettable powder is stored for long periods in humid areas or when a high concentration is used. Sometimes, even the water used can cause problems. Some municipal water supplies cause foaming while others require the addition of more wetting agent.

3.2.7. Emulsifyable concentrates. Emulsifyable concentrates consist of the technical grade pesticide (typically 45% to 75%), a solvent, and an emulsifying agent, usually a synthetic detergent. This agent is used to allow the concentrate to be diluted in water, resulting in an emulsion. The golf course has many uses for emulsifyable concentrates because of their low cost in final diluted form.

3.2.8. Emulsion. When water is added to an emulsifyable concentrate, an emulsion is formed, and the concentration of pesticide is reduced to the desired field strength. Emulsifyable concentrates are usually clear, but emulsions look similar to milk. Finished sprays are emulsions or solutions diluted to field strength. Unlike solutions, most emulsions need a little periodic agitation to keep the concentrate from separating out of the water. Golf course superintendents commonly use emulsions to apply residual treatments to solid surfaces. The pesticide residue kills pests that contact these surfaces. Some emulsions remain effective for a longer time on masonite and bare or painted wood than on glazed tile or shiny metal. This is an important consideration when the golf course superintendent must determine the time interval between residual applications. Emulsions with a high percentage of the pesticide (or solvent) may burn plants. When treating plants with an emulsion, make sure it has a low percentage of pesticide and solvent and a high percentage of water. Otherwise, it's safer to use a suspension. Mosquito larvicidal treatments with emulsions are usually confined to shallow bodies of water and to treatment of water containers, where excessive dilution will not take place. Oil solutions are more suitable for deeper bodies of water. Emulsions may damage aluminum, varnish, and painted surfaces, due to the action of solvents such as xylene. Emulsions are often corrosive to metal sprayers and their fittings. Since emulsions can corrode some equipment, use sprayers made of stainless steel, aluminum, fiberglass, or other noncorrosive materials.

3.2.9. Oil solutions. These formulations consist of a technical grade pesticide dissolved in a solvent such as kerosene, diesel oil, or xylene. Solutions are available as ready-to-use formulations (for example, ordinary household fly and mosquito sprays with a low percentage of pesticide) and as solution concentrates. These concentrates contain a high percentage of insecticide and must ordinarily be diluted in oil or another suitable solvent. Some concentrates are used without dilution in ultralow volume (ULV) applications. In residual spraying, the solvent evaporates from the treated surfaces, leaving a deposit of the pesticide. Some technical-grade pesticides cause a "blooming" of fine crystals that are readily picked up by the feet and bodies of insects. Others don't crystallize, but form a thin film of insecticide on treated surfaces. Oil solutions applied as finished sprays often kill insects on contact, since the oil helps the pesticide penetrate the insect's waxy body wall. However, oil burns, so be very careful not to use it near open flames and areas of intense heat. Oil-based products can also harm plant foliage, so be careful about using them on desired foliage such as ornamentals. Cold will cause oil solutions to drop the pesticide out of solution, resulting in a reduction of the percentage of active ingredient in the finished spray.

3.2.10. Aerosols. Aerosols or "bug bombs" are pressurized cans containing a small amount of pesticide driven through a small nozzle. They're commonly used as space sprays for flying insects and as residual sprays, depending on the formulation. Some aerosols in the golf course inventory are uncontrolled, so they're commonly used in small areas, such as tents, office buildings, and aircraft. Controlled uses include aircraft disinfecting and as flushing agents during residual treatments. Be careful when disposing of empty aerosol containers; they can explode if punctured or overheated, even after the pesticide has been dispensed.

3.2.11. Ultra-low volume (ULV). While most items of ULV pesticide dispersal equipment use the readily available solutions or technical grade formulations, there are special ULV formulations available, which use special solvents designed to enhance the performance of the equipment.

3.2.12. Gases. Gases are primarily used in fumigation operations. They may be prepared as liquefied gases and packaged in pressure containers or in a material form that reacts with the moisture in the air to form a gas. Upon release from the container, a true gas is formed. Gases can be very dangerous and are strictly regulated in their use.

3.2.13. Resin strips. Pesticide-impregnated resin strips release a vapor as they are heated or exposed to normal room temperatures. However, due to their respiratory mode of action and uncontrolled release rate, they aren't generally used in golf course programs, except as the killing agent in pest collection killing jars or tubes. The use of resin strips in rooms occupied by the young, the elderly or in food preparation and food serving areas is strictly prohibited.

3.2.14. Baits. Baits are commonly used to manage scavenging pests such as rodents, ants, flies, and cockroaches, which are particularly difficult to manage with standard techniques. Golf course superintendents can make baits from concentrates or purchase them premixed and often prepackaged. Baits consist of the toxicant mixed with a food attractive to the target pest or with water. For this reason, baits made with local foods are normally more effective than premixed formulations.

3.2.15. Flowables. Some active ingredients can be manufactured only as a solid or a semi-solid material. They usually have relatively low solubility in water or other organic solvents. These pesticides are often formulated as flowable liquids. The active ingredient is very finely ground and suspended in a liquid along with special suspending chemicals and additives.

3.3.Persistence. Persistent pesticides leave residues that stay in the environment without breaking down for a long time. Sometimes these pesticides are desirable because they provide long-term pest control and may reduce the need for repeated applications. However, some persistent pesticides that are applied to or spilled on soil, plants, lumber, and other surfaces or into water can later cause harm to sensitive plants, animals, or humans that contact them. Clues on pesticide labeling that a particular pesticide product is likely to be persistent include: "can remain in the soil for 34 months or more and cause injury to certain plants other than those listed as acceptable on the label," "this product can remain phytotoxic for a year or more."

3.3.1. When using persistent pesticides, consider whether their continued presence in the environment is likely to harm people, plants or animals.

3.3.2. When pesticides build up in the bodies of animals or in the soil, they are said to accumulate. When the same mixing/loading site or equipment cleaning site is used frequently without taking steps to limit and clean up spills, pesticides are likely to accumulate in the soil. When this occurs, plants, animals, and objects that come into contact with the soil may be harmed. When pesticides accumulate in the soil, there is also a higher likelihood that the pesticides will move offsite and contaminate the surrounding environment or move into surface or ground water.

3.3.3. Dangers of predation. Sometimes animals can be harmed when they feed on plants or animals that have pesticide residues on or in them. A special concern is for predator birds or mammals that feed on animals that have been killed by pesticides. The predators may be harmed by the pesticide residues remaining on or in the bodies of the dead animals.

3.3.4. Industry is developing new, low toxicity, persistent pesticides that are much safer to use and more effective than those they are replacing. Good examples of this new generation of pesticides are Merit and Mach2. These pesticides have a more selective effect and have shown less damage to beneficials.

4. Insecticides. Insecticides are pesticides designed primarily to kill insects, although the word "insecticide" is typically used to identify pesticides that control non-insect arthropods such as mites, ticks, and spiders. Most insecticides kill by damaging the insect's nervous system. As with all pesticides, many are toxic to people and animals and can damage the environment if not used properly.

4.1.Inorganic insecticides. Inorganic insecticides are made from naturally occurring minerals and do not contain carbon. When they were developed in the 1940s and 1950s, many inorganic insecticides were among the first to be used in large-scale control programs. Except for boric acid, many are not available in the U.S. Any that are available are severely restricted in their use. Golf course superintendents may encounter these insecticides outside the United States, so it's necessary to be aware of some of the important members of this group.

4.1.1. Inorganic arsenicals. Paris green (copper acetoarsenate) was one of the most commonly used mosquito larvicides before the introduction of synthetic organic insecticides.

4.1.2. Boric acid dusts and baits are used for cockroach control in buildings.

4.1.3. Sulfur, used as a dust, was formerly used as a fungicide and is still used to control spider mites, psyllids and plant bugs.

4.2.Synthetic organic insecticides. These are man-made insecticides that are commonly used today. They have replaced the inorganic insecticides as the major chemical group used against arthropods and are classified on the basis of their chemical structure.

4.2.1. Chlorinated hydrocarbons. This group of insecticides came into use with the development of DDT during World War II. They are primarily central nervous system poisons and were used effectively against a wide range of insect pests. Because of their persistence in the environment, some have created major environmental problems and many have been removed from the market. Insecticide resistance has also led to a decrease in their use. The EPA has greatly restricted uses of chlorinated hydrocarbons, with the whole group closely monitored by the EPA and environmental groups. Lindane is an example of a chlorinated hydrocarbon that is still in limited, but very restricted use.

4.2.2. Organophosphates. Organophosphate insecticides have largely replaced chlorinated hydrocarbons in many pest control programs. This group contains phosphorous and they kill by inhibiting the enzyme, cholinesterase, which is necessary for proper nerve function in arthropods (and people). Organophosphates are less persistent than chlorinated hydrocarbons in the environment, but are generally more acutely toxic to handlers. Insect resistance to these pesticides has been reported. Diazinon, Malathion and chlorpyrifos are examples of this insecticide group.

4.2.3. Carbamates. The carbamates are the latest group of insecticides and have slowly replaced some organophosphates. They also act by inhibiting the enzyme cholinesterase. Carbamates tend to have selective toxicity; they have no effect on houseflies but are very toxic to honeybees. Many carbamates provide rapid knockdown of insect populations. Carbaryl, propoxur and bendiocarb are examples of carbamates widely used in pest management activities.

4.2.4. Pyrethroids. Pyrethroids are synthetic but similar in mode of action and chemical structure to the natural pyrethrins. Pyrethroids act on the central nervous system of the arthropod and produce a more complete kill than the natural pyrethrum products. They generally have a low order of toxicity. Pyrethroids have been used successfully on fabrics to protect against the clothes moth and carpet beetle and in public health, agricultural and structural pest management. Pyrethroids offer a major advantage to natural pyrethrins, because they are easily available to golf course superintendents. Natural pyrethrins are often obtained from countries which may be experiencing political unrest, adverse growing conditions, crop failures, etc. Cypermethrin, d-phenothrin and allethrin are examples of pyrethroids.

4.2.5. Growth regulators. Growth regulators cause pests to improperly develop or otherwise stop their normal reproductive processes. Methoprene is an insect growth regulator (IGR) used against mosquitoes, fleas and various agricultural pests. Hydroprene, another IGR, is used against cockroaches and shows no specificity with cockroaches. Both are "juvenile hormone analogs" designed to disrupt insect growth cycles at critical developmental stages. They're essentially nontoxic, affect only target pests, show little persistence in soil or water and leave no residue to cause staining and odor problems. Because of these characteristics, IGRs are also referred to as "biorational" products and as a group they have gained rapid acceptance in the pest management field.

4.2.6. Miticides and Nematicides. In an effort to reduce toxicity to predatory nematodes, mites and other beneficials, researchers and the chemical industry are developing very specialized pesticides that control narrow ranges of species. Miticides attack only selected harmful mites and likewise nematicides are designed to control specific varieties of nematodes.

4.3. Natural organic compounds.

4.3.1. Botanicals. Botanical pesticides are derived from plants. Pyrethrum is the term applied to the insecticide components of flower heads such as pyrethrum cinerariaefolium. Four separate compounds are included, of which pyrethrin is the most active. Pyrethrum is a contact insecticide that gives a rapid knockdown of treated insects. Synergists, such as piperonyl butoxide, increase the efficiency of these compounds. Pyrethrum has been used successfully in aerosol space sprays against fleas, mosquitoes and other flying insects, and has a low toxicity to mammals. Nicotine is an alkaloid contained in tobacco plants. It has been used against soft-bodied, sucking insects such as scales, thrips, aphids and mealybugs. It is highly toxic to both insects and mammals and its volatility makes it an excellent contact insecticide.

4.3.2. Biologicals. There is a great deal of effort to research and discover natural controls for turfgrass pests. The use of biological organisms is one area that is receiving great attention amongst natural pest control. A good example is the use of parasitic nematodes, which are non-complex, colorless, roundworm type organism. Parasitic nematodes have shown promise in controlling troublesome insect populations especially white grubs. In the turfgrass area of study some other pests that nematodes seem to control are fungus gnats, scarabs, mole crickets, billbugs and armyworms to name a few. In addition to nematodes, various fungi are being research as to the potential for prevention of harmful diseases on turfgrass.

4.3.3. Petroleum and coal tar natural organics.

4.3.3.1. Kerosene is used mainly as a solvent for insecticides but by itself has considerable insecticidal properties. A refined, odorless form is used as the carrier in many household sprays. It has also been used alone as a mosquito larvicide. Kerosene is generally toxic to plants and must be treated with the same caution given to other flammable liquids.

4.3.3.2. Summer oils are slightly higher-grade distillations than kerosene. They have been used in water emulsions on orchard and shade trees to control sucking insects. The summer oils are used when trees are in foliage.

4.3.3.3. Dormant oils are more highly sulfonated than summer oils. They are used against the same pests but only when the trees are dormant (without foliage).

4.3.4. Biological. Researchers are spending vast amounts of time and effort to discover natural means to control pests via the use of biological mechanisms. Here are just two examples that have proven to be effective.

4.3.4.1. Milky spore. Several strains of the bacterium, *bacillus popilliae*, have been found that attack white grubs. However, the commercial preparations of this bacterium are extracted from Japanese beetle grubs and are most active against this species. Feeding grubs picks up this bacterium and it causes the body fluids to turn a milky-white before grub death. Fresh bacterial preparations should be used and three to five years are needed to provide lasting controls. Unfortunately, some studies indicate that the currently available products have not performed well in all soils.

4.3.4.2. Insect parasitic nematodes in the genera *steinernema* (=*neoaplectana*) and *heterorhabtitis* have been shown to be effective against white grubs. Field trials of *s. Carpocapsae* strains have generally resulted in less than 50% control, though *h. Heliothidis* strains have achieved 80% control or better. At present, available strains do not appear to be effective from one season to the next. Check with state extension specialists for current information on strain efficacy and usage.

5. Herbicides. Plants, to include grasses, when growing in a desired location, are considered ornamental and add to the natural beauty and playability of the golf course. These same plants become weeds or undesirable vegetation if they attract pests, can become a safety hazard, nuisance or detriment to the quality of the course, and increase maintenance. When plant management is required, herbicides, (chemicals used for killing or interrupting the normal growth of plants) may need to be used. Like all pesticides, the label is the law for herbicides.

5.1. Types of herbicides.

5.1.1. Selective herbicides kill some plants while having little effect on others. The selective nature of some herbicides allows golf course superintendents to use them to eliminate weeds without damaging desirable plants in the same location. An example of a selective herbicide is 2,4-D, which is used to control broadleaf weeds, but leaves grasses unaffected.

5.1.2. Nonselective herbicides kill vegetation without regard to species. Paraquat, glyphosate and glufosinate are examples of non-selective herbicides. Caution: in some cases, selective herbicides may act as nonselective herbicides, if used at too high a rate. Likewise, some nonselectives may be selective when applied at low rates.

5.2. Modes of herbicidal action. There are basically three modes by which herbicides affect vegetation. In order to properly use herbicides, golf course superintendents need to know the plant requiring management and the mode of herbicidal action needed to get the desired results.

5.2.1. Contact. The first mode of action is by direct contact. With this mode of action, the herbicide kills only the plant tissue it actually contacts. Contact herbicides are normally applied in a liquid form, and effective control depends on whether a plant's growing points are protected from or exposed to the spray. For example, perennial weeds with underground buds are not completely killed by a contact spray that reaches only top growth. As a result, golf course superintendents can expect new growth to occur soon after they apply a contact herbicide to a perennial plant.

5.2.2. Translocated. Translocated herbicides are absorbed by the leaves, stems or roots and move through the vascular system to leaves, buds and root tips. When absorbed by the leaves and stems, the herbicide is commonly moved with food materials as they are synthesized in the leaves and stems. When absorbed by the roots, the herbicide moves into water conducting plant tissue. The regulators then build up in rapidly dividing cells, upsetting the normal metabolism of the plant and causing death. Foliage application of translocated herbicides can be of practical value, as small amounts are usually effective. They can be applied in small amounts of diluent. These herbicides work best when the plant is aggressively growing.

5.2.3. Soil sterilants. Soil sterilants make treated soil incapable of supporting higher plant life, but they don't necessarily kill all life in the soil, such as fungi, bacteria, and other microorganisms. Toxic effects may remain for only a short time or for years. Residual toxicity depends on: 1) the chemical and its rate of decomposition or leaching, 2) the colloidal and chemical content of the soil, 3) species tolerance, and 4) the rate of application.

5.2.4. When selecting an herbicide it’s always wise to research the various formulations available and check with other superintendents who have used the herbicide in a similar manner. GCSAA is a great resource to find experts on various herbicide types and turfgrass varieties. The GCSAA on-line forum is also a great means to access other superintendents and ask questions prior to using a new herbicide.

5.3.Herbicide longevity. Herbicides vary in their rate of disappearance from the soil because of volatility, susceptibility to decomposition by soil microorganisms, and solubility. For example, some carbamates are volatile at high temperatures and rapidly lose their toxic effect during the summer months. Certain soil microorganisms effectively decompose 2,4-D. Some water-soluble herbicides are readily leached from the soil.

5.4.Herbicide resistance. Weeds with resistance to herbicides are becoming more common. “It is believed that within any population of weeds, a few plants have sufficient tolerance to survive any herbicide used. Since only the survivors can produce seed, it is only a matter of time until the population of the resistant weeds outnumbers the susceptible type” (Hock and Brown). It is recommended that golf course superintendents do not use the same class, or herbicides with the same mode of action, every year. In addition, if the herbicide does not seem to be effective there may be an underlying problem that is generating the plant pest to be present and inhibiting the desired plant.

6. Fungicides. A major problem in turfgrass management is the presence of disease caused by pathogenic fungi in combination of a susceptible host and climatic conditions. The key to controlling turfgrass diseases is constant surveillance to detect problems early, proper

management of turfgrass to have a healthy stand that resists disease organisms and cultural controls first. However, certain fungi can rapidly destroy a healthy stand of turfgrass if not treated immediately. Therefore, fungicides are available to treat and manage most golf course turfgrass diseases. Fungicides are found in both organic and inorganic compound formulations. There are basically two types of fungicides:

6.1.Contact fungicides that are sprayed onto the infected plant to prevent the fungi from further infecting the plant. Contact fungicides, such as chlorothalonil (Daconil), act on the surface of the plant to prevent fungal invasion. As new growth proceeds and new untreated vegetation is exposed, they need to be reapplied. Usually a 7-14 day application schedule is required.

6.2.Systemic fungicides like Propiconazole (Banner MAXX), on the other hand, are taken up by the plant and act inside the plant's system to prevent fungal invasion. Systemic fungicides are absorbed by the plant after they are sprayed on and translocated as the plant moves them upward. This upward movement protects newly emerging parts of the plant. Because they work from the inside of the plant, they cannot be washed off and tend to have a longer duration of effectiveness (4-6 weeks).

6.2.1. Sterol Inhibitors are a common class of systemic fungicides that prevent ergosterol production in sensitive fungi.

6.2.2. Benzimidazole Derivatives is another class of systemic fungicide that is not toxic to pythium or several other fungal species.

6.3.Fungicide resistance. Fungicide resistance is defined as the stable, inheritable adjustment of a fungal cell or a fungal population to a fungicide, resulting in a less than normal sensitivity to that fungicide. A certain proportion of strains in a pathogen population are naturally resistant to a fungicide. Application of a fungicide at frequent intervals selected for these resistant strains causes the population as a whole to become less sensitive. Numerous cases have arisen where some fungi develop a resistance to specific fungicides after regular application. There are various theories as to what causes this to occur and how to prevent it. Superintendents should research and develop a fungicide program that addresses the common problems they experience on their courses under their specific conditions. With regard to prevention of fungicide resistance as it applies to Dollar Spot, Dr. Joe Vargas recommends that “it is far better to use one site-specific fungicide chemistry until resistance develops and then switch to another site-specific chemistry. This will extend the useful life of the fungicide chemistries beyond what can be achieved with rotation.” (Vargas, J.M., Ph.D, 2002)

7. Plant Growth Regulators (PGR). Turfgrass plant growth regulators are used to impact the normal growth pattern of turfgrass. They normally create small, dense plants by shortening internodes and leaves. They also reduce mowing needs, produce uniform turfgrass stands and help provide a smooth putting surface.

7.1. Growth regulators are used in overseeding to prompt an established turf to yield to the newly seeded grass. They can reduce mowing and turfgrass encroachment at the edges of bunkers, paths and flowerbeds. Because some growth regulators cause turf to become denser and then "rebound" with vigorous growth after the chemical wears off, they can apparently precondition turf for stressful conditions.

7.2. Caution may be advised, however, before using some growth regulators on turf infested with grassy weeds. For example, some growth regulators suppress bermudagrass (Cynodon species) more effectively than they do weeds, thereby giving an advantage to pre-existing weeds.

7.3. Applications of growth regulators, which have so many different uses, have increased dramatically in the 1990s.

7.3.1. In turfgrass, the Type II growth regulators in common use are flurprimidol (Cutless), paclobutrazol (TGR) and trinexapac-ethyl (Primo). They inhibit gibberellic acid synthesis (a plant hormone needed for cell elongation). Mefluidide (Embark), a Type I growth regulator, inhibits cell division and differentiation.

7.3.2. According to various studies, growth regulators can reduce plant height and clippings.

7.3.3. Three trinexapac-ethyl applications reduced mowing of Tifway bermudagrass by 70 percent within a 12-week period.

7.3.4. Kentucky bluegrass (*Poa pratensis*) was reduced by four to five mowings within an eight-week period following growth-regulator applications.

7.3.5. Tall fescue (*Festuca arundinacea*) mowing was also reduced by three to four mowings within a five-week period following mefluidide and trinexapac-ethyl treatments.

7.4. Growth regulators may also influence weeds. One researcher noticed increased spring broadleaf weeds in bermudagrass treated with flurprimidol and mefluidide. Decreased turf density led to increased crabgrass (*Digitaria* species) infestations in Kentucky bluegrass-red fescue (*Festuca rubra*) turf following applications of an experimental growth regulator.

7.5. In contrast, annual bluegrass populations declined in creeping bentgrass greens after experimental paclobutrazol and flurprimidol treatments, and growth regulators have become commonly used to control this tenacious weed on golf courses.

8. Fertilizer. With all the various soil and turfgrass types used on golf courses and variations of fertilizer types, it would be impossible to provide a complete fertility overview and an accurate recommendation for turfgrass fertility in this manual. Therefore, a brief review of fertilizers is provided with basic information on nutrients.

8.1.The fertilization program is vital in the maintenance of healthy, attractive turfgrass. Application of the correct type and amount of fertilizer at the right time is critical. However, the fertilization program must be combined with cultural practices such as mowing and watering to obtain the best results. Fertilizing on a regular basis without establishing a requirement or need can be wasteful and damaging to both the turfgrass and the environment. Therefore, a thorough nutrient program combined with a preventative pest management program needs to be implemented for best results.

8.2.Fertilizers usually have the grade or analysis described as the percentages of nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) in the particular formulation. A 12-12-12 grade fertilizer contains 12 percent N, 12 percent P_2O_5 and 12 percent K_2O.

8.3.“A fertilizer ratio is the ratio of the percentages of N, P_2O_5 and K_2O in the fertilizer. Examples of a 1-1-1 ratio fertilizer are 10-10-10 and 8-8-8. An example of a fertilizer with a 3-1-2 ratio is 12-4-8. To figure the ratio, take the smallest number in the grade and divide it into each number of the grade. For example, 4 is the smallest number in a 12-4-8 grade and it can be divided into 12, three times and into 8, two times for a 3-1-2 ratio; that is, 12-4-8 = 3-1-2.” (Landry, G. Jr, 2000)

8.4.Fertilizer producers display the guaranteed analysis (grade) on the fertilizer container. The grade or analysis of this fertilizer is 16-4-8. The first number (16) represents the percent nitrogen (N); the second number (4) represents the percent phosphorus (P_2O_5); and the third number (8) represents the percent potassium (K_2O). The 50-pound bag of 16-4-8 fertilizer contains 8 pounds of N (50 x 0.16 = 8), 2 pounds of P_2O_5 (50 x 0.04 = 2), and 4 pounds of K_2O (50 x 0.08 = 4), for a total of 14 pounds of nutrients. The other 36 pounds of material in the bag is called filler or carrier. (Landry, G. Jr, 2000)

8.5.Turfgrass fertilizer recommendations are usually given in pounds of nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) per 1000 square feet of area.

8.6.To determine how many pounds of fertilizer it would take to supply one pound of nitrogen to a 1,000 square-foot area, divide the percent nitrogen of the fertilizer into 100. (NOTE: This is only true when working on a 1000 square-foot basis).

8.7.Examples: How many pounds (1) 34-0-0 or (2) 12-4-8 are needed to apply 1 pound of nitrogen per 1000 square feet?

8.7.1. 100/34 = 3 pounds of 34-0-0

8.7.2. 100/12 = 8.3 pounds of 12-4-8

8.8.The application rates can be changed for a 10,000 square-foot area, an acre or any size area. Example: It takes 8.3 pounds of 12-4-8 to supply one pound of nitrogen to a 1000 square-foot area. So, 8.3 x 10 = 83 pounds of 12-4-8 are needed to supply 1 pound of nitrogen to a 10,000 square-foot area. Since there are 43,560 square feet in an acre, multiply 8.3 x 43.6 to get 362 pounds of 12-4-8 to supply 1 pound of nitrogen to an acre (Landry, G. Jr, 2000).

8.9.If substituting complete fertilizers of different rations, base the application rate on the amount of fertilizer needed to supply the recommended quantity of nitrogen. Therefore, 6 pounds of 16-4-8 can be substituted for eight pounds of 12-4-8 or vice versa. Proper substitutions of other materials can also be calculated as shown before. When substituting fertilizers, remember to select a fertilizer grade that most nearly matches the grade recommended (Landry, G. Jr, 2000).

8.10. Nitrogen Source. Nitrogen materials can be divided into two groups. One is "quickly available" or "water soluble," and the second is "slowly available," "water insoluble," or "controlled-release." The quickly available nitrogen is immediately available to plants provided there is adequate soil moisture. In addition, these materials generally (1) are less expensive**,** (2) can cause growth flushed, (3) have short soil residual, (4) can leach and (5) have high burn potential. Quickly available nitrogen materials include ammonium nitrate, urea, ammonium sulfate and potassium nitrate (Landry, G. Jr, 2000).

8.11. Slowly available materials release nitrogen more gradually and over a longer period. The rate of nitrogen release depends on microbial decomposition alone or physical and/or chemical processes along with microbial activity. Environmental factors that affect microbial activity and release of these fertilizers most are temperature and moisture. High temperature and moisture increase microbial activity and nitrogen release. The slowly available materials generally (1) are more expensive, (2) require fewer applications, (3) reduce losses to leaching and (4) have low burn potential. Examples of slowly available materials include sewage sludge, ureaformaldehyde (UF) [Don't confuse with urea, which is a fast release material], methylene urea, isobutylidine diurea (IBDU) and sulfur-coated urea (SCU) (Landry, G. Jr, 2000).

8.12. Slowly available nitrogen is usually identified on the label as "water insoluble nitrogen" (WIN), UF, IBDU or SCU. The 16 percent nitrogen represents the total percentage of nitrogen in the bag. Dividing the percentage of water insoluble nitrogen by the total percentage of nitrogen and multiplying by 100 can calculate the percentage of the total nitrogen that is water insoluble. Thus, 4 percent divided by 16 percent x 100 = 25 percent of the total nitrogen is water insoluble or slowly available. A high quality, slow release lawn fertilizer should contain at least 30 percent of the nitrogen in a slow release form. If 50 percent or more of the nitrogen is in the slow release form, apply twice the recommended amount of nitrogen half as often (Landry, G. Jr, 2000).

9. Fumigants. Sometimes nonselective and selective herbicides are not appropriate, nor effective for controlling or preventing weeds. For instance, new soil for topdressing may need to be sterilized of weed seed. This is an application where fumigants may be used. Fumigants are the most dangerous pesticides used in golf course pest management operations. More than with any other type of pesticide, it's absolutely critical to follow the label (and all associated labeling) very carefully when using any fumigant. The label is also extremely important since it identifies the time and concentration needed to achieve complete kill within the fumigated area or product. It's critical to reach (but not exceed) the recommended concentration range and minimum time requirements called for on the product label. Also, keep in mind that fumigants have no residual characteristics; if fumigated materials or areas aren't adequately protected, a new infestation can occur in very little time.

9.1.Required training. Golf courses should only be using fumigants if they have experienced, trained and proven applicators, proficient at using the specific fumigant(s) required.

9.1.1. Compressed gas. This is the most common form of fumigant used in golf course IPM. In this form, the fumigant is compressed under pressure into liquid form, and then made available in cans and large metal cylinders. The liquid reverts to a gas at normal atmospheric pressure. Methyl bromide and sulfuryl fluoride are examples of compressed gasses.

9.1.2. Methyl bromide has been the predominant broad-spectrum fumigant for controlling pests, including weeds, pathogens and plant-parasitic nematodes in turfgrass sites. Methyl bromide, however, has been targeted for removal because it has been identified as contributing to ozone depletion in the upper atmosphere. Under Title VI of the Clean Air Act (amendments of 1990), the EPA has prohibited the production and importation of methyl bromide starting Jan. 1, 2001. Research being conducted at the University of Florida is designed to evaluate potential methyl bromide replacements. This GCSAA Foundation-funded project proposed to evaluate methyl iodide, Dazomet, metham sodium, Dazomet/chloropicrin co-applications and metham sodium/chloropicrin co-applications.

9.2.Applications of fumigants. Standard fumigants are generally classified according to their application, being commonly referred to as stored products fumigants, structure fumigants, or soil fumigants.

9.2.1. Methyl bromide. This is the most common fumigant used by golf courses. It is a colorless gas with a low odor resembling chloroform, is noncorrosive and nonflammable. Its most common use is for fumigating soils. Methyl bromide is very poisonous to humans. It is a narcotic and a nerve poison, giving no warning of danger because of delayed symptoms. Fatal human cases have long, dormant periods followed by collapse. Due to the combination of low odor and the delayed toxic reaction, it is usually formulated with a warning agent, such as chloropicrin.

9.2.2. Structural treatments. Structural treatments are normally not required of golf course superintendents. When they are, treatment is normally accomplished under contract.

10. Rodenticides. These compounds are used mostly as poisons in food baits or in water solutions. Carefully follow directions for their use to prevent program failure and minimize the hazard to nontarget organisms.

10.1. Bait materials. Since the success of any poisoning program depends upon the rodent accepting the bait, select the bait material with care. Acceptable bait material will vary, depending upon the preferences of the species or population of rodents requiring control. Raw products the rodents are already familiar with generally work better than unfamiliar foods. If rodent food preferences are unknown, golf course superintendents should "prebait," or apply baits with no poison added. Select test foods from each of the following types: a) cereals (cornmeal, bread, oatmeal, whole grains, poultry mash); b) proteins and fats (meats, fish, cooking grease, chunky peanut butter); c) fruits and vegetables (melons, sweet potatoes, coconuts, bananas). Test a variety of baits for a day or two to determine which are preferred, unless the situation demands an immediate rodent reduction or premixed anticoagulants be used.

10.2. Types of rodenticides. The rodenticides described here may be classified as multiple or single dose. Multiple dose rodenticides are moderately toxic poisons, which require a number of feedings, with death occurring over a period of time. Conversely, single dose rodenticides are highly toxic poisons that kill rapidly, normally after a single feeding.

10.2.1. Multiple dose. The only type of multiple dose rodenticides used on the golf course are anticoagulants. These are chemicals, which cause internal bleeding by reducing the clotting ability of the blood. Except for birds, all warm-blooded animals are affected in this manner, so take precautions to keep humans, domestic animals and pets from eating anticoagulant baits. Anticoagulants are stable, odorless and tasteless to rodents in the concentrations used. Two formulations are available: a prepared, ready-to-use material, and a concentrate used to prepare food or water baits. Some common anticoagulants include warfarin, diphacinone, fumarin, pival,