A PRACTICAL RESEARCH DIGEST FOR TURF MANAGERS

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IN THIS ISSUE

Managing Turf for Minimum Water Use

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Available water is rapidly becoming one of the least reliable resources needed to maintain high quality turf. Municipal water supplies frequently become over taxed during periods of drought and landscape uses often are assigned a low priority. Even in suburban and rural areas, water supplies used to irrigate turf are limited and are in competition for use by agriculture, recreation, industrial and commercial enterprises. It is clearly in the best interest of the turf manager to conserve water whenever possible and to design irrigation programs which provide quality turf with minimum water use.

The conservation of water while maintaining quality turf is something of a contradiction. Grass uses water and healthy vigorous turf uses more water than a thin sickly turf. So, how can the turf manager conserve water aside from avoiding waste through runoff or leaching? Research conducted over

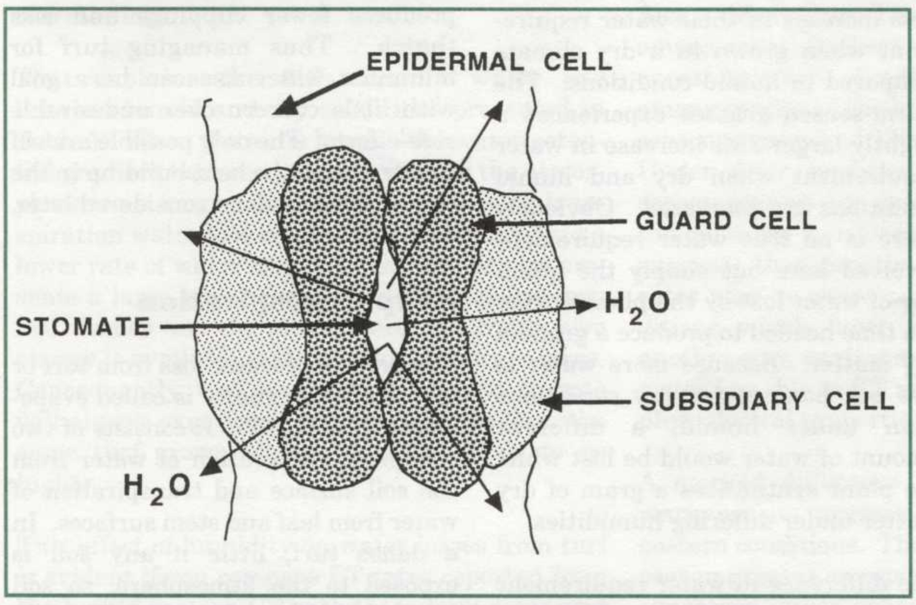

Figure 1. Stomate in a grass leaf surface showing water vapor flux from open stomate. Turgor of guard cell controls size of stomatal opening.

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the past 15 years has provided a scientific basis for analyzing water use by turf and for modifying management strategies to reduce water consumption without compromising turf quality. This article will consider some of this research and its possible application by turf managers to achieve greater efficiency in water use.

Water use efficiency

How much water does turf need? Most textbooks on water use by crop plants make mention of water requirements. This is the amount of water used by a plant to make a unit of plant tissue. Often water requirement is expressed as kilograms (kg) of water used per each gram (g) of plant produced. Given such a value, one could estimate the water required to maintain a crop of known production rate. In terms of turf, one could estimate water needs if the clipping production rate were known.

There is of course a fundamental problem with the concept of water requirement. This is evident from the data presented in Table 1. The cool-season grasses experienced a 29% increase in their water requirement when grown in a dry climate compared to humid conditions. The warm-season grasses experienced a slightly larger 35% increase in water requirement when dry and humid conditions are compared. Obviously there is no true water requirement involved here but simply the quantity of water lost by the plant during the time needed to produce a gram of dry matter. Because more water is lost per hour under dry conditions than under humid, a different amount of water would be lost while the plant synthesizes a gram of dry matter under differing humidities.

The difference in water requirement between cool-season and warm-season grasses also makes one question the importance of this value. Cool-season grasses use about three times more water while producing a gram of dry matter than do warm-season grasses. This difference between grass types remains relatively constant even when atmospheric humidity levels are varied (Table 1). Warm-season grasses are more efficient in fixing carbon dioxide (CO_2) from the atmosphere than are cool-season grasses for reasons explained in an earlier article (Hull, 1996). Again, water use is determined by the time required for enough CO_2 to be fixed to make a gram of plant, not by any inherent fixed relationship between plant growth and water usage.

This lack of a strict relationship between water use and plant growth is fortunate for the turf manager. It means that measures taken to minimize water use may have no effect on the growth or performance of turfgrasses. This is even more the case for turf management than for field crop production because dry matter accumulation is much less important in turf culture than it is where a large crop yield is the major criterion of success. Most turf managers will experience little grief if their turf produces fewer clippings and less thatch. Thus managing turf for minimum water use can be a goal with little concern over undesirable side-effects. The only possible area of concern might be heat build-up in the turf and that will be considered later.

Evapotranspiration

The process of water loss from turf or any plant community is called evapotranspiration (ET). It consists of two elements: evaporation of water from the soil surface and transpiration of water from leaf and stem surfaces. In a dense turf, little if any soil is exposed to the atmosphere, so soil evaporation is a minor component of water loss; most water loss results

Table 1. Water requirements of plants as influenced by atmospheric water content (relative humidity).**

Plant	Plant type*	Water requirement Humid air	Dry air
		g water/g dry matter	
Wheat	c-s	826	1052
Barley	c-s	758	1037
Rye	c-s	875	1100
Rice	c-s	585	743
Average		761	983
Millet	w-s	267	386
Sorghum	w-s	223	297
Corn	w-s	210	263
Average		233	315

c-s = cool-season grass, w-s = warm-season grass
** Based on data reported by Levitt (1980)

Table 2. Evapotranspiration rates of cool- and warm-season turfgrasses grown in the field in the eastern and western US.

Turfgrass	Grass type*	East	West
		mm water/day	
Ky. bluegrass	c-s	3.7 [1]	5.3 [3]
Per. ryegrass	c-s	3.7 [1]	6.4 [4]
Tall fescue	c-s	3.6 [2]	6.8 [5]
Average		3.7	6.2
Bermudagrass	w.s	3.1 [2]	5.0 [6]
St. Augustine	w.s	3.3 [2]	5.6 [6]
Zoysiagrass	w.s	3.5 [2]	5.6 [6]
Average		3.3	5.4

[1] (RI) Aronson et al. 1987
[2] (GA) Carrow 1995
[3] (NB) Shearman 1986
[4] (NB) Shearman 1989
[5] (NB) Kopec et al. 1983
[6] (TX) Kim & Beard 1988
c-s = cool-season grass, w-s = warm-season grass

from transpiration. Therefore, reducing water use by turf comes down to minimizing transpiration.

What controls transpiration from plants and by how much can it be controlled? The basic physics behind transpiration and its role in plant function were recently discussed elsewhere (Hull 1996). Briefly, water moves from regions of high water potential (concentration) to regions of low water potential. Plant tissues normally constitute a site of high water potential while the atmosphere normally has a low water potential. The magnitude of difference in water potential between two areas provides the energy for water movement and pretty much determines the rate of water loss.

That explains the difference in water use between humid and dry conditions presented in Table 1. When the air is humid, the water potential gradient between grass leaves and the atmosphere is not so great and the energy driving transpiration water loss is less. This translates into a lower rate of water loss. By contrast, dry air presents a large water potential difference between leaf tissues and the atmosphere, much diffusive energy is available and water loss rates are large. Consequently, turf managed in an arid climate will always experience greater ET rates than the same turf grown where humidity tends to be higher.

This effect of humidity on water losses from turf is evident if you compare ET rates reported from the humid eastern US with those from more arid western states (Table 2). Water loss rates in the western states (Nebraska and Texas) were 68% and 64% greater than those reported from eastern states (Georgia and Rhode Island) for cool- and warm-season grasses, respectively. Using a larger data set than presented in Table 2, cool-season grasses were found to lose 75% more water in the West than in the East while warm-season grasses grown in the West lost 46% more water than eastern grown grasses. These grasses were grown under comparable conditions where water was not limiting so the principal differences in ET between East and West were relative humidity, solar intensity and prevalence of wind. All these factors strongly influence transpiration rates as we shall see shortly.

Also evident from Table 2 is differences in ET among grass species were much less than differences between climatic conditions. Variation among species in the humid East was 3% for cool-season grasses and 13% for warm-season grasses. Under drier conditions, variation among cool-season grasses was greater at 28% but remained the same for warm-season species at 12%. This suggests that genetic variables influencing ET rates may be expressed more clearly under conditions which favor greater water loss. Put another way, environmental conditions influence water loss due to ET more than morphological or physiological properties of the grass.

A marked difference between cool-season and warm-season grasses was not evident under eastern conditions. The greater ET rates for cool-season grasses as reported by Beard (1973) were expressed more when grasses were growing under conditions favoring high water loss. In the

East, cool-season grasses lost 3% more water to ET than did warm-season grasses (based on a larger data set than presented in Table 2). However, under dry western conditions, cool-season grasses transpired 23% more than their warm-season counterparts. It appears that when cool-season grasses are grown outside their natural climatic range, they compensate for the hot dry conditions by transpiring more water.

Stomates and Their Function

Leaves do not transpire throughout their surface. Most of the leaf is covered by a waxy cuticle which seals the leaf and resists water loss. However, since gas exchange with the atmosphere is essential for normal leaf function (photosynthetic CO_2 influx & O_2 efflux), openings in the leaf surface must be provided. These openings result when specialized epidermal cells (guard cells) become turgid and form an opening called a stomate (Fig. 1). Stomates provide an avenue by which the leaf interior spaces can exchange gases with the atmosphere. Stomates form in the morning light when guard cells accumulate potassium ions (K+) from adjacent subsidiary and epidermal cells. These ions, along with various organic anions (malate-2) synthesized within the guard cells, reduce the water potential in these cells so water flows into them from surrounding cells. This 'blows up' the guard cells causing a stomatal pore to form between them (Fig. 1). It is through these pores that gases, including water vapor, move between the leaf and its surrounding atmosphere.

In the evening twilight, the process is reversed and guard cells lose solute ions and water to surrounding cells, they become 'deflated' and the stomate closes. Thus, gas exchange between leaves and atmosphere occurs in most plants primarily during the daytime. Leaves lose water mostly when stomates are open which is why transpiration occurs mainly during the day.

When plants are subjected to drought stress, the guard cells may be unable to reduce their water potential below that of surrounding cells; they lose water, become flaccid and the stomate closes. This frequently occurs during the heat of midday and is a common way for the plant to reduce water loss when transpiration exceeds the rate of water delivery from roots (Hull 1996). Even when soil water is abundant, mid-day transpiration may be so great that guard cells lose turgor, stomates close and gas exchange between leaf and atmosphere is suspended for a few hours. This conserves water but it also impedes photosynthesis and causes leaves to heat.

Water conservation in turf management comes down to reducing transpiration but not stopping it. After all, transpiration serves two valuable functions. It provides a water stream by which nutrients absorbed by roots are carried to the stems and leaves where they are needed to support growth and cell function. Also, the evaporation of water from the surfaces of cells within a leaf draws heat from the leaf causing it to cool or at least not become as hot as it would if water were not being lost. The temperature difference between turf and an adjacent asphalt drive on a bright day offers some idea of the cooling caused by ET. There are also good physiological reasons why it is desirable to prevent grass from becoming too hot.

While transpiration from turfgrass is essential, it may be reduced without causing harm to the plants and thereby conserve water. Reducing ET is easier said than done, however. To attempt an ET reduction, it is important to understand those factors which contribute to or regulate water loss from leaves.

Factors Controlling ET

Since transpiration depends on the water potential gradient between the interior of a leaf and the surrounding atmosphere, anything which tends to reduce the size of that gradient will lower transpiration rates. The interior spaces of a leaf are surrounded by wet cell walls so the air in the leaf is assumed to be saturated (100% relative humidity). Based on that assumption, the water potential gradient between leaf and air is always directly proportional to the prevailing relative humidity of the atmosphere. There is not much a turf manager can do to change the basic physics behind water evaporation. But, anything which holds a layer of humid air over a leaf surface will lower the water potential gradient and reduce the ET rate. So, while the water potential difference between a wet leaf and dry atmosphere is beyond control, the distance over which that gradient is extended can be managed.

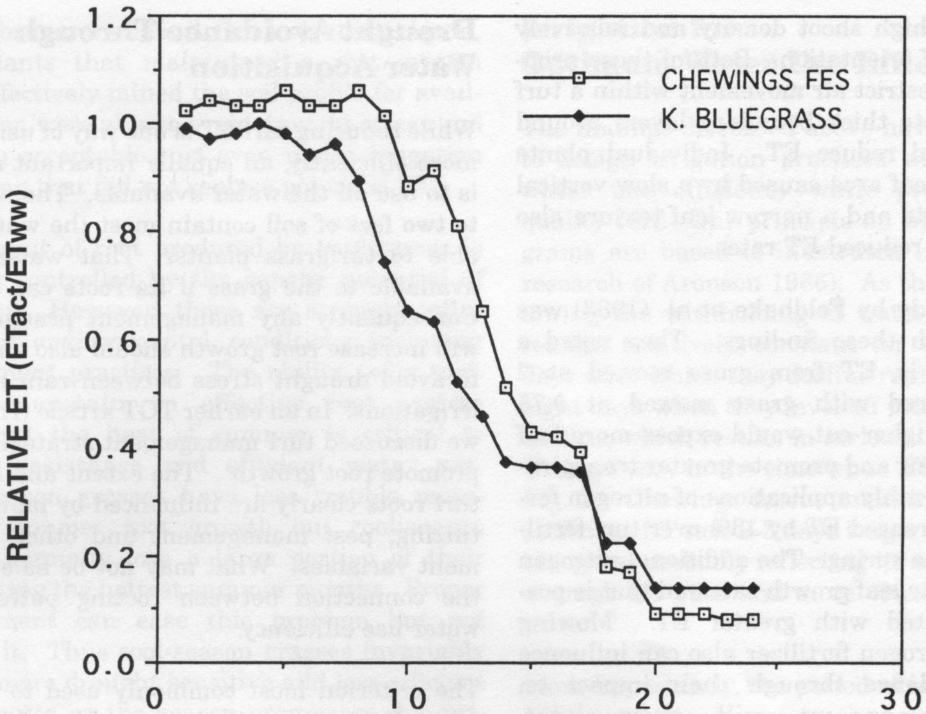

Figure 2. Change in relative ET during 24 day dry-down of Kentucky bluegrass and chewings fescue turf. ETac = Actual ET, ETww = ET of well-watered turf.

Several factors are involved.

Boundary layers: Surrounding a leaf or any object suspended in the air, is a layer of air that is largely unstirred. This layer results from attraction of air molecules to molecules of the leaf surface. Such attractions are not strong but they do reduce the motion of air molecules (kinetic energy) creating a zone of still air called a boundary layer. The thickness of this layer depends upon the amount of air turbulence (wind) and the presence of protuberances from the leaf surface which further reduce air movement. An uneven cuticle surface or leaf hairs or ridges all tend to increase the thickness of boundary layers.

The significance of leaf boundary layers becomes evident if you remember that the steepness of the water potential gradient between the saturated leaf interior and the adjacent atmosphere determines the rate of water loss. This gradient operates at open stomates and that is where a boundary layer plays its role. When molecules of water vapor exit a stomate, they increase the humidity of the atmosphere immediately surrounding the stomatal opening. The more humid that boundary layer of air becomes the more the water potential gradient is reduced. Therefore, the thicker the boundary layer, the more humidity it will retain and the more it will 'insulate' the stomatal pore from additional water loss. In theory, if the leaf boundary layer became saturated (100% relative humidity) there would be no net diffusion of water vapor through a stomate and there would be no transpiration.

Of course, so long as the atmosphere is not saturated, the boundary layer will lose water to it and water vapor molecules will diffuse through the stomates; there will be measurable transpiration. Thus anything that increases the boundary layer of a leaf will tend to reduce the rate of transpiration.

Canopy Resistance: Grass stand factors that contribute to thick boundary layers and reduced ET rates are collectively termed canopy resistance. The term implies that water lost by ET encounters several resistances as it passes through and exits the turf canopy. Kim and Beard (1988) evaluated 12 turfgrasses for ET rates and related those rates to six morphological characteristics of the grasses. They found that ET rates were depressed by high shoot density and relatively horizontal leaf orientation. Both of these properties would restrict air movement within a turf canopy, promote thick boundary layers around the leaves and reduce ET. Individual plants having a low leaf area caused by a slow vertical leaf growth rate and a narrow leaf texture also contributed to reduced ET rates.

An earlier study by Feldhake et al. (1983) was consistent with these findings. They noted a 15% increase in ET from grass mowed at 2 inches compared with grass mowed at 0.75 inches. The higher cut would expose more leaf surface to the air and promote greater transpiration rates. Monthly applications of nitrogen fertilizer also increased ET by 13% over turf fertilized once in the spring. The additional nitrogen would stimulate leaf growth rate and that is positively correlated with greater ET. Mowing height and nitrogen fertilizer also can influence drought avoidance through their impact on root growth as we will show later. Evapotranspiration increased linearly with solar radiation (light intensity) due to the greater energy available at high light to evaporate water.

A clear connection between leaf extension rate and ET has not always been observed. Beard et al. (1992) failed to find a significant relationship between leaf growth rate and ET for 24 well-watered bermudagrass cultivars. Significant differences in both ET rates and leaf growth were observed but no correlation between the two was evident. Green et al. (1991) also did not show a correlation between leaf growth and ET for 11 zoysiagrass genotypes or for ten St. Augustinegrass selections (Atkins et al. 1991.). On the other hand, Shearman (1989) found a strong correlation between rates of ET and leaf extension for 12 perennial ryegrasses. Similar correlations have also been found between other measurements of shoot growth and ET rates for tall fescue (Bowman and Macaulay 1991).

It may be that leaf extension rate of stoloniferous warm-season grasses does not have the same effect on turf canopy architecture as it does for bunch type cool-season grasses. In any event, abundant evidence supports the idea that ET rates are influenced by canopy resistance factors and these can be influenced by management.

Drought Avoidance Through Water Acquisition

While reducing turf ET is one way of using water more efficiently, an equally important approach is to use all the water available. The upper one to two feet of soil contain most the water available to turfgrass plants. That water is only available to the grass if its roots can reach it. Consequently any management practice which will increase root growth should also enable turf to avoid drought stress between rain events or irrigations. In an earlier TGT article (Hull 1996) we discussed turf management strategies which promote root growth . The extent and health of turf roots clearly are influenced by mowing, fertilizing, pest management and other management variables. What may not be as evident is the connection between rooting patterns and water use efficiency.

The criterion most commonly used to evaluate root effects on water use is the avoidance of drought injury when water is withheld. Leaf firing and wilting are early signs of drought stress and the time interval after water withdrawal when these symptoms appear is an indication of drought avoidance. Obviously, such a measure integrates all water use efficiency factors, including root properties. But, when drought avoidance time is correlated with individual plant measurements, it is possible to determine which contributes most to the delay in drought symptoms.

In a recent report, Carrow (1996) evaluated six tall fescue cultivars and found drought resistance was linked most with late summer root length density (cm of root per cm^3 of soil) in the 8 inch to 2 foot soil depth. Late summer total root length also contributed to drought resistance and ET variation was the third factor. In other words, drought resistance in tall fescue, which is, in fact, mostly drought avoidance, was enhanced most by the maintenance of an extensive functional root system. Variations in ET played a secondary role.

A similar study from Arizona (Marcum et al. 1995) investigated 25 zoysiagrass cultivars and species and attempted to correlate rooting characteristics with drought resistance. They too found that average maximum root depth, total root weight and number of roots in the 8 through 16 inch soil depths were all positively related to turf performance under deficit irrigation. Again, those plants that maintained a root system which effectively mined the soil profile for available water, were able to avoid drought stress and maintain acceptable turf even under irrigation scheduling that did not replace potential ET.

The amount of root produced by turfgrasses is basically controlled by the genetic potential of the plants. However, these are strongly influenced by environmental conditions including management practices. The ability of a turfgrass to sustain an effective root system throughout the heat of summer is critical to drought resistance and efficient water use. Warm-season grasses have less trouble maintaining summer root growth but cool-season grasses normally lose a large portion of their roots during the hottest summer months. Proper management can ease this problem but not prevent it. Thus cool-season grasses invariably become more drought sensitive and less efficient in water use as the season progresses due primarily to a declining root system.

Soil conditions can play an important part in determining drought resistance of turfgrasses. A plant may be genetically disposed to producing a deep root system, but if the presence of toxic elements or an impenetrable soil restrict root growth, the potential for drought resistance may never be realized. Carrow (1996b) evaluated drought resistance in seven turfgrasses common to the southeastern US. These were grown in an acid soil of high density (high soil strength) and rated for drought resistance and rooting characteristics. He found that those grasses which tolerated the hostile soil conditions and produced a deep root system (Tifway bermudagrass & Rebel II tall fescue) exhibited greater drought resistance than grasses which experienced root suppression (Meyer zoysiagrass & common centipedegrass). Under the conditions of this test, Meyer zoysiagrass produced only 4% of the root length density observed in Tifway bermudagrass. This did not agree with results from root column studies where grasses were grown in sand or clay granules, a near ideal rooting medium. Consequently, when managing turf for efficient water use, the entire system must be considered. The soil environment may be as important in determining water use as the grasses selected or the management employed.

Irrigation for Optimum Water Use Efficiency

The findings discussed above have been utilized to design irrigation practices which maximize water use efficiency while preserving high quality turf. One principle on which these programs are based is illustrated in Fig. 2 (from research of Aronson 1986). As the soil dries following the withholding of water, the ET rates remain relatively constant for the first eight days after which they decline rapidly for another eight days when they level off prior to their final decline, which results in serious injury or death. Grasses vary in the time when ET decreases. In Fig. 2, Chewings fescue maintained its water-sufficient ET rate 2-3 days longer than Kentucky bluegrass probably reflecting its somewhat lower average ET rate and more conservative use of water.

More importantly, the period of initial decline in ET causes no injury to the grass if water is restored before ET drops to less than half its normal rate. That means irrigation can be delayed for several days after ET rates begin to decrease with no damage to the turf. In short, irrigation scheduling can be set to apply less water than ET models would predict was lost. Basing irrigation, not on anticipated ET but rather on soil moisture potential, allows a savings of from 1/4 to 1/3 the water normally applied. This approach has been used successfully in most climates and is easily adapted to computerized automated irrigation systems. Irrigation is called for by tensiometers installed in the soil which activate the system whenever the soil moisture potential drops below a preset point. Irrigation is set to deliver only about 2/3 of the water which would have been lost through ET from well watered turf. In this way, the turf is maintained much of the time under mild drought stress.

Mild drought stress actually makes turf more drought resistant because stressed roots send hormonal signals to the shoots causing growth to slow and transport to roots of photosynthetic products (sugars) to increase (Hull 1996). This promotes root growth, especially deep rooting because growth is stimulated in those roots which have most water available (deep roots). Thus deficit irrigation scheduling not only conserves water but it promotes a turf that is better able to avoid drought stress.

The turf manager clearly is not at the mercy of water suppliers. Significant water conservation can be practiced which may result in as much as a 50% reduction in water use without compromising turf quality. To practice water conservation turf management effectively, it is good to be familiar with the principles, both physiological and agronomic, on which such management is based. This I have tried to do here but more comprehensive discussions are available in some of the references cited below and in technical publications available from irrigation systems suppliers.

Terms to Know

1. Cool-Season Grass - Also known as C-3 grasses. Grass species adapted to growth under temperate conditions. These grasses exhibit light stimulated respiration (photorespiration) which reduces their photosynthetic rates during conditions of high light and temperature.

2. Evapotranspiration - The combined water loss from a plant community as a result of evaporation from the soil and transpiration from plant surfaces.

3. Stomate - (Technically 'stoma plural stomata') Pores formed in the epidermis of leaves due to the enlargement of guard cells resulting from a solute induced increase in their turgor pressure.

4. Transpiration - The evaporative loss of water from plant surfaces.

5. Warm-Season Grass - Also known as C-4 grasses. Grass species adapted to tropical climates characterized by a dry season. These grasses exhibit no measurable photorespiration so their photosynthetic rates increase as light and temperature increase.

6. Water Potential - The chemical activity of water in a plant cell or tissue or in a free solution. Term refers to the functional concentration of free water in a solution defined in terms of pressure such a solution could develop in an osmometer. Water moves passively from areas of high water potential to areas of low water potential.

7. Water Requirement - Mass of water used by a plant during the time required for the plant to synthesize a unit mass of dry matter. Often expressed as grams of water per gram of dry plant weight.

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Field Tips

Water Conservation Practices

The laws governing water loses by turf cannot be changed, but their impact on the efficiency of water use can be moderated through management practices. What follows are a few suggestions for water conservation turf management.

1. Select turfgrass cultivars known to have lower than average ET rates. Cultivars of many turfgrasses have been compared for their water loss due to ET and significant differences normally are found. These differences tend to be consistent over several years within a given location. Unfortunately, such measurements have not been made at enough different sites to evaluate the climatic stability of ET rankings. Such information will be available in time and even now some can be obtained through your local university turfgrass program.

2. Do not stimulate rapid shoot growth during periods of high water demand. This will accelerate ET and increase water use. Avoid nitrogen applications when dry, hot conditions are anticipated. It is better to concentrate nitrogen usage during the spring and fall.

3. Raise mowing height during the hot summer months. This might seem counterproductive to water conservation since higher cut results in greater ET rates. However, a higher cut will stimulate root growth which will enable the grass to obtain water from greater soil depths. This has been shown to influence drought resistance in most turfgrasses. Also, higher cut will promote a thicker turf canopy which will retard air flow and reduce ET rates. Thus, a greater mowing height may actually have only a modest impact on actual ET rates. Taller grass in midsummer also is better able to compete with seedling weeds, especially warm-season species, and minimizing such weeds might also reduce water use.

4. Stimulate root growth by whatever management practice you have available. Increase mowing height, reduce nitrogen fertility, insure good soil aeration, reduce thatch, control root-feeding insects and root infecting diseases. A strong deep root system will maximize water availability and delay drought stress during dry periods.

5. Reduce root inhibiting conditions of the soil profile, especially acidity, toxic ion concentrations, anaerobic layers and excess compaction. Most such conditions are best corrected during installation but also can be addressed by deep coring, soil injection of soluble lime and nutrients, and by selecting acid-tolerant turfgrasses.

6. Develop irrigation practices based on the concept of deficit water management. By applying less water than would be lost through ET under well-watered conditions, turf can be maintained under managed drought stress, which not only conserves water but stimulates deep rooting.

In time, the concepts outlined here will be better developed and turfgrasses will be bred for drought resistance. Such advances will significantly reduce the water required to maintain high quality turf even in arid climates.