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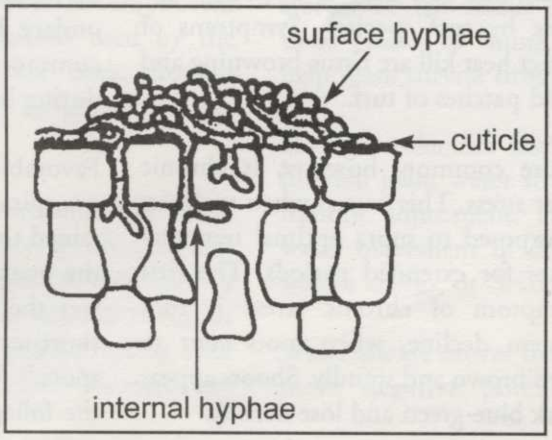
Turfgrasses Have a High-Stress Occupation

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.

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 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.

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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