TURFGRASS WATER CONSERVATION STRATEGIES

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Water is critical to the growth, survival, and functional use of turfgrasses. The water status of an individual plant is actually a dynamic system involving the transfer of water from the soil through the plant into the atmosphere. More specifically, water in the soil is taken up through the root system by the process of absorption and is then translocated upward through the vascular system in the stems and leaves of the plant. Through a diffusion process that occurs along a gradient from zones of higher water content to zones of lower content, water reaches the peripheral portions of the plant, especially the leaves, where it is transpired into the atmosphere. Transpiration, which occurs primarily through stomata in the leaves, involves the conversion of water from a liquid to a vapor state. The rate at which these processes of water absorption, translocation, and transpiration occur are strongly influenced by the environment surrounding the plant.

Only 1 to 3% of the water absorbed by the plant is actually used in metabolic-growth processes. The remainder is lost to the atmosphere by the process of transpiration; however, this is not a complete loss in that the transpirational process cools the leaf surface and thus avoids a build-up of heat to lethal temperatures. The evapotranspiration rate of a turf is greater than the evaporation rate from bare soil.

THE TRANSPIRATION PROCESS

In order to fully understand the implications of various environmental and cultural factors that affect the water use rate, one must first understand the basic process of transpiration. Most of the transpiration occurs through the leaves, although it can occur through stems in limited amounts. Transpiration is of two types: cuticular and stomatal.

Cuticular transpiration occurs directly through the epidermal cells of the leaf, with the rate varying directly in relation to the thickness of the cuticle, which is a wax-like layer on the leaf. This form of transpiration occurs on a continuous basis at relatively low levels.

Stomatal transpiration occurs through small structures distributed across the leaf surface, termed stomata, which are essentially pores with an underlying cavity (Figure 1). The conversion of water from a liquid to a vapor state occurs along the mesophyll cell surface of the inner stomatal cavity. Subsequently, the water vapor diffuses through the cavity and outward into the atmosphere. Although these stomatal pores represent only 2 to 3% of the total leaf surface area, they can be responsible for as much as 90% of the total water transpired from the leaf. Stomatal transpiration is limited to

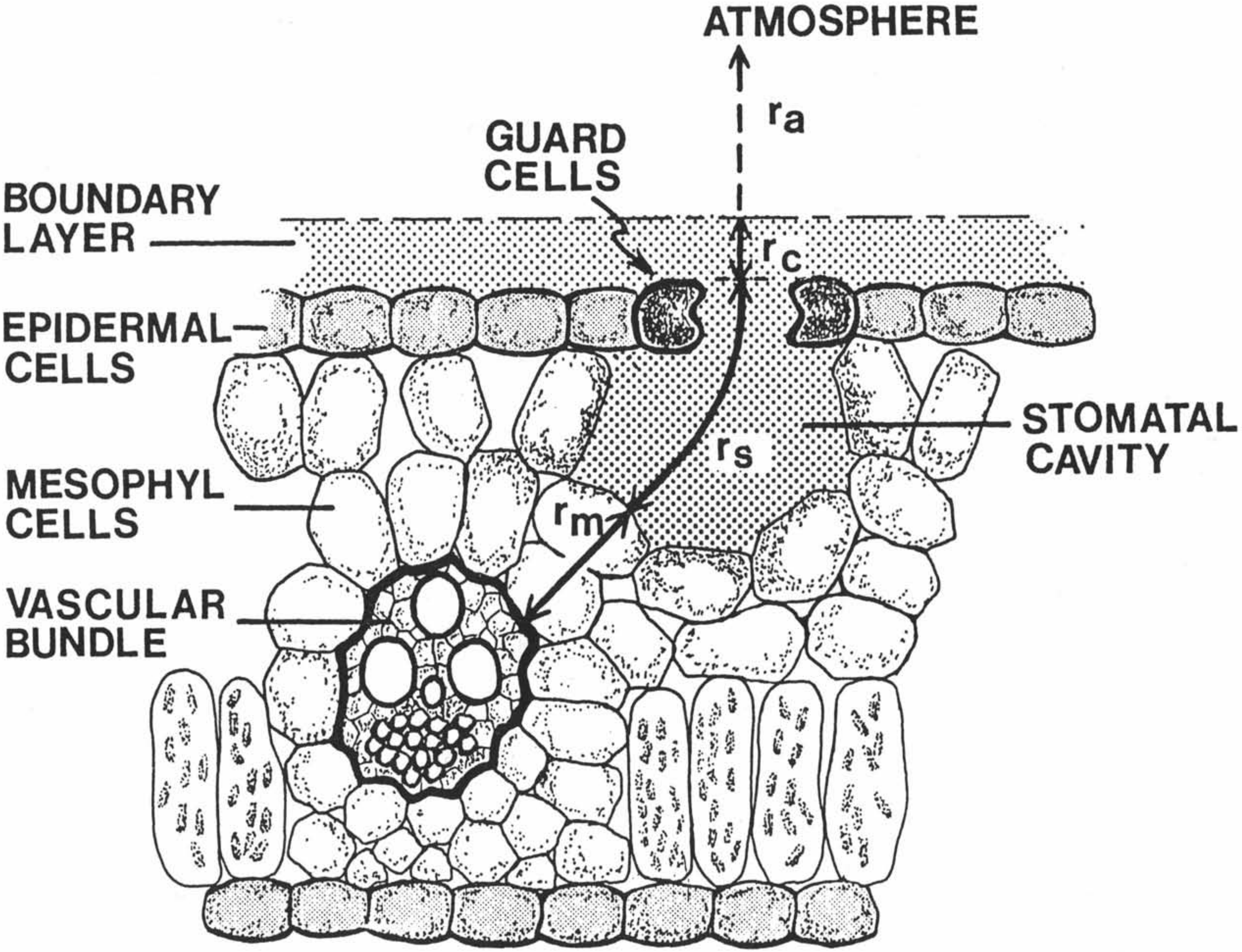

Figure 1. Cross sectional drawing of a leaf through a stomate.

the day-light hours since light is required to stimulate opening of the stomata.

The process of stomatal transpiration is driven by a vapor pressure gradient. The outward diffusion rate of water vapor is dependent on the relative amounts of water vapor outside the leaf versus that within the stomatal cavity. The greater the differential between these two vapor contents, the more rapid the outward water movement by diffusion.

Environmental Influences

From an environmental standpoint, any factor that increases the external water vapor content will suppress the transpiration rate. Environmental factors enhancing transpiration include a low atmospheric water vapor content, moderate wind velocities, medium to high temperatures, and full sunlight; while cool, cloudy, humid days without wind movement will suppress water loss by transpiration. The former condition increases the likelihood of an internal water deficit and subsequent wilt of a turf that would necessitate irrigation. In contrast, the latter situation would greatly reduce transpiration, which is desirable from a water conservation standpoint. However, if combined with relatively high temperatures it could adversely restrict the transpirational cooling process, thus resulting in heat stress to the grass.

A high atmospheric water vapor level surrounding the leaves is more likely to occur under conditions of poor soil water drainage and/or excessive irrigation. The water vapor level is further accentuated by positioning turfs in sites surrounded by trees, shrubs, and/or hills which restrict normal air movement across the area. From this discussion one can conclude that the specific water use rate of a particular turf may vary significantly depending on the site conditions and cultural practices that affect the environment surrounding the turfgrass leaves.

WATER USE RATES

The total amount of water required for plant growth plus the quantity lost by transpiration and evaporation from soil and plant surfaces is termed the water use rate (WUR). The transpiration component represents a major portion of the water use rate. The water use rate can vary significantly depending on the specific environmental and cultural conditions under which the turf is grown. Thus, the turfgrass manager can manipulate a number of cultural practices to enhance water conservation. The typical range in water use rates for most turfgrasses across the United states is between 0.1 and 0.3 inch per day (2.5 to 7.5 mm d^{-1}). However, a WUR as high as 0.45 to 0.5 inch per day (1.1 to 1.3 cm d^{-1}) has been reported, especially in the warm, semiarid regions of the United States.

Environmental Effects

The total annual water use rate (WUR) increases in proportion to the length of the growing season. Within a growing season, conditions that favor rapid shoot growth and transpiration cause an increase in the WUR. Thus, maximum WUR generally occur in midsummer in most regions and decline to relatively low levels during the winter. On a daily basis, higher WUR typically occur under conditions of full sun, high temperature, low atmospheric humidity, and moderate wind.

These environmental factors not only affect the rate at which the evapotranspiration process occurs, but also affect the basic morphology and physiology of the plant that influence the water use rate. For example, the percent water loss from a creeping bentgrass turf is reduced by almost 50% as the light intensity is reduced from full sunlight to a low intensity found under a very dense tree canopy. This reduction in WUR is highly correlated with a reduced leaf stomatal density caused by the low light conditions under which the turfgrass leaves were formed. A similar response was found when the growing temperature of creeping bentgrass was increased from 50 to 70°F (10 to 21°C). This 20°F (11°C) increase in growing temperature caused a 25% increase in water loss and an associated increase in the leaf stomatal density. It is evident from these data that turfgrasses growing under suboptimal temperatures and/or shaded conditions will have a substantially reduced WUR. Thus, irrigation practices need to be adjusted accordingly for optimum water conservation.

Cultural Effects

The effects of specific cultural practices on the water use rate (WUR) are not fully understood for each turfgrass species. However, based on our current level of knowledge some general guidelines can be presented.

The height of cut selected can have a strong influence on the WUR of turfs. The WUR was doubled as the mowing height was increased from 0.25 to 1 to 5 inches (0.6 to 2.5 to 12.7 cm). This response was caused by the increased leaf area from which evapotranspiration occurred, combined with a more extensive root system that enhanced the water absorption capability needed to support the higher evapotranspiration rate.

The water use rate also is influenced by the mowing frequency. As the mowing frequency of creeping bentgrass was increased from bi-weekly to weekly to 6 times per week, the WUR increased 41%. This response was most probably the result of an increased duration when the mower wounds were exposed, thereby increasing the evaporation component of WUR.

Similar effects can be demonstrated from a nitrogen nutritional standpoint. Typically, turfs receiving modest nitrogen fertilization will have a lower leaf extension rate and, thus, a lower water use rate. As the nitrogen nutritional level is increased, the WUR increases proportionally with the increasing leaf extension rate and associated leaf area. However, WUR may decline at excessive nitrogen nutritional levels due to a significant reduction in the depth and number of roots.

A third cultural factor influencing the water use rate is the irrigation frequency. Soils which are irrigated to maintain a moist to wet condition tend to have an increased WUR. Studies have shown that irrigations scheduled

3 times per week versus only when the turf visually wilts results in a 33% increase in the WUR when irrigated 3 times per week. Thus, adjustments in specific irrigation practices can affect the water use requirements of turfs.

The extent of water conservation that can be achieved with any one of these cultural practices on a particular species is not known as adequate data are not yet available. However, the relative responses reported should be comparable.

Turfgrass Species and Cultivar Effects

Specific information concerning the comparative water use rates among various turfgrass species is just now evolving. Generally, turfgrass species that have a lower shoot density, a more erect leaf orientation, a wider leaf, a more rapid vertical leaf extension rate, and/or a higher cutting height requirement also possess a higher water use rate. Among the cool season turfgrass species, the fine leafed fescues have a lower water use rate in comparison to the creeping bentgrasses, bluegrasses, and ryegrasses (Table 1). Among the warm season turfrass species, buffalograss, centipedegrass, and bermudagrass have much lower water use rates than either St. Augustinegrass or seashore paspalum. These rankings are based on the grasses being grown under their respective preferred climatic and cultural regimes. Cutting heights and nitrogen levels that diverge substantially from the optimums can cause shifts in the WUR rankings. Also, keep in mind that the water use rate is not necessarily related to the drought resistance of a turfgrass species.

Differences also exist among cultivars within each species, as reported by Beard et al for Kentucky bluegrasses. However, the specific water use rate differentials are not yet documented for each species. Considerable research is now underway to generate information concerning the specific water use rates of the commonly used turfgrass species and cultivars. The next few years will be characterized by a major research thrust in this vital area. For example, a major water conservation research program is underway within the Texas Agricultural Experiment Station that encompasses a breeding dimension as well as the stress physiology and cultural aspects. This research supported by the United States Golf Association will be especially critical in contributing to enhanced water conservation during the 1990's and beyond.

SUPPRESSING TRANSPIRATION

Another approach to water conservation is the use of techniques that reduce transpirational water loss through stomatal openings in leaves. There is considerable interest in a range of materials for this use. For example, there has been success with coatings sprayed upon the leaves of transplanted ornamental plants. These include both plastic and wax-type coating materials. However, such coatings have not proven effective on actively growing turfgrasses since the period of effectiveness is short-lived due to the frequent mowing practiced on most turfs. Another approach involves the application of an antitranspirant chemical which causes closure of the stomata. Phenyl mercury acetate (PMA) and several other experimental materials have shown a degree of effectiveness in stomatal closure under controlled conditions on non-turf species. Scientific documentation that these antitranspirants reduce the water use rates of turfgrasses is lacking.

More recently, Drs. Johns and Beard at Texas A&M University have demonstrated in principle that certain types of growth regulators have potential for use in water conservation on turfs. Specifically, flurprimidol (Cutless) and mefluidide (Embark) reduced the water use rates from St. Augustinegrass and bermudagrass turfs in the order of 20 to 35% for a 12- to 14-week period.

MAXIMUM WATER ABSORPTION BY ROOTS

Cultural practices that maximize the rooting depth will enable turfs to absorb moisture from a greater portion of the soil profile; thus delaying the onset of drought stress. There are environmental and cultural factors which the turf manager can manipulate to ensure as deep a root system as possible. They are summarized as follows:

Soil Environmental Factors:

Temperature - Root growth of cool season turfgrasses is greatest at soil temperatures of 50 to 60 °F (10 to 16°C); while the root growth of warm season turfgrasses is most active in the 75 to 85°F (24 to 30°C) range. Soil temperatures above 77°F (25°C) cause the cessation of root initiation from cool season turfgrasses plus the loss of existing roots by increased maturation.

Soil pH - Root growth is seriously restricted and root functions limited at soil pH's below 5.6 and above 7.4. Soil tests at 1- to 3-year intervals should be utilized to monitor the trend in soil pH. Ground agricultural limestone (calcium carbonate) may be used to raise the pH, and a sulphur-containing material to lower the pH.

Compaction - Compaction problems are associated with an increased soil density which results in impaired water movement into and through the soil. Existing soil compaction problems can be partially alleviated by coring or slicing in multiple directions. In the case of intensively trafficked areas such as greens and sport fields, a preventive approach involving root zone modification is preferred. Sand is the most common coarse-textured material utilized in root zone modification. However, the sand selected must be of the proper particle size distribution and must be mixed off-site in the proper portions with the existing local soil, based on the analyses and recommendations of a reputable physical soil testing laboratory. Alternatives to sand which can be used where costs are competitive include calcined clay of the proper firing intensity and expanded shale. Other materials which may be available locally include waste-ash or blast furnace slag. These are industrial by-products which can be utilized in soil modification, if free of potentially toxic materials, excessive salt levels, and/or improper pH levels.

Waterlogging - Waterlogging fills the soil pores with water and, thus, causes problems due to the elimination of adequate oxygen levels needed for shoot growth and general turfgrass health. One or a combination of conditions can produce a water-logging problem, including the following: (a) Improper surface drainage. A slope of 1% is minimal with 2% or more preferred; (b) Improper subsurface drainage. In many situations this condition can be corrected through the use of a subsurface drain line system, with french drains, dry wells, and surface catch basins also being installed as needed; (c) Excessive irrigation. This may involve scheduling irrigations too frequently or applying the water at an excessive rate in relation to the infiltration rate of soil; and (d) Excessive rainfall.

Lack of Oxygen - Roots require oxygen for maintenance of their life processes and for continued growth. Soil compaction and waterlogging can seriously limit the soil oxygen level.

Toxic Gases - Anaerobic conditions, formed under water logged soils, can produce gases and related compounds that are toxic to grass roots.

Toxic Herbicides - Some preemergent herbicides have a degree of toxicity to turfgrass roots. These effects may not be evident in terms of above ground shoot growth under normal growing conditions; but can become quite striking during water stress periods when the lack of a root system restricts water absorption. Thus, a herbicide should be applied only as needed to correct a potentially serious weed problem.

Salinity and Sodic Soils - Adverse soil salinity levels cause a reduction in turfgrass rooting that is expressed through increased proneness to wilt symptoms. The development of a salinity problem is best prevented by applications of water at a rate greater than the evapotranspiration rate. This approach is required so that the salts are constantly being leached downward through the soil profile to depths below the upper 8 to 12 inches (20 to 30 cm), since a major portion of the turfgrass root system is located above this. Subsurface drainage facilitates this approach. Sodic soils are best corrected by an application of gypsum, preferably by incorporation, followed by downard leaching of the sodium after its displacement from the clay particles.

Insect, Nematode, and Disease Injury - There are a whole range of pests which can feed actively on root systems causing serious damage. White grubs and wireworms are particularly damaging to roots. The appropriate pesticide should be applied to correct the target pest problems when a serious problems starts to develop, rather than as a broad spectrum protectant.

Hydrophic Soils - This problem is caused by a surface physical condition on the soil particles which causes them to repel water. It is particularly common on sandy soils and may be associated with soil fungi activity. It is best prevented or corrected by the application of certain effective wetting agents, such as AquaGro or HydroWet. Effectiveness is maximized by watering-in the wetting agent immediately after application.

Cultural Factors:

Cutting Height - As the cutting height is lowered, the depth and extent of rooting is restricted proportionally due to a decrease in leaf area available for photosynthesis. Cutting heights of one inch (2.5 cm) or less are especially detrimental to deep rootings.

Excessive Nitrogen Fertility - Excessive nitrogen applications that force leaf growth cause the reserve carbohydrates to be drawn from the roots and may result in death of the root system. For this reason, an individual nitrogen application should not exceed 1 pound of nitrogen per 1,000 square feet (0.5 kg are^{-1}) as a water soluble carrier or its equivalent rate as a slow release carrier. The latter is dictated by the percentage of nitrogen that is immediately released for shoot growth. High quality putting green turfs are maintained at a much lower rate, usually not exceeding 0.3 pound of nitrogen per 1,000 square feet (0.15 kg are^{-1}) of a water soluble nitrogen carrier or equivalent as a slow release carrier.

Deficiencies of Phosphorus and Potassium - These two nutrients have a striking effect in enhancing root growth and should be maintained at adequate available soil levels. Soil tests conducted at 1- to 3-year intervals should be used to establish proper base levels of both nutrients. Also, additional potassium should be applied at a rate that is 50 to 70% of the nitrogen.

Excessive Thatch Accumulation - A thatch problem causes an increased percentage of the roots to be concentrated in the thatch layer, thus limiting the zone from which water uptake occurs. For this reason, no more than 0.3 to 0.5 inch (0.7 to 1.3 cm) of mat/thatch should be allowed to accumulate.

PREPARING FOR DROUGHT

Water availability and water quality are projected to be major limiting factors threatening turfgrass use in the industrialized societies in future years. This developing problem is an even greater threat to the turfgrass industry than that of the world energy shortage or plant nutrient availability. Future projections, particularly for urban areas, indicate that less water will be available for turfrass and landscape purposes and that the water which is available will be more saline and lower in quality than the present supplies. The increase in salinity and water quality problems will be most apparent in locations which shift to the use of effluent water. In more arid locations and during droughty years, the turfgrass manager may be forced to cease irrigation of certain areas.

Drought develops as a result of an extended period without precipitation, combined with the lack of an irrigation capability and a high evapotranspiration rate. The severity of soil drought is affected by the duration without rain, the evaporative power of the air, and the water retention characteristics of the soil. The frequency with which a soil drought occurs is greater in the more arid western portion of the United States. Localized drought is more severe on the upper portions of slopes where evapotranspiration rate is increased and the soil water infiltration rate is poor. Droughts are most likely to occur during the midsummer period, although the actual timing of occurrence and frequency are not predictable.

The turfgrass manager has a number of options available to prepare a turf for drought stress. Included are: (a) maximize precipitation effectiveness, (b) select drought resistant species, (c) maximize root absorption of water, and (d) optimize turfgrass hardiness to drought stress.

MAXIMUM PRECIPITATION EFFECTIVENESS

Typically, some rainfall occurs during the winter and spring period prior to the onset of a drought. Thus, it is important to maximize the amount of available water that enters the soil rather than being lost by surface runoff. Soil cultivation, such as coring, slicing, or spiking, is utilized to ensure surface soil conditions that are receptive for maximum soil water penetration. Such an approach is particularly helpful on sloping areas where water loss by runoff is greatest.

In some cases, a limited supply of irrigation water may be available for use at the discretion of the turf manager. In such situations, there are other considerations in addition to maximizing the precipitation effectiveness. A key concern in this regard is that the irrigation water be applied at the proper rate and as uniformly as possible. The turfgrass manager should check to be sure the water application rate is adjusted for each distinctly different turfgrass area being maintained. The water use rate is typically in the range of 0.1 to 0.3 inches per day (2.5 to 3.5 mm d^{-1}) with rates as high as 0.45 inch (1.1 cm) occurring in regions where the evaporative demand is extremely high. The manager also should check to be sure that each sprinkler is applying the water uniformly. Finally, each irrigation should be scheduled so that (a) the water is applied under low wind conditions, in order to ensure adequate uniformity of application and (b) the water is applied during periods when evaporative losses will be minimal. These conditions are most likely to occur in the predawn nocturnal period.

SELECTION OF DROUGHT RESISTANT SPECIES

Turfgrass species vary greatly in their relative resistance to drought stress (Table 2). Where one knows prior to establishment that the area will not be irrigated or that the capability to irrigate will be limited, it is usually advisable to consider the use of a more drought resistant turfgrass species. Buffalograss and bermudagrass are warm season C_4 grasses known for superior drought resistance. Unfortunately, the comparative drought resistance of the more recently released turfgrass cultivars is not yet documented. Hopefully, specific cultivar information will be generated from current turfgrass research within the near future.

OPTIMUM TURFGRASS HARDINESS TO DROUGHT STRESS

The inherent internal physiological hardiness of turfgrasses to water stress may be affected by the cultural practices employed. Slow growing tissues possessing a small cell size and a high carbohydrate content are more drought hardy. Thus, cultural practices that avoid excessive shoot growth stimulation will result in increased drought hardiness. Factors that enhance drought hardiness include (a) moderate to low nitrogen fertilization rates, (b) adequate potassium levels, (c) moderate to low intensity of irrigation, and (d) full sunlight conditions. The same cultural practices also maximize turfgrass hardiness to heat stress, which is frequently associated with summer drought stress. There are a number of cultural practices that the turf manager can apply to delay the onset of drought stress and, should drought stress occur, produce a turfgrass plant that has the best potential to survive the drought stress. A brown, dormant turf possessing a healthy lateral stem system is not dead. Rather, such a turf possesses the recuperative potential to initiate new growth after the occurrence of the first significant rainfall.

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Table 1. The comparative potential evapotranspiration rates (water use rates) of the major cool and warm season turfgrasses when grown in their respective climatic regions of adaptation and proper culture regime, including irrigation.

Relative Ranking	Turfgrass	
	Cool season	Warm season*
Very low		Buffalograss Centipedegrass
Low		Bermudagrass Zoysiagrass Grama Bahiagrass
Medium	Hard fescue Chewings fescue Red fescue	Bahiagrass Seashore paspalum St. Augustinegrass
High	Perennial ryegrass Tall fescue	
Very high	Rough bluegrass Annual bluegrass Creeping bentgrass Kentucky bluegrass Italian ryegrass	

*After K. Kim and J. Beard.

Table 2. The comparative drought resistance of 22 turfgrasses grown in their respective climatic regions of adaptation and proper cultural regime.

Relative Ranking	Turfgrass	
	Cool season	Warm season*
Excellent		Buffalograss Bahiagrass Bermudagrass (C. dactylon)
Very good		Bermudagrass hybrids Centiptedegrass
Good	Turf alkaligrass	St. Augustinegrass Seashore paspalum
Medium	Fairway wheatgrass Kentucky bluegrass Tall fescue	Zoysiagrass
Fair	Hard fescue Chewings fescue Red fescue	
Poor	Colonial bentgrass Creeping bentgrass	
Very poor	Italian ryegrass Annual bluegrass Rough bluegrass	

*After K. Kim and J. Beard.