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Turfgrass Water Requirements and Factors Affecting Water Usage

Bingru Huang

Introduction

Turfgrasses, like other agronomic, horticultural, and landscape vegetation, requires water for growth and survival. Without adequate water, turfgrass becomes brown, desiccated, and may die in severe instances. Loss of ground cover by turfgrass can have significant negative impacts on the aesthetics and functionality of our environment because healthy turfgrass provides many important benefits (see Section 2). Therefore, irrigation is desirable to maintain the functional benefits of healthy, actively growing turfgrass in areas where rainfall cannot meet the water demand of plants. As water availability is becoming increasingly limited and more costly, water conservation in turfgrass culture has become extremely important.

Water use of turfgrasses is evaluated based on the total amount of water required for growth and transpiration (water loss from the leaf) plus the amount of water lost from the soil surface (evaporation). Transpirational water consumption accounts for over 90% of the total amount of water transported into the plants, with 1 to 3% actually used for metabolic processes (Beard 1973; Hopkins 1999). Water usage rates vary with species and cultivars and are affected by many external factors, especially environmental conditions. This article reviews the water-use characteristics of different turfgrass species and examines environmental factors affecting turfgrass water use.

The amount of water used under deficit irrigation may be calculated based on the actual evapotranspiration (ET) rate. One of the simplest and oldest methods to estimate ET is to measure the evaporation from a large standardized pan. Actual ET may be measured more accurately using weighing lysimeters. More recently, researchers have developed mathematical models (or modified Penman equations) to estimate potential evapotranspiration (PET) using climatic data of solar radiation, wind speed, relative humidity, and temperature. PET values represent a nonlimiting plant water status and an extended cover of short, green vegetation over the soil surface. Reference ET is a starting point for estimating irrigation needed for turfgrass areas by multiplying with the crop coefficient (Kc). The Kc for turfgrass depends on the type of grass (warm- or cool-season), cutting height, and desired turfgrass quality.

Water Use Characteristics of Cool-Season and Warm-Season Turfgrass Species

Turfgrasses are classified into two groups based on their climatic adaptation: cool-season and warm-season. Cool-season grasses mainly grow in temperate and subarctic climates, whereas warm-season grasses are adapted to tropical and subtropical areas (see U.S. climatic regions in Section 5). These two groups of turfgrass species have different water requirements (Table 11.1) and vary in water-use characteristics. Most cool-season grasses generally are higher water users than warm-season grasses. Typical ET rates range from 3 to 8 millimeters (mm) per day for cool-season grasses and from 2 to 5 mm per day for warm-season grasses (Beard 1994). Declining soil moisture levels will progressively lower the water-use rate by up to 80% (Figure 11.1). In addition, the comparative water-use rankings for different species and cultivars may change across different climatic conditions and cultural regimes, and also depends on individual species and cultivar adaptation.

Table 11.1. The relative maximum evapotranspiration rates of 24 turfgrass species (Modified from Beard and Beard 2004)

Relative ranking	ET rate (mm d-1)[a]	Turfgrass species[b]
Very low	<6	*American buffalograss
Low	6 – 7	*Hybrid bermudagrass Centipedegrass *Dactylon bermudagrass *Zoysiagrass
Moderate	7 – 8.5	Hard fescue Chewing fescue Creeping red fescue Bahiagrass Seashore paspalum St. Augustinegrass
High	8.5 – 10	Perennial ryegrass Kikuyugrass
Very high	>10	Tall fescue Creeping bentgrass Annual bluegrass *Kentucky bluegrass Rough bluegrass Annual ryegrass

[a] The ranges of ET are based on the most widely used cultivars of each species when grown in their respective climatic regions of adaptation and preferred culture regimes.

[b] Asterisk (*) indicates cultivars within these species may vary significantly.

threatens to derail one of the key engines of the national economy: suburban sprawl. Despite its negative image, sprawl is efficient and reflects consumer preference. In a nation where so much developable land remains, sprawl is hardly the environmental threat it is made out to be. The real threat is that the nation might adopt policies that halt development and frustrate the millions of people who seek their share of the suburban dream."

Such a dream must be in balance with nature when it comes to the design and maintenance of living spaces and landscapes. John Lyle (1993) argues, "For thousands of years, cities have existed apart from nature. They rush the water falling upon their roofs and streets as rain out through concrete pipes and channels into the nearest bay or river and at the same time, bring water in from distant landscapes through similar concrete channels."

Urban Landscapes

Urban landscapes can provide beauty, decrease runoff from storm events, provide cooling, and remove environmental pollutants, to name just a few good reasons they are valuable. Unfortunately, urban landscapes also can require significant amounts of water, and this water often is applied inappropriately. In some regions of the United States, water issues are not as critical as in other regions. For example, the Colorado River Basin is currently in an extended 5-year hydrologic drought. During the twentieth century, at least six major droughts impacted North America. Unfortunately, it is difficult to predict when droughts may occur, where they may occur, and for how long they may last. It is essential that communities develop and implement sustainable water management plans. Even the best-laid plans, however, will be severely tested by unpredictable growth in populations. In times of drought when municipalities look to other sectors of society for additional water, it is essential they first demonstrate good stewardship of the water they use. The focus on water conservation programs for urban landscapes in many communities is appropriate and can lead to significant water savings.

Urban landscapes vary not only in size, composition, functionality, microenvironments, and edaphic factors, but also in the cultural management practices imposed. As such, the amount of water applied and the potential to conserve water varies with each landscape setting. But it is clearly the species, size, and number of plants (density) used in a landscape that drive its water requirement. Irrigations must satisfy transpiration and evaporation losses, irrigation inefficiencies, and any leaching requirements, which in turn dictate the total amount needed. Except under extreme drought conditions, the goal of conservation efforts in urban landscapes is to apply water more closely in parallel with landscape requirements while meeting the quality expectations of the end user.

Because of water restrictions, regulations, and pricing, landscape water managers in the southwestern United States (whether they are homeowners or professionals) have begun the process of decreasing total irrigation amounts, improving irrigation systems, and redesigning

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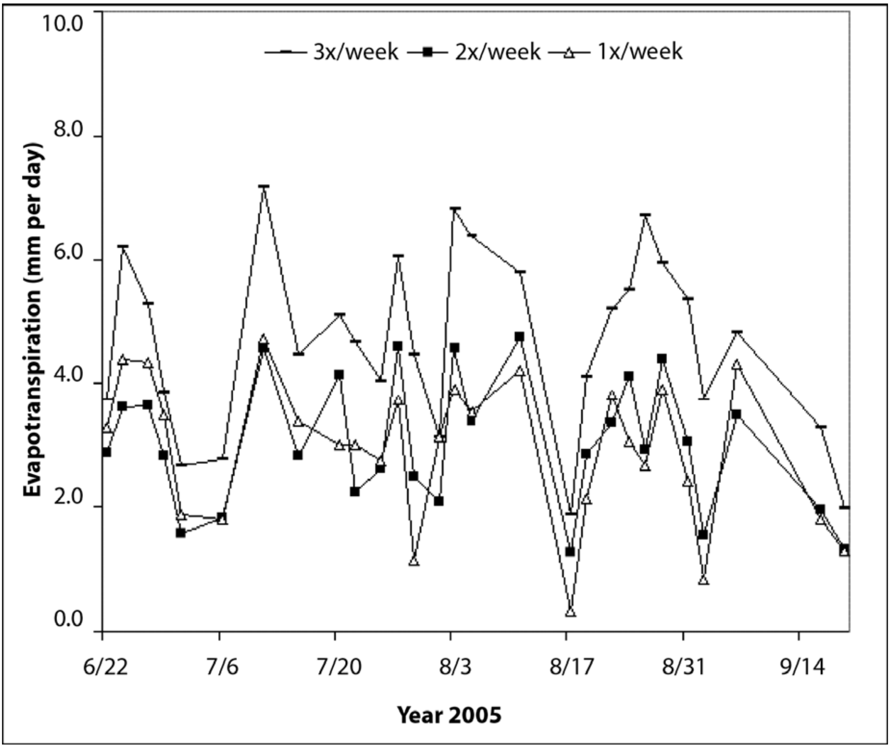
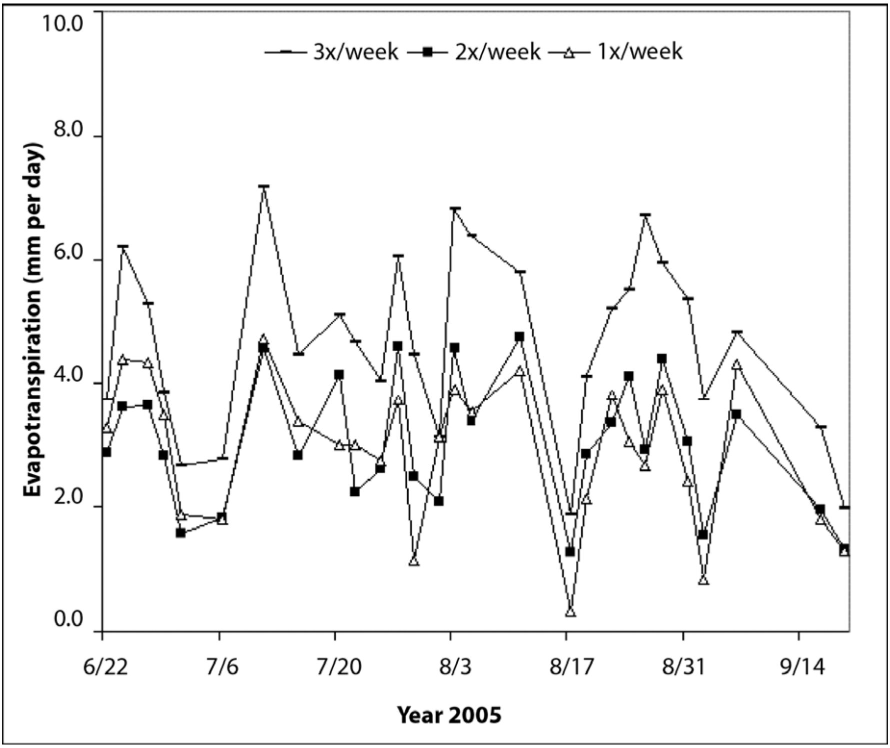


Figure 11.1. Evapotranspiration rate of creeping bentgrass (cv. Penncross) irrigated once per week (1x), twice per week (2x), and three times per week (3x). The test was performed in turfgrass grown in loamy soil and mowed at 3/8 inch height in field plots at the Rutgers University Turfgrass Research Farm, North Brunswick, New Jersey.

Cool-Season Turfgrasses

Commonly used cool-season turfgrasses in lawns, sports fields, parks, grounds, golf courses, and roadsides include *Festuca* L., *Poa* L., *Agrostis* L., and *Lolium* L. Within the cool-season turfgrasses, species vary in maximum ET rate, ranging from 7 to 8.5 mm per day to more than 10 mm per day (Table 11.1). Tall fescue (*Festuca arundinacea* Schreb.), creeping bentgrass (*Agrostis stolonifera* L.), and annual bluegrass (*Poa annua* L.) are considered to be the highest water users, whereas hard fescue (*Festuca longifolia* Thuill.), Chewing's fescue (*Festuca rubra* L. ssp. *commutata* Gaud.), and creeping red fescue (*Festuca rubra* L. ssp. *rubra*) are the lowest water users (Beard 1989, 1994). DaCosta and Huang (2006) in New Jersey compared water use among three bentgrass species and found that velvet bentgrass *(Agrostis canina* L.) used less water than creeping bentgrass and colonial bentgrass (*Agrostiscapillaries* L.).



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There can be as much variation in the water-use rate among cultivars within certain species as between turfgrass species (Beard 1989). The difference in ET between cultivars may range from 20 to 60% (Kjelgren, Rupp, and Kilgren 2000).

Warm-Season Turfgrasses

Warm-season turfgrasses include *Cynodon* L.C. Rich, *Buchloe* Engelm., *Zoysia* Willd., *Paspalum* L., *Eremochloa ophiuroides* [Munro] Hack., and *Stenotaphrum secundatum* [Walt.] Kuntze. Their maximum water use ranges from less than 6 mm per day to 8.5–10 mm per day (Table 11.1). Among warm-season grasses, bermudagrass (*Cynodon* spp.), zoysiagrass (*Zoysia* spp.), and buffalograss (*Buchloe dactyloides* [Nut.] Engelm.) have relatively low water-use rates, whereas seashore paspalum (*Paspalum vaginatum* Swartz.) and St. Augustinegrass (*Stenotaphrum secundatum* ([Walt.] Kuntze.) have relatively high water-use rates (Table 11.1). Within a warm-season turfgrass species, cultivars may vary in water-use rate.

Plant Growth Characteristics Affecting Water Use

Water use of the turfgrass canopy is affected by water loss through shoot transpiration and soil evaporation, and by water uptake from the soil via the root system. Therefore, turfgrass species variations in water-use rates are associated with differences in shoot and root characteristics, such as canopy configuration or leaf orientation, tiller or shoot density, growth habit, rooting depth, and root density (Beard 1973; Huang and Fry 1999).

Canopy/Shoot Characteristics

Species that have a prostrate shoot growth habit typically have a lower water-use rate than grasses with an upright growth habit (Kim and Beard 1988). The former group often has higher resistance to evapotranspiration (Johns, Van Bavel, and Beard 1981, 1983). Generally, turfgrasses with a rapid vertical shoot extension rate tend to have higher water-use rates than slower-growing or dwarf-type grasses because of increasing leaf area from which transpiration occurs (Kim and Beard 1988; Shearman and Beard 1973). Shearman (1986) reported that shoot vertical extension rate was positively correlated with water-use rate for 20 Kentucky bluegrass cultivars with upright growth pattern. No correlation was found, however, between water use and leaf extension rate within several warm-season turfgrass species that have a prostrate growth habit, such as bermudagrass (Beard, Green, and Sifers 1992) and zoysiagrass (Green, Sifers, and Beard 1991). The more horizontal growth characteristic may be dominant because of higher canopy resistance. Dense and compact type turfgrass canopies have lower water loss from soil evaporation than thin, open canopies. It is apparent that low-water-use grass species may possess at least one of the combined characteristics of slow vertical growth, prostrate growth pattern, and dense canopy. Under plant water stress, stomatal closure and cuticle formation can be key factors controlling water use (Beard 1973; Kim 1983).

Rooting Characteristics

An extensive, well-branched, deep root system is important for efficient water uptake from the soil. Plants with deep and dense root systems typically have a high capacity for water extraction from soil. Deep rooting enables plants to avoid water stress by taking up water from deeper in the soil profile when the surface soil is dry. Tall fescue, which develops a deep, extensive root system, has been shown to use more water than most other cool-season turfgrasses. But, not all grasses with extensive root systems are necessarily high water users. For example, bermudagrass has a prostrate growth habit, slow shoot growth rate, and a deep root system, but exhibits a low water-use rate (Kim and Beard 1988; Youngner 1985).

Root distribution strongly responds to spatial variations in water availability. Generally, roots tend to proliferate or extend in localized wet zones in a soil profile. For example, when soil surface is maintained wet constantly because of frequent irrigation or rainfall, plants develop extensive, shallow root systems. When a soil surface is allowed to dry periodically, production of roots increases considerably in the lower layer where water is available. This root response has been observed in various turfgrass species (Beard 1973; Huang 1999; Huang, Duncan, and Carrow 1997). The ability of roots to follow moisture into deeper layers of the soil profile conditions the ability of a plant to tolerate or avoid short and long periods of drought. Development of a deep root system could be related to a faster elongation rate of roots under drying conditions. When limited soil water is stored in deeper soil profiles, however, faster root extension into deeper soil profiles may be detrimental for plants because of rapid depletion of water.

As soil dries, root hairs increase in length and number (Huang and Fry 1998). Increases in root hairs in dry soil have a pronounced effect on total root surface area. This response may be an adaptive mechanism to maintain liquid continuity around the growing roots and to provide greater root surface for nutrient absorption because the rate of nutrient diffusion to the root decreases in drier soil. Root hairs can be sites for extensive mucilage production. Mucilage can enhance the ability of the hair to attach to soil particles and thereby prevent air gaps from developing between the soil and root surface when the soil dries; decrease water efflux from plants into drying soils; and ultimately delay root desiccation. Extensive development of root hairs enhances water uptake and facilitates water retention under soil-drying conditions.

Dormancy and Water Use

Another important plant characteristic of low water use is dormancy, a phenomenon in which turfgrass leaves may turn brown in response to a water deficit, but the meristematic crowns and stem nodes are not dead. Dormant turfgrass plants have limited or no transpirational water loss, and thus, have low water usage. Limited water in dormant plants may be concentrated in the crown and rhizomes. Dormancy is a mechanism of turfgrass escape from drought stress such that dormant plants survive (without growth) for extended periods of drought stress and resume growth when soil moisture becomes available (Beard 1973).

In general, dormant turfgrasses, especially those with rhizomes (underground stems), can survive without water for several weeks or months with limited damage, depending on the air temperature. After rainfall or irrigation, the grass will quickly recover. Allowing certain turfgrasses to go dormant in low maintenance areas can result in significant water savings without loss of turfgrass. The lengths of time turfgrasses can survive in a dormant condition vary with temperatures and turfgrass species. In general, turfgrasses can be expected to survive in a dormant condition for several weeks at temperatures at or below normal, but may survive in dormant conditions for a shorter period of time during the summer when temperature is elevated. Kentucky bluegrass is a good example of a species that has the capacity for survival during extended water stress because it has extensive rhizomes that generate new roots and shoots once soil moisture is replenished. But bunch-type turfgrasses such as perennial ryegrass and tall fescue are slow to recover to their full canopy upon rewatering, once the turf canopy becomes desiccated and thinned under nonirrigated conditions.

Environmental Factors Influencing Turfgrass Water Use

In addition to species and cultivar variations, water use of turfgrasses is influenced by many external factors in their growing environment, including temperature, wind, solar radiation, relative humidity, and edaphic factors such as soil moisture (Beard 1973). These factors affect both plant transpiration and soil evaporation. Understanding major environmental factors influencing water use is important for developing efficient cultural strategies for turfgrasses, especially in areas with a limited water supply.

Water loss through transpiration from turfgrass plants is controlled by three major processes: external boundary layer resistance, vapor pressure gradient between the leaf and air, and internal leaf diffusion resistance (Fu, Fry, and Huang 2004; Johns, Van Bavel, and Beard 1981, 1983). High transpirational water loss may be because of lower boundary layer resistance, higher vapor pressure gradient, and/or lower internal diffusion resistance. Internal leaf diffusion resistance is associated with stomatal density and conductance, intercellular space, cell size and density, and leaf cuticle thickness, which are all basically controlled by genetics. The boundary layer is a layer of stagnant air over the leaf surface, which creates resistance to water vapor escape from the leaf. Atmospheric environmental factors affect transpiration mainly though alteration of the boundary layer resistance and vapor pressure gradient between the leaf and air.

Solar Radiation

Water use of turfgrasses typically is much higher in areas exposed to full sun than in shaded or dark nocturnal conditions. Evapotranspiration is an energy-dependent process. If more energy is available, there is potentially a greater rate of evapotranspiration. A linear relationship between irradiance and water use rate has been reported in turfgrasses (Aurasteh 1983; Beard, Green, and Sifers 1992; Feldhake 1981; Kim and Beard 1988; Shearman and Beard 1973). Our study in New Jersey with creeping bentgrass, velvet bentgrass, and colonial bentgrass found a strong correlation between water-use rate and solar radiation level with a correlation coefficient of 0.81.

Temperature

Plants transpire more water at higher temperatures because water evaporates more rapidly with increasing temperatures under nonlimiting water availability. This is reflected by increasing water demand of turfgrass during midday and summer months. Increasing water use rate was highly correlated with increasing temperatures, with a correlation coefficient of 0.81 (1.0 = perfect correlation) in our New Jersey study. A leaf exposed to 30°C may transpire three times as fast as it does at 20°C when leaves are fully hydrated.

Temperature influences transpiration through its effect on vapor pressure, which in turn affects the vapor pressure gradient between the leaf and air (Beard 1973). Leaves of a well-watered plant maintain a near 100% relative humidity or high vapor pressure within the leaf. High temperature dries the air or lowers the relative humidity of air, creating a larger gradient in vapor pressure between the air and the leaf, thereby resulting in high transpirational water loss (Shearman and Beard 1973).

Relative Humidity

Relative humidity of the atmosphere affects water use mainly by influencing the vapor pressure gradient between the leaf and air. Low relative humidity, or dry air, surrounding the leaf causes rapid water loss from the leaf because of the increased vapor pressure gradient (Beard 1973). Therefore, water use typically increases with decreases in relative humidity. Carrow (1995) reported turfgrass ET was 40 to 60% less in a humid environment compared with the same cultivar in an arid environment.

Wind

Water-use rate of turfgrasses typically is higher on windy days than on calm days and in open areas compared with areas enclosed with trees, shrubs, and other structures. The effects of wind on water use are associated with changes in the water vapor pressure gradient between the leaf and air and the external boundary layer resistance, particularly the latter factor (Beard 1973). Wind above the leaf dries the air adjacent to the leaf and therefore causes increases in the vapor pressure gradient. Also, the thickness of the boundary layer is primarily a function of leaf size and shape, the presence of leaf hair, and wind speed. The thickness of the boundary layer decreases with increasing wind speed, which may lead to increases in the transpiration rate at a lower wind speed; however, high wind speed may cause stomatal closure and low transpiration rate before the leaves become desiccated (Hopkins 1999). Grace (1974) reported that the transpiration rate of a tall fescue cultivar increased as wind speed increased from

1 m s^{-1} to 3.5 m s^{-1}. Beard, Green, and Sifers (1992) also observed a positive relationship between water-use rate and wind speed.

Soil Moisture

Water-use rate can be restricted by water supply from the roots and in turn depends on the availability of soil moisture. When soil moisture supply is not enough to replace what is lost from the shoots, stomata will be closed and a plant cannot continue to transpire. Therefore, plants in general tend to use less water when the soil water content is low. Water-use rates of both cool-season and warm-season turfgrasses have been found to decline with decreases in soil water content (Biran et al. 1981; DaCosta and Huang 2006; Kim 1983). Not all water in the soil can be used by plants. Only water retained in the soil by capillary forces can be extracted by the plant. Available soil water is the water held by the soil between field capacity, defined as the amount of water remaining in the soil when drainage ceases, and permanent wilting point, defined as the soil water content below which there is no available water and plants wilt and do not recover. Soil moisture availability is affected by water supply through rainfall or irrigation. Efficient irrigation should maintain soil moisture above the permanent wilting point, but below field capacity. Irrigation above field capacity results in waste of water.

Frequently irrigated turfgrasses (soils that are kept wet constantly) use more water than turfgrasses that receive less frequent irrigation (allowing soil to dry between irrigation events) (Gibeault et al. 1985; Kneebone, Kopec, and Mancino 1992). For example, creeping bentgrass irrigated three times per week had a higher ET rate than that irrigated once per week or twice per week on many days from June to September 2005 (Fig. 11.1). Vertical shoot growth may be promoted with increasing irrigation frequency or quantity, resulting in increased demand for water. Maintaining wet soil constantly also promotes shallow root systems, which decreases water utilization in deeper soil profiles.

Turfgrass maintained under water deficit conditions typically uses less water than well-irrigated plants. Deficit irrigation can decrease water uses in various turfgrass species (see Section 12). The level of deficit irrigation varies with plant species, soil types, and climatic conditions. Many turfgrass species—such as Kentucky bluegrass, perennial grass, tall fescue, creeping bentgrass, velvet bentgrass, colonial bentgrass, zoysiagrass, and bermudagrass—are able to tolerate certain levels of deficit irrigation with little or no loss of aesthetic turfgrass quality.

Soil Texture and Physical Properties

The amount of water that turfgrass can actually use also is affected by soil type and texture. Both soil texture and type affect water retention and infiltration, and thereby influence water use and irrigation quantity or frequency. Generally, larger-particle-size soils, such as sandy soil, have better drainage and hold on to less water than fine-particle soils, such as clay and silt, and have about 50% of the soil water available to plants. Therefore, sands and sandy soil require more frequent irrigation to meet plant needs, but with smaller amounts of water per irrigation event. Conversely, fine-textured soils, such as clay loams and clay, hold larger amounts of water, but only about 30 to 35% of the total water in the soil is available to plants. Deep, infrequent irrigation of fine-textured soils may be needed to meet plant needs. Compared with plants grown in clay soils, Kentucky bluegrass grown in a sand-peat mix had a 6% higher ET in a study conducted during the summer in Colorado (Feldhake, Danielson, and Butler 1983).

Traffic and compaction are major problems in recreational turfgrass areas. Both stresses may adversely affect soil infiltration, water holding capacity, and plant growth, and thus, indirectly affect water use. Soil compaction increases bulk density, water retention, and soil strength, and decreases aeration porosity and oxygen needed for root growth. O'Neil and Carrow (1983) reported a 21 and 49 % decrease in water use for perennial ryegrass grown in moderate and severely compacted soils, respectively, than that under noncompacted soils in Kansas. Similarly, Kentucky bluegrass grown in compacted soils also exhibited a lower water-use rate (Agnew and Carrow 1985).

Summary

As discussed, turfgrass water use is a function of plant growth characteristics and environmental conditions. Therefore, an effective conservation program should be developed based on plant needs and environmental conditions. Use of less water and/or drought-resistant turfgrass species and cultivars is a primary means of decreasing water needs. Selection of turfgrass species and cultivars adapted to local climatic conditions can result in significant water savings. For example, in arid and semi-arid regions, warm-season turfgrasses provide a better turfgrass and use less water than cool-season turfgrasses. Quantification of actual water use by measuring evapotranspiration rate under local environmental conditions at different times of the year helps to decide how much to irrigate under different conditions, as has been described for San Antonio, Texas, in Section 15. Knowledge of critical plant physiological status and soil moisture content of different types of soils also is important for scheduling when to irrigate, how much water to apply by irrigation to replenish water lost through evapotranspiration, and how deep to irrigate in the soil (see also Section 15).

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