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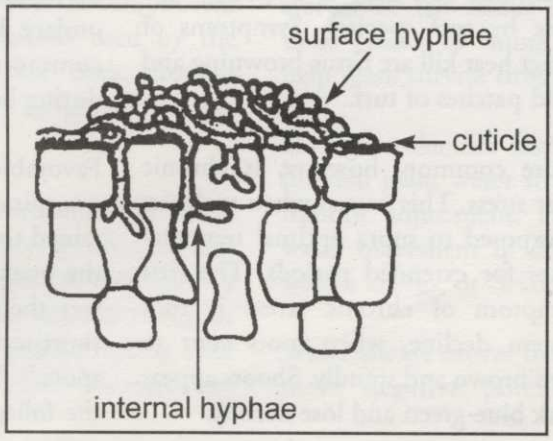
Turfgrasses Have a High-Stress Occupation

by Michael D. Richardson, Ph.D., Rutgers University and Kenneth Marcum, Ph.D., University of Arizona

Golf course superintendents have one of the most demanding and stressful occupations in the world. On the other hand, practitioners of this profession gain a tremendous amount of satisfaction from their position.

The grasses they manage are very much a reflection of their stressful occupation. A finely manicured turf produces an aesthetically pleasing landscape that also can provide many forms of recreation. As the major component of a demanding ecosystem where climate, poor soil, pollution, traffic, and hostile organisms produce stress, turfgrasses can be said to have a high-stress occupation.

Turfgrasses are exposed to a range of environmental stresses, which are divided into two classes. **Biotic** (biological) stresses are caused by organisms that attack grass plants, such as fungi or insects. **Abiotic** (not biological) stresses include factors such as drought, salinity, or temperature extremes. Although advances in breeding and management have improved the overall performance of most turfgrasses, the ability of specific grasses to survive and even thrive under extreme stress is fundamentally associated with the physiology of the grass. In the following pages, we will describe some of the basic



When a fungus infects a grass leaf, its mycelium will penetrate both the cuticle and the underlying leaf cells to form a continuous, moist channel from the leaf's interior to the atmosphere. This channel allows water to move freely from the leaf tissue to the atmosphere. As a result, a fungal-infected leaf can no longer prevent water loss by closing its stomates.

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mechanisms of stress tolerance in turfgrasses and take an ecological look at how other organisms can also affect the stress physiology of the grass.

Abiotic Factors

Heat Stress — High temperature is the major factor limiting the use of C3 turfgrasses (cool-season, e.g. bluegrass, bentgrass, ryegrass) in southern states. The ability of turfgrasses to withstand high temperatures varies, depending on the species and cultivar. Optimum shoot growth of C4 turfgrasses (warm-season, e.g. bermudagrass, buffalograss, zoysiagrass), occurs at temperatures of 80 to 95 degrees F, compared to 60 to 75 degrees for C3. The optimum temperature range for root growth is even lower (50-65 degrees for C3). Therefore, heat stress is usually a problem for C3 grasses grown in warmer or transitional climactic regions. A good example is the compulsion to grow creeping bentgrass in southern states, which necessitates expensive management practices. Even in northern states, loss of turf to heat stress is common on greens containing annual bluegrass during the summer.

Heat stress directly injures or kills plant cells by denaturing important enzymes or proteins. The critical cell temperature that results in plant death is around 106 degrees F (some variance by turf species). Symptoms of direct heat kill are tissue browning and dead patches of turf.

More common, however, is chronic heat stress. This occurs when turfgrass is exposed to supra optimal temperatures for extended periods. The first symptom of chronic stress is root system decline, when roots start to turn brown and spindly. Shoots appear dark blue-green and lose density.

Chronic heat stress weakens turf, making it more susceptible to other stresses, such as diseases, insects, drought, and traffic. Every effort should be made during extended heat stress to eliminate or control other stresses. For example, preventative fungicides are frequently applied to C3 turfgrasses during the hot summer months to control root-damaging diseases, such as summer patch. Traffic also should be minimized since turfgrass recovery from injury might be slow under supra optimal temperature conditions.

Heat and drought stress are closely related and sometimes difficult to separate. One stress will often precipitate the other. For example, the first symptom of heat stress in C3 grasses is root decline or die back. As root surface and depth decline, water uptake can no longer keep up with evapotranspiration, resulting in secondary drought stress.

As plants transpire, heat energy is absorbed from the leaves, resulting in "transpirational cooling." This is because water molecules have a high heat of vaporization and require a lot of energy to evaporate. Under drought stress, water uptake by roots slows and stomates close. The result can be a decline in transpiration and tissue dehydration. Without transpirational cooling, the turfgrass canopy can heat up rapidly on a hot day and cause secondary heat stress. Both stresses are commonly present on C3 grasses during hot summer months.

Favorable plant water balance and transpirational cooling must be maintained to reduce heat stress. Syringing, the practice of brief hand watering to wet the foliage only, provides rapid, short-term alleviation of turfgrass "hot spots." Syringing immediately cools the foliage and rehydrates leaf tissues.

This allows stomates to reopen and transpirational cooling to resume.

Long-term alleviation of heat stress requires management practices that encourage favorable root depth and soil water status. These include raising the mowing height, irrigating deep and infrequently, proper nutrition (high potassium, low to moderate nitrogen), alleviating soil compaction, controlling traffic, and reducing thatch buildup. Proper management practices must be in place prior to periods of heat stress so that sufficient root mass is present.

Drought Stress

Water shortage is the single most pressing problem facing the turfgrass industry today. This is particularly true in the Sun Belt states where population is rapidly increasing. In some western states, 40-50 percent of urban water use during the summer is attributed to irrigating turfgrass in landscapes.

Drought stress is the prolonged period of water shortage that reduces turfgrass growth and quality. The severity of drought stress depends on many factors. They include the amount of rainfall or irrigation available, temperature and relative humidity, soil type (heavy-textured soils hold more water than sands), and turfgrass species. South-facing slopes are also prone to drought, due to higher intensity of radiation, greater evapotranspiration (ET) rates, and lower water infiltration capacity. As described in the previous section, drought and heat stress often occur together, and are additive (i.e. high temperatures will worsen a drought condition).

Drought resistance in turfgrasses is complicated because of the many mechanisms used by the plant. However, there are three basic drought resistance strategies utilized by turfgrasses: escape, avoidance, and tolerance.

Drought escape is a survival mechanism in which the plant either rapidly completes its life cycle and produces seed prior to drought, or goes into a dormant state during drought. Annual bluegrass utilizes the first strategy — prolific spring seed production ensures its survival through the summer. In contract, Kentucky bluegrass and bermudagrass can escape severe drought by going dormant because their rhizomes or stolons can survive the drought in a dormant state. Drought escape allows survival, but the quality of a turf canopy is lost.

Relative Heat Tolerance Of Turfgrass Species (Beard, 1973)

Heat Tolerance	*Turfgrass Species*
Excellent	zoysiagrass bermudagrass buffalograss centipedegrass St. Augustinegrass
Good	tall fescue
Medium	colonial bentgrass creeping bentgrass Kentucky bluegrass
Fair	red fescue, annual bluegrass perennial ryegrass
Poor	Italian ryegrass rough bluegrass

Drought avoidance entails maintenance of a favorable water balance in the plant either by reduced ET rates (water loss) or by deep, extensive root systems that can absorb more water from the soil. Under drought, ET rates can be reduced in all grasses by stomatal closure. Leaf folding or rolling is common with bentgrass, tall fescue, and zoysiagrass. Bermudagrass and zoysiagrass can produce a thick waxy leaf cuticle to lower ET. Bermudagrass has sunken stomates and buffalograss has leaf hairs to reduce ET. In contrast, the deep, extensive root system of tall fescue and bermudagrass enable these grasses to "mine" the subsoil for water to help them survive drought periods.

Drought tolerance allows the plant to "tolerate" internal plant water stress by a process known as osmotic adjustment. The basic driving force for water movement in the soil-plant system is the water's energy, or "water potential."

Water always moves from areas of less negative to more negative potential. Water potential is

affected by the quantity of water present (the drier an area, the more negative its water potential) and by the solute content of the water (the more solutes dissolved in the water, the more negative its potential). A plant can increase water uptake from the soil through osmotic adjustment, by increasing the solute content of its water. Bermudagrass, zoysiagrass, and St. Augustine are turfgrasses that do this to increase water uptake from drying soils.

Management Techniques for Drought Resistance

Even though drought resistance mechanisms of turfgrasses are complex, there are a number of management techniques that can maximize potential drought resistance. Water infrequently and deeply, allowing the turf to stress slightly before irrigating. This will encourage deep rooting. Use soil tensiometers or examine plants for first signs of wilt to determine when to water. Weather station data can be used for irrigation scheduling.

Discourage vigorous vegetative growth that uses excessive water. Excess nitrogen stimulates shoot growth at the expense of rooting. Keep N on the low side of optimum. Potassium should be kept high, however. N:K ratios of 1:1 have been shown to improve drought resistance. Apply fertilizers to cool-season grasses in early and late fall to encourage root growth. Avoid soil compaction that can limit root growth and efficient water uptake.

If possible, raise the mowing height to the high side of optimum. Mowing closely does reduce water use, but it also reduces rooting depth and branching. Mow frequently with sharp blades to encourage a uniform, dense turf with minimal water loss. Finally, plant growth regulators (PGRs) have shown some promise for reducing ET in turfgrasses. However, they also can reduce rooting. Long-term effects of PGRs on drought resistance are not known.

Enhancing turfgrass drought resistance is a long-term process that is optimized by encouraging healthy, deep-rooted plants while discouraging vigorous shoot growth. By using these management practices, drought resistance will be enhanced and significant water savings can be achieved.

Salinity Stress

The demand on limited fresh water resources in recent years has increased the problem of salinity stress on turfgrasses. This is especially true in western states where rapid development is straining potable water resources to the limit. Many turfgrass facilities are required to use secondary water sources Arizona, California and other western states. Salinity problems also occur in coastal states where sea spray can reach turf areas and overpumping of wells causes salt water intrusion.

Salinity injures turfgrasses in several ways. Initial injury is generally due to water stress. Initial symptoms are the same as drought stress, blue-green or gray-green turf. As discussed previously, water always moves from areas of high to low water potential. Dissolving solute (e.g. salts) in water lowers its water potential. As soil water gets saltier, its water potential declines to a point where the turfgrass roots have difficulty taking in water, even though the soil might be moist.

Secondly, salts are also toxic to turfgrasses. Injury symptoms are leaf firing and canopy thinning. Finally, salts can indirectly injure turfgrasses by their effect on the soil. Sodium chloride (table salt) is a primary component in salty water. Irrigating with high sodium water can result in a breakdown of soil structure, which impedes drainage and aeration. This results in compacted, waterlogged conditions.

Turfgrasses utilize several tolerance mechanisms to cope with salinity. To adjust to secondary water stress caused by salts, they lower their internal water potential below that of the surrounding soil by accumulating solutes (e.g. sugars). There is evidence that saline conditions can stimulate the roots of some grasses to elongate deeper into the soil profile. These grasses include seashore paspalum, zoysiagrass, and bermudagrass.

Salts are toxic to all plants. Recent research has revealed that salt tolerance in turfgrasses is associated with exclusion of salts. Salts can be excluded either by active efflux from root cells or by specialized leaf salt glands, which accumulate and secrete excess salts. Finally, certain organic compounds,

Relative Salt Tolerance of Major Turfgrasses (Marcum, 1994)

Exceptional Salt Tolerance (18+ dSm-1)
- seashore paspalum (*Paspalum vaginatum*)
- alkaligrass (*Puccinellia spp.*)

Very Good Salt Tolerance (12-18 dSm-1)
- bermudagrass (*Cynodon spp.*)
- Manillagrass (*Zoysia matrella*)
- St. Augustinegrass (*Stenotaphrum secundatum*)

Good Salt Tolerance (8-12 dSm-1)
- creeping bentgrass (*Agrostis palustris*)

Fair Salt Tolerance (4-8 dSm-1)
- tall fescue (*Festuca arundinaceae*)
- perennial ryegrass (*Lolium perenne*)

Poor Salt Tolerance (<4 dSm-1)
- centipedegrass (*Eremochloa ophiuroides*)
- Kentucky bluegrass (*Poa pratensis*)
- colonial bentgrass (*Agrostis tenuis*)
- annual bluegrass (*Poa annua*)
- creeping red fescue (*Festuca rubra*)

known as "compatible solutes" have been found in "halophytes" (plants that grow well under high salinity). These compounds protect the cells of the plant from salt injury. Some of these compounds also accumulate in salt tolerant turfgrasses under saline conditions.

Drainage is the most critical factor in managing saline irrigation water. With each irrigation, salts from saline irrigation water are added to the soil. They must be periodically leached out of the root zone to avoid toxic buildup. The amount of leaching required to maintain an acceptable level of soil salinity, or the "leaching fraction (%LF)" is given by:

% LF = ECiw/ECdw
ECiw = salinity of the irrigation water
ECdw = salinity of the drainage water or salt tolerance of the turfgrass
Salinity is measured as electrical conductivity (EC) in decisiomons per meter (dSm-1)

For example, if your irrigation water has a salinity of 3 dSm-1, while the bermudagrass you are irrigating has a salinity tolerance of 9 dSm-1, the percentage leaching fraction is 3/9, or 33 percent. Therefore, you need to supply 33 percent more irrigation water than normally required by the bermudagrass to maintain the soil salinity level at or below 9 dSm-1.

Frequent aerification or installation of subsurface tile drains might be required to maintain adequate soil drainage for leaching. Also avoid high sodium water, which can destroy soil structure and permeability. The SAR value, or ratio of sodium to calcium and magnesium, indicates water's suitability for irrigation.

Water having SAR values greater than four (4) can cause loss of soil structure in most soils. However, sandy soils, such as those in USGA specification greens, can usually tolerate SARs up to nine (9). Gypsum or sulfuric acid, can be used to amend high SAR or sodic soils.

If salinity problems are anticipated, salt-tolerant turfgrasses should be used. Salinity tolerance varies widely among species, and to some extent among cultivars. The most salt tolerant turfgrasses are C4 (warm-season) grasses.

Managing saline irrigation water is a long-term process. Water salinity must be tested periodically by a reputable lab for total salinity, SAR, and other toxic ions (e.g. boron). The leaching fraction must be maintained through maintenance of good soil drainage. Finally, soil or water amendments might be required if sodium is a problem.

Biotic Factors

Fungal Diseases — We have discussed the physiological changes that occur in turfgrasses under stress from drought, heat, or saline conditions. Fungal diseases alter some of the same physiological processes, including photosynthesis, carbon allocation, and water use. While a great deal of attention is focused on the proper diagnosis and control of turf diseases, the underlying effects of fungal infection on general stress physiology is rarely considered.

Many of the changes that occur in a grass infected by a fungal disease reflect those basic differences by which plants and fungi obtain energy. Grasses

are autotrophic, meaning they are self-sufficient and can utilize solar energy through the process of photosynthesis. Fungi are heterotrophic, meaning they cannot obtain energy by photosynthesis and are dependent on a host plant for their energy needs. Therefore, one of the basic facts about any fungal infection is that the grass must supply energy for both itself and the fungus. This might not represent a substantial amount of energy at the onset of a fungal infection, but as more grass tissues become infected, the fungus can become a large energy sink and eventually drain the energy reserves of the grass.

A grass that is infected by a fungus will attempt to compensate for this loss of energy either by increasing photosynthesis or tapping into energy reserves. Since energy is most often stored as carbohydrates in the crown, roots, and rhizomes, using reserves can weaken the root system and make the plant more susceptible to other stresses. Pathogenesis can also disrupt normal plant response to water stress resulting in abnormal plant water loss and more rapid depletion of soil water reserves. Regardless of whether grass mobilizes energy reserves or increases photosynthesis to meet the energy demand of disease organisms, the long-term effects are negative.

Leaf-infecting fungi can also cause specific damage to photosynthetic tissues and limit the plant's ability to obtain energy. In order for photosynthesis to operate properly, leaf tissues must remain turgid, have functional chloroplasts, and working vascular tissues, among other things.

Leaf-infecting pathogens, such as leaf spots, dollar spot, and red thread, cause lesions or wounds that damage or kill photosynthetic cells. Each disease lesion reduces the functional leaf area of the grass and consequently, decreases the plant's ability to acquire energy. If the photosynthetic capacity of grass leaves is reduced below the level required to support the plant's growth, it will tap into energy reserves and additional stress will be placed on the root system.

Lesions occurring near the base of a grass leaf probably do not cause a significant reduction in photosynthetic leaf surface. However, they present a threat to the vascular tissues transporting photosynthetic products and water between the roots and leaves. This is a common symptom of dollar spot, where small lesions develop away from the leaf tip, form a collar around the leaf and might girdle it.

Another area of stress physiology that is impacted by fungal infections is the ability of the grass to control water loss. The epidermis (skin) of a grass leaf is covered by a waxy cuticle that is almost completely impermeable to water. A series of pores (stomates) located within the epidermis allow CO_2 and H_2O to pass between the leaf interior and the atmosphere. The stomates open during daylight to allow CO_2 needed for photosynthesis to enter. At night, the stomates close to restrict water loss.

In contrast, fungal cells are not protected from water loss by a cuticle and water easily evaporates from their entire surface. This is the primary reason why fungi thrive in wet places.

When a fungus, such as *Rhizoctonia spp.*, infects a grass leaf, its mycelium will penetrate both the cuticle and the underlying leaf cells to form a continuous, moist channel from the leaf's interior to the atmosphere. This channel allows water to move freely from the leaf tissue to the atmosphere. As a result, a fungal-infected leaf can no longer prevent water loss by closing its stomates. This causes additional water to be lost under very dry conditions or even during the night when stomates are closed.

Clearly, turf disease has more far-reaching effects than a simple reduction in aesthetic value. Plants that are infected by fungi are physiologically stressed for water and nutrients. Combined, these stresses weaken the plant and make it more susceptible to injury by drought, high temperature, or other environmental stresses. Even though turf will generally recover from many of the common diseases, the strains placed on energy reserves, root function, and photosynthesis should not be overlooked because they might lead to future, stress-related problems.

The many methods of fungal disease control are outside the scope of this text, but we will briefly mention some of the more common management practices that can reduce disease problems. Proper

use of irrigation is critical for controlling fungal diseases. Grasses should be irrigated as infrequently as possible to prevent additional wetting of leaves. Irrigation should be applied late at night or very early in the morning to reduce the period of time that leaves are wet. Early morning irrigation has the extra advantage of rinsing off sugar-laden water produced by the leaves at night (guttation) on which fungi feed.

Overfertilization, especially with soluble nitrogen sources, should be avoided to prevent leaf succulence. Mowing can also increase the incidence of some diseases, particularly on close-mown turf. Raising the cutting height during periods of high disease pressure can reduce disease damage. The use of preventative fungicides is advocated when diseases can place excessive stress on the turf.

Insects

Complex interactions among environmental conditions, stress tolerance and pest damage are just as important with respect to insects as fungal diseases. A basic understanding of turf insect biology is helpful for predicting the types of stress that an insect can cause turf. Insect pests are categorized according to their geographic region of adaptation, life cycle, and way they feed.

Insects are also classified by the part of the turfgrass plant they attack. Armyworms and chinch bugs feed on the uppermost part of the canopy, so they are considered stem/thatch insects. Because sod webworms reside in the thatch and feed on the base of the leaves, they are named, accordingly, as stem/thatch insects. The final group, the thatch soil insects, feed exclusively on the crown or roots, such as grubs and mole crickets.

Insect damage can be diagnosed by the type of mouthparts used to feed on turfgrass. Those with chewing mouthparts that macerate plant tissues are categorized as chewing insects. They include armyworms, grubs, and sod webworms. Insects that pierce the epidermis and suck out fluids from inside the host plant are categorized as piercing/sucking insects. Chinchbugs and aphids are members of this class.

Turf insects cause some of the same physiological symptoms for their hosts as fungi. Insects, like fungi, are heterotrophic and obtain their energy from the host. When an insect begins to feed on turfgrass, the grass must compensate for the loss of energy (in the form of carbohydrates) to the insect.

Insects also require a significant amount of nitrogen (N) in their nutrition. As much as seven (7) percent of an insect's body can be composed of nitrogen. Grass tissue, on the other hand, contains only one to four percent N, with slightly higher levels in young, actively growing organs. Insects are surprisingly capable of detecting high tissue N levels and feed on the youngest, actively growing tissues. Sucking insects seek out high N materials by feeding specifically on the phloem sap, which contains up to ten times more N than the xylem fluid.

The dependency of insects on high levels of nitrogen is one of the major reasons that overfertilization with soluble N can increase insect damage. Fertilization increases the soluble nitrogen in the leaves, making leaf tissue more attractive to the insect causing insects populations to increase. Tissue N levels are believed to be the major factor regulating the density of insect populations in a turf ecosystem.

Chewing insects can cause widespread damage to leaves, roots and crowns of plant. This damage impacts photosynthesis, water and nutrient absorption, and overall stress tolerance. Again, any damage to photosynthetic tissue will reduce the plant's ability to manufacture carbohydrates. Energy reserves will therefore be depleted.

Damage to the crown or root tissues will limit the water absorption capacity of the grass and lead to a reduction in drought and heat tolerance. Furthermore, turfgrasses that are already stressed by drought or heat are more easily killed by root feeders, such as grubs.

Sucking insects create stress on a turfgrass by feeding on the phloem sap. Phloem cells transport energy compounds (sugars) from the site of photosynthesis in leaves to the area of use in the crowns and roots. Consequently, an insect that has tapped into this supply can significantly reduce the

amount of energy available for leaf, tiller, and root growth. Sucking insects can also deposit salivary material into the conductive phloem cells that restricts movement of both nutrients and water within the plant.

The timing of insect activity is perhaps more critical than the direct stress caused to turfgrass by insects. Some insects, such as sod webworm, are most damaging during periods of high temperature and drought.

While damage from sod webworms is most visible during dry periods, the serious damage occurred earlier when soil moisture levels were close to optimum for the grass and the insect. At that time, the turfgrass was vigorous and able to mask the symptoms of insect injury. Only when the plant's ability to recover from injury is reduced by other stresses is the damage caused earlier by the insect noticeable in decreased turf quality. Plant vigor and regrowth are very important in masking the symptoms of many turfgrass insect pests.

Some insects are strongly influenced by their environment and cause the most damage when conditions are ideal. For example, Japanese beetle grubs tend to reside and feed for much of their lives in soils that are relatively moist. They move deeper into the soil profile during periods of drought.

Turf managers can exploit this avoidance of dry soil. Infrequent, deep irrigation will keep the upper few inches of soil less suitable for grub activity. Do not overwater turf sites that have a history of grub damage. However, downward movement of grubs might not stop feeding. Instead, it might merely change the location of the feeding from surface roots to deeper roots. If treatment is needed, keep soil moist to keep the grubs near the surface so insecticides can reach them. Then, go back to less frequent irrigation.

On the other hand, chinchbugs need a dry soil for optimum survival and reproduction. Populations of chinchbugs can be reduced by watering the turf during its nymph stage. Damage from the chinchbug can also be masked by maintaining the turf in a well-watered, well-fertilized condition which promotes rapid grass regrowth.

Integrated, Year-Round Approach

The environmental stresses placed on turfgrasses have many interacting effects that must be considered as a group rather than as a set of individual stresses. An integrated, year-round approach to stress management is still the most effective way to reduce stress-related damage. The proper selection of species and cultivars, sound irrigation and fertility management, and judicial use of pesticides can produce a turf that is able to tolerate most of the stresses discussed in this paper.

Remember, these grasses and their ancestors have survived an onslaught of drought, heat, disease, and insects for thousands of years by developing strategies to overcome these stresses. It is the job of the turf manager to five grass the opportunity to employ its defense mechanisms to overcome environment stresses.

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Insecticide Series: Part IV
How Insecticides Work

By Dr. Patricia J. Vittum, University of Massachusetts

Pesticides are chemical agents that are designed to kill (or otherwise control) various kinds of pests. Insecticides are one group of pesticides designed to control insects. Many of the insecticides that are currently available to turf managers are "broad spectrum" materials, meaning they control many different kinds of insects. They are broad spectrum because they affect most insects in the same way, often by interfering with the functioning of their nervous systems.

While some turf managers might find the concept of broad spectrum attractive at first glance, it often backfires. There are numerous beneficial insects active in the turf environment that can be killed by broad-spectrum insecticides. Some of them are **predators**, actively feeding on harmful insects. Others are **parasites**, which lay eggs on or inside the bodies of other insects. These eggs hatch into small larvae that feed on harmful insects.

The third group is **saprophytes**. They feed on dead organic material (such as thatch) and assist in decomposition as part of the natural process of growth, death, decay, and rebirth.

Routes of Entry

An insect might come in contact with an insecticide in three ways. The first is by **dermal exposure**. Some insecticides are able to penetrate an insect's cuticle, or outer skin that protects the internal organs. These insecticides are often chemically complex because they must be able to pass through several different layers of "skin," each with different chemical properties. Once they get into the body, they often target some function of the nervous system.

An insect might ingest a plant or another insect that has pesticide residue on it. This is a type of **oral exposure**. Entry through the digestive system allows disruption of the digestive process or absorption into the insect's internal tissues, where insecticides can attack the nervous system of the victim.

The third way an insect is exposed to lethal doses of insecticide is through **inhalation**. These insecticides evaporate and give off vapors that the insect breathes. Once inside the insect, most current insecticides interfere in some fashion with the nervous system of the target pest.

People who come in contact with insecticides are subject to the same routes of entry — dermal, oral, and inhalation. Dermal exposure is the most likely avenue for accidental exposure, particularly during the mixing and loading process.

Worker protection standards have been mandated to protect pesticide applicators from exposure while handling insecticides. Oral ingestion accounts for many of the accidental exposures occurring around the home. Inhalation exposure occurs more often when pesticide applications are made indoors without proper ventilation.

Measuring Toxicity

Chemists (both in the private sector and government) have tried to establish procedures for measuring the toxicity of various compounds. Testing for toxicity requires killing test organisms to determine how large a dose and how many doses are necessary to kill the target organism. Scientists have devised a procedure that gives fairly specific toxicity measurement. However, considerable controversy surrounds the interpretation of this measurement.

Acute toxicity occurs when an organism is adversely affected by a single, often relatively large, exposure to a toxic material. **Chronic toxicity** refers to exposure by low doses over an extended period of time or on several successive occasions.

Chemical toxicity is measured in laboratory settings using test animals, such as mice, rats, and rabbits. Initial screening tests are aimed at determining acute toxicity. These tests can be completed quickly and less expensively. Toxicologists determine the LD50 for a compound — the dose that kills 50 percent of a test population of animals.

An example will help to describe this procedure. A laboratory has 600 male white rats, each weighing one pound. The rats are divided into six groups of 100 each. The first group is fed 1/4 teaspoon of the test material, the second group get 1/2 teaspoon, the third group gets 1 teaspoon, the fourth group receives 2 teaspoons, and the fifth group is fed 4 teaspoons of the material. The sixth group is fed a teaspoon of water instead of the test material. All groups are handled identically. They are left in their cages for 24 hours (or 48 or 72 hours, depending on the material being tested and various other factors), after which the researchers record the number of survivors in each group. The results might look something like this:

Group	Dose	Number Alive After 24 Hours
A	0.0	99
B	0.25	94
C	0.5	76
D	1.0	50
E	2.0	27
F	4.0	3

In this test, the dose of one teaspoon per rat killed 50 of the rats. Therefore, the LD50 for the compound would be one teaspoon per one pound of male rat. The LD50 for female rats, mice or rabbits might be quite different. The age, overall health, and treatment of the test animals can also have a significant effect on their response. LD50 values can only be used as guidelines for determining the toxicity of compounds.

Obviously, laboratory tests are not conducted on every conceivable animal and using data generated from rats (mice or rabbits) to estimate how toxic a material might be to humans is risky. The way different animals metabolize or detoxify materials might vary greatly.

LF50s are expressed in amount of material per unit body weight of the particular test organism. LD50s are normally expressed metrically as milligrams (mg) of material per kilogram (kg) of body weight. This is equivalent to part per million. The key point to recognize is that the lower the LD50, the more toxic the material. For example, the lethal dose for an average man (154 pounds) of a chemical with an LD50 of 10 mg/kg would probably be 0.7 g, which is equivalent to less than half the weight of a paper clip.

LD50s are measured for both dermal and oral exposure. There is often a considerable difference in the LD50 between the two exposures. Usually, the oral LD50 is lower than the dermal for a given species of animal, although there are exceptions.

Signal Words

The Environmental Protection Agency (EPA) assigns a signal word to each pesticide formulation to indicate its toxicity and need for special handling. The EPA often uses the LD50 of a compound (either the pure or the formulated material) as one guideline for determining what the signal word should be.

The most restricted materials carry the signal words, "**Danger - Poison**," and prominently display the skull and crossbones on the label. Such materials usually have an oral LD50 of 0 to 200 mg/kg, the equivalent of a taste to a teaspoon for an average man or woman.

Pesticides carrying a "**Warning**" signal word usually have an oral LD50 of 51 to 500 mg/kg or a dermal LD50 of 201 to 2,000 mg/kg. A lethal dose for an average man or woman would probably one to two teaspoons.

Pesticides that carry a "**Caution**" signal word usually have an oral LD50 or 501 to 5,000 mg/kg or a dermal LD50 of 2,001 to 5,000 mg/kg. This is equivalent to a lethal dose of one ounce to one pint for an average man or woman. Some of the newer insecticides carry a caution label even though their LD50s are greater than 5,000 mg/kg.

The measurement of acute toxicity is not the only criteria used for determining signal words. Some materials have LD50s high enough to warrant a

"Caution" label, but instead carry a "Warning" label. Usually, this is because the material is highly irritating to eyes or causes an allergic respiratory response in some sensitive people. A more restrictive label can be assigned because a material is particularly prone to leaching into groundwater or volatilization.

Toxicity to bees, fish, or birds can also result in upgrading the signal words. Sometimes, the signal word on a label will be more restrictive than its toxicity to vertebrates would seem to indicate.

How Insecticides Work

Now that we understand a few things about pesticide toxicity, how do insecticides actually kill insects? Most insecticides currently on the turf market affect the nervous system in some fashion. Nerve cells carry information throughout the body. These messages move extremely quickly. An organism's response to various stimuli, such as wind, light, heat, or touch, is governed by information being sent through a string of nerve cells. Therefore, insecticides affecting the nervous system can disrupt both metabolism and survival response.

Chlorinated Hydrocarbons

Nerve cells are very complex. For the purposes of this discussion, we can consider them a series of cells lined up end-to-end, not quite touching. Membranes of the cells allow certain ions (charged particles) to pass through. When a nerve cell is not receiving or transmitting impulses, its interior is charged negatively and its exterior is more positively charged. When a one cell receives an impulse, it passes positively charged sodium ions over to increase the positive charge on the next cell. The electrical impulse is thus sent from one cell to the next.

Normally, this movement of ions in and across the cell membrane occurs very quickly. As soon as an impulse has passed through, the cell returns to normal, waiting for the next impulse to arrive.

Some insecticides, such as DDT and most of the chlorinated hydrocarbons, interfere with the ability of ions to move across the cell's membrane. As a result, the normal sharp spike of activity is spread out over a much longer period and the cell takes longer to return to its normal position. The cell acts as if it were receiving an impulse for an extended period of time, rather than for an instant. The effect is of constant firing.

The functional effects of these insecticides is very similar on both insects and humans. Poisoning symptoms include muscle twitching, stomach cramps, difficulty breathing, and difficulties with other types of muscle control. Examples of chlorinated hydrocarbons are chlordane, DDT, dicofol (Kelthane) and methoxychlor.

Organophosphates and Carbamates

As discussed earlier, nerve cells occur in "strings" but are not physically connected to each other. There is a space between the cells, called the synaptic gap, which contains different kinds of molecules. One such substance is a neurotransmitter called acetylcholine (ACh). A neurotransmitter transmits nerve impulses from one cell to the next. When an impulse arrives at the end of one cell, acetycholine in the synaptic gap bridges from one cell to the next to deliver the impulse. When the impulse has been transferred to the next cell, the acetycholine bridge breaks to let the nerve cell return to a normal resting position.

For a nervous system to work efficiently, there must be a way to remove the acetycholine from the receiving cell so that the sending cell can return to normal and be ready for the next impulse. This is the job of another molecule, acetycholinesterase. The cholinesterase attaches to the acetycholine on the receiving cell membrane and pulls its off. Once the combined molecule (ACh:ChE) is free of the cell membrane, the two components split apart and are available for the next impulse.

Organophosphate and carbamate insecticides are often called cholinesterase inhibitors because they tie up the cholinesterase in the synaptic gap. Acetycholine remains attached to the receiving cell membrane. The cell never returns to normal and impulses keep firing. Thus, poisoning symptoms

in humans include nausea, headaches, tremors, muscle twitches, and difficulty breathing. Examples of organophosphates are acephate (Orthene), chlorpyrifos (Dursban), diazinon, fonofos (Crusade, Mainstay), isazofos (Triumph), isofenfos (Oftanol), and trichlorfon (Dylox, Proxol). Carbamates include bendiocarb (Turcam) and carbaryl (Sevin).

Antidotes

A couple of antidotes are available for persons who have been poisoned as a result of exposure to organophosphates and carbamates. They must be administered by a physician and are very tricky to use. Dosages are difficult to determine, and incorrect dosages of antidote can result in serious injury or death.

Atrophine works by inactivating the membrane on the receiving cell, which functionally numbs the system and stops the constant onslaught of nerve impulses. Atropine can be used for both organophosphate and carbamate poisoning.

The second antidote, **2-PAM**, can only be used for overexposure to organophosphates. It works by competing with the organophosphate at the receiving cell membrane. This improves the chance that the cholinesterase will remove the acetycholine normally and permit cells to relax.

Cholinesterase Blood Tests

Blood tests can be carried out to determine the base level of cholinesterase for each person. "Normal" values vary among individuals so each pesticide applicator should have a blood test performed to establish his or her base level. Then, if an overexposure to an organophosphate or carbamate insecticide occurs, a physician will be able to determine the amount of reduction in the individual's cholinesterase. There are two different types of blood tests for cholinesterase, so it's important to know which type established the base line.

Insect Growth Regulators

Insect growth regulators (IGRs) are relatively new compounds in the turf and ornamental markets that interfere with the target insect's ability to grow normally. Some IGRs interfere with the molting process. Others interfere with hormones governing development.

Some of the most exciting developments are occurring in the identification of "juvenile hormones." Each insect completes a series of molts during its growth to adulthood. The insect has juvenile hormones in its body throughout most of that process. As long as the juvenile hormone is present, the insect will not make the final molt to the adult stage. When the concentration of this hormone decreases, the insect molts one last time and emerges as an adult. Juvenile hormones tend to be quite specific in regard to species.

Chemists have identified juvenile hormones for several kinds of insects. They can artificially produce them and they can be applied to confuse the insect's life cycle. When the artificial juvenile hormone is applied to an area where a sensitive insect in active, the insect does not make the final molt to adult and remains juvenile. These juveniles can't reproduce like adults.

Because IGRs are so specific, the have little to no measurable effect on humans and other mammals. Examples of IGRs are azadirachtin (Azatin, Bioneem, Turplex), halofenozide (RH 0345) and methoprene (altosid).

Many insecticides have detrimental effects on humans and other mammals, in addition to insects. Therefore, it is imperative that pesticide applicators follow all the safety precautions outlined on the label and avoid any use that can jeopardize themselves, wildlife, or local water safety.

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Hurdles Facing Irrigation Management With Satellites

by Tom Clarke
USDA-ARS, Phoenix, AZ

Earth observation satellites have orbited the planet for decades. Unfortunately, we have seen little use of satellite imagery for practical, day-to-day decisions by golf course superintendents.

For many years, the only civilian access satellite with turf management potential was LANDSAT. It only can look straight down, which means it must pass directly over a target to acquire imagery. The orbit is such that only one image acquisition can be executed every 16 days.

At best, without cloud interference, this would provide a "snapshot" assessment of turf condition and water status every two weeks. The presence of a few clouds on the acquisition day would mean going an entire month without information. Daily coverage is the ideal situation.

Another problem with current satellites is their spatial resolution. Weather satellites image every part of the country several times a day with sensors that could be very useful for irrigation management, but the smallest area they can resolve is one kilometer across.

LANDSAT has a resolution of 30 meters in the visible, near-infrared and mid-infrared bands. The thermal infrared sensor necessary for irrigation management has a resolution of 120 meters. This is much too large for golf courses. The French SPOT satellites have a 20-meter resolution, but they lack the critical thermal sensor.

Correcting for Orbital Changes

The information collected by satellites loses its value rapidly. Data should be in a golf course superintendent's hands within hours of acquisition so that irrigation and pest management decisions can be made before there is a significant loss. Even a day is too long for some information.

Assuring the accuracy of the data received is also more difficult than imagined earlier. If a satellite image were acquired at the same time of day every day, one would expect the data to be comparable. However, the sun angle changes slightly as the season progresses. A ground target can appear darker or brighter just from changing illumination angles rather than from any actual change in the target.

Atmospheric clarity also has a major effect on image quality. A hazy sky can reduce the amount of sunlight reaching the surface, as well as the amount of reflected light and radiant heat reaching orbiting sensors from the surface. In order for satellite information to be useful, particularly over a time sequence, the brightness registered by the sensors must be corrected for the angular and atmospheric influences. If this is not done, a user could get erroneous indications of change in turf status where none has occurred, or have a real change masked by these effects.

Superintendents already spend long hours each day making decisions. They coordinate actions and glean important information from all they see and hear. Raw satellite imagery can take many hours to interpret. It must be processed before interpretations can be made.

One of the most promising applications for satellite imagery is for irrigation scheduling. In arid environments, high daytime temperatures along with low humidity result in a large amount of evaporation from the soil surface and transpiration from plant material. The transition from no stress to an economically harmful level of water stress can occur quite rapidly. This makes the time to process satellite data and to implement changes in irrigation schedules an important concern. Satellite data, combined with ET data from local weather bureaus, gives superintendents the extra

information needed to conserve water and provide high quality turf for golfers.

The State of Satellite Data Evaluation

Visual evaluation of plant water status, while time consuming, can be remarkably effective for golf courses. Regular soil sampling to assess water depletion is also a good method, but it must assume uniformity in soil water holding capacity for large areas so that a few point measurements can be used to characterize water retention properties. Evapotranspiration (ET) models assume a freely transpiring reference crop with uniform canopy cover and soil type within the course. Many times, this is not the case.

In the past, hand-held infrared thermometers (IRTs) have been effective tools to detect water stress in crops. As the water supply in the rootzone becomes depleted, transpiration is reduced. Solar energy, normally absorbed through evaporation from the leaves, is converted to heat. The leaf temperature can increase as much as ten degrees C when humidity is relatively high. A fully stressed plant (no transpiration occurring) can have a leaf temperature greater than the air temperature.

For plants with known planting densities, such as turf, the percent cover can be determined and compensated for the influence of soil background. The combination of three sensors (red, near-infrared, and thermal infrared) provides two powerful tools for the golf course irrigation manager.

The first is a measure of the actual evapotranspiration relative to the potential ET. This is called the water deficiency index. It shows what percent of the maximum possible water loss through surface evaporation and plant transpiration was at the time of measurement.

The ET computer models used to calculate the water deficiency index from weather history, soil water holding capacity and estimated cover can be tailored to varying soil fertility and water holding capacities found on golf courses. A separate model could be run for different parts of the course.

The second tool is an image that assumes the exposed soil surface dries out before the root zone - almost always the case in the desert Southwest. This assumption allows soil background effects to be eliminated entirely, and water-stressed turf becomes clearly visible.

The Future

In order to make satellite imagery more economically attractive to the golf course superintendent and satellite image provider, a more valuable product than irrigation scheduling is needed. Work is ongoing to develop sensors for detecting fertilizer deficits and pest infestations. Satellite information can be added to important degree-day data to predict the onset of insect and disease outbreaks.

The launching of satellites specifically designed for golf course management is possible within the next few years. Difficulties associated with sun angle and satellite look angle are being addressed by scientists.

Increased image resolution will allow the use of ground targets with known reflectance for calibrating the images. This will greatly improve their accuracy and reliability.

Automation of image processing can and is speeding up the delivery time of processed information to the user, while orbiting data relay stations have helped increase the ability to handle a larger volume of images. Researchers are working on ways to meld satellite imagery with growth and ET computer models. The crowning achievement will be to tie all of these technologies together to form a product that is both reliable and easy to use. That time is rapidly approaching.

Tom Clarke is a scientist at the USDA-ARS Water Conservation Laboratory in Phoenix, AZ. *Companies working on satellite modeling for farm and other uses include Earthwatch (303) 682-3800, Resource 21 (303) 768-0015, and Space Imaging EOSAT (303) 254-2071. This article is adapted from the April 1997 issue of Irrigation Business & Technology .*

From the Editor

Many folks believe the turfgrass business is a "gold mine." New products are advertised in nearly every industry trade magazine. Every month you see articles about new products or management techniques.

Lots of companies want to sell you their products. If you only read their literature and listen to their sales pitches, you could easily come to the conclusion that all of your troubles can be solved by buying their products. We all need unbiased research to help us make decisions now and then.

Dr. Knoop

I've had the unpleasant experience of learning about a golf course that lost all 18 greens because a product was misapplied. It turned out that the product had never been subjected to good third party research. If it had, the company would have known better than to recommend that it be applied to greens, considering the environmental conditions. Evidently, the company did not choose to take the time or spend the money necessary for a research study.

Third party research simply means that a disinterested person performs the research on a new product or technique. The research study results must then be analyzed statistically. Only through statistics can we be sure that the research results are true and not due to random chance.

The research that we bring you in the pages of **TurfGrass TRENDS** must meet all of the standard criteria associated with university-based research. In addition, we are setting up a new Editorial Review Board to make absolutely sure we only print the best available information.

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