DISSERTATION

COOL SEASON TURFGRASS QUALITY AS RELATED TO EVAPOTRANSPIRATION AND DROUGHT

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ABSTRACT OF DISSERTATION

COOL SEASON TURFGRASS QUALITY AS RELATED TO

EVAPOTRANSPIRATION AND DROUGHT

Irrigation is required in semi-arid regions to produce acceptable turf (at least 70 percent live biomass). This study was conducted to provide turfgrass water management information. Irrigation amount and frequency to produce acceptable Kentucky bluegrass (*Poa pratensis* L.) or to insure recovery when water eventually became available was determined. Deficit irrigation effects were studied using sand filled weighing lysimeters. Grass watered at 100 percent irrigation every 2 days (maximum ET) used 4 to 8 percent more water than that irrigated every 7 days. Acceptable Kentucky bluegrass was produced when grass was watered every 2 days and ET was 77 percent of maximum. Lysimeter turf quality was acceptable when the average soil moisture tension was 0.9 to 1.5 bars.

'Merion' Kentucky bluegrass, grown in field plots on clay loam soil, was watered at 100, 75, 50, 25 and 10 percent every 2, 4, 7, or 14 days. Kentucky bluegrass appearance improved as water amounts increased and irrigation interval decreased. Average soil moisture tensions between 4.5 and 1.4 bars produced acceptable turf. Irrigation at 75 percent every two days provided acceptable turf during July and August, however, only 25 percent irrigation was needed during this time to provide acceptable turf after an irrigated recovery period in September.

Four grasses were grown on sand in lysimeters to determine their water use. When soil moisture did not restrict ET, water use was greatest by tall fescue (*Festuca arundinacea* Schreb.) and lowest for fine fescue (*Festuca* sp. L.), while Kentucky bluegrass and perennial ryegrass (*Lolium perenne* L.) were intermediate in water use. These grasses provided acceptable turf during most of July and August with 75 percent irrigation.

Drought tolerant cultivars of Kentucky bluegrass, perennial ryegrass and fine fescue were identified by withholding irrigation during two summers except for a recovery period in September. 'Majestic' and 'H-7' Kentucky bluegrass and 'Aristocrat', 'Bellatrix', 'Citation' and 'Yorktown' perennial ryegrass had the best drought tolerance. None of the fine fescues produced suitable turf under severe drought conditions.

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DEDICATION

This dissertation is dedicated to my brother, Sergeant Thomas Michael Minner MI who served in the United States Army as a member of the Eighty Second Airborn during the stabilization of the Caribbean island of Grenada. He and his comrads served our country so that we may freely choose our educational opportunities.

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INTRODUCTION

Turfgrass managers in the semi-arid regions of the United States are often faced with keeping acceptable swards with limited amounts of water. Water conservation programs must be initated to ensure that an adequate supply of water is available for development. Water conservation and metering agencies in Colorado have monitored domestic water use (Bode and Olson, 1980). They found that approximately 75 gallons per day per person was used for inside needs. Eighty percent more water was used outside compared to inside during the summer. The primary use of outside water was for lawn irrigation. This high demand for water by vegetation is not unusual when we consider that most plants are comprised of 99 percent water (Madison, 1971).

The returns from a well irrigated and functional turf are immense. Asthetic and recreational values of turfgrass are important to the mental health of modern man because of increased urbanization and changes in life style. Turf has also been noted for its control of wind and water erosion, glare, noise, air pollution, and heat build up (Beard, 1973). Feldhake (1981) found that turf canopy temperatures may increase 1.5 C for every 10 percent decrease in evapotranspiration (ET) below maximum. Restricted irrigation could then result in higher temperatures causing increased discomfort during outside recreational activities and higher energy costs for air conditioning. The impact of restricted water use on a turfgrass community needs to be assessed in detail.

The functional aspect of a turf should be considered when water savings are of concern. On most golf course greens water application may be high and frequent since any degree of wilt or moisture stress is unacceptable. However, many parks and untrafficked areas could utilize a lower turf quality for water savings. Large area water savings may be affected by utilizing conservation efforts. The Denver, Colorado Water Department has initiated an ET awareness program to reduce water use in residential areas. This program used a three day irrigation interval based on 80 percent of the calculated ET using the modified Jensen-Haise equation.

Irrigation techniques aimed at water conservation are more successful when seasonal and functional aspects of turfgrass are considered. Native grasses that have adapted to a given climate would obviously contribute to the conservation of water since the need for supplemental irrigation would be low; however, native grasses have limited use as functional turf. Warm season C-4 grasses have been shown to use water more efficiently than C-3, cool season grasses (Biran, et al., 1981; Black, 1971; and Feldhake, et al., 1983). Warm season grasses such as bermudagrass (*Cynodon dactylon* (L.) Pers.), zoysiagrass (*Zoysia japonica* Steud.) and St. Augustinegrass (*Stenotaphrun secundatum* (Walt.) Kuntze) are dominant turfgrasses in southern climates. Only a few warm season grasses are adapted to cool climates since they are dormant from the first frost of the fall until it warms in the spring. Elaborate irrigation systems, new cultivars, and pesticides have expanded the southern limits for cool season grasses such as creeping bentgrass (*Agrostis palustris* Huds.) and tall fescue (*Festuca arundinacea* Schreb.) Although tall fescue can be kept green through the year in Tucson, Arizona, bermudagrass overseeded with annual ryegrass (*Lolium multiflorum* Lam) provided year round green with less water (Kneebone and Pepper, 1982). Grasses, such as Kentucky bluegrass (*Poa pratensis* L.), that go dormant when water is limited and then start to regrow when adequate water becomes available can be used to conserve water (Hanson and Juska, 1969). Selection of drought tolerant cool season species and cultivars is necessary to improve their performance in dry climates. A drought tolerant turf in a dormant state has been conditioned to survive low soil moisture; however, a dormant turf is not always suitable for most needs.

In areas of adaptation cool season grasses, with proper irrigation, will maintain adequate quality through the growing season. Proper irrigation is an elusive term since it relates to many factors such as water use rate, root capacity, soil texture, amount of water applied, irrigation interval, dormancy, desired turf quality, turf species, etc. These factors are further complicated by the variability in rainfall. Current recommendations for turf irrigation are characterized by two words, deep and infrequent. The research supporting these irrigation practices contends that deep irrigation supports deeper rooting and that an infrequent period of irrigation facilitates root expansion that does not restrict roots to the surface (Hagan, 1955; Jacques and Edmond, 1952; Madison and Hagan, 1962; and Schmidt, 1973). Thus, deep and infrequent irrigation has been associated with deeper and more abundant root systems that were better adapted to drought conditions. Root system performance under various irrigation treatments is difficult to study; however, a few researchers (Beach, 1958; Madison and Hagan, 1962; and Youngner et al., 1980) have determined quantitative results of root performance as they relate to irrigation practices. While irrigation affects on root growth have been evaluated, to a limited extent, the effect of irrigation on overall turf performance has not been thoroughly studied.

One goal of water use research is to discover species or cultivars that maintain adequate quality turf with less water. In this study turf water research had three main objectives. The first objective was to determine turf quality for specific amounts of water and irrigation intervals. The second objective was to evaluate water use of four cool season turf species at various levels of water application. The third objective was to identify the most drought tolerant cultivars of Kentucky bluegrass, perennial ryegrass (*Lolium perenne* L.) and fine fescue ((*Festuca rubra* L.) and (*Festuca longifolia* Thuill.)). For each objective a rating system based on turf quality was used to quantify the responses of turfgrass at various levels of moisture. Small weighing lysimeters were used to directly measure the amount of water lost to the atmosphere from a grass canopy.

LITERATURE REVIEW

Environmental and Plant Water Relations

Evapotranspiration is the combined water loss from plant transpiration and direct evaporation from the soil. When the soil is covered with a dense turf, water lost to the atmosphere is mainly due to plant transpiration rather than evaporation. When soil moisture is sufficient to maintain plant turgidity ET is regulated by the energy available to vaporize water and by the characteristics of the boundary layer through which the water vapor must diffuse.

Environmental Factors that Affect ET

Air temperature, wind speed, relative humidity, solar radiation and soil moisture are among the most important environmental factors that influence ET rate. These factors may change dramatically during the course of a day. As the sun rises and proceeds towards noon solar radiation and air temperature increase, if clouds are not present. Wind speed normally increases during daylight hours. Energy in the air as heat and energy from solar radiation warm the plant surface and cause water to move from the leaf into the atmosphere. A low relative humidity also creates a vapor pressure gradient that causes plant water to move into the atmosphere. Increasing wind speed facilitaties the mixture of a humid boundary layer near the leaf with the less humid air of the atmosphere. Danielson et al. (1979) measured a higher ET for urban lawns that were exposed to open winds compared to lawns that were sheltered from the wind by residential areas.

Soil Factors that Affect ET

Edaphic factors that influence ET have been reported. Water use declines as the moisture content of the soil decreases (Gerakis et al., 1975; Hagan, 1955; and Quackenbush and Phelan, 1965). Biran (1981) indicated that tall fescue maintained a constant ET rate as soil moisture tension increased from 1/3 bar to 20 bars during a 13 day period. After 15 days of withholding water and when soil moisture tension was above 20 bars, ET finally decreased from 200 to 50 mg H_2O $dm^{-2}hr^{-1}$. If irrigation is not given until needed, the total water transpired (actual ET) may be much lower than the potential ET (Tovey et al., 1969).

Soil texture is also related to water use. Krans and Johnson (1974) studied the water use of creeping bentgrass grown in a siphon type lysimeter on sand or a 24 percent soil, 24 percent loamite, and 52 percent sand mixture. Grass grown on sand used 1500 mm/yr whereas grass grown on the mix used 1360 mm/yr (9.3 percent more water used by sand grown grass). It was concluded that slightly greater water use with the sand material may be related to greater root development in the porous material. Feldhake (1979) reported a highly significant seven percent decrease in water use by grass growing in a clay soil compared to a sandy loam soil. Root washings from soil cores clearly showed that there was much more root growth in the sandy loam than in the clay soil. Both lower ET and limited root development may have been due to restricted soil aeration in the clay soil. Letey et al. (1966) showed that plants grown in soils low in oxygen often wilted during midday, when transpiration rates were high, due to reduction of root membrane permeability. In a more recent study Feldhake et al. (1983) have shown that in some years there was no significant decrease in water use by turf grown on clay soils compared to sand soils. Tovey et al. (1969) reported a slightly higher water use (6 percent, 59.29 vs. 55.93 cm/season) by a Kentucky bluegrass--fine fescue mix grown in lysimeters on a loam soil compared to a sandy loam soil. Penman (1956) generalized that for complete crop covers of different plants that have the same color, i.e. the same reflection coefficient, the potential transpiration rate is the same irrespective of plant or soil type.

Soil temperature can affect water absorption. Kramer et al (1967) stated that "the principal cause of reduced water absorption is the reduction in root cell permeability and the increase in viscosity of water itself which increases the resistance to passive movement of water through roots". Soil temperatures below approximately 20 C significantly reduce water absorption (Kramer et al., 1967). These authors also noted that the reduction in water absorption is much greater in warm season grasses such as bermudagrass compared to cool season grasses such as Kentucky bluegrass.

Soil temperature has a direct effect on root and shoot growth. This can result in variable water use by turf. Brown (1943) showed that maximum shoot production of Kentucky bluegrass occurred when plants were grown at soil temperatures ranging from 16 to 18 C. Shoot dry matter production and leaf extension rate were more closely related to soil temperature in field studies than air temperature (Brown, 1943). The optimum soil temperature for 'Newport' Kentucky bluegrass is 15.6 C, while soil temperatures above 30 C result in little root growth, loss of root weight and a reduction in carbohydrates (Maun, 1968). The relationship between plant growth and water use is evident from research by Biran et al. (1981). They found a significant and positive correlation (r=0.71) between water consumption and growth rate for several turfgrass species. Thus, it appears that soil temperatures which maximize shoot and root growth also attribute to maximum water use.

Soil fertility, especially nitrogen, can influence water use by grasses. It is well established that nitrogen fertilization increases the total amount of water used but decreases the water required per unit of dry matter production (Krogman, 1967; Mantell, 1966; and Sprague and Garber, 1938). Actually higher nitrogen application causes more vegetative growth that results in a greater water use by grass. Mantell (1966) found that a considerable savings in water and labor could be had if turf was fertilized with nitrogen and irrigated infrequently compared to frequent irrigation with no nitrogen. Feldhake (1981) evaluated adequate and deficient levels of nitrogen in combination with irrigation treatments that resulted in various levels of ET. In agreement with Mantell (1966), he found that grass had higher quality where nitrogen was adequate for most water application rates.

Plant Factors That Affect ET

Water is required for mechanical support and transport of mineral nutrients from the soil to the roots. It is also a medium for biochemical reactions and prevents lethal high plant temperatures through the process of transpiration. Water use varies among turfgrass species (Biran et al., 1981; Dillman, 1931; Feldhake et al., 1983; Kim et al., 1983; and Weaver, 1941). Beard (1973) stated that

> species variations in the transpiration rate are due to inherent differences in rooting depth; total number of roots; root-shoot

ratio; total leaf surface area; cuticle thickness; osmotic pressure of the cells in the leaf; leaf morphology; leaf orientation; internal leaf structure; structure, spacing, size, and location of stomata; and leaf rolling or folding capability.

Morphological Features--When soil moisture is not limiting ET, differences in growth habit can regulate water use. Grasses with a slow vertical leaf extension rate, high shoot density, low leaf area and prostrate growing habit exhibit lower ET rates (Kim et al., 1983). As previously noted, Biran et al. (1981) found a good correlation (r=0.71) between water consumption and growth rate of grasses.

Under conditions of low soil moisture some grasses develop structural modifications that contribute to lower water use. Among these modifications are stomatal alteration, increased cuticle thickness, presence of surface hairs, less intercellular space, small conductive tissue, and the ability of leaves to roll or fold (Beard, 1973).

As soil moisture is depleted, less water is available for transport to the leaves and a loss of turgidity in the guard cells surrounding a stomatal opening results in closure. Sunken stomates, an increased number of stomates per unit area of leaf surface, small stomatal openings, and presence of hairs covering stomates also decrease transpirational losses. Meusel (1964) found that water stress and high light intensity increased the number of functional stomata differentiated from epidermal cells. Shearman and Beard (1973) are in agreement with Meusel (1964) with respect to the effect of light intensity on stomatal density, however, they reported a negative correlation (r=-0.98) between density and nitrogen nutrition.

Accumulation of abscissic acid (ABA) accompanies water stress and inhibits stomatal opening (Hsiao, 1973). In some cases increased ABA resulted in a more efficient use of water by restricting stomatal opening to the amount that optimized CO_2 uptake in relation to water available (Dubbe et al., 1978).

A thick, dense cuticle that is impermeable to water will reduce cuticular respiration. Parker (1968) noted that the cuticle is complex and varies among species both in chemical composition and structure. Even though the cuticle is related to water loss it is questionable if cuticular thickness alone is responsible for decreasing water loss. Low light intensity, low atmospheric humidity or high calcium tend to increase the thickness of the cuticle (Lee and Priestly, 1924). The cuticle thickness of turfgrass leaves developed under frequent irrigation is reduced compared to infrequent watering (Meusel, 1964).

The presence of leaf hairs extends the water vapor boundary and increases the resistance to water vapor diffusion away from the leaf. Hairs also scatter incoming radiation and break up soil reflected radiation thereby decreasing the potential of water loss from the leaf surface.

Some grasses have the ability to fold or roll their leaves during periods of water stress. Folded leaves, as a result of collapsed bulliform cells, have less area exposed to the atmosphere and therefore lose less water.

Physiological Features--There are two distinct pathways by which plants metabolize carbon. Loss of CO_2 by photorespiration in C-4 species is almost undetectable while C-3 species readily lose carbon by photorespiration. High light intensity, high O_2 levels, low CO_2 levels, and high temperature result in more rapid photosynthetic rates in C-4 than C-3 species and subsequently result in a lower water requirement for the C-4 species (Salisbury and Ross, 1978). Several researchers (Biran et al., 1981 and Black, 1971) have shown that warm season C-4 grasses use considerably less water to sustain the same level of growth as cool season C-3 species.

As water moves from the soil into the plant and is released to the atmosphere there are a number of resistances that affect water movement through the plant. Root conductivity influences the water supply from the soil and stomatal control regulates the plant response to the atmospheric demand for water from the plant (Slayter, 1967). Letey et al. (1966) found that the slower growth of roots in compacted soils resulted in fewer young root areas. They also found that root permeability decreased due to root maturation, which reduced water uptake. Marhart et al. (1979) reported that abscissic acid levels increased in stressed plants and this caused a decrease in root conductivity. Meyer and Ritchie (1980) compared the resistance to water movement in roots and shoots. They found that resistances to water movement were strongly dependent on the transpiration rate. For plants with moderate to high transpiration rates the roots had a slightly greater resistance than the shoots. In this study the authors noted specific resistances to water flow such as the connection resistance between the plant crown and the leaf, total connection resistance above the crown, resistance of water flow into the root, and total resistance of the root system (Meyer and Ritchie, 1980).

Rooting--Water for shoots is dependent upon the ability of a root system to take water from the soil and transport it upward. Estimates of root systems such as root volume, depth, number, and growth rate have been related to turfgrass performance (Beach, 1958; Madison, 1962;

Tovey et al., 1969; and Youngner et al. 1980). It is not clear which of these characteristics is most important in supplying water to the shoots. One study with wheat (*Triticum aestivum* Purdix.) by Andrews and Newman (1968) involved root pruning to obtain a normal root system and a root system reduced in volume by 60 percent, with no alteration of root depth. At field capacity plants with pruned roots used 25 to 30 percent less water. When soil moisture tension was at 1 to 15 bars, 1 to 12 percent less water was used by pruned roots. They concluded that as soil dries the volume of roots has less effect on water use than when it is wet. They hypothesized that root growth rate may be more important than the amount of root present when considering water use. In support of the importance of root growth rate Rosene (1941) found that water uptake by roots was greatest just behind the growing tip. Dittmer (1937) estimated that a single rye (*Secale cereal* L.) plant could produce 114 thousand new roots per day and that daily new root length averaged 3.1 miles. Kramer and Coile (1940) calculated the amount of water made available by root extension, based on Dittmer's measurements. They concluded new root growth into moist soils might absorbe enough water to meet the ET demand by a single rye plant.

Most of the root research pertaining to grasses does not deal with the amount of water used by different root systems, but instead is concerned with rooting characteristics as a result of irrigation treatments. Kramer et al. (1967) stated that

> one of the best insurances against drought injury is a deep, wide spreading, and many branched root system which can remove all of the readily available water from the soil to a considerable depth. Thus, varieties of plants with deep and

> abundantly branched root systems are more drought resistant than those with shallow and sparsely branched root systems.

Danielson (1967), reviewing work done by Bierhuizen (1961), stated that "frequent, light irrigations will restrict root penetration and increase the degree of drought damage if dry periods subsequently occur." It seems possible that intentional drying of the soil surface may force roots deeper. Deep roots may be beneficial when avoiding drought, but it is not clearly understood if they are necessary or beneficial to conserve water with limited irrigation. Lunt and Seeley (1967) stated that "the desirability of maintaining deep rooting is axiomatic."

The following discussion elucidates the relationship between irrigation frequency and root growth. Tovey et al. (1969) evaluated the root growth of a Kentucky bluegrass--fine fescue turf grown on loam and sandy loam soils in lysimeters. Irrigation treatments consisted of watering at four, seven, and ten day intervals. The quantity of water applied in each case was 5.08 cm of water per week. Excavation showed that most of the roots were in the top 15 to 20 cm of the soil, with some roots extending to 30 cm. Root development was most extensive in those lysimeters receiving adequate moisture (four day interval for both soil types and seven day interval for the loam soil). Grass growing on sand lysimeters at the seven day interval and both soil types at the ten day interval had poor root development. Tovey et al. (1969) explained that shallow-rooted turfgrasses will not seek out soil moisture when soil moisture levels are approaching the wilting point on sandy soil.

Madison and Hagan (1962) evaluated root growth by assuming that water extraction was directly proportional to the number of absorbing roots, thereby giving an indirect estimate of root growth. While this relationship between root growth and water extraction appears logical, Mantell (1966) found no relation between root distribution and moisture extraction. Although it is not clear if root growth may be estimated from observations of soil moisture extraction a review of the work by Madison and Hagan (1962) is in order. Madison and Hagan (1962) evaluated soil moisture extraction by Merion Kentucky bluegrass irrigated at 2, 10, and 20 day intervals. The total amount of water applied for each interval was not presented. Water extraction by the 3 to 4 year old Kentucky bluegrass sod occurred almost entirely in the top 50 cm of the soil. They found that frequent irrigation resulted in sparser and more shallow rooting with a higher number of plants per unit area. These findings indicate that as the interval between irrigations is increased, roots are increased, but shoot density is decreased. Density is a component of turf quality. In this study turf density, irrigation interval or root growth were not associated with turf quality.

Beach (1958) attempted to quantify the effect that limited irrigation had on root growth and turf quality. Irrigation treatments ranged between 0.75 and 5.00 cm per week of water applied at 2, 4, 6, and 8 day intervals. Core sampling showed that most of the roots were in the 0 to 15 cm depth when compared to the 15 to 30 cm depth. In the 0 to 15 cm depth greatest root weights were produced with minimum irrigation (0.75 cm) and the 8 day interval between irrigations; however, the best quality turf was under the frequent irrigation schedule.

More recently Youngner et al. (1980) found no differences in root growth of Kentucky bluegrass or tall fescue with respect to variable irrigation treatments. Their treatments consisted of irrigation based on visual need, irrigation based on 80 percent of open pan evaporation, and irrigation controlled by tensiometers set to cause irrigation at soil moisture levels of 15, 35, and 55 cb.

The importance of root depth has been generalized by some researchers. Coupland (1958) summarized work by Weaver and Albertson (1939, 1943). He stated that "during drought some grasses increase rooting depth, but as drought progressed and available moisture was limited to current precipitation, plants became dependent on moisture near the surface and deep roots were of no advantage." Gerakis et al. (1975) found that sudden replenishment of moisture following impoverishment resulted in rapid shoot growth for a while, with very little root growth.

Jacques and Edmond (1952) cut perennial ryegrass roots at 30, 60, and 90 cm depths to determine the importance of deep roots in resisting drought. Plants with roots cut at 30 cm below the surface died during the dry summer while growth of plants with roots cut at 60 and 90 cm were only slightly checked.

A summary of information pertaining to irrigation and root growth indicated:

1. Frequent irrigation, approximately every two days, resulted in more roots near the surface than infrequent irrigation.
2. Frequent irrigation resulted in denser turf (more shoots per unit area) with a better appearance.
3. Deep roots aid grasses in their ability to avoid drought.

Canopy--Factors that effect the canopy and subsequent water use are mowing, texture, color, density, and species. Several reports of increased water use at higher mowing heights have been reported (Biran et al., 1981; Feldhake et al., 1983; Madison and Hagan, 1962; Mitchell and Kerr, 1966; and Shearman and Beard, 1973). Madison and Hagan (1962) found soil water extraction to be directly proportional to mowing height. They also attributed increased water use to a deeper root system as a result of higher mowing. Taller grass should be expected to transpire more than short grass because more advected energy can be intercepted (Biran et al., 1981; Feldhake et al., 1983; and Mitchell and Kerr, 1966).

Mowing frequency has also been related to water use. Shearman and Beard (1973) found that water use rate increased 41 percent when grass was mowed 6 times a week compared to 2 times weekly.

Mower blade sharpness can influence water use. Beard (1973) stated that "cutting with a dull, improperly adjusted mower mutilates the leaf tissue and increases the water use rate of turf." More recently Steinegger et al. (1983) determined that water use was approximately 1.3 times greater for turfs mowed with sharp mower blades compared to dull blades. In this research the reduced water use rate associated with dull mower treatments was positively correlated ($r=0.88$) to reduced shoot density.

Under some conditions decreased shoot density is not positively correlated with water use. Biran et al. (1981) have observed a significant and negative correlation ($r=-0.85$) between stand density and water consumption of two C-4 grasses. They attributed the higher water use to a sparse, vertical growth habit. A direct study of the relationship between turf density and water use was conducted by Marlatt (1961). Grass was planted in rows with varying percent cover. He found that

50 to 75 percent cover had higher ET than full cover or bare soil. This is probably due to a "clothesline" effect which enhances wind flow through the canopy. It may also be attributed to a "black box" effect in which solar radiation heats the bare surface where plants are sparse and then is reflected to the under side of living plants where it is also used to transpire water.

Feldhake (1979) also demonstrated that turf with reduced density can use considerable amounts of water. He found that under a full canopy with only 30 percent live biomass that there was an ET rate of nearly 70 percent of a canopy with 100 percent live biomass.

Inherent differences in canopy structure and rooting habit may result in variable water use among different grass species. Most studies compare the water use of only a few grasses. Therefore, it is difficult to rank a wide range of grasses into an appropriate water use category. Beard (1973) stated that the water use rate of most turfgrasses is 0.25 to 0.75 cm per day. Dillman (1931) compared water requirements of grasses in the northern great plains. Smooth bromegrass (*Bromus inermis* Leyss.) used 2 percent less water than crested wheat (*Agropyron cristatum*(L.) Gaertn.) during the early season when growth was rapid, but used 24 percent less water later in the season when the bromegrass was growing very slowly. Weaver (1941) also studied the water use of native grasses under prairie and pasture conditions. Greatest water loss was from big (*Andropogan furcatus* Muhl.) and little bluestem (*Andropogan scoparius* Michx.). Smallest water losses were from bluegrama (*Bouteloua gracilis*(H.B.K.) Lag.) and Kentucky bluegrass while side oats grama (*Bouteloua curtipendula* (Michx.) Torr.) and western wheat (*Agropyron smithii* Rydb.) had intermediate water loss.

Youngner et al. (1980) over a 3 year period, when grass was irrigated by automatic tensionmeter controllers set to come on at 35 cb, reported that tall fescue used 104.1 cm and Kentucky bluegrass used 98.0 cm (6 percent more water used by tall fescue). Welton and Wilson (1931) determined that the water use rate of chewings fescue (*Festuca rubra* subsp. *commutata* Gaud.) turf is much less than Kentucky bluegrass, while the rate for 'Washington' creeping bentgrass is slightly less than for Kentucky bluegrass.

Kim et al. (1983) observed ET rates of 12 C-4 warm season turf grasses. They stated that "those grass species possessing a slow vertical leaf extension rate, high shoot density, low leaf area, and prostrate growing habit tended to have low ET rates." They concluded that water use among species can vary as much as 50 percent and that this criterion can be used to select turf grasses for water conservation.

Irrigation Scheduling

Water conservation and proper irrigation require that many factors be considered. Fundamental considerations that relate to the role water plays in plant growth and the need for growth and a green sward must be correlated with the availability of water and irrigation equipment. Until irrigation requirements are expressed in quantitative terms, watering of turfgrass will remain an art and not a science.

Quantity of Water

Irrigation recommendations concerning the amount of water to apply are best ascertained by research. Early experiments used porous porcelain soil points to measure the water supplying power of the soil (Livingston and Koketsu, 1920; Welton and Wilson, 1931; and Wilson, 1927). Wilson (1927) determined that 500 mg of water per soil point per hour at the

6 cm depth represented the water supplying power which should always be sufficient for good growth of lawn grasses. Other researchers found 100 mg of water to be the minimum water supplying power of the soil necessary to avoid turf injury through lack of water (Livingston and Ohga, 1926 and Welton and Wilson, 1931). They concluded that turf irrigated in Ohio should receive 1.5 times the normal rainfall to maintain soil moisture above this critical level. Welton et al. (1934) stated that "grass should be maintained in a good growing condition provided it is watered as soon after a rain as the evaporation from a black atmometer equals 320 cc of water".

Soil tensiometers have been used to automatically control turf irrigation. Successful application of tensiometer controlled irrigation systems on golf courses in California have been reported (Morgan, 1969). Tensiometers need regular maintenance and are most effective when placed at two depths. The upper tensiometer can indicate how long irrigation may be delayed and the lower one when sprinklers should be run longer to replenish the water reservoir at the lower soil-root zone depths (Morgan, 1969).

Youngner et al. (1980) grew Kentucky bluegrass and tall fescue subjected to five irrigation treatments: a control based on common practice, irrigation based on evaporation from an open pan, and three automatic irrigations activated by tensiometers at different settings. They observed better quality Kentucky bluegrass when tensiometer controlled irrigation was set for 15 or 35 cb compared to 55 cb. They also observed that tall fescue was only affected during the first part of the study and that after the root system had developed fully there were no differences in turf quality among irrigation treatments.

The suprising and most significant result of their study was that the irrigation treatments had few differential effects on the turf. A possible explanation may be that tensiometers measure soil moisture in the 0 to 60 cb range; field capacity is around 33 cb, and the permanent wilting point of most plants is near 1500 cb. Since soil moisture tension was maintained at or below 55 cb it is unlikely that water stress was severe enough to cause dramatic differences in turf quality between treatments. Biran et al. (1981) have demonstrated that water use and photosynthesis for tall fescue were constant between 0 and 100 cb of soil moisture tension. This indicates that some turf grasses may perform quite well at soil moisture tensions that are beyond the measurable range of tensiometers.

The water budget method is another means of scheduling irrigation. ET can be calculated over a short period of time and when it approaches the amount of available moisture in the soil reservoir then sufficient water is applied to replenish the soil-root zone. There are many equations that can be used to calculate ET amounts (Tanner, 1967). Research at Riverside, California used daily evaporation readings from a class A U.S. Weather Bureau evaporation pan to calculate expected evapotranspiration by turf (Gibeault et al., 1982). In this study Kentucky bluegrass, perennial ryegrass, and tall fescue were irrigated at 100, 80, and 60 percent of the calculated ET. They found that turf irrigated at 60 percent ET showed significant reductions in quality during summer stress, but recovered well during an irrigated recovery period. Turf quality ratings at 100 and 80 percent ET were not significantly different. They concluded that a 20 percent water saving can be realized without significantly affecting turf quality. Davenport

(1967) used antitranspirants and found that a 20 percent reduction in water use had no damaging effect on turf growth or quality. Mantell (1966) has observed better turf when irrigation was below maximum usable levels.

Danielson et al. (1981) have also related turf quality to water use. In this study water treatments consisted of various fractions of maximum measured ET, using small weighing lysimeters. They found that turf quality decreased between 100 and 70 percent. At 70 percent ET turf quality was very good (rating of 8.5 were dead grass = 0 and 10 = 100 percent live biomass). An inflection occured at 70 percent ET and from that point until 30 percent ET, quality decreased in a linear response as ET decreased. At 60 percent ET turf quality was determined to be 70 percent live biomass. They concluded that 70 percent of the maximum measured ET is probably the point where damage occurs to grass as a result of high canopy temperature and desiccation overrides a mere reduction in growth as the dominant reason for decreased quality.

Specific irrigation guidelines that can be adapted to rapidly changing evaporative demands and irrigation systems have been discussed. A summary of recommendations for the quantity of water required to maintain a green, dense, actively growing and otherwise healthy turf are:

1. The water supplying power of the soil should be maintained between 100 and 500 mg of water per soil point.
2. When 2 tensiometers are used to automatically control a turf irrigation system, the shallow tensiometer should be set at 35 cb.
3. Long term irrigation, based on calculated or measured ET, should be at the 70 to 80 percent level.

These recommendations assist in developing irrigation schedules, but the question of how often water should be applied remains. The resistance to a soil penitrometer or simple screwdriver forced into the ground can provide the turf manager with an estimate of when to irrigate; however, such procedures cause turf irrigation scheduling to remain more of an art than a science.

Irrigation Frequency

The proper interval between water aplications is important in developing a sound irrigation program. Madison (1971) recommended from one to three irrigations per week in the summer for most turf on most soils. Since there are two components of irrigation scheduling, amount of water and interval between waterings, one or both components should be altered as the plant demand for water changes. The best way to make changes in irrigation scheduling is to change the frequency of irrigation rather than the amount applied at each irrigation (Madison, 1971). Morgan (1969) also noted the need for irrigation of different durations.

He indicated that, following a deep irrigation, water was extracted more rapidly from the top soil layer than from lower depths. This is where most roots are found. Consequently, following deep watering, only shallow irrigations of short duration were needed the next time or two. Gibeault (1977) offers two simple equations that can be used to calculate irrigation amounts and frequencies when the available water per meter of soil, effective root depth, and water use per day are known.

$$\underset{\text{(cm)}}{\text{soil water reservoir}} = H_2O \text{ available/meter of soil (cm)} \times \underset{\text{(meters)}}{\text{root depth}}$$

$$\underset{\text{(days)}}{\text{irrigation frequency}} = \frac{\text{soil water reservoir (cm)}}{\text{water use (cm/day)}}$$

The amount of water to be resupplied should be equal to, or slightly greater than, the amount used.

It has been stated by Madison (1971) that changing the irrigation interval is more desirable than changing the amount of water applied. Research has been conducted using variable irrigation intervals to elucidate its effect on root growth, water use, and turf quality.

There are two common methods of studying irrigation frequency. One of these involves a range of irrigation intervals (days between water application) that results in a decreased or increased amount of total water applied throughout the growing season (Gerst and Wendt, 1983; Mantell, 1966; and Shearman and Beard, 1973). Since the irrigation interval and the quantity of water applied have been changed simultaneously, it is not known which of these independent variables causes a noted response in the dependent variable. A review of the conclusions of this type of literature is in order.

Mantell (1966) grew kikuyagrass (*Pennisetum clandestinum* Hochst.) at irrigation intervals of 7, 11, 21, 25, and 30 days. The total water applied and subsequently the consummative water use by kikuyagrass, increased as the interval between irrigations shortened. He concluded that infrequent irrigation resulted in considerable water savings with little sacrifice of turf quality compared to high water use by frequent irrigations. To expand upon Mantell's conclusions it appears that the increased amount of water applied in conjunction with the more frequent irrigation should be credited for causing the increase in consumptive water use and irrigation frequency alone should not be associated with increased water use.

Gerst and Wendt (1983) have also studied irrigation frequency and turf quality. Bermuda grass grown in Texas was irrigated 1, 2, and 4 times in a 120 day period, however, 17 percent (12.0 v.s. 8.4 cm) more water was applied under the less frequent irrigation. They concluded that an infrequent heavy irrigation maintained the best quality turf for the longest period of time and had the lowest water use. This conclusion is made even though the heavy irrigation received more water, 3.8 cm, than the frequent irrigation treatment. If both irrigation treatments had received the same amount of water, turf quality under frequent irrigation may have been comparable, or even better than turf irrigated infrequently.

The relationship of irrigation frequency with stomatal density, vegetative cover, and water use rate has been investigated by Shearman and Beard (1973). 'Pencross' creeping bentgrass, grown in half liter waxed cartons, was irrigated at wilt (approximately two times a week), and at three and seven times a week. Each container was irrigated to saturation when treated. Under these conditions the more frequent irrigation received more total water than the infrequent treatment. They found that the grass treated with frequent irrigation had more stomata, less vegetative cover, and a lower water use rate than grass irrigated less frequently. In contrast, Meusel (1964) found that annual bluegrass (*Poa annua* L.) irrigated six times a week, compared to two waterings a week, had a higher ratio of stomates to epidermal cells and as a result this grass was particularly susceptible to wilt.

It was previously mentioned that there are two common methods of studying irrigation frequency. The second method involves a range of irrigation intervals that result in the same amount of water being applied at each irrigation interval (Beach, 1958 and Tovey et al., 1969). Under these conditions the irrigation interval effects can be separated from other dependent variables, such as irrigation quantity. Beach (1958) irrigated Kentucky bluegrass during the drought years from 1954 to 1957 in Colorado. Treatments consisted of 2, 4, 6, and 8 day irrigation intervals at several irrigation amounts between 0.75 and 5.0 cm of water per week. In 1955 he found that root growth increased as the frequency of irrigation decreased; however, turf appearance was best at the two day interval and progressively poorer on the four, six, and eight day intervals. A study with results similar to these was conducted in Reno, Nevada with a mixture of Kentucky bluegrass and fine fescue grown in lysimeters filled with loam or sandy loam soils (Tovey et al., 1969). The lawngrass was irrigated at 3, 7, and 10 day intervals, each totaling 5.08 cm of water per week (enough to bring the soil root zone to field capacity at each irrigation). They observed that the frequent irrigation (twice weekly) produced the best quality turf, while the ten day irrigation interval produced a thin grass stand that was susceptible to intrusion of undesirable grass species and weeds. They recommended that twice weekly irrigations for a sandy loam soil and weekly irrigations for a loam soil were adequate to maintain grass with good appearance and condition during the hot part of the growing season, if sufficient water was applied to bring the plant root zone to field capacity at each irrigation. Another important point that was not discussed by the authors, (Tovey et al., 1969), but is clearly evident from their data, involves the relation between irrigation interval and consumptive water use. Irrigation intervals of 3, 7, and 10 days exhibited measured ET values of 0.53, 0.41, and 0.46 cm per day (average from June 1 to September 30), respectively. Expressed as a percentage, the 3 day irrigation interval used 4 and 13 percent more water than the 7 and 10 day intervals, respectively.

Other research (Biran et al., 1981; Madison and Hagan, 1962; and Meusel, 1964), has evaluated irrigation frequency with no indication of the total amount of water applied. Biran et al. (1981) irrigated tall fescue and perennial ryegrass on a two day or a five day schedule. They found that the longer irrigation interval resulted in a 24 to 34 percent reduction of water consumption. Furthermore, delaying irrigation to the onset of temporary wilt caused a significant (35 percent) reduction in grass growth. They also observed that wilt occurred more frequently when irrigation was at the longer interval. In contrast, Meusel (1964) found that annual bluegrass irrigated six times a week wilted faster than annual bluegrass irrigated two times a week when bright lights and hot wind were applied to the plants. He also noted that an increased number of stomata caused higher water use and wilting when plants were grown with frequent irrigation.

There is much confusion in the literature about the influence of irrigation frequency on turfgrass. Some of the contradictions may be attributed to the variability in the amount of water applied as the interval between irrigation is changed. Other problems may relate to species differences or to climatic and edaphic conditions under which studies were conducted.

Drought Resistance

Drought is a condition that exists when soil moisture is limited. An inadequate level of soil moisture for growth of one species may be sufficient for another. A plant's ability to adapt to low soil moisture determines its resistance to drought.

Kearney and Shantz (1911) classified drought resistance. Plants that grow in regions subject to drought are classed as either drought escaping, drought evading, drought enduring or drought resisting. Drought escaping plants maximize use of moisture by growing during periods when there is no drought. These plants have a short rapid growing period and then produce seed. Annual bluegrass is a turfgrass that typifies drought escaping plants. Drought evading plants grow slowly or use water at a slower rate during drought. This conserves moisture and increases the period of growth. Such plants conserve water because of wide spacing, small leaves with a small leaf surface, limited annual growth, and extensive root systems. Fine fescue and tall fescue, for different reasons, could be considered drought evading plants. Welton and Wilson (1931) suggested that the narrow leaves of chewings fescue place a small demand on the available soil moisture. They felt that this combined with the fact that it enters a drought period with a greater reserve of soil moisture, probably enables this grass to survive drought periods better than Washington creeping bentgrass and Kentucky bluegrass. Tall fescue has high water use (Feldhake et al., 1983) but it also has a deep root system which can draw water from a larger soil reservoir than the more shallow rooted fine fescue. Drought enduring plants become dormant during periods of moisture stress. They do not grow during dormancy, but live until water is again available. Kentucky bluegrass commonly endures drought by stopping growth and going dormant during periods of stress. Buds in crowns and rhizomes of Kentucky bluegrass are extremely drought tolerant and initiate growth when soil moisture becomes favorable (Laude, 1953). Drought resistant plants include succulents which store large quantities of water and are able to expand their root systems into dry soils. Plants do not always fall into the precise classifications of Kearney and Shantz (1911). It would be expected that some individual plants could have a combination of the characteristics described in these four classes of drought resistance.

As soil dries a threshold level may be reached wherein drought avoiders are unable to avoid moisture stress. Drought survival then depends on the ability of the plant to endure critical water stress, which is termed drought tolerance. Drought tolerant tissues usually have small cells with a small vacuole. Iljin (1957) found that cells with a large amount of protoplasm and small vacuoles were least disturbed by desiccation and were protected from injury.

Plants that are able to survive extreme desiccation, followed by rehydration, must have sufficient carbohydrate reserves to support growth. Rhizomes of Kentucky bluegrass serve as storage organs for carbohydrates. These reserves are needed for regrowth from dormancy (MacLeod, 1965). Grasses may not be able to recover from dormancy if reserves are too low (Zanoni, et al., 1969).

The carbon budget and heat tolerance of grasses have been related to drought tolerance. Watschke et al. (1972) evaluated several cultivars of Kentucky bluegrass grown at 25-35 C. Their results indicated that Kentucky bluegrasses ('Merion' and 'Belturf') which grew best had the lowest CO_2 compensation points, and normally had high photosynthesis and low respiration rates. This combination of factors gave these two grasses the most desirable carbon budget of those studied, which allowed them to maintain good quality turf after prolonged high temperatures. Julander (1945) reported that heat resistance is a measure of drought resistance. He noted that the ability of a species to resist heat corresponds with aridity of their natural habitat. He stated that "hardening by drought increased food reserves and the ability of these plants to resist heat." Minner et al. (1983) reported that the overall heat tolerance of three perennial ryegrasses and three Kentucky bluegrasses correlated with the amount of precipitation (r=0.91) and average high temperature (r=0.93).

Morphological and physiological plant factors that reduce ET have been previously discussed. Since these factors reduce water use they should also be considered as drought resistant plant features that aid in avoiding plant moisture deficits. Dernoeden and Butler (1979) evaluated the relationship between many plant characters and the drought resistance of many Kentucky bluegrass varieties. The parameters investigated were: stomatal number and size, relative growth rate, bulliform cell morphology, chlorophyll levels, width of leaf blades, compactness of tissue, tissue dry weight, leaf thickness, length and width of epidermal cells and diameters of vascular bundles. They concluded that anatomical variations may contribute to the drought resistance or susceptibility of a particular cultivar; however, there was no significant correlation between drought resistance and the anatomical features of the cultivars investigated.

To accurately evaluate drought tolerance a practical understanding of this term is needed. Drought tolerance could mean the ability to remain green and grow during periods of moisture stress (Burton et al., 1954) or the ability to simply survive a drought period (Wright and

Streetman, 1960). Previous discussions in this literature review have elucidated the effects that water use, irrigation amount and frequency, rooting, and species selection have on turfgrass quality. Cultural practices are also important considerations influencing drought tolerance.

Three cultural practices that are important when maintaining drought tolerance are: irrigation, fertility, and mowing. In early spring, when ET rates are low, drought hardiness may be induced by restricting irrigation (Schmidt, 1973). He also stated that "moderate soil water suction during the spring will limit foliar growth, decrease cell size, and increase root development, all of which increases drought resistance and hardiness". Carrol (1943) also reported that grass plants can be hardened to atmospheric drought by brief exposure to either soil or atmospheric drought. He also noted that Kentucky bluegrass hardened very swiftly, as compared to other turfgrasses.

Proper fertility is required to drought harden turfgrasses. Excess nitrogen applications, especially during the spring, will stimulate top growth, utilize reserve carbohydrates and limit root development (Schmidt, 1973). Dexter, 1937; Carrol, 1943; and Levitt, 1951 have shown that grasses fertilized with high levels of nitrogen suffered greater injury from drought than grasses maintained at low levels. Excess nitrogen will stimulate rapid shoot growth, enlarge cells, increase tissue hydration and cause a general reduction in drought hardiness.

Parker (1968) reported increased drought tolerance of wheat, barley (*Hordeum vulgare* L.) and cotton (*Gossypium hirsutum* L.) with applications of phosphorus fertilizer. He noted that phosphorus increased the number of stomates per unit leaf surface, the water retaining capacity of leaves, bound water, and yields of these crops. Beard (1973) reported that potassium deficiencies will reduce drought hardiness, while Levitt (1951) found that boron increased the drought resistance of plants.

Raising the mowing height will permit more leaf area and consequently an increase in photosynthate. The additional carbohydrate will enable the plant to develop a more extensive root system. Dernoeden and Butler (1978) demonstrated that higher mowing resulted in more drought tolerant turf.

Discussions above have indicated that turfgrasses have variable water use rates. Schantz (1927) stated that there is little evidence that drought resistant plants have a low water requirement. The relative drought resistances of several turfgrass species (Beard, 1973; Butler and Feldhake, 1981; Welton and Wilson, 1931; and Wilson and Livingston, 1932) and specific differences within a species have been reported (Dernoeden and Butler, 1979).

KENTUCKY BLUEGRASS LYSIMETER STUDY

Materials and Methods

The objectives of this study were: 1) to determine the minimum level of irrigation that Kentucky bluegrass can tolerate, and 2) to determine if irrigation interval has any effect on ET.

Evapotranspiration was measured using small weighing lysimeters described by Feldhake et al. (1983) (Fig. 1). Each lysimeter was filled with 15 kg of air dry sand (Table 1). Mature 'Merion' Kentucky bluegrass sod, cut to a depth of 2.0 cm, was washed free of soil and placed on the sand. Sod in the lysimeters was allowed to become established in the greenhouse from early May until mid-June in 1982. During this period the lysimeters were fertilized to supply 195 kg N, 317 kg P, and 85 kg K/ha. During establishment drain plugs were removed from the bottoms of the lysimeters and grass was irrigated as needed to maintain active growth. On June 15, 1982 lysimeters without drain plugs were placed in the field and watered every other day until irrigation treatments began on July 1, 1982. Drain plugs were replaced at this time.

In 1983 grass was reestablished in the lysimeters using new sand and sod. Grass was established in the greenhouse from early March until late May. During this period grass was fertilized to supply 195 kg N,

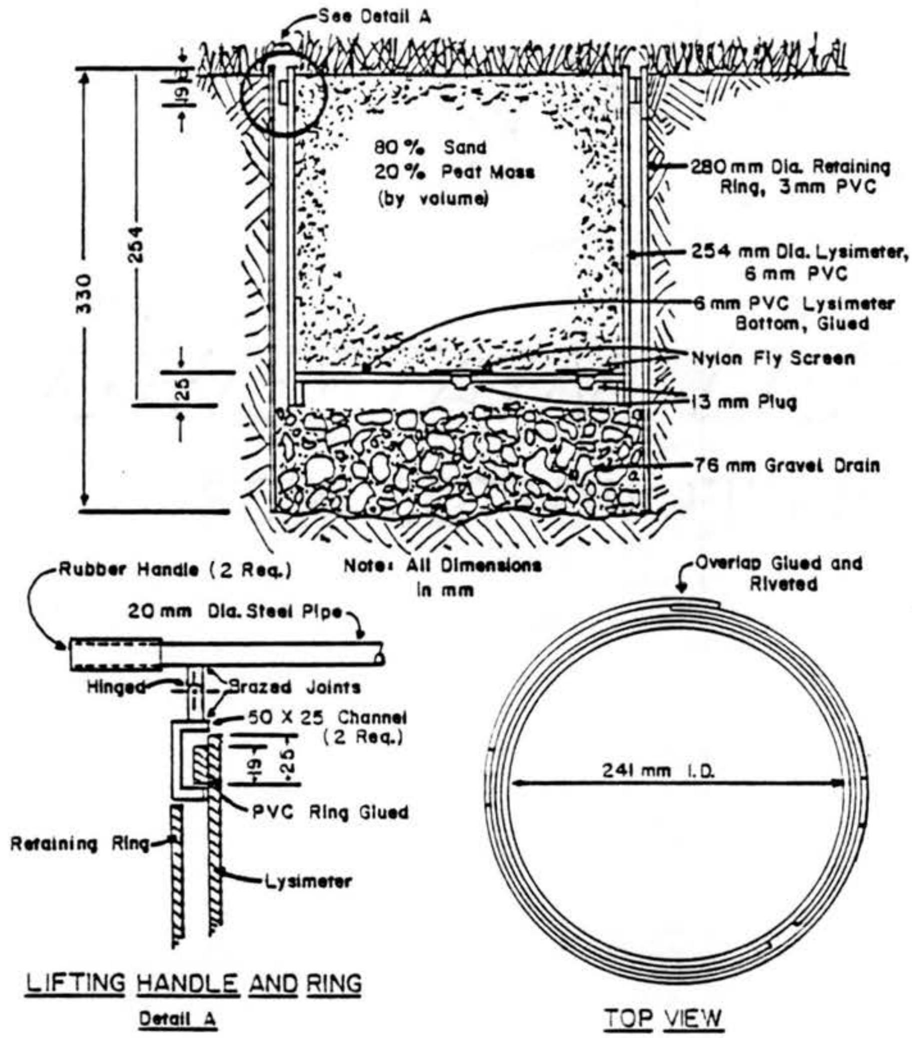

Fig. 1. Schematic diagram of installed lysimeter and lifting handle.

Table 1. Particle analysis of the sand used in all lysimeter studies.

Particle size (mm)	Weight (%)
1.000 - 2.000	7.0
0.500 - 1.000	36.9
0.250 - 0.500	35.9
0.125 - 0.250	15.9
0.053 - 0.125	3.6
<.053	0.7

98 kg P and 195 kg K/ha. On May 23, 1983 the lysimeters were placed on the field and watered every other day until irrigation treatments began on June 1.

The lysimeters were situated in a well maintained field of Kentucky bluegrass located at the W.D. Holley Plant Environmental Research Center on the Colorado State University main campus. Kentucky bluegrass turf that surrounded the lysimeter excavations was fertilized with 195 kg N/ha/yr, mowed 3 times a week at 5 cm and irrigated when necessary to prevent wilt. Irrigation only occurred at night with the lysimeters being covered to prevent water entry. Rainfall, which occurred when the lysimeters were not covered, was measured for inclusion in ET calculations.

The lysimeters were weighed every Monday, Wednesday, and Friday morning during July and August 1982 and June, July, and August 1983. The heavy duty Ohaus Solution Balance used throughout the study was capable of weighing to the nearest gram which was equivalent to 0.02 mm of evapotranspiration. Irrigation water, when required, was measured with a graduated cylinder and applied immediately following weighing. Grass in the lysimeters was mowed along with the surrounding turf.

The experimental design was a randomized complete block with a split plot arrangement. Whole plot treatments consisted of 5 levels of irrigation (100, 75, 25, and 10 percent IRR). The 100 percent IRR treatment was used to determine maximum ET (not restricted by soil moisture content). Levels of irrigation less than 100 percent were considered to be deficit irrigation. Subplot treatments consisted of two irrigation intervals (2 day = ΔT 2; 7 day = ΔT 7). ΔT represents a change in time expressed as days. This experiment was replicated three times. A total of 30 lysimeters were employed in carrying out this study.

"Field capacity" was determined for each lysimeter by allowing the saturated lysimeters to drain, with plugs removed, for 24 hr. Maximum ET, which was considered to occur with 100 percent irrigation, was determined by bringing the 100 percent irrigation lysimeter back to field capacity following the appropriate irrigation interval (ΔT 2 or 7). Feldhake et al. (1983) determined that field capacity allowed for 30 mm of ET before water availability limited ET. They also reported that 'Merion' Kentucky bluegrass used an average of 5.68 mm/day during June and July. Using these figures (30 mm of water and 5.68 mm/day) it can be determined that soil moisture would limit ET after about 5 days. Research reported in this thesis found that grass watered at ΔT 7 100 percent IRR had slightly reduce ET compared to the ΔT 2 treatment (Table 2). Thus, if ΔT 7 had received the same amount of water as ΔT 2, then the ΔT 7 100 percent IRR lysimeters would have exceeded field capacity. To avoid irrigation beyond field capacity in 1982 a separate maximum ET was calculated for ΔT 2 and ΔT 7. These separate maximum values were used to determine the amount of water to be applied for each deficit irrigation treatment. Consequently, grass watered every 2 days received 4.2 percent more water during the experiment than grass watered every 7 days.

In 1983 ET from only the ΔT 2 100 percent IRR treatment was used to determine the amount of water applied to all deficit irrigation treatments. This resulted in equal application of water for both the

Table 2. Reduction in cumulative ET by prolonging the irrigation interval or decreasing the percent irrigation. Data are for the months of July and August in 1982 and June, July and August in 1983.

Percent irrigation	1982			1983		
	2 day	7 day	Difference	2 day	7 day	Difference
	----------mm--------		----%-----	----------mm---------		----%-----
100	325.29 a[Z]	311.63 a[Z]	4.2*	541.27 a[Z]	496.89 a[Z]	8.2*
75	297.19 b	270.44 b	9.0*	432.40 b	302.25 b	31.1*
50	227.13 c	204.19 c	10.1*	311.88 c	202.11 c	35.2*
25	163.27 d	141.88 d	13.1*	220.49 d	148.17 d	32.8*
10	122.97 e	112.64 e	8.4*	160.39 e	134.56 e	16.1*

[Z] Means in a column are separated by FLSD, 5% level.

* Difference significant at the 5% level.

ΔT 2 and ΔT 7 day treatments within a level of deficit irrigation. The ΔT 7 100 percent IRR treatment was treated the same as in 1982.

All treatments in the Kentucky bluegrass lysimeter study were subjected to a stress period followed by a recovery period. During the stress period deficit irrigation treatments were imposed from July 1 to August 29 in 1982 and from June 1 to August 31 in 1983. Immediately following the stress period the drain plugs were removed from each lysimeter and the lysimeters were irrigated to field capacity by saturating the sand three times a week. Each lysimeter also received 96 kg N/ha during the first week of September. Recovery of the grass was observed until growth slowed with cold weather.

In 1982 moisture resistance blocks were installed to determine soil moisture tension in each lysimeter at 10 cm from the surface.

Turfgrass quality was evaluated in 1982 and 1983 using the method discussed by Feldhake et al. (1983). In this method percent live biomass was visually compared to a color card. A scale of 0 to 10 was used (0 = tan, dead leaves and 10 = 100 percent green, living leaves) (Fig. 2).

Results and Discussion

In the summer of 1982 and 1983 various amounts of water were applied at two or seven day intervals. These irrigation treatments resulted in a broad range of soil moisture tension (Fig. 3), ET (Table 2 and Fig. 4), and turf quality (Fig. 3 and 5). The purpose of this study was to determine the level of ET and soil moisture necessary to produce an acceptable turf during a period of summer moisture stress and following an irrigated recovery period.

Fig. 2 Green and tan color cards for evaluating turf quality, ranging from 0 to 100 percent green in 10 percent increments.

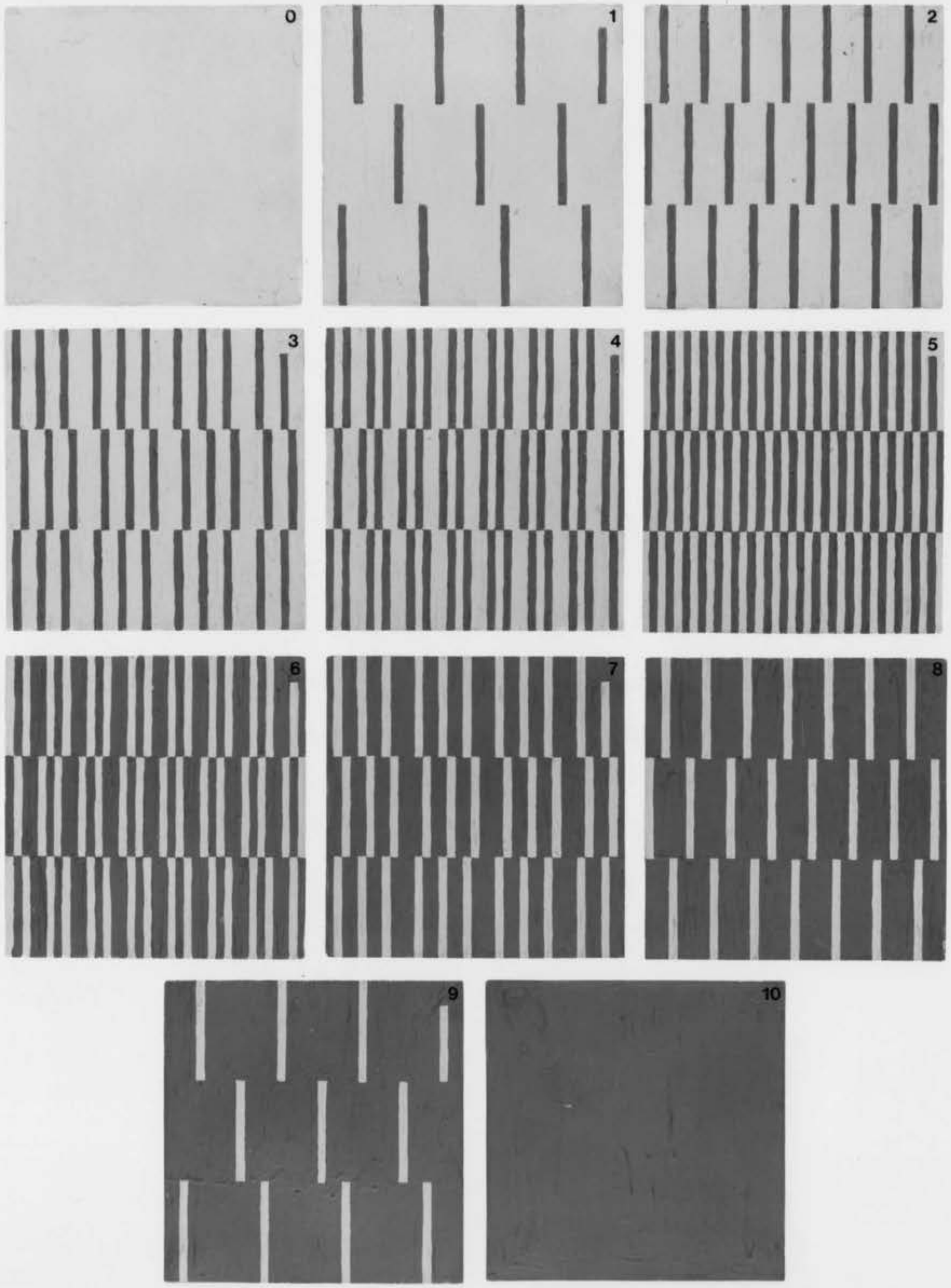
0
1
2
3
4
5
6
7
8
9
10

Fig. 3. Soil moisture tension and quality of lysimeter grown Kentucky bluegrass during July and August 1982. Treatments consisted of 5 amounts of water applied at 2 intervals. Lines represent the average of 3 replications observed on Monday and Friday for the periods indicated.

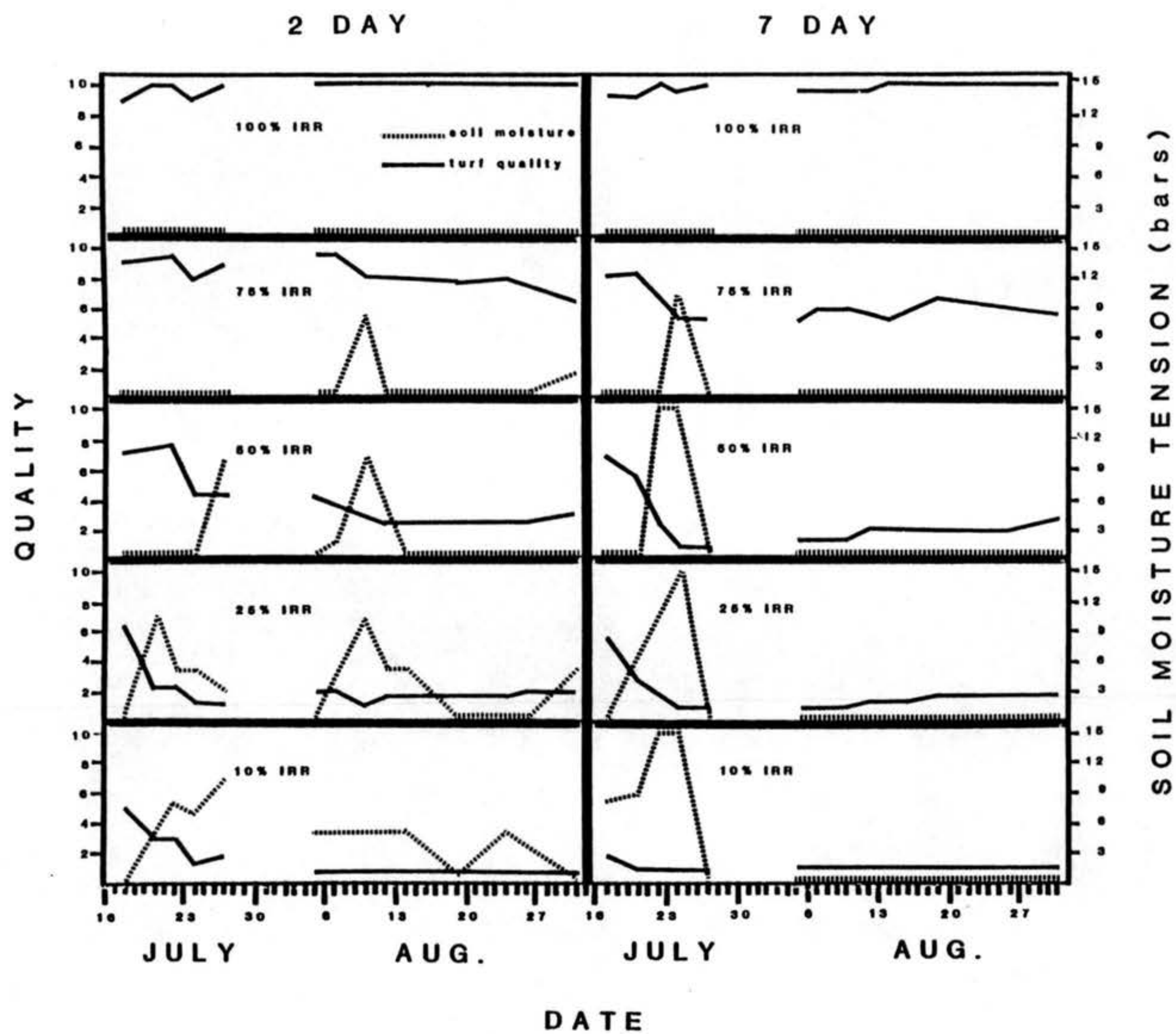
2 DAY
7 DAY
100% IRR
75% IRR
50% IRR
25% IRR
10% IRR
soil moisture
turf quality
QUALITY
SOIL MOISTURE TENSION (bars)
JULY
AUG.
DATE

Fig. 4. Average weekly ET of lysimeter grown Kentucky bluegrass during the summer of 1982 and 1983. Each weekly value is the average of measurements taken on Monday, Wednesday and Friday that were replicated 3 times for each level of irrigation applied at a 2 or 7 day interval. Weekly values within a figure (a,b,c or d) were separated by FLSD multiple comparison test, 5% level.

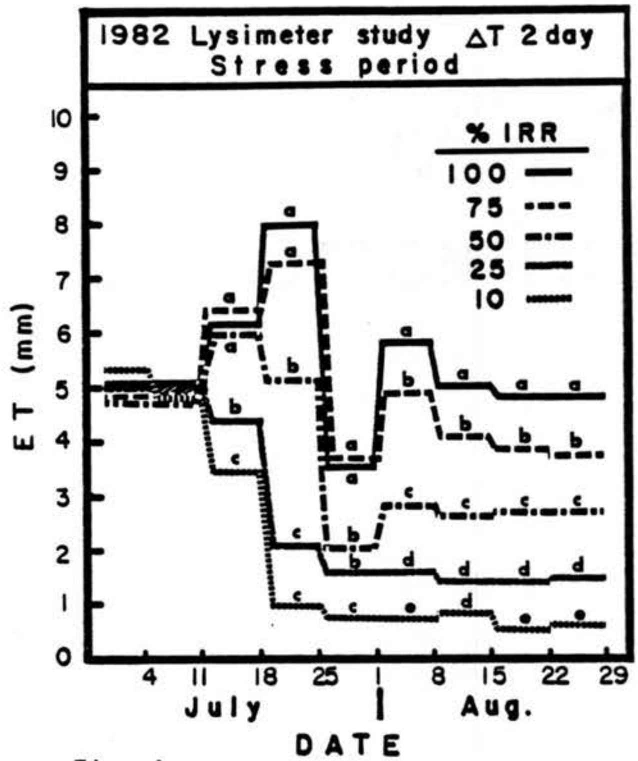
1982 Lysimeter study ΔT 2 day
Stress period
% IRR
100
75
50
25
10
ET (mm)
July
Aug.
DATE

Fig. 4a.

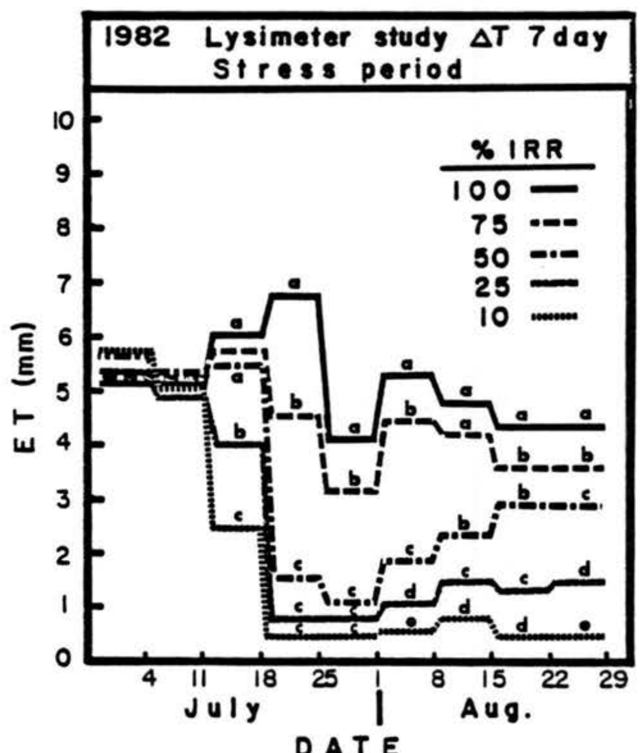
1982 Lysimeter study ΔT 7 day
Stress period
% IRR
100
75
50
25
10
ET (mm)
July
Aug.
DATE

Fig. 4b.

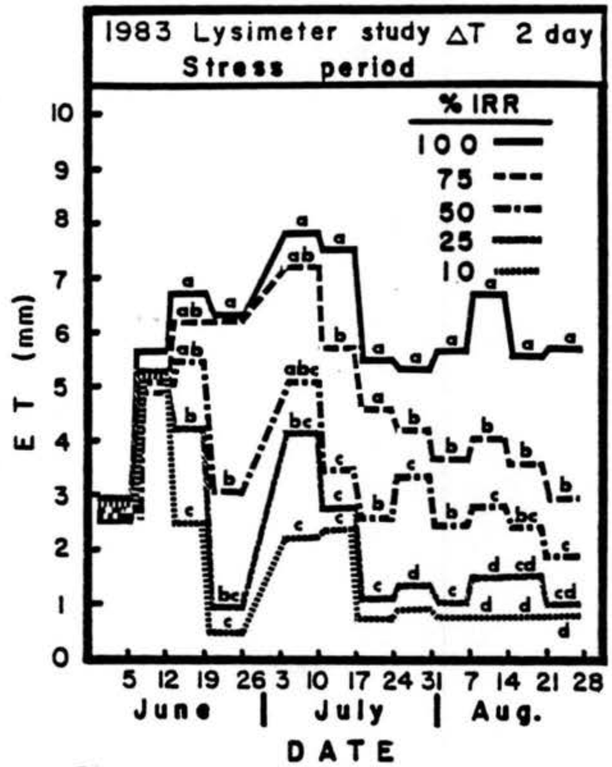
1983 Lysimeter study ΔT 2 day
Stress period
% IRR
100
75
50
25
10
E T (mm)
5 12 19 26 3 10 17 24 31 7 14 21 28
June | July | Aug.
DATE

Fig. 4c.

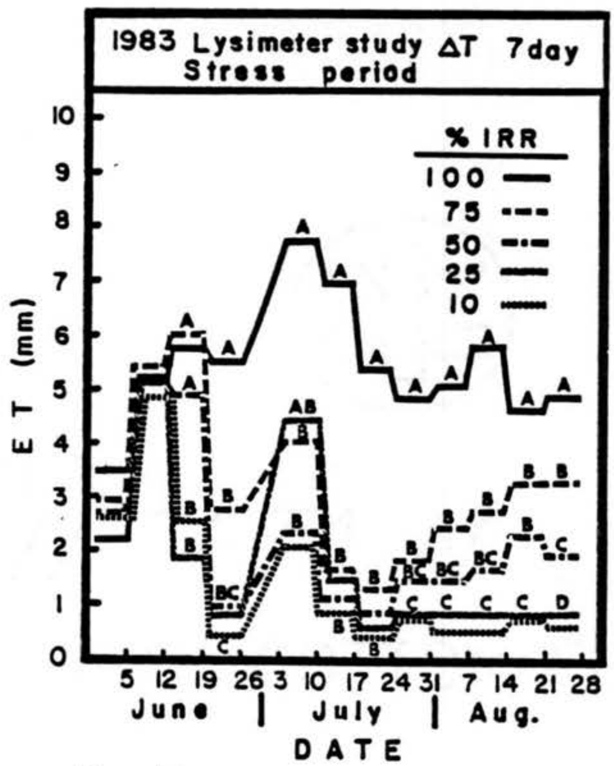
1983 Lysimeter study ΔT 7day
Stress period
% IRR
100
75
50
25
10
E T (mm)
5 12 19 26 3 10 17 24 31 7 14 21 28
June | July | Aug.
DATE

Fig. 4d.

Fig. 5. Average weekly quality of lysimeter grown Kentucky bluegrass during the summer in 1982 and 1983. Each weekly value is the average of measurements taken on Monday, Wednesday and Friday that were replicated 3 times for each level of irrigation applied at a 2 or 7 day interval. Weekly values within a figure (a,b,c or d) were separated by FLSD multiple comparison test, 5% level.

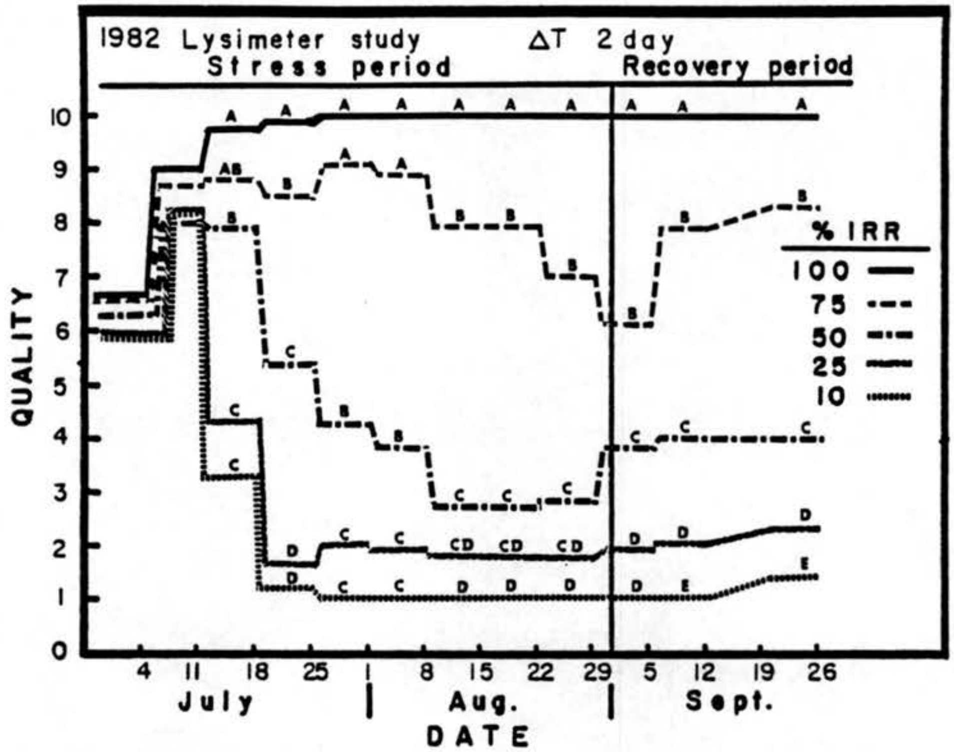
1982 Lysimeter study ΔT 2 day
Stress period
Recovery period
QUALITY
% IRR
100
75
50
25
10
July
Aug.
Sept.
DATE

Fig. 5a.

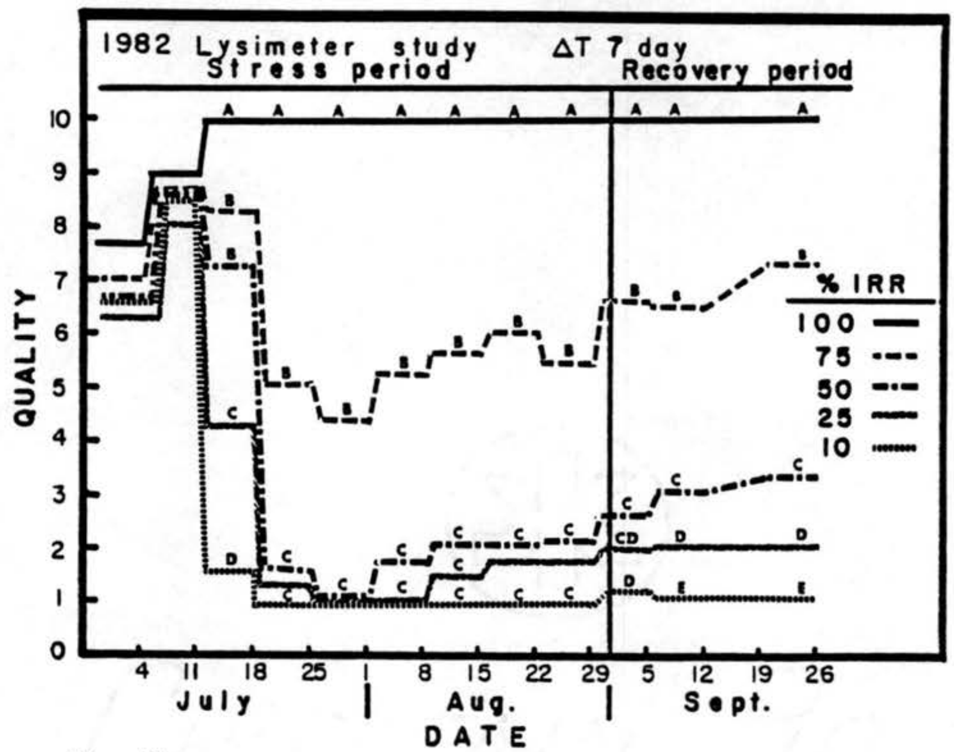
1982 Lysimeter study ΔT 7 day
Stress period
Recovery period
QUALITY
% IRR
100
75
50
25
10
July
Aug.
Sept.
DATE

Fig. 5b.

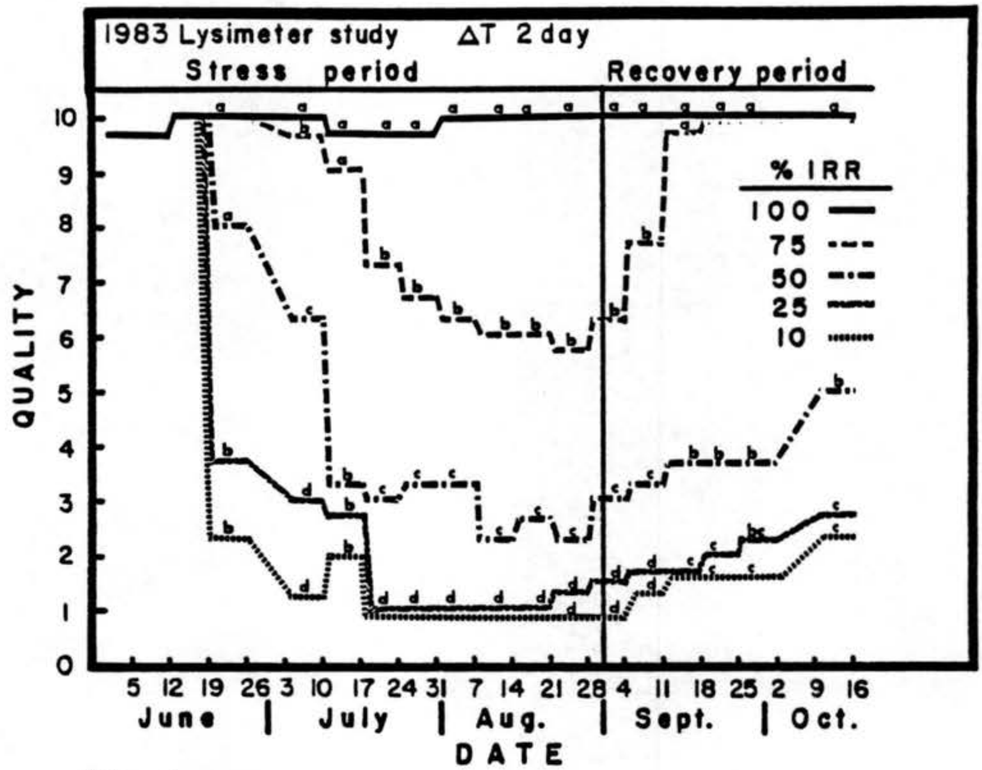
1983 Lysimeter study ΔT 2 day
Stress period
Recovery period
QUALITY
% IRR
100
75
50
25
10
5 12 19 26 3 10 17 24 31 7 14 21 28 4 11 18 25 2 9 16
June
July
Aug.
Sept.
Oct.
DATE

Fig. 5c.

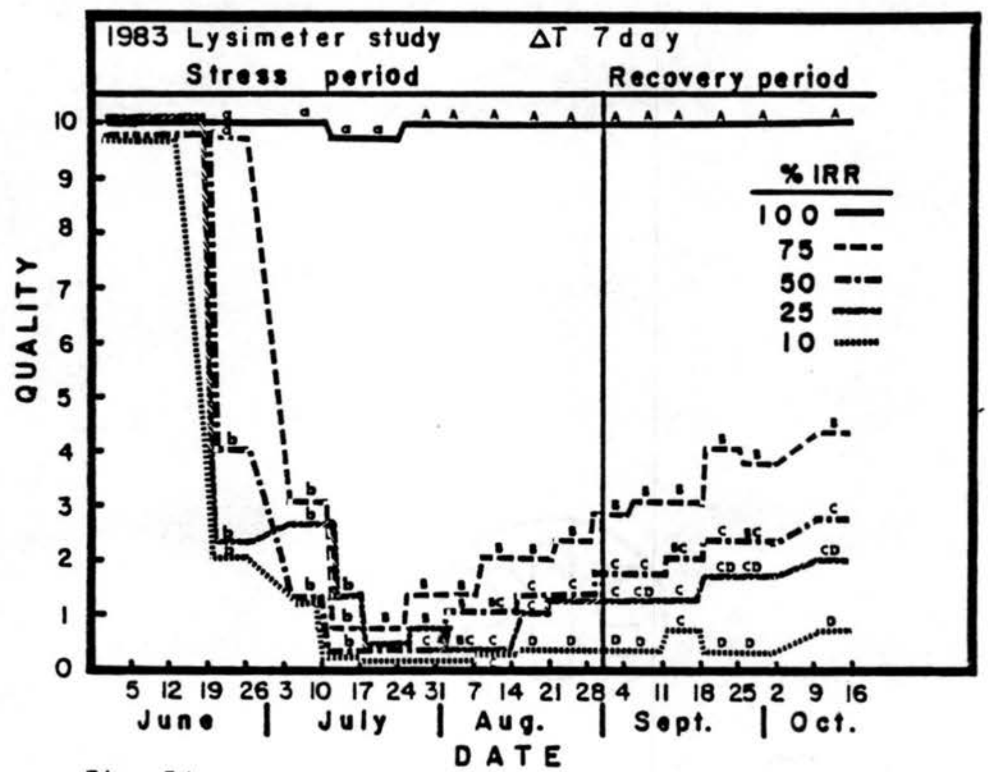
1983 Lysimeter study ΔT 7 day
Stress period
Recovery period
QUALITY
% IRR
100
75
50
25
10
5 12 19 26 3 10 17 24 31 7 14 21 28 4 11 18 25 2 9 16
June
July
Aug.
Sept.
Oct.
DATE

Fig. 5d.

Evapotranspiration

Figure 4 shows ET as a function of time. Maximum ET was determined by supplying enough water every other day (ΔT 2) to bring the lysimeter system back to field capacity (100 percent IRR). Thus, maximum ET (100 percent IRR ΔT 2 day) was measured when soil moisture was not limiting ET. Maximum ET decreased from July to August in 1982 and 1983 (Fig. 4a and 4c). Maximum ET values of 8.58 and 8.94 mm/day were observed on July 19, 1982 and July 4, 1983. ET was greatly reduced from earlier measurements during the week following July 25, 1982 and following July 17, 1983 (Fig. 4), because of rainy weather (Fig. 6a and 6b). Deficit irrigation treatments began on July 1, 1982 and June 1, 1983. Before deficit irrigation was begun all lysimeters were kept at field capacity. Deficit irrigation both years did not result in significant ET reductions until the third week of treatment. During the remainder of the summer significant reductions in ET were associated with decreased amounts of irrigation water. Total ET during the summer of 1982 and 1983 significantly decreased with each decrease of percent IRR (Table 2). Feldhake et al. (1984) also observed reduced ET when deficit irrigation treatments were employed.

The total amount of water used during the summer of 1982 and 1983 was affected by the duration of the irrigation interval (Table 2). The longest irrigation interval, ΔT 7, for each percent IRR treatment in both years resulted in a significant reduction in ET, compared to the shorter interval ΔT 2. At 100 percent IRR the difference in ET, although significant, was small in 1982 (4.2 percent) and 1983 (8.2 percent) (Table 2). During periods of peak water use (July 18-25, 1982 and August 7-14, 1983) grass watered at 100 percent IRR used

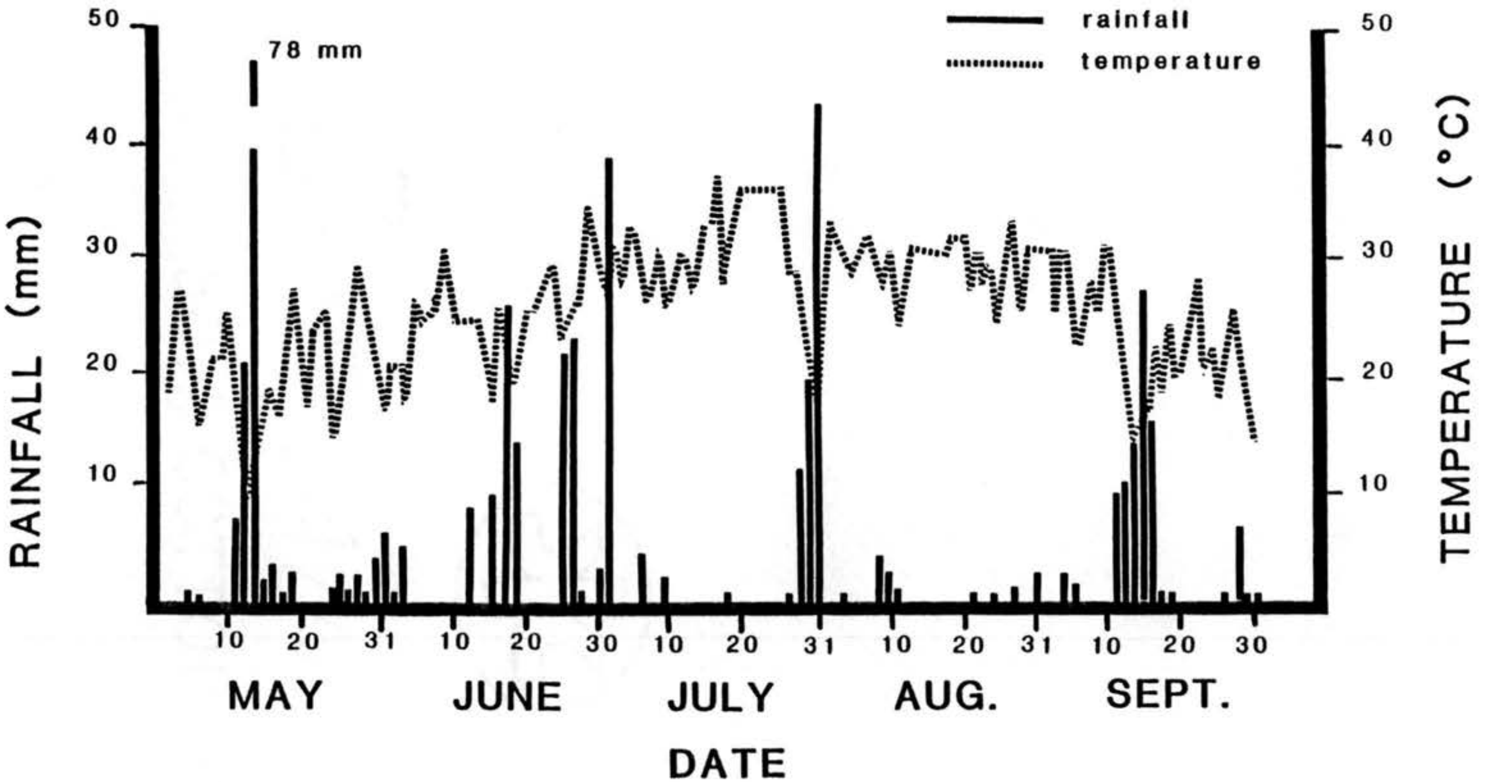

Fig. 6a. Rainfall and maximum temperature data from May thru September 1982. Data were recorded by the Colorado Climate Center, Fort Collins, Colorado.

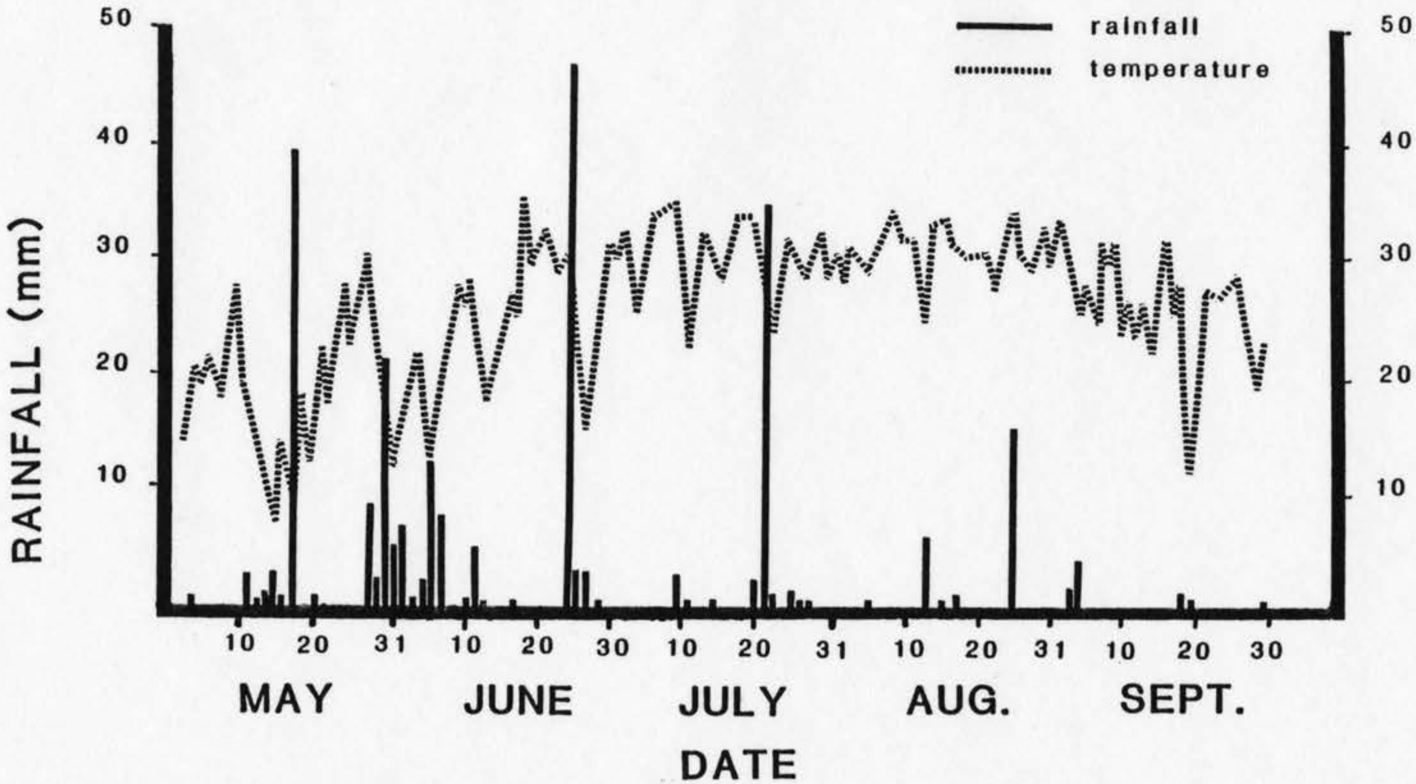

Fig. 6b. Rainfall and maximum temperature data from May thru September 1983. Data were recorded by the Colorado Climate Center, Fort Collins, Colorado.

less water (approximately 1 mm/day) when irrigated every 7 days compared to every 2 days (Fig. 4). It was postulated that stomatal closure or wilt, that did not result in decreased turf quality (Fig. 5), caused a reduction in water use for the ΔT 7 treatment. This small reduction in ET with an increase in the irrigation interval should be taken into consideration when predicting maximum ET, however, it is of limited value as a means of saving water.

Watering at different intervals also affected ET under conditions of deficit irrigation. Figure 4a and 4c indicated that ET generally decreased or remained constant at ΔT 2 day for deficit irrigation treatments during the latter part of the stress period. However, Figures 4b and 4d indicated an increasing ET trend when deficit irrigation treatments were applied at the seven day interval during the last four to six weeks of the stress period. When turf quality was observed the reason for the increased ET trend was obvious. Turf quality for the deficit irrigation treatments decreased more rapidly and to a lower level with ΔT 7 compared to ΔT 2. This was true after the second week of treatment both years (Fig. 5). The rapid decrease in turf quality (lower percent live biomass) resulted in very low water use. After a period of time (two weeks in 1982 and five in 1983) soil moisture was restored, dormancy broke, and turf quality began to increase by the end of the stress period. This increase in turf quality for the deficit irrigation treatments watered every seven days (Fig. 5b and 5d) resulted in an increase in ET during the later portion of the stress period (Fig. 4b and 4d).

Turf Quality

Figure 5 shows turf quality during the stress period, when deficit irrigation treatments were applied, and following a well irrigated recovery period. On a weekly basis there were clear and significant turf quality differences between various irrigation levels. In general, turf quality decreased as percent IRR decreased. Irrigation interval also had a pronounced effect on turf quality, especially at 50 and 75 percent IRR. A comparison of ΔT 2 and 7 for these amounts of irrigation indicate that ΔT 7 greatly reduced turf quality compared to ΔT 2 (Fig. 5). Other research supports this concept that frequent irrigation, that does not result in water saturated soils, produces better appearing turf compared to infrequent irrigation (Beach, 1958; Biran et al., 1981; Tovey et al., 1969).

In this study it was important to determine the amount and frequency of irrigation that produced acceptable quality turf. On a scale of zero to ten the lowest acceptable level of turf quality was given a value of seven. In 1982 the treatment that provided acceptable quality turf with the least amount of water during the stress period and following the recovery period, was 75 percent IRR at ΔT 2 (Fig. 5a and 5b). In 1983 75 percent IRR at ΔT 2 produced acceptable quality turf for the first eight weeks of the stress period (Fig. 5c). For the remainder of the stress period this treatment resulted in turf quality ratings between six and seven (just below an acceptable level of quality). During the recovery period grass that had been irrigated at 75 percent IRR rapidly returned to excellent quality (value of ten). Feldhake et al. (1983) noted similar results in that irrigation deficit up to 27 percent only decreased growth whereas larger deficits caused additional damage and quality decreased rapidly. Thus, the ET value determined by Feldhake et al. (1983) to cause rapid decrease in turf quality (73 percent) is very closely related to the amount of water (75 percent IRR) that was necessary to support acceptable quality turf in this study (Fig. 5a and 5c).

Figures 7 and 8 show the relation between turf quality and relative ET. Evapotranspiration by the 100 percent IRR treatment was given a relative value of 1. Figure 7 indicated a strong linear relation between relative ET and turf quality of Kentucky bluegrass when deficit irrigation treatments were averaged over the summer stress period. From this linear relation relative ET values that related to an acceptable level of turf quality were calculated (Q7 = the ET value that results in an acceptable level of quality). Q7 values for the 2 and 7 day irrigation intervals were 77 and 79 percent of maximum ET, respectively. Feldhake et al. (1984) also found a linear relation between turf quality and relative ET when quality ranged between 9 and 1, and relative ET ranged between 73 and 30 percent of maximum. Using the regression equation from this linear relationship a Q7 value of 63 percent ET was determined. This ET value of 63 percent and the previously mentioned ET value of 73 percent may indicate breakpoints beyond which further decreases in ET cause severe plant damage and a noticeable decrease in turf quality (Feldhake et al., 1984). The findings by Feldhake et al. (1984) were substantiated (Fig. 7) but no obvious break point occurred. It was determined that ET values below 77 percent resulted in unacceptable turf (Fig. 7). Break point positions may change under other climatic conditions, but it appears that the minimum

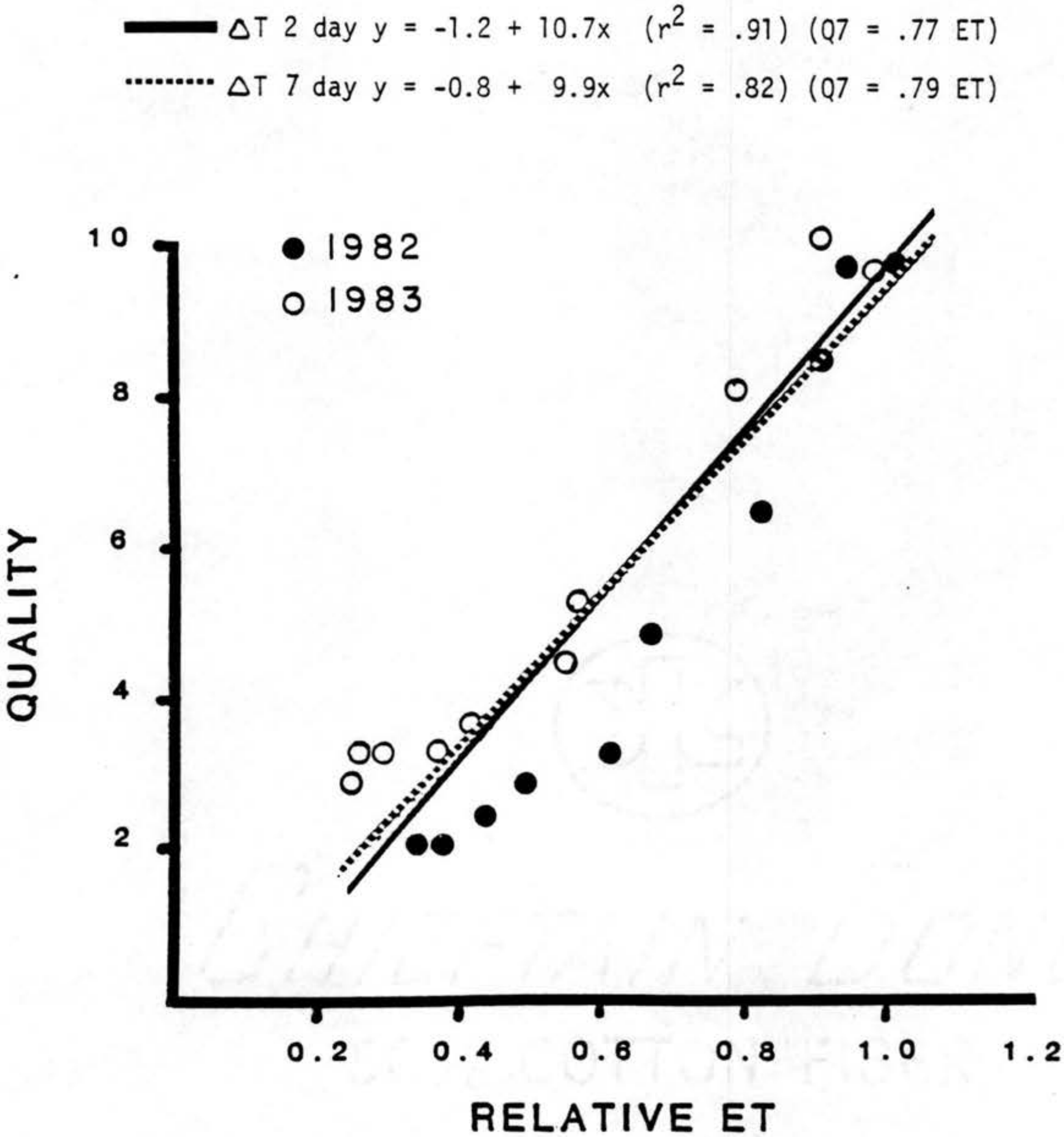

Fig. 7. Relation between turf quality and relative ET averaged over the stress period in 1982 and 1983. Each point is the average of 3 replications. Q7 refers to the relative ET that corresponds to the lowest acceptable level of turf quality.

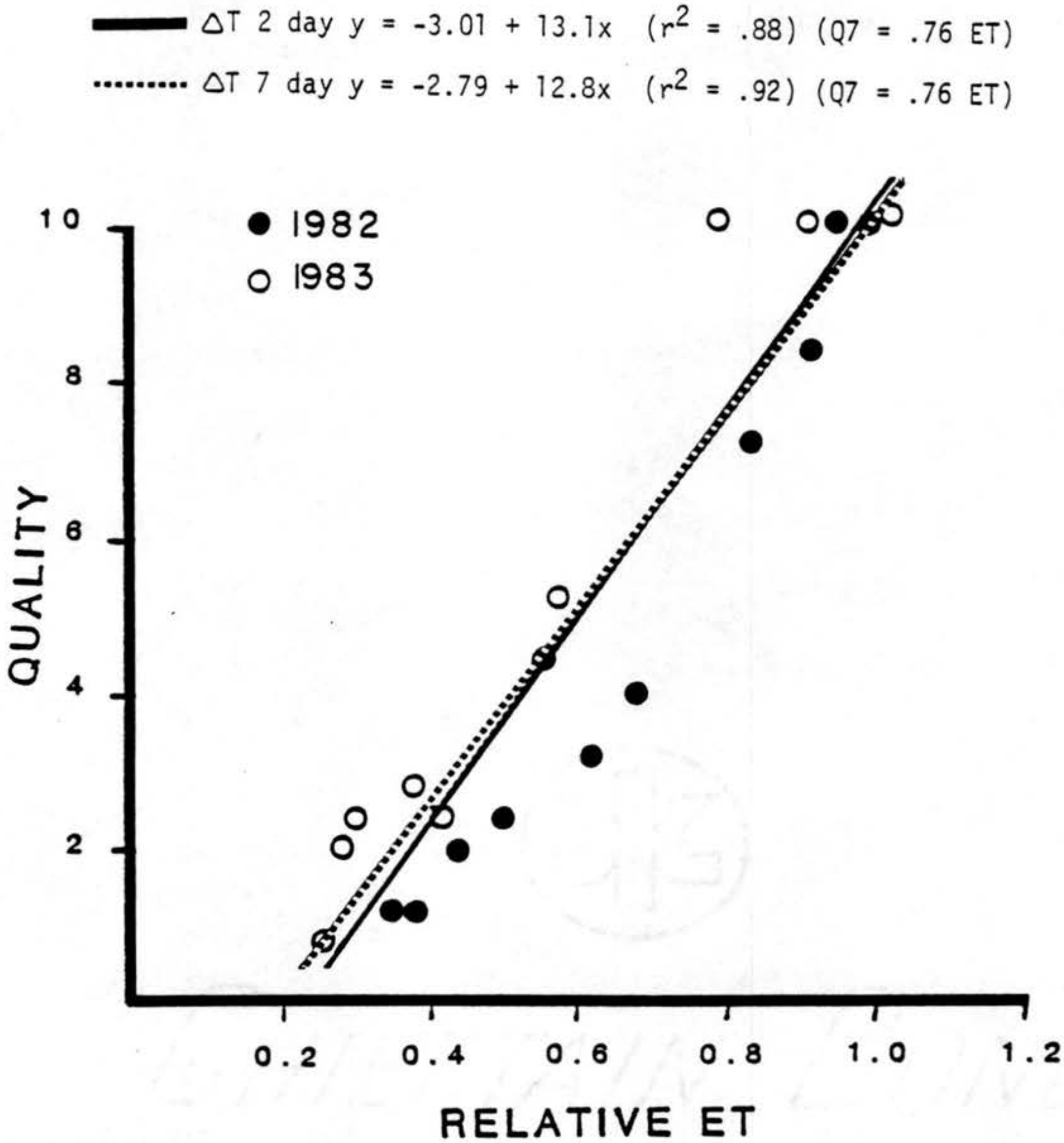

Fig. 8. Relation between turf quality (at the end of the recovery period) and relative ET (averaged over the stress period) in 1982 and 1983. Each point is the average of 3 replications. Q7 refers to the relative ET that corresponds to the lowest acceptable level of turf quality.

ET value that can produce actively growing Kentucky bluegrass in Colorado would range between 63 and 77 percent of maximum ET.

Figure 8 shows that there was also a strong linear relation between relative ET during the stress period and turf quality following the recovery period. Relative ET during the stress period that related to an acceptable level of turf quality following the recovery period was 76 percent for both the 2 and 7 day irrigation interval. Regression analysis averaged over both summers for ΔT 7 predicted an acceptable level of turf quality at 79 percent of maximum ET (Fig. 7); however, it is important to note that in both years grass watered every 7 days required 100 percent IRR to produce an acceptable level of turf quality during the entire stress period (Fig. 5b and 5d). Following the recovery period in 1982 only the grass treated with 75 and 100 percent IRR ΔT 2 reached an acceptable level of turf quality.

Soil Moisture

In addition to turf quality and ET, soil moisture was also measured at the 10 cm depth in each lysimeter. It was anticipated that a Q7 value for soil moisture tension could be calculated. Since the soil moisture tension of irrigated soil is in a state of constant fluctuation such a value must be comprised of many observations over the growing season. Even then such a value may be erroneous since soil moisture tension can not be maintained at a constant level throughout the growing season. Nevertheless, an average soil moisture tension that relates to a given level of turf quality could be useful when irrigation systems are controlled by soil moisture sensing devices.

Figure 3 shows the variation in turf quality and soil moisture when Kentucky bluegrass was under deficit irrigation during July and August of 1982. For the ΔT 2 day treatment soil moisture tension generally increased and turf quality decreased as smaller percentages of irrigation were applied (Fig. 3). For the ΔT 7 day treatment soil moisture tension sharply increased and turf quality decreased under the deficit irrigation treatments during July. This resulted in severe Kentucky bluegrass injury since turf quality did not improve during August, eventhough soil moisture tension during this time remained near 1/3 bar (Fig. 3). When grass was irrigated every 7 days only the 75 and 100 percent IRR treatments were able to acceptably recover from this stress. The decrease in turf quality and increase in soil moisture tension occurred gradually and over a longer period of time for the two day irrigation interval compared to the seven day interval.

Figure 9 shows the relation between turf quality and soil moisture tension. This relation was linear when averaged during July and August even though there was a broad range of soil moisture tension and turf quality expressed as point measurements in Figure 3. Obvious problems when predicting turf quality from soil moisture tension are best observed when irrigating every seven days (Fig. 3). The 50, 25, and 10 percent IRR treatments at ΔT 7 decreased in quality shortly after deficit irrigation began. Consequently, these treatments did not use much water and after a period of time (since water was being added every seven days) the soil moisture tension dropped to near field capacity. Thus, during August, following cessation of growth from low soil moisture in July, soil moisture tension was low and so was turf quality. This response at the end of the stress period is contradictory to the linear

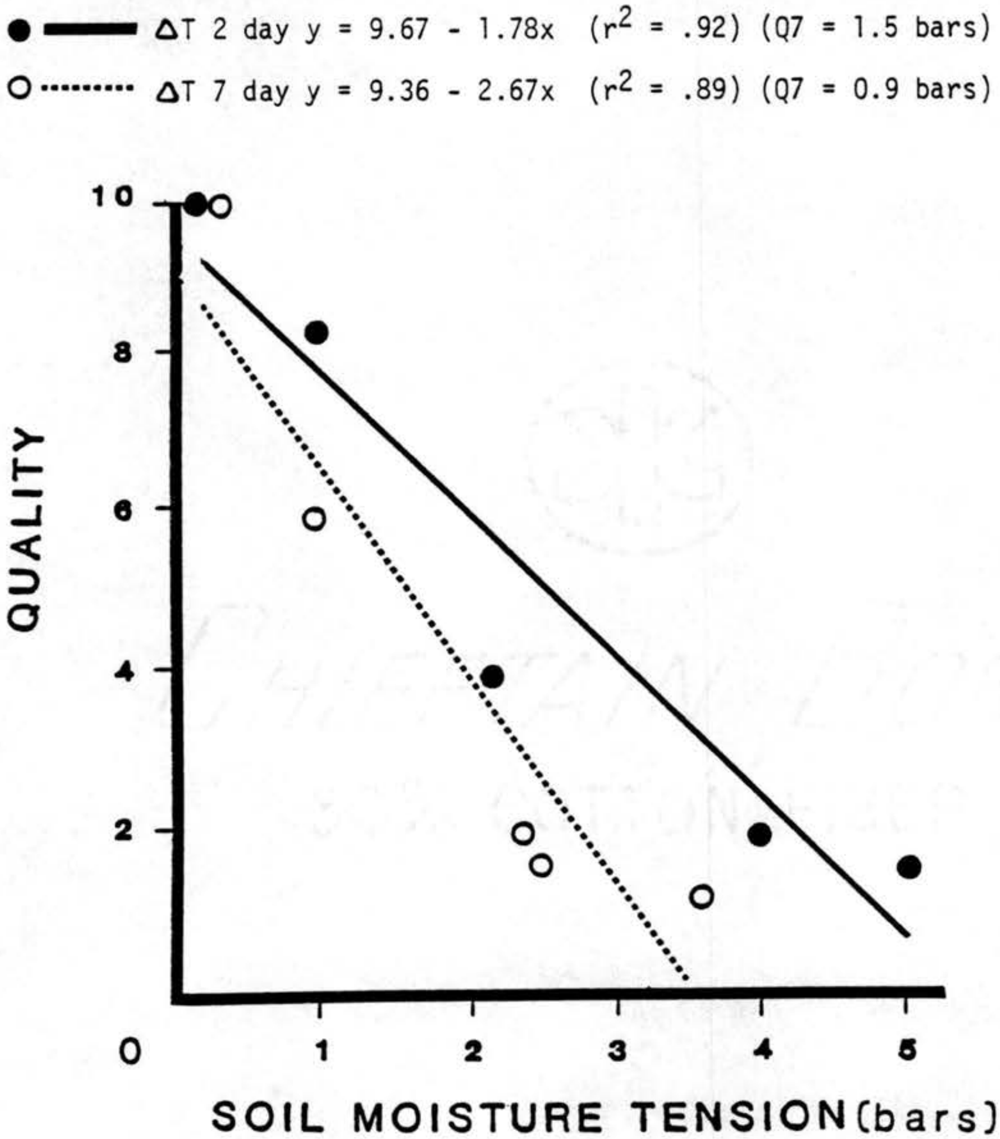

Fig. 9. Relation between Kentucky bluegrass quality and soil moisture tension averaged during July and August 1982 when deficit irrigation treatments were applied. Each point is the average of 3 replications.

relation between turf quality and soil moisture tension found in Fig. 9. Eventhough this conflict in the data occurs it is still desirable to predict a level of soil moisture that is associated with an acceptable level of turf quality. Such a value would be helpful when setting automatic irrigation devices that monitor soil moisture tension. Q7 values for soil moisture tension were 1.5 and 0.9 bars for irrigation intervals of 2 and 7 days, respectively.

Conclusions

The observations in this study pertain to 'Merion' Kentucky bluegrass that was grown in small sand filled lysimeters surrounded by an actively growing sward of Kentucky bluegrass.

1. Grass irrigated at 100 percent IRR every 2 days (maximum ET) used 4-8 percent more water than grass irrigated every 7 days.

2. Grass required 75 percent IRR every 2 days during July and August to maintain acceptable quality turf. This level of turf quality was also evident when grass used 77 percent of its maximum ET.

3. Turf quality remained acceptable when the average soil moisture tension was 0.9 to 1.5 bars during July and August. Therefore, this range of soil moisture tension could be used when moisture sensing devices are used in combination with automatic irrigation systems.

LYSIMETER STUDIES WITH FOUR COOL SEASON GRASSES

Materials and Methods

The objectives of this study were: 1) to determine the water use levels of four cool season turfgrasses ('Merion' Kentucky bluegrass, 'Pennfine' perennial ryegrass, 'Fawn' tall fescue and 'Dawson' creeping red fescue (*Festuca rubra* subsp. *trichophylla*(L.) Gand.) in 1982 and 'Biljart' hard fescue (*Festuca longifolia*) in 1983: and 2) to determine which species performs the best when given deficit irrigation.

The grasses were established in lysimeters and placed in the field using the same procedures described in the Kentucky Bluegrass Lysimeter Study. All four grasses in this study were watered every two days. The experimental design was a randomized complete block design with a split plot arrangement. Treatments consisted of 3 whole plot levels of irrigation (100, 75, and 50 percent IRR) split into 4 subplot levels of species. The experiment was replicated 3 times, thus, a total of 36 lysimeters were employed in this study.

In 1982 deficit levels of irrigation were derived from the 100 percent IRR treatment for each species. Consequently this resulted in a different amount of water being applied to each species within a level of percent IRR. In 1983 deficit irrigation was derived from only the 100 percent IRR Kentucky bluegrass treatment. This resulted in equal water application to all species within a level of deficit irrigation.

In 1982 ET was measured for all levels of irrigation. In 1983 ET was measured for only the 100 percent IRR treatments. Turf quality was evaluated in 1982 and 1983 as described under the Kentucky Bluegrass Lysimeter Study.

Results and Discussion

Kentucky bluegrass is widely used in the United States. The pronounced use of this grass has greatly influenced irrigation management. Supplemental irrigation is obviously necessary to maintain a green, actively growing Kentucky bluegrass turf in arid and semi-arid regions, and during dry periods in humid areas. To conserve water, Aurora, a rapidly expanding suburb of Denver, Colorado developed an ordinance which limits the size of Kentucky bluegrass lawns (Waldo, 1981). Grasses that are exempt from this ordinance include the fescues and ryegrasses. It is important to understand water use rates of turfgrasses when selecting grasses for water savings. In addition to water use it is important to determine which species provides acceptable quality with the least amount of supplemental water and which species can recover from poor turf quality caused by drought.

Evapotranspiration

Table 3 shows the total water use by four cool season turfgrasses during part of the summer in 1982 and 1983. Tall fescue used significantly more water than Kentucky bluegrass, perennial ryegrass, and fine fescue in 1982 (16, 14, and 18 percent, respectively) and significantly more water than fine fescue in 1983 (14 percent). These results are in general agreement with Youngner et al. (1980) who reported a 6 percent increase in water use by tall fescue (104.1 cm) compared to Kentucky bluegrass (98.0 cm) over a three year period. The increased

Table 3. Cumulative ET by four cool season grasses during July and August in 1982 and June, July and August in 1983. Grasses were watered (at the 100 percent irrigation level) and ET was measured every Monday, Wednesday and Friday. ET values represent the average of three replications.

	1982		1983	
Species	ET	Difference	ET	Difference
	---mm----	-----%-----	---mm----	-----%-----
Tall fescue	388.12 a[Z]	--	584.51 a[Z]	--
Kentucky bluegrass	325.29 b	16	540.96 ab	8
Perennial ryegrass	333.61 b	14	539.43 ab	8
Fine fescue	317.85 b	18	501.40 b	14

[Z] Means in a column followed by the same letter are not significantly different at the 5% level according to Duncan's New Multiple Range Test.

water use by tall fescue may be attributed to its open and upright growth habit which provided for greater wind movement through its canopy. Total water use during part of the summer in both years, although not significantly different, was less for fine fescue than for Kentucky bluegrass (Table 3). Maximum ET reported on a weekly basis (Fig. 10a) was significantly higher for Kentucky bluegrass than for fine fescue during the fourth and last week of the stress period. This substantiates work reported by Welton and Wilson (1931).

Turf Quality

As a rule turf quality decreased both years as percent IRR decreased (Fig. 10a, 10b, 10c, 11a, 11b, and 11c). In 1982 maximum ET (100 percent IRR treatment) was determined every Monday, Wednesday, and Friday for each species. Based on the maximum ET value of each species deficit irrigation of 75 or 50 percent IRR was applied. It can be seen from Table 3 that maximum ET values of the four species were not the same. Since deficit irrigation was based on maximum ET for each species, the actual amount of water applied with deficit irrigation (75 to 50 percent IRR) was not the same for each species. Deficit irrigation treatments for perennial ryegrass, Kentucky bluegrass, and fine fescue received, 14, 16, and 18 percent, respectively, less water than deficit irrigation treatments for tall fescue. Eventhough the level of deficit irrigation (75 or 50 percent) was the same for all species the actual amount of water applied was not the same. This presents a conflict when comparing turf quality for different species within a level of deficit irrigation (Because the actual amounts of water applied were dissimilar).

Fig. 10. Average weekly ET and quality of 4 cool season grasses during 1982. Evapotranspiration and turf quality values are the averages of 3 replications determined on Monday, Wednesday and Friday of each week. Deficit irrigation treatments of 75 and 50% IRR, for each species, were based on the maximum water use (ET for 100% IRR) by each species. Weekly values within a figure (a,b or c) were separated by FLSD multiple comparison test, 5% level.

1982 Lysimeter study 100% irrigation

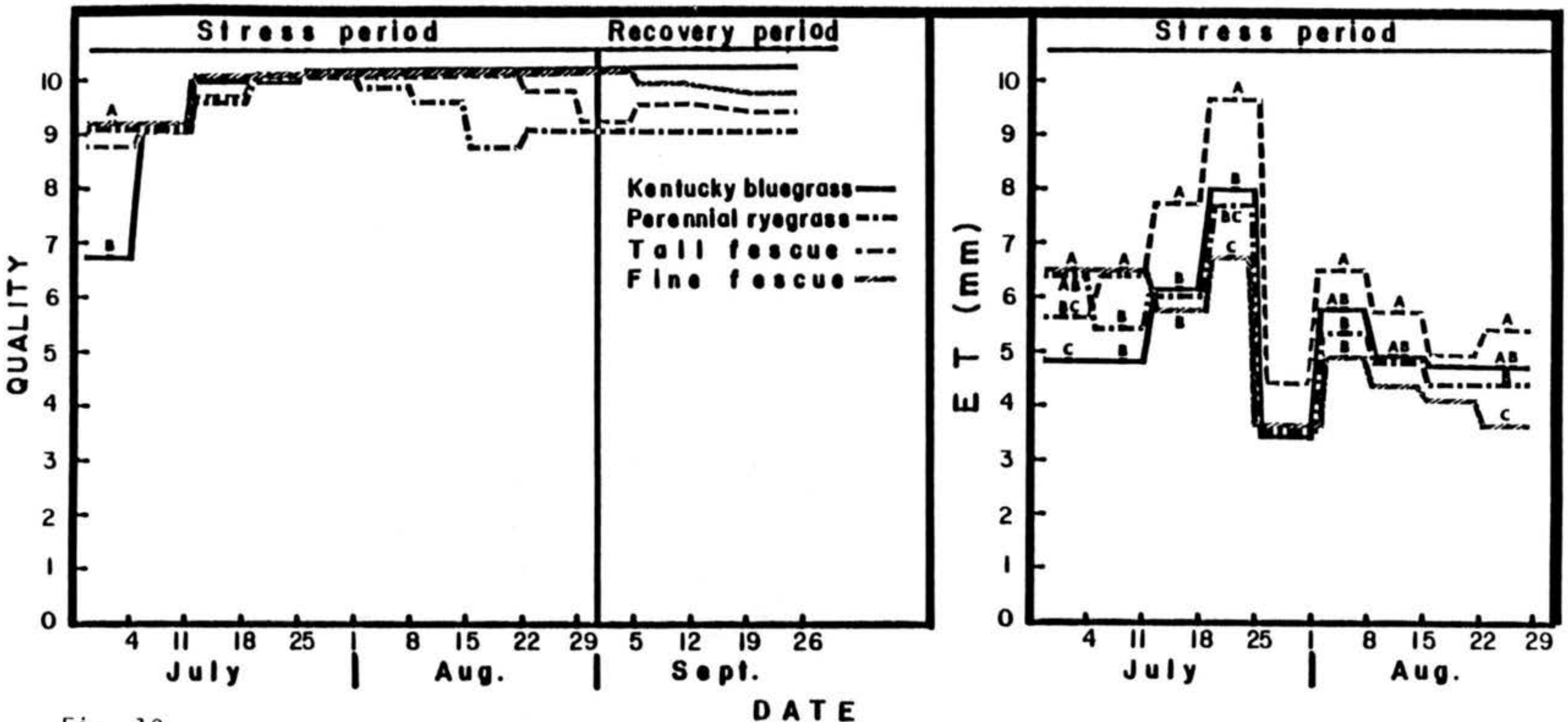

Fig. 10a.

1982 Lysimeter study 75% irrigation

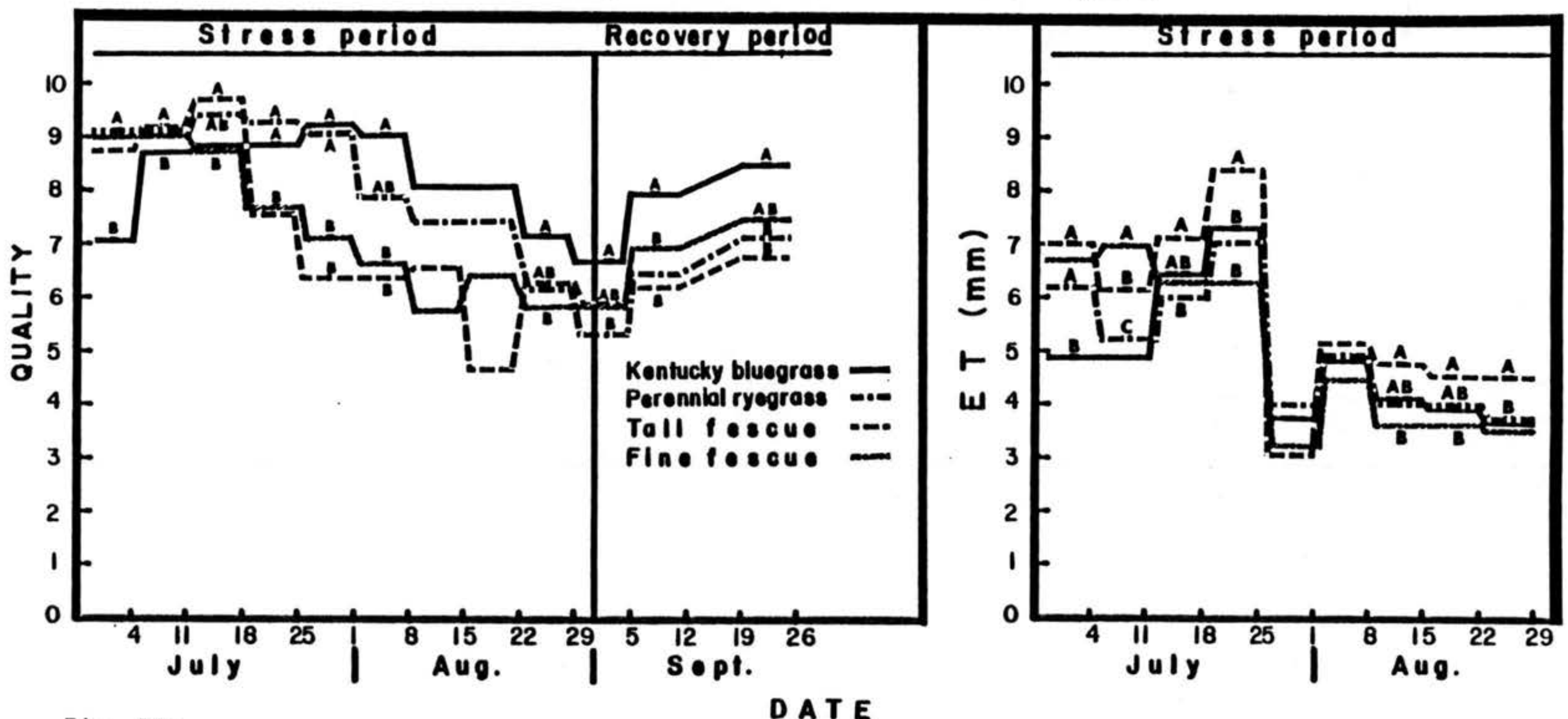

Fig. 10b.

1982 Lysimeter study 50% irrigation

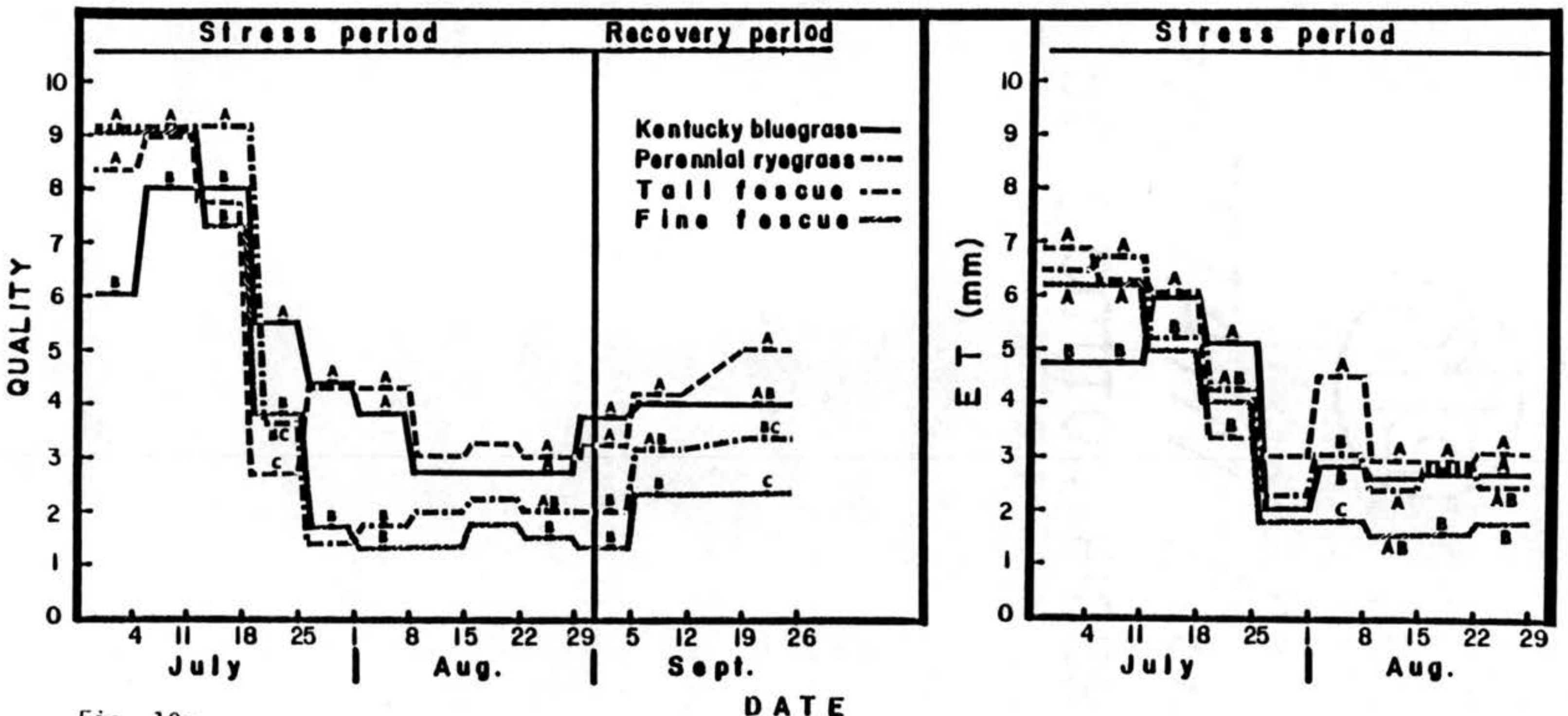

Fig. 10c.

Fig. 11. Average weekly ET and quality of 4 cool season grasses during 1983. Evapotranspiration and turf quality values are the average of 3 replications determined on Monday, Wednesday and Friday of each week. Deficit irrigation treatments of 75 and 50% IRR, for each species, were based on the maximum water use (ET for 100% IRR) by Kentucky bluegrass. Weekly values within a figure (a,b or c) were separated by FLSD multiple comparison test, 5% level.

1983 Lysimeter study 100 % irrigation

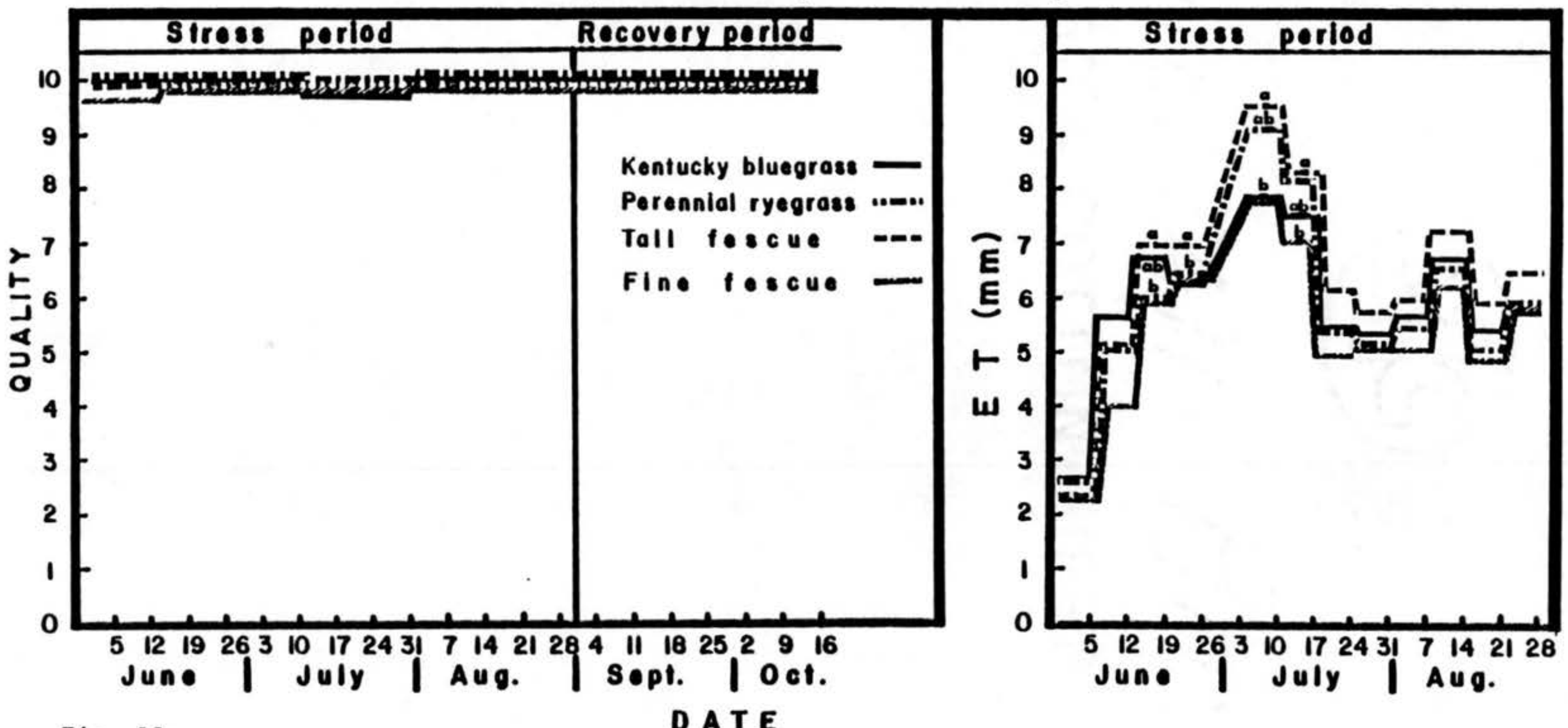

Fig. 11a.

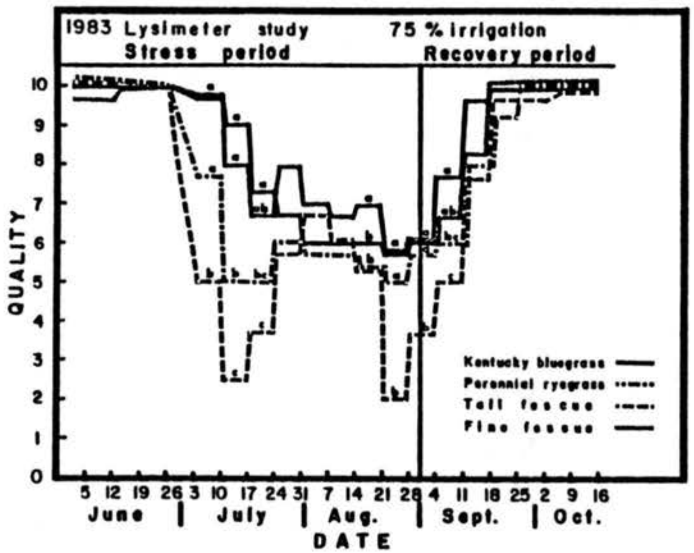

Fig. 11b.

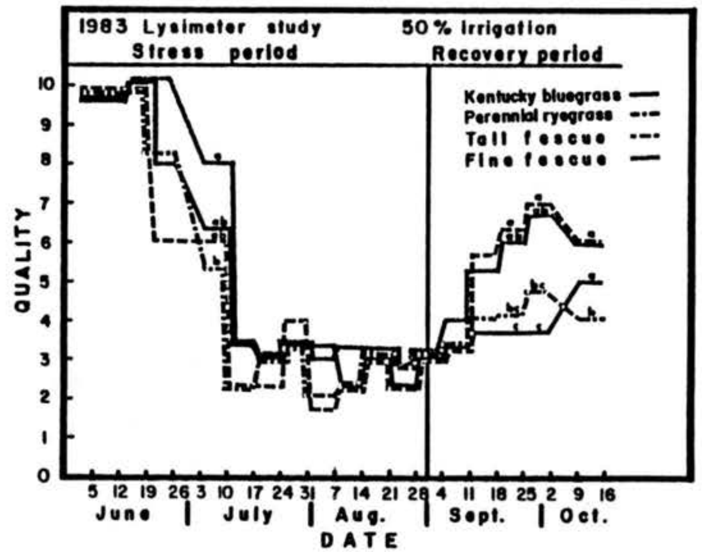

Fig. 11c.

When the effects of the actual amounts of water applied within a level of irrigation (100 percent IRR = very little moisture stress, 75 percent IRR = moderate moisture stress, and 50 percent IRR = severe moisture stress) are discussed, some meaningful relations between species, turf quality and water savings become evident. In 1982 and 1983 all four species irrigated at 100 percent IRR provided good turf quality during the stress period and following the recovery period (Fig. 10a and 11a).

In 1982 under moderate moisture stress (75 percent IRR) Kentucky bluegrass received 16 percent less water and generally had better turf appearance (significantly better on 3 of the 9 weeks) than tall fescue during the stress period (Fig. 10b). Kentucky bluegrass received 2 percent more water than fine fescue and also had a significantly better appearance on two of the nine weeks during the stress period. Perennial ryegrass received 2 percent more water than Kentucky bluegrass, but their turf appearance was similar during the stress period (Fig. 10b). These results indicate that Kentucky bluegrass, perennial ryegrass, and fine fescue under moderate moisture stress (75 percent IRR) can provide better turf with less water than tall fescue. Under the same conditions Kentucky bluegrass and perennial ryegrass may provide better quality than fine fescue. During the last week of the stress period in 1982, only Kentucky bluegrass rated above the lowest acceptable quality level of seven. During that week the appearance of Kentucky bluegrass was significantly better than fine fescue. Following a four week recovery period all four grasses provided acceptable quality turf, however, at that time Kentucky bluegrass displayed significantly better turf appearance than tall fescue and perennial ryegrass (Fig. 10b).

These results indicate that all 4 grasses can withstand moderate moisture stress (75 percent IRR) during part of the summer (turf quality may range between 5 and 7) and recover to an acceptable quality level (above 7) during a well irrigated period following summer moisture stress.

In August of 1982 at 50 percent IRR all species dropped below a quality rating of 4 (Fig. 10a). This quality rating of 4 corresponds to 40 percent live biomass which is far below the acceptable level of 70 percent live biomass. During three of the last five weeks of the stress period Kentucky bluegrass and tall fescue had significantly better turf appearance than perennial ryegrass and fine fescue (Fig. 10c). This combined with the variability in actual water applied can be used to make some gross statements about water savings and turf quality under severe moisture stress (50 percent IRR). Fine fescue received 18 and 2 percent less water than tall fescue and Kentucky bluegrass, respectively, but the appearance of fine fescue suffered greatly. Perennial ryegrass received 14 percent less water than tall fescue, and the quality of perennial ryegrass was significantly poorer than tall fescue. Perennial ryegrass received 2 percent more water than Kentucky bluegrass, yet Kentucky bluegrass generally displayed better turf quality. At the end of the recovery period none of the 4 grasses were able to adequately recover, during the allotted time, from the 50 percent IRR treatment. At the end of the recovery period the quality of tall fescue was significantly better than perennial ryegrass or fine fescue (Fig. 10c). Also at this time the quality of Kentucky bluegrass was similar to perennial ryegrass but significantly better than fine fescue.

Because of the variability in the actual amount of water applied to the different species in 1982 it was decided that a more direct, and less time consuming procedure could be employed. In 1983 deficit irrigation for all species was based on the maximum water use (100 percent IRR) by Kentucky bluegrass. This resulted in the same amount of water being applied to each species at a given level of deficit Irrigation (75 or 50 percent IRR). Thus, in 1983 deficit irrigation treatments did not represent the percentage (75 or 50 percent IRR) of maximum ET for each species, but instead represented the percentage of maximum water use by Kentucky bluegrass. The actual percent of maximum irrigation for each species at 75 percent IRR was 69 percent for tall fescue, 75 percent for perennial ryegrass and 80 percent for fine fescue. At 50 percent IRR the actual percentage of maximum irrigation was 46 percent for tall fescue, 50 percent for perennial ryegrass, and 54 percent for fine fescue.

Figures 11a, 11b, and 11c compare turf quality of four cool season grasses at three amounts of irrigation. At 100 percent IRR (maximum ET, very little moisture stress) all 4 species displayed excellent turf quality during the stress and recovery period (Fig. 11a). At 75 percent IRR tall fescue generally ranked lower in turf quality than the other three grasses tested (Fig. 11b). Two rapid and severe reductions in the quality of tall fescue were observed during the 7th (July 10-17) and 13th (August 21-28) week of the stress period (Fig. 11b). These periods of reduced quality were preceeded by a week of high water use by tall fescue (July 3-10 and August 7-14 at 100 percent IRR, Fig. 11a). It appeared that tall fescue used the available water in the closed lysimeter system faster than the other 3 grasses.

Consequently, it wilted first and reached a lower level of quality compared to the other grasses. In contrast, observations of field grown grasses usually indicate that tall fescue sustains active growth after Kentucky bluegrass and fine fescue have gone drought dormant (Meyer 1984, personal communication). The deeper and more extensive root system of tall fescue increases the amount of water available from the soil moisture resevoir. This may account for its continued growth when other grasses are drought dormant. The volume of the lysimeter could restrict the ability of a tall fescue root system to expand into moist soil and meet the demand for water. Thus, the lower quality of tall fescue may be an artifact of the restricted capacity for root growth in the lysimeter system plus the high water use rate of tall fescue. Regardless of the reason for the poor quality of tall fescue during mid July and late August (Fig. 11b) it is important to note that this grass had the ability to adequately recover in six weeks from a very low rating of turf quality. From July 10 to August 7 ET decreased (Fig. 11a) and could have enabled the tall fescue lysimeters to gain in available water because 75 percent IRR was being applied three times a week. During this same period the quality of tall fescue increased from 2.5 on July 17, to 7 on July 31. The quality of tall fescue dropped to a low of 2.0 on August 21 (Fig. 11b), following an increased period of water use from August 7-14. Water was applied during the recovery period and the quality of tall fescue again quickly rose from a rating of 2 on August 28 to a rating of 10 on September 18.

At 75 percent IRR (Fig. 11b) fine fescue generally ranked high in turf quality during the stress period. It was previously established that fine fescue used less water than the other three grasses during the summer (Table 3 and Fig. 10a and 11a). Since fine fescue used less water during the stress period and since all four grasses received equal amounts of water, it is likely that fine fescue had more available water at any given time than the other three grasses during the stress period. This advantage in available soil moisture could have been responsible for the somewhat better appearance of fine fescue at 75 percent IRR during the summer of 1983. Welton and Wilson (1931) also observed a similar increase in the water supplying power of the soil under chewings fescue that resulted in a more favorable water budget during the summer.

At one time or another all 4 grasses at 75 percent IRR dropped below the acceptable quality level of 7. However, following the well irrigated recovery period all four grasses recovered to an excellent quality level of ten (Fig. 11b).

Figure 11c at 50 percent IRR shows that the quality of all 4 grasses decreased between the fourth and seventh week following the start of the deficit irrigation treatments. During this period the reduction in quality was not as severe for fine fescue. This is again probably due to its more conservative water use. For the rest of the stress period all grasses remained at a quality value near three. Following the recovery period all four grasses failed to recover to an adequate level of quality. During the last week of the recovery period tall and fine fescue recovered to a significantly greater level of quality than perennial ryegrass (Fig. 11c).

Conclusions

The observations in this study pertain to Kentucky bluegrass, perennial ryegrass, tall fescue, and fine fescue grown in small sand filled weighing lysimeters surrounded by an actively growing sward of Kentucky bluegrass.

1. When the quantity of water in a soil system did not limit ET, tall fescue used more water than Kentucky bluegrass, perennial ryegrass, and fine fescue. Kentucky bluegrass and perennial ryegrass used approximately the same amount of water and fine fescue used the least water.

2. These 4 cool season grasses did not produce acceptable turf when summer irrigation was below 75 percent of maximum ET.

3. When all 4 grasses received the same amount of irrigation (75 percent IRR) fine fescue remained green and viable longer because it had a lower water use rate. It should be noted that in the Species and Cultivar Drought Evaluation Study when severe drought conditions prevailed the quality of fine fescue rapidly declined.

KENTUCKY BLUEGRASS FIELD IRRIGATION STUDY

Materials and Methods

The objectives of this study were: 1) to determine the combination of irrigation frequency (ΔT days) and amount (percent IRR) that results in acceptable quality turf (established as 70 percent or greater live biomass) with the least amount of water used; and 2) to determine the combination of irrigation frequency (ΔT days) and amount (percent IRR) that results in recovery (70 percent or greater live biomass following a recovery period after summer moisture stress) of Kentucky bluegrass with the least amount of water used.

The irrigation treatments in this study were applied to a mature stand of 'Merion' Kentucky bluegrass growing on a clay loam soil located adjacent to the lysimeter area. The plot area received 96 kg N/ha in the spring of each year prior to the stress period and 96 kg N/ha each year during the first week of the recovery period. Prior to the stress period irrigation was applied as needed to prevent wilt (approximately once a week). During the stress period a large plastic tarp was used as a cover to prevent rain from entering the plot area. On occasions when rain did fall on the plot area, it was measured and the irrigation treatments were adjusted accordingly. Turf was mowed at the 5 cm height three times a week.

In 1982 the experimental design and the levels of all factors were identical to the treatments in the 1982 Kentucky Bluegrass Lysimeter

Study. In 1982 each field plot was 2.1 by 2.1 meters. The Kentucky bluegrass field plots received the same amount of water as the Kentucky bluegrass lysimeters on an area basis. Irrigation treatments were applied with a hand held hose and a fan type sprinkler. The amount of water applied to each plot was measured using a flowmeter (Rockwell Mfg. Co., 5/8 in. connections). Irrigation treatments that required large amounts of water were cycled within a one hour period to prevent surface water runoff.

The stress period, during which the irrigation treatments were applied, began on July 13 and ended on August 31, 1982. During the recovery period, September 1 to October 14, plots were well irrigated and received a single application of 96 kg N/ha. By the end of the recovery period all plots had recovered to a quality level of 10 or 100 percent live biomass. It was determined at this time to increase the number of irrigation intervals to provide more information about deficit irrigation.

In 1983 each plot was divided in half to give two additional irrigation intervals (4 days = ΔT 4 and 14 day = ΔT 14). Thus, in 1983 irrigation intervals were 2, 4, 7, and 14 days. The amount of irrigation applied for each treatment was based on the amount of water used by the ΔT 2 100 percent IRR treatment in the adjoining Kentucky bluegrass lysimeter study. Under these conditions each irrigation interval received the same amount of water within a level of percent IRR. The stress period (deficit irrigation treatments) began on June 1, 1983.

In 1983 soil moisture tension was measured using gypsum blocks situated in each plot at the 10 cm depth. Soil moisture tension was determined every Monday, Wednesday, and Friday prior to watering plots.

Turf quality was evaluated every Monday, Wednesday, and Friday during the stress and recovery periods in 1982 and 1983.

Results and Discussion

The first step in determining an efficient irrigation schedule is to accurately measure water application and water use. This was done by growing turf on a sand soil in small weighing type lysimeters. Water application and use were accurately measured and turf appearance determined during part of the summer. It was determined in the lysimeter research that an acceptable level of quality for Kentucky bluegrass required at least 75 percent irrigation every two days. The intent of this study was to determine the influence of water application rate on turf appearance when grass was grown in field plots on a clay loam soil.

Quality

Figures 12a and 12b show the appearance of field grown Kentucky bluegrass during the stress and recovery periods in 1982. The week prior to July 18 all irrigation treatments displayed acceptable turf quality. As percent IRR decreased turf quality also decreased for both the two and seven day irrigation intervals (Fig. 12a and 12b). Significant reductions in turf quality were observed for the final six weeks of the stress period. During the period July 18-25, 1982 ET was high (Fig. 4a, Kentucky Bluegrass Lysimeter Study). Consequently, the grass treated with deficit irrigation rapidly decreased in appearance (Fig. 12a and 12b). Even the ΔT 7 100 percent IRR treatment showed a rapid

Fig. 12. Average weekly quality of field grown Kentucky bluegrass during a stress and recovery period in 1982. Each weekly value is the average of observations taken on Monday, Wednesday and Friday from 3 replications for each level of irrigation at a 2 or 7 day interval. Weekly values within a figure (a or b) were separated by FLSD multiple comparison test, 5% level.

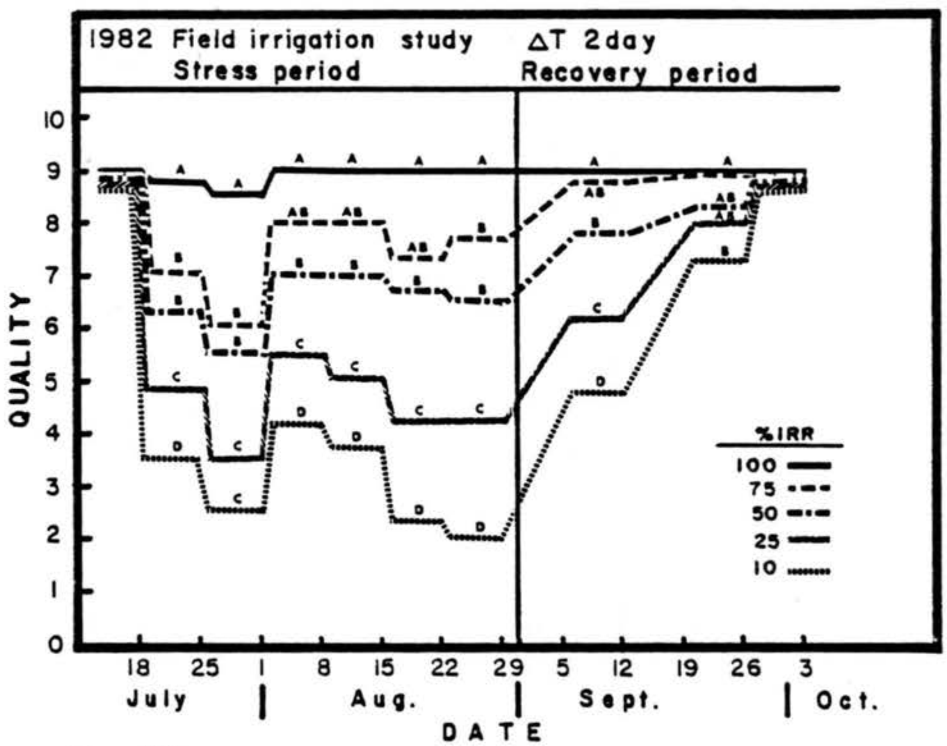

Fig. 12a.

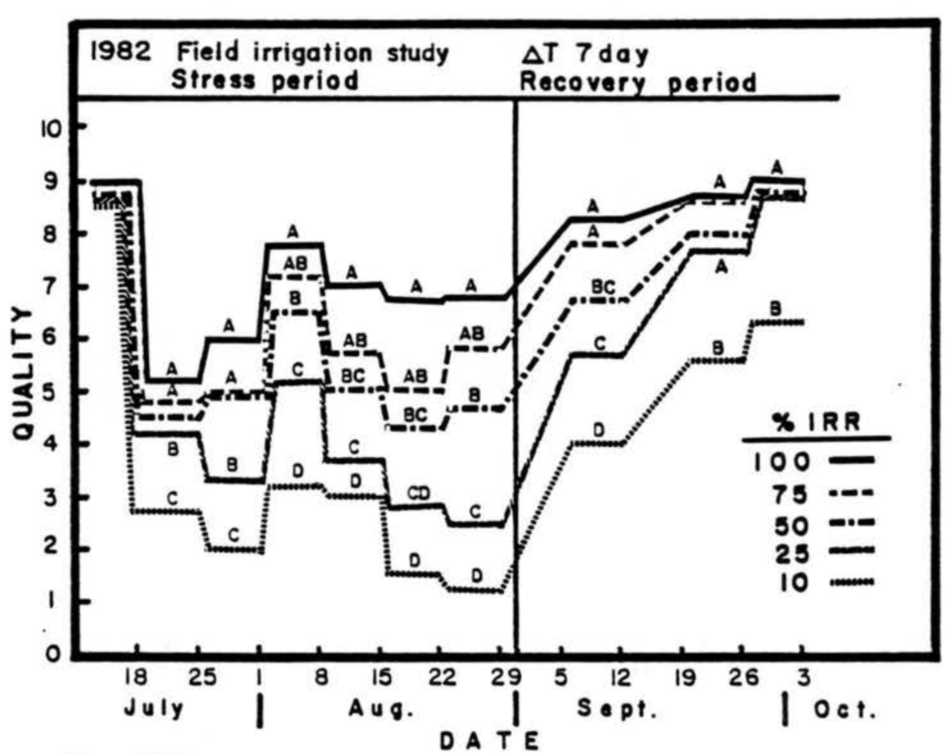

Fig. 12b.

decrease in turf quality (Fig. 12b). Turf quality for the ΔT 2 100 percent IRR treatment (Fig. 12a) was unchanged by high ET during the stress period (Fig. 4, Kentucky Bluegrass Lysimeter Study).

Acceptable quality turf resulted from irrigation at 75 percent every 2 days during 5 of the 7 weeks in the 1982 stress period (Fig. 12a). For the same period 100 percent IRR every 7 days was required to produce an acceptable quality on 4 of the 7 weeks. Figure 13 shows the linear relation between Kentucky bluegrass quality and percent IRR when weekly values were averaged between July 18 and August 29, 1982. Q7 values calculated from the regression equations in Fig. 13 were 68 percent IRR for ΔT 2 and 108 percent IRR for the ΔT 7. These results indicate that grass could be irrigated with less water, every two days than at seven days, and still produce an acceptable Kentucky bluegrass turf. These findings for field grown Kentucky bluegrass are in agreement with the results from lysimeter grown Kentucky bluegrass.

During the recovery period, in 1982, only the 10 percent IRR at ΔT 7 treatment did not recover to an acceptable level of turf quality (Fig. 12b). In contrast, irrigation amounts of 50, 25, and 10 percent for lysimeter grown Kentucky bluegrass did not produce an acceptable turf following an identical recovery period in 1982 (Fig. 5b, Kentucky Bluegrass Lysimeter Study). Calculated Q7 values for the lysimeter grown Kentucky bluegrass indicated that 76 percent of maximum ET was required during the stress period to produce acceptable grass following a well irrigated recovery period (Fig. 8, Kentucky Bluegrass Lysimeter Study). The inability of the lysimeter grown Kentucky bluegrass to recover from the lower amounts of deficit irrigation may be attributed to a greater stress for grass grown on sand in lysimeters compared to

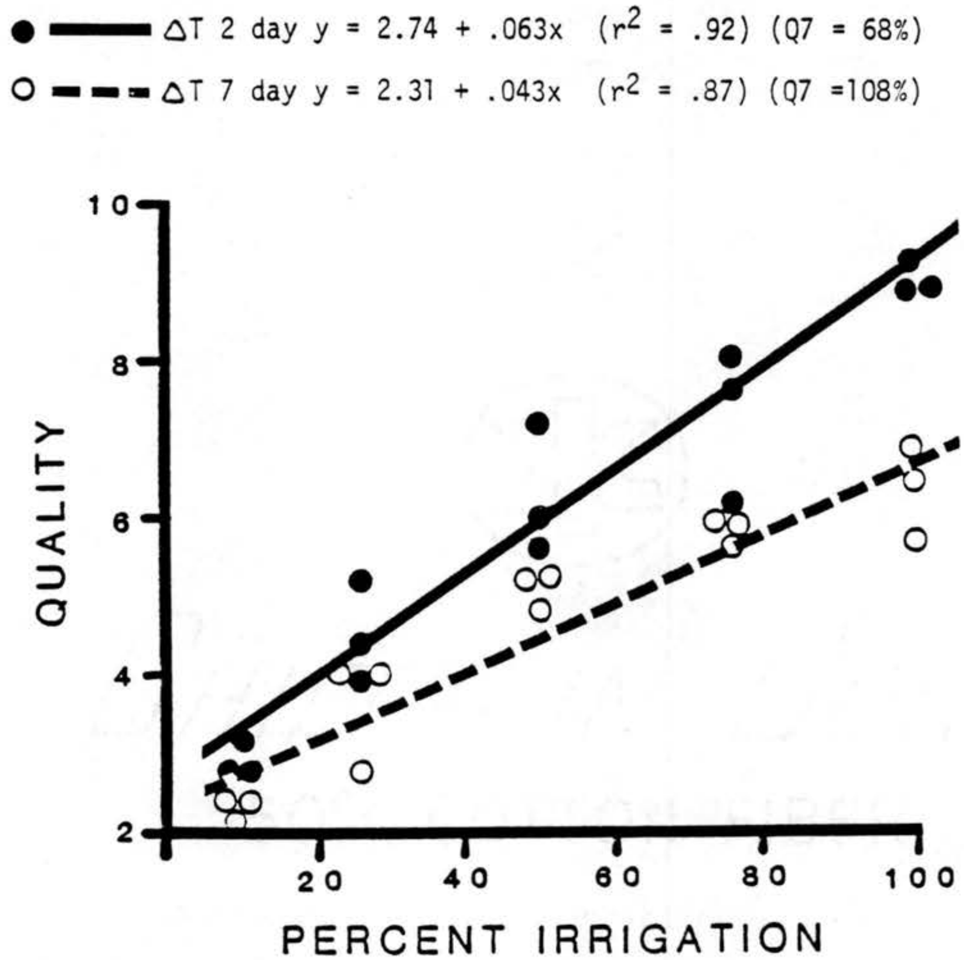

Fig. 13. Relation between quality of field grown Kentucky bluegrass and 5 levels of irrigation based on measured ET. Treatments consisted of waterings to supply 100, 75, 50, 25, and 10% IRR at 2 and 7 day intervals. Each point represents the average of quality values observed on Monday and Friday from June 18 to August 29, 1982. Q7 values represent the percent of irrigation that results in an acceptable level of turf quality.

the clay loam soil of field plots. Turf quality did not measure the amount of stress in a Kentucky bluegrass plant; it measured the visual strain that resulted from an unmeasured level of plant stress caused by water deficit. In 1982 drought stress (a soil condition) was measured in the lysimeters. It had been previously determined that average soil moisture tension greater than 1.5 bars during the stress period could not produce acceptable quality turf (Fig. 9, Kentucky Bluegrass Lysimeter Study). The average soil moisture tensions for deficit irrigation treatments of 50, 25, and 10 percent IRR in the lysimeters were above 1.5 bars (Fig. 3, Kentucky Bluegrass Lysimeter Study). In these studies Kentucky bluegrass grown on sand at deficit irrigation did not recover from an average drought stress level greater than 1.5 bars of tension. This was in agreement with Tovey et al. (1969) who found that a loam soil produced better turf and more root growth than a sand soil when irrigated every seven days with the same amount of water. The sand filled lysimeters and the clay loam field irrigation plots in our study received equal amounts of water for a given treatment. Thus, it was postulated that the field plots would have lower soil moisture tension (less drought stress) than the lysimeters, provided water use was similar under both soil conditions. Feldhake et al. (1983) found no substantial difference in water use when Kentucky bluegrass was grown on a clay versus a sand soil. Unfortunately, soil moisture tension was not measured in the field plots during 1982. In 1983 soil moisture tension was measured in each field plot so that it could be related to turf quality under field conditions.

Figures 14a, 14b, 14c, and 14d show the appearance of field grown Kentucky bluegrass during the stress and recovery periods in 1983. As

Fig. 14. Average weekly quality of field grown Kentucky bluegrass during a stress and recovery period in 1983. Each weekly value is the average of observations taken on Monday, Wednesday and Friday. Treatments were replicated 3 times for each amount of water applied at the 2, 4, 7, or 14 day interval. Weekly values within a figure (a, b, c, or d) were separated by FLSD multiple comparison test, 5% level.

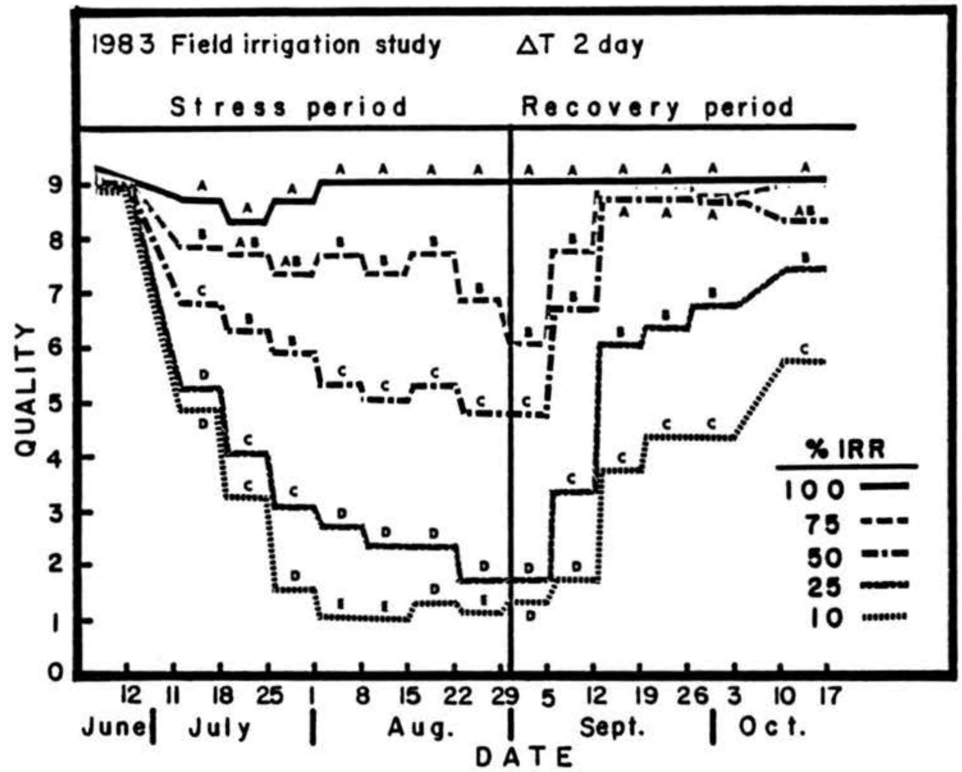

Fig. 14a.

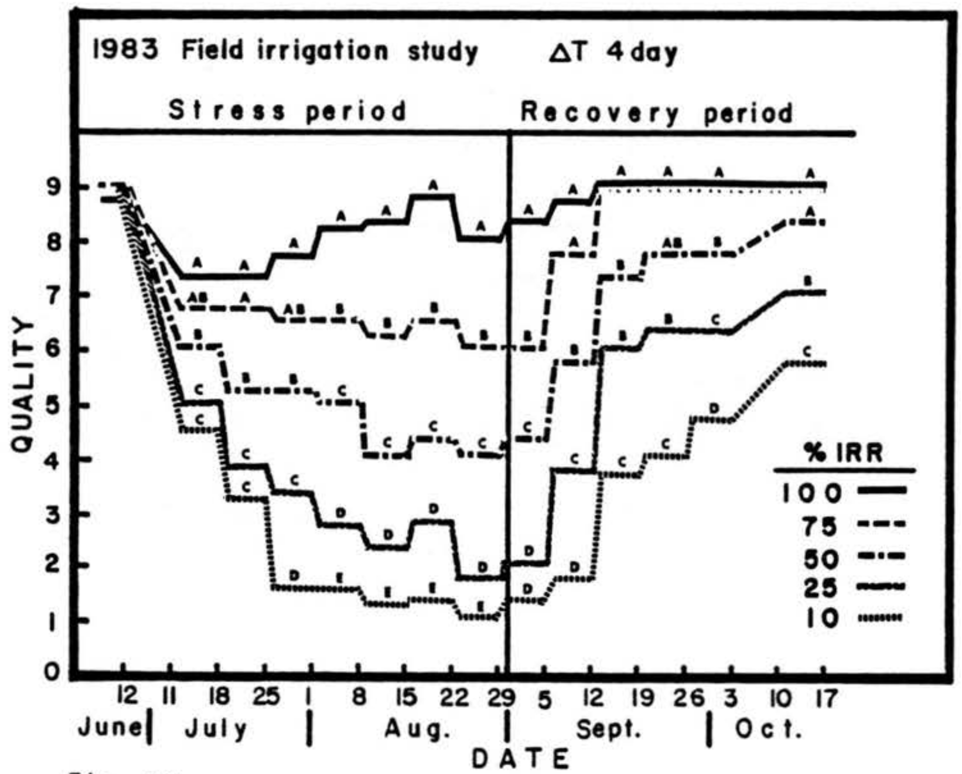

Fig. 14b.

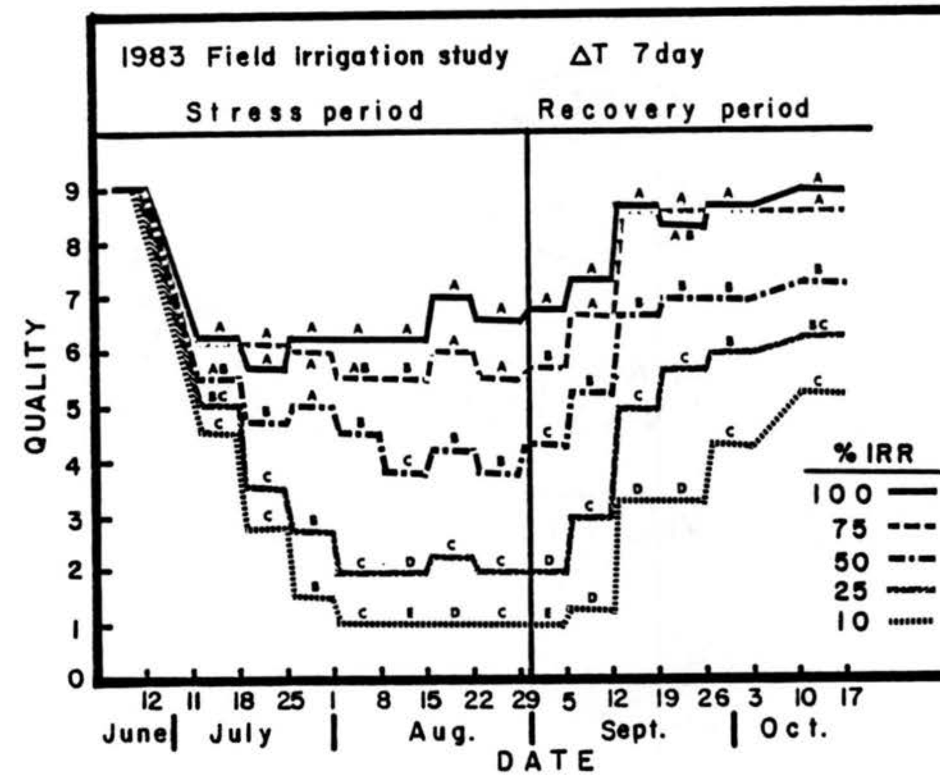

Fig. 14c.

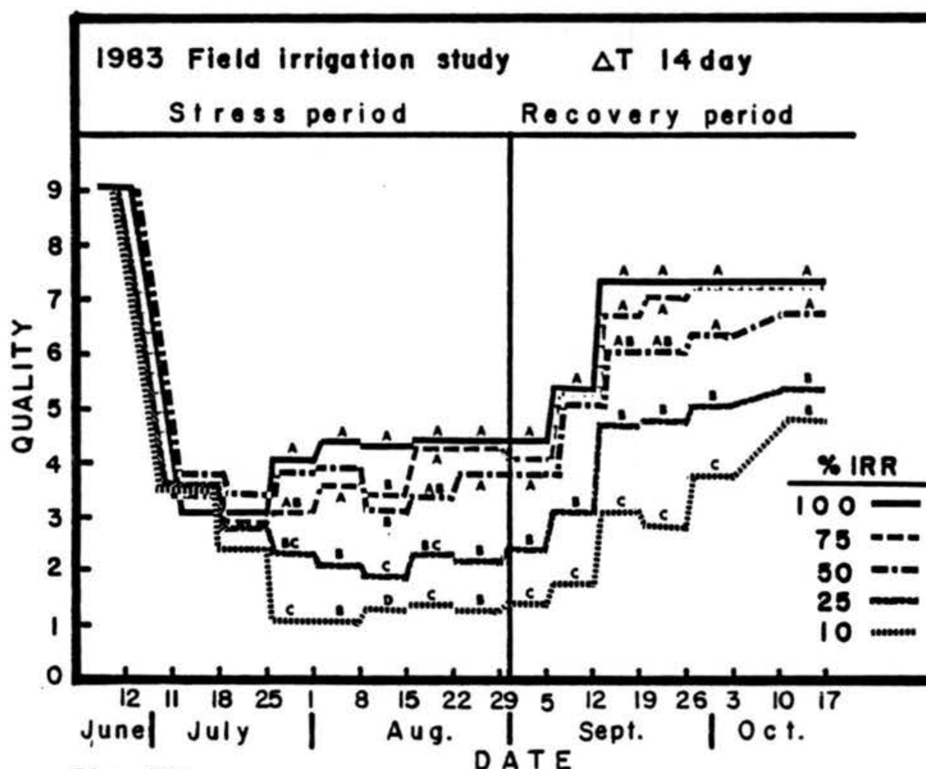

Fig. 14d.

in 1982, quality decreased as percent IRR decreased during the stress period. During the period July 3-10, 1983 ET was high (Fig. 4a, Kentucky Bluegrass Lysimeter Study). Consequently, grass that received infrequent irrigation, ΔT 7 (Fig. 14c) or ΔT 14 (Fig. 14d), or deficit irrigation frequently, ΔT 2 (Fig. 14a) or ΔT 7 (Fig. 14b) at 50, 25, and 10 percent IRR, rapidly decreased below an acceptable quality level of 7. During the stress period, irrigation at 75 percent or greater for the 2 or 4 day interval resulted in a turf quality level near or above the acceptable level of 7 (Fig. 14a and 14b). Since there was a linear relation between the average quality and percent IRR during the stress period a Q7 value for percent IRR could be calculated (Fig. 15) for each irrigation interval. The Q7 values for the 2, 4, 7, and 14 day intervals were 73, 85, 106, and 221 percent IRR, respectively. The Q7 values for ΔT 7 and 14 are estimated beyond the capability of the data, however, these values indicated that 100 percent IRR would not produce acceptable quality turf during the stress period when water was applied every 7 or 14 days. Also the lower Q7 value at ΔT 2 compared to ΔT 7 indicated that less water may be required to keep acceptable turf when irrigation occurred more frequently. These results substantiated findings by Beach (1958) and Tovey et al. (1969), who also found better turf quality at irrigation intervals of 2 or 3 days compared to 4, 6, 7, or 10 days.

In 1983 data indicated that turf quality for some amounts of deficit irrigation could not improve to an acceptable level within the six week recovery period. At the end of the recovery period below acceptable turf occurred for ΔT 2 and 4 at 10 percent IRR, ΔT 7 at 25 and 10 percent IRR, and ΔT 14 at 50, 25, and 10 percent IRR (Fig. 14a, 14b, 14c, and 14d). The relation between turf quality at the end of the recovery period and percent IRR during the stress period was linear (Fig. 16). Q7 values calculated for this relation were 27, 30, 44, and 75 percent IRR at ΔT 2, 4, 7, and 14, respectively. These values again indicate that less water (percent IRR) was used to ultimately produce a better turf when irrigation was applied more frequently. Another means of saving water was evident from the Q7 values in Figures 15 and 16. During the stress period Q7 required 73 percent IRR at ΔT 2, but following the recovery period Q7 required for recovery was 27 percent IRR. This means that although turf quality may suffer during the stress period, a 46 percent reduction in water applied during the stress period would still result in acceptable turf following a fairly short recovery period. This information could be especially useful when preparing irrigation guidelines in preparation for serious lawn watering restrictions.

Soil Moisture

Turf quality and ET have been observed for a broad range of irrigation treatments (100, 75, 50, 25, and 10 percent IRR) at 2, 4, 7, and 14 day intervals. It was anticipated that this regime of irrigation treatments would result in a broad range of soil moisture levels that could then be related to turf quality. This type of information would be beneficial to watering programs that irrigate by monitering soil moisture.

Figures 17a, 17b, 17c, and 17d show the response of soil moisture at 10 cm below the surface and turf quality from mid July to late August in 1983. For each irrigation interval soil moisture tension increased as percent IRR decreased. A comparison between the wetting cycles of

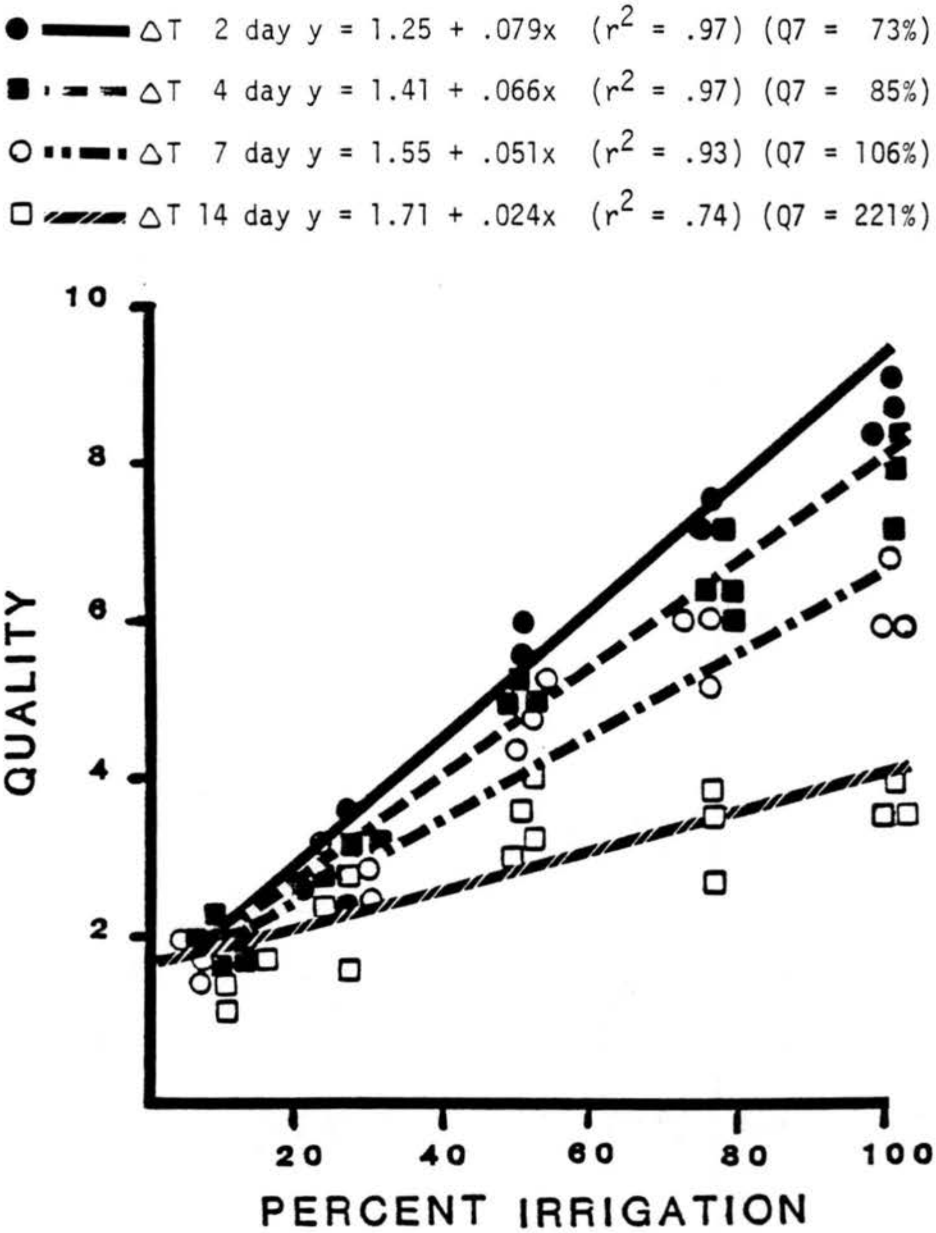

Fig. 15. Relation between quality and percent irrigation for field grown Kentucky bluegrass. Treatments consisted of 5 amounts of irrigation (100, 75, 50, 25, and 10% IRR) applied at 4 intervals. Each point represents the average of quality ratings taken on Monday and Friday during the period July 11 to August 22, 1983. Q7 values represent the percent irrigation that results in an acceptable level of turf quality.

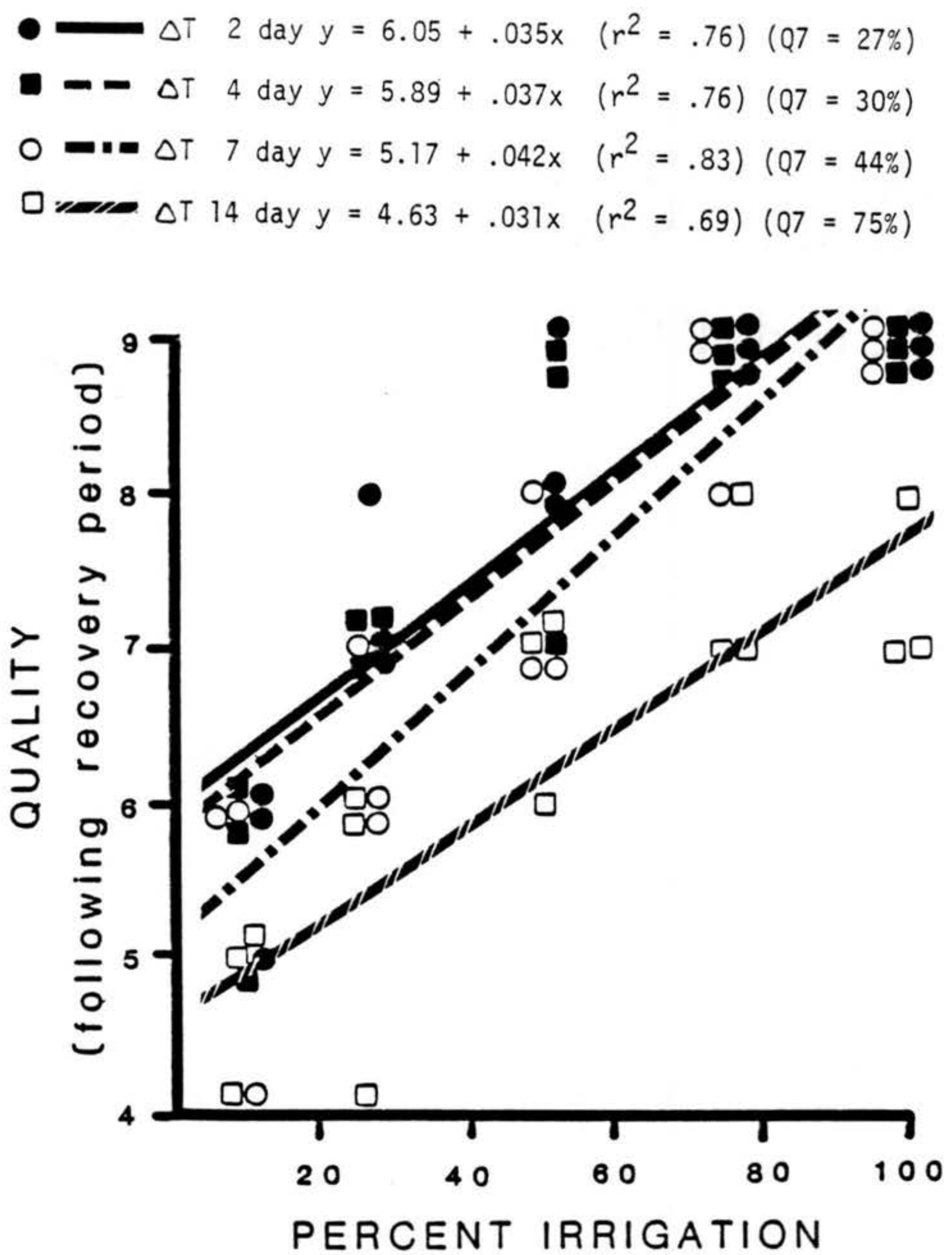

Fig. 16. Relation between quality and percent irrigation for field grown Kentucky bluegrass. Treatments consisted of 3 replications of 5 amounts of irrigation (100, 75, 50, 25, and 10% IRR) applied at 4 intervals during the period June 12 to August 31, 1983. From September 1 to October 17, 1983, grass was well irrigated and recovery was observed. Each point corresponds to a quality value observed on October 17, 1983. Q7 values represent the percent irrigation that results in an acceptable level of turf quality.

the 4 irrigation intervals is evident from the 100 percent IRR treatment in Figures 17a, 17b, 17c, and 17d. Watering every 2 days at 100 percent IRR, kept soil moisture tension below 1 bar and produced a high quality turf (Fig. 17a). The same treatment at a 4 day interval resulted in 2 short periods (July 15 and 22) of very high soil moisture tension (15 bars) but still resulted in adequate turf quality (Fig. 17b). At ΔT 7 soil moisture tension displayed a weekly cycle of wetting (approximately 1/3 bar) and drying (approximately 15 bars). This resulted in unacceptable Kentucky bluegrass (Fig. 17c). Watering every 14 days resulted in short periods of reduced soil moisture tension just after watering on July 13, August 1, and August 15 (Fig. 17d). On dates other than these high soil moisture tensions consequently resulted in very poor turf quality. These results indicate that increasing the irrigation interval beyond two days provided a soil wetting and drying cycle that does not necessarily improve turf quality. It is generally thought that deep and infrequent irrigation in the spring produces a larger root system (Beach, 1958; Madison and Hagan, 1962) and decreased cell size (Schmidt, 1973), both of which increase drought resistance and hardiness. Infrequent spring irrigations when ET is low may produce more roots and a healthier turf, however, these results indicate that during higher summer ET turf quality rapidly decreased as the irrigation interval lengthened. It appeared that irreversible root and shoot damage occurred at some critical level of soil moisture tension based on the amount and frequency of irrigation. Tovey et al. (1969) observed better turf appearance and more root growth when grass was watered every 4 days compared to 7 or 10 days. They noted that shallow-rooted turfgrasses

Fig. 17. Quality and soil moisture tension for field grown Kentucky bluegrass measured on Monday and Friday of each week in 1983. Values are the average of 3 replications.

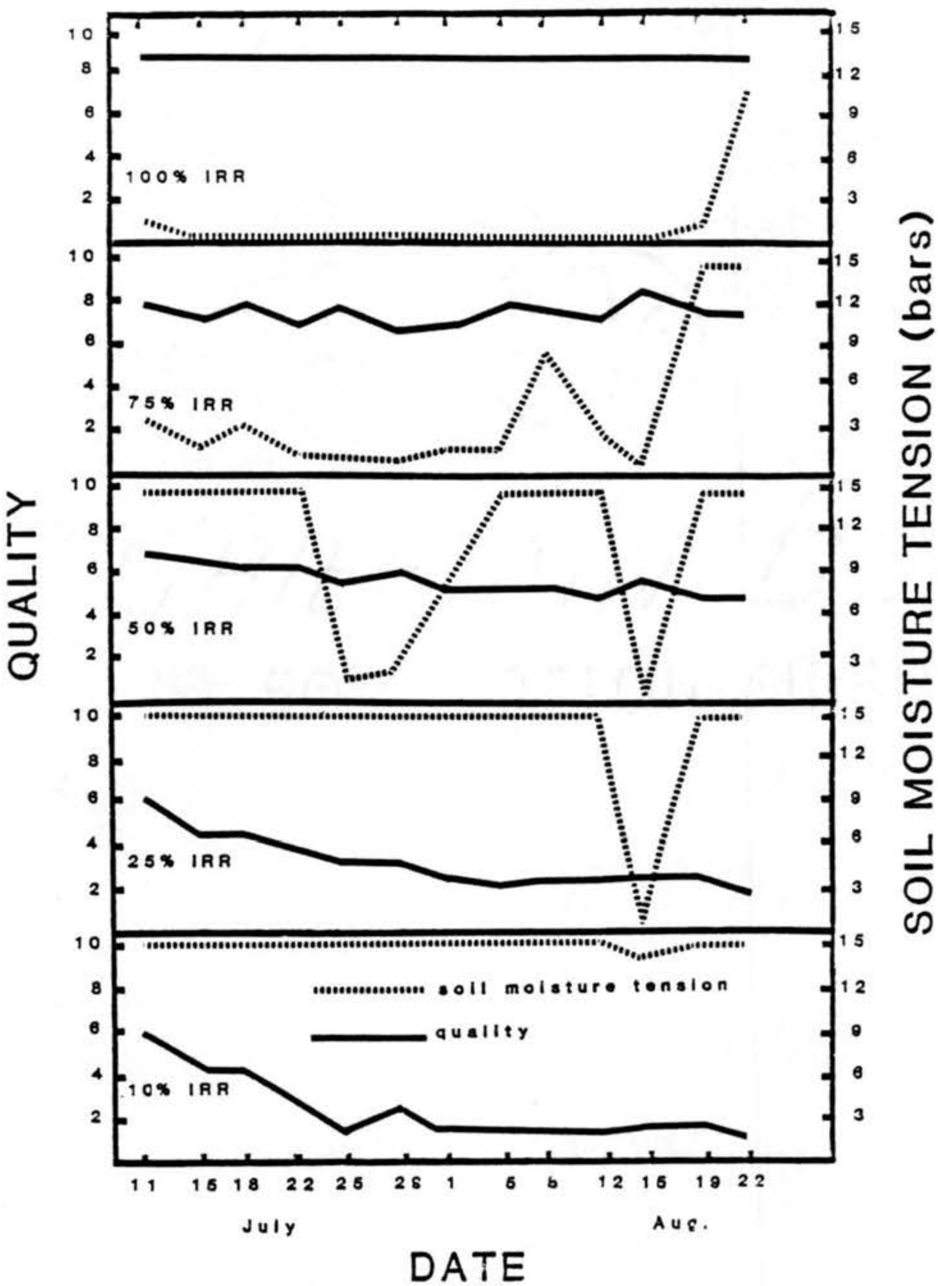

Fig. 17a. Irrigation treatments applied every 2 days.

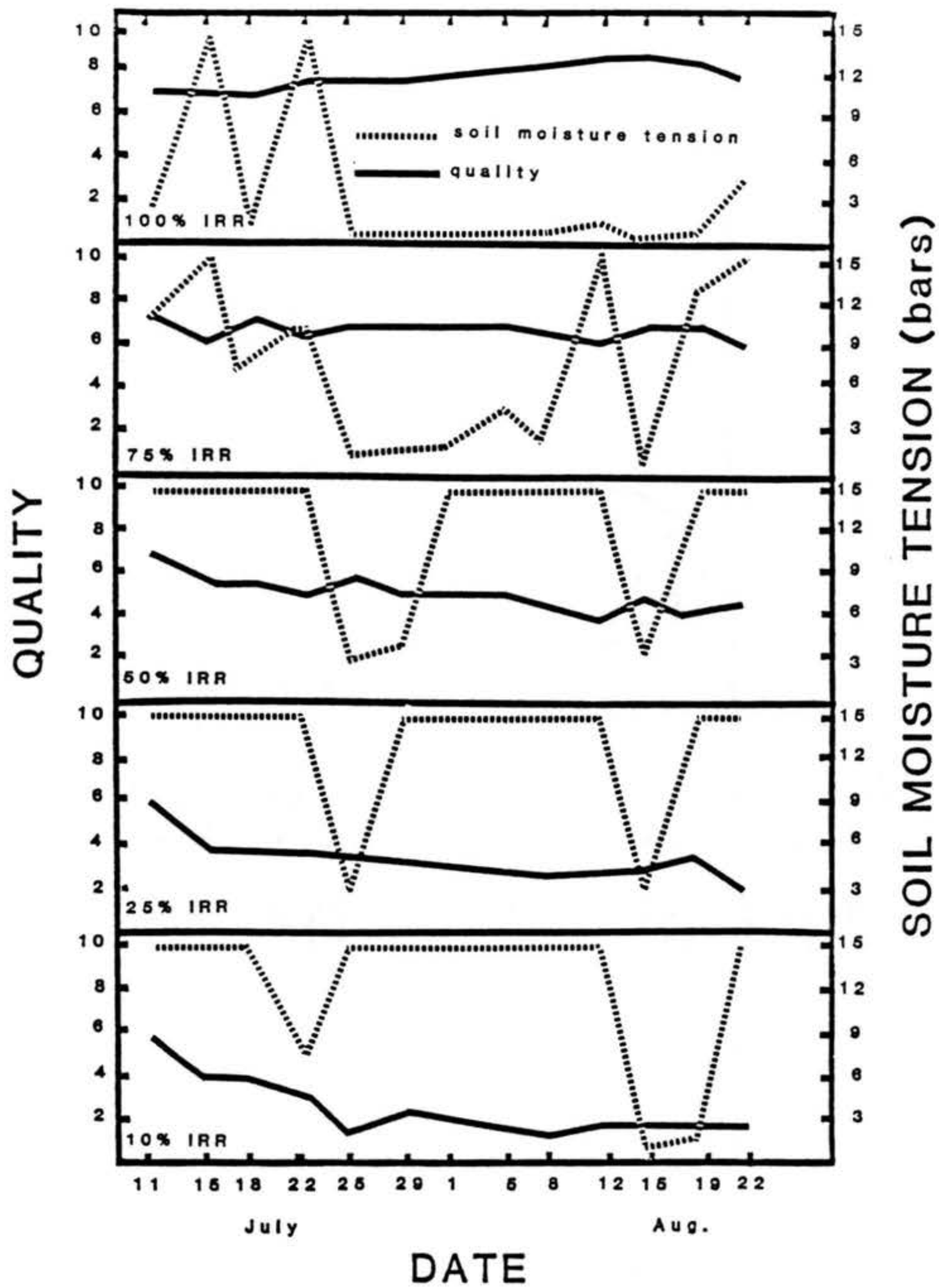

Fig. 17b. Irrigation treatments applied every 4 days.

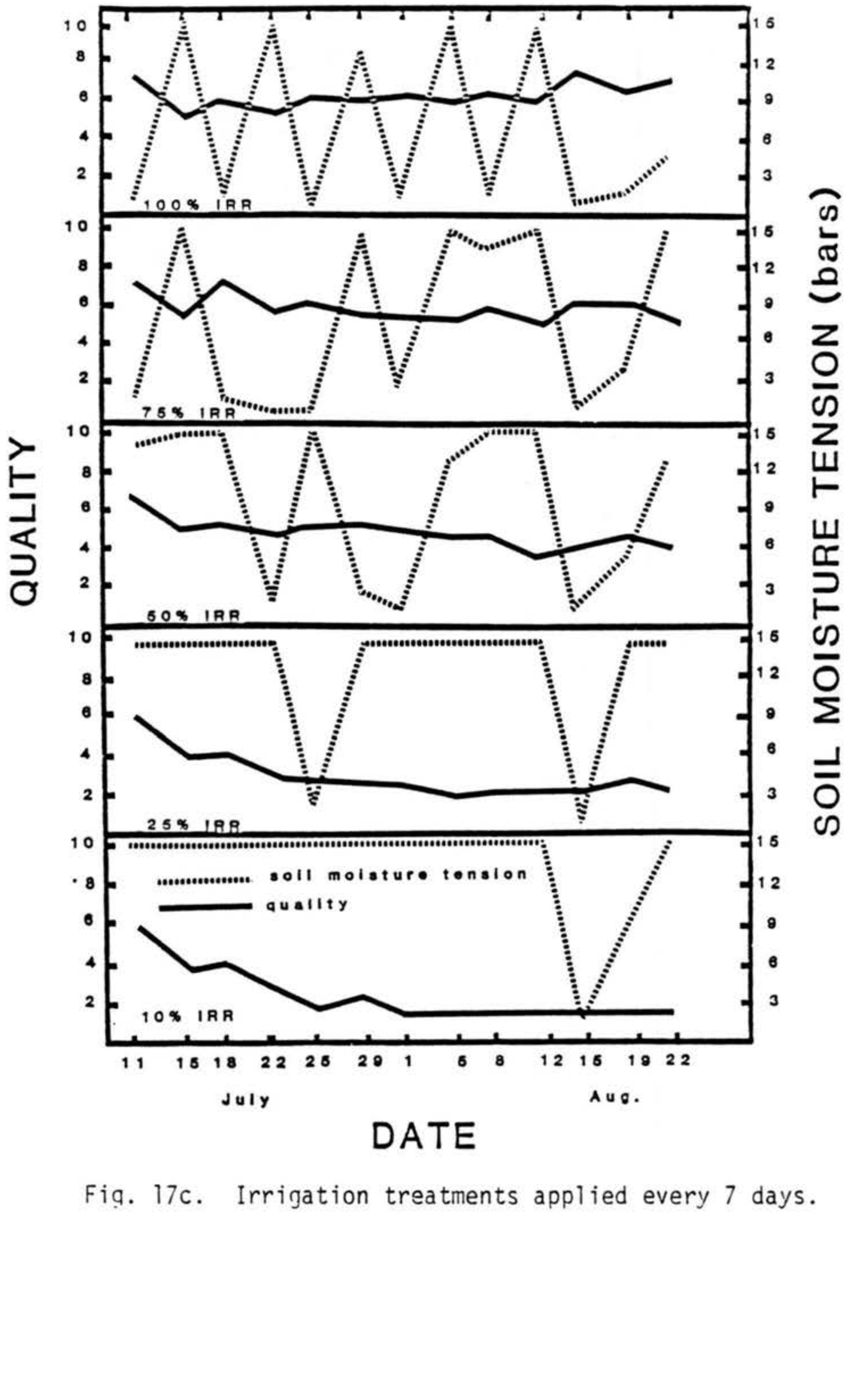

Fig. 17c. Irrigation treatments applied every 7 days.

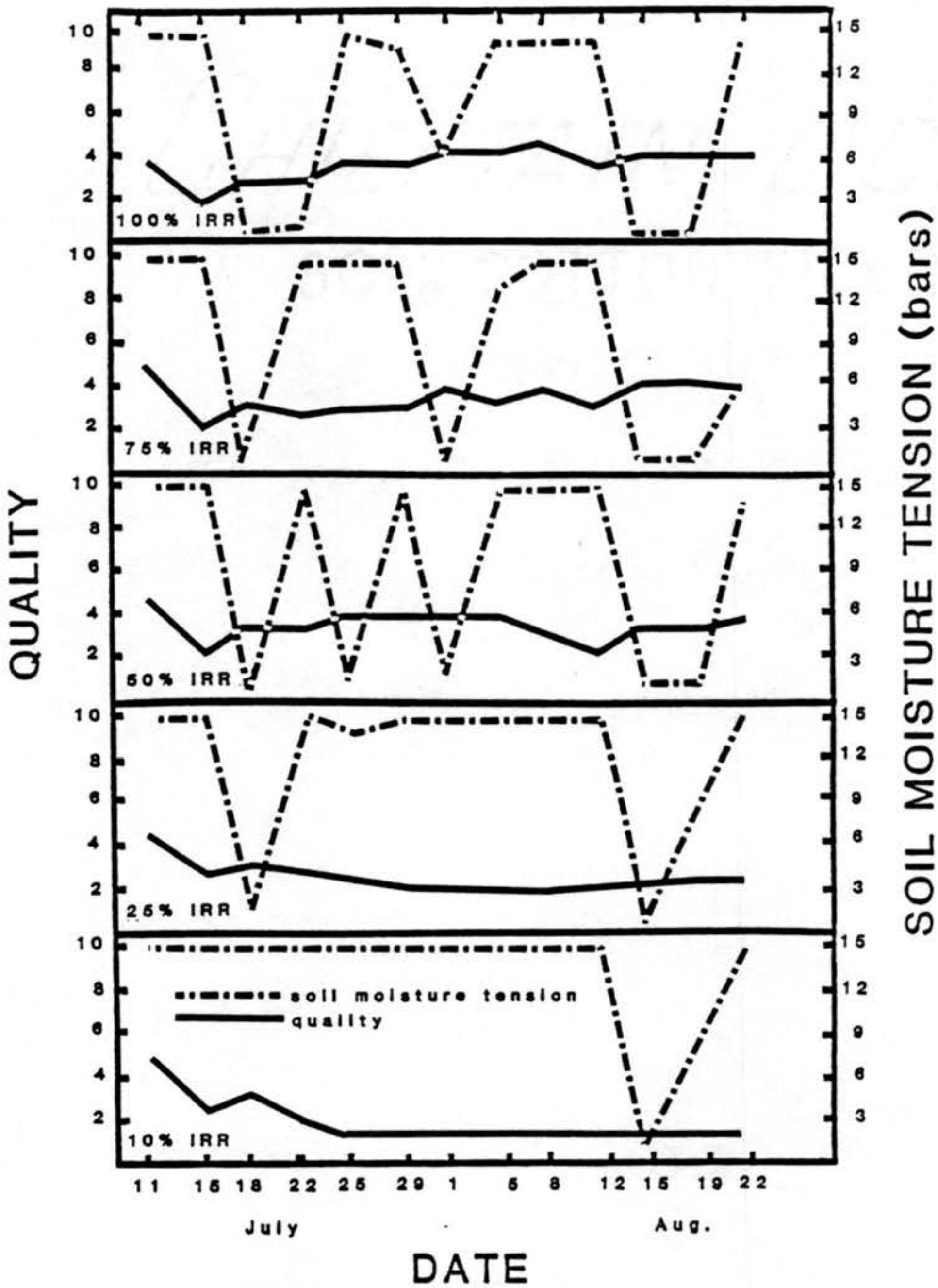

Fig. 17d. Irrigation treatments applied every 14 days.

will not seek out soil moisture when soil moisture levels are near the wilting point. Research presented in this thesis did not measure root growth, however, it supports the findings by Tovey et al. (1969) in that short periods of high soil moisture tension (100 percent IRR Fig. 17c) resulted in poorer turf quality than when adequate soil moisture (100 percent IRR Fig. 17a and 17b) was constantly present.

Figures 17a, 17b, 17c, and 17d show many combinations of irrigation amount and frequency that result in several combinations of soil moisture and turf quality. These values were averaged from mid-July to late August to determine the relation between average turf quality and average soil moisture tension. Fig. 18 shows that this relation was linear when average soil moisture tension was used. It should be pointed out that soil moisture tension, based on irrigation frequency and amount, can fluctuate over a short period of time as seen from Fig. 17a, 17b, 17c, and 17d. Q7 values for soil moisture tension were 4.5 bars at ΔT 2 and 1.4 bars at ΔT 4 (Fig. 18). Q7 values for soil moisture tension at 7 and 14 day intervals were negative, thus, they were of little value in predicting irrigation guidelines based on soil moisture tension.

These results with field grown Kentucky bluegrass on a clay loam soil, combined with the results of Kentucky bluegrass grown on sand in lysimeters, indicate that 75 percent IRR every 2 days will result in soil moisture tensions (1.5-4.5 bars) that produce acceptable quality turf during July and August.

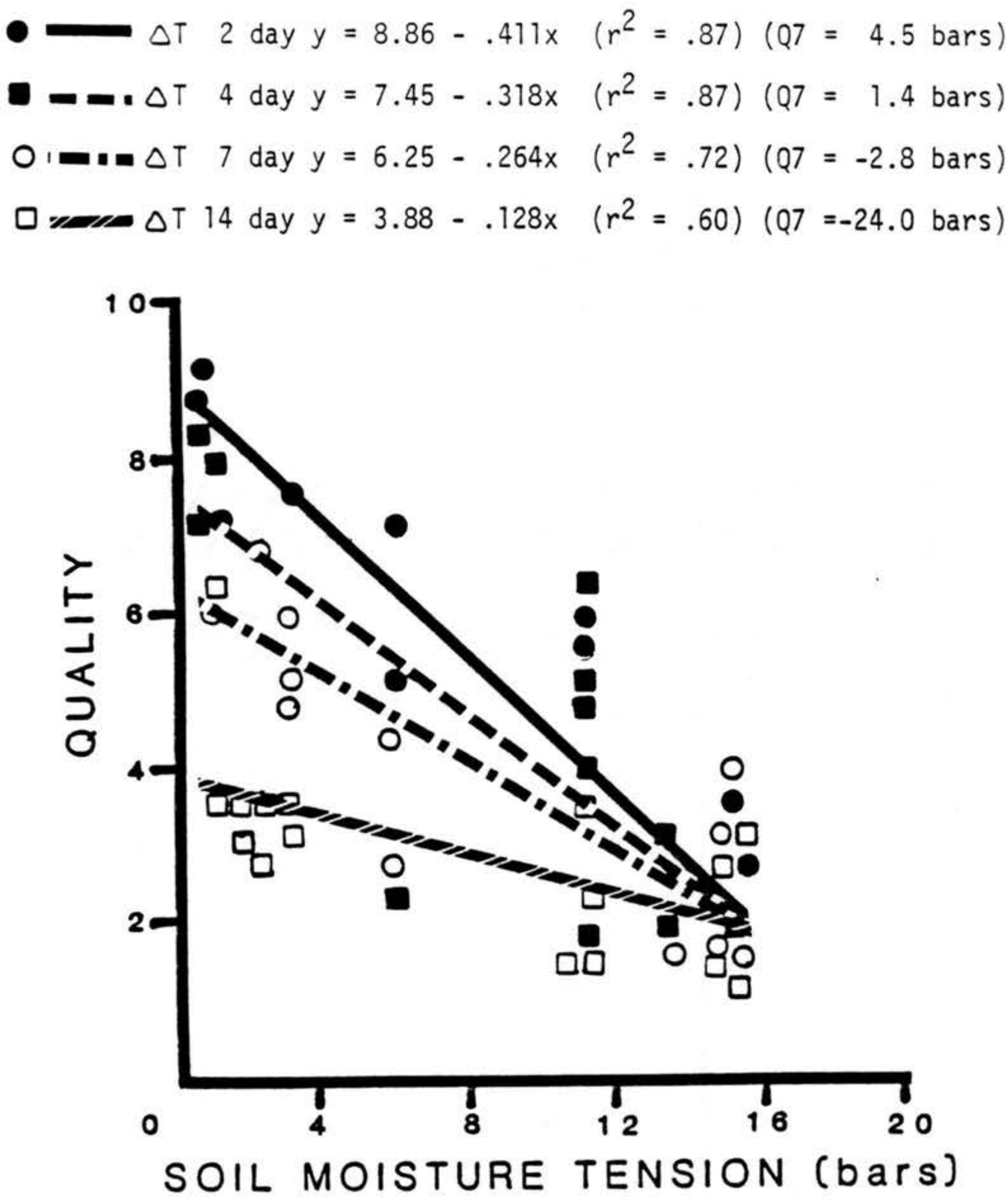

Fig. 18. Relation between quality and soil moisture tension of field grown Kentucky bluegrass. Treatments consisted of 3 replications of 5 amounts of irrigation (100, 75, 50, 25, and 10% IRR) applied at 4 irrigation intervals from June 12 to August 31, 1983. Each point represents the average of quality and soil moisture tensions observed on Monday and Friday from July 11 to August 22, 1983. Q7 represents soil moisture tensions that result in a turf quality value of 7.

Conclusions

The observations in this study pertain to 'Merion' Kentucky bluegrass grown on a clay loam soil under field conditions.

1. During July and August when irrigation was based on measured maximum ET and watering treatments consisted of 100, 75, 50, 25, and 10 percent IRR applied at 2, 4, 7, and 14 day intervals, turf appearance improved as the amount of water increased and the irrigation interval decreased.

2. The irrigation treatment that used the least amount of water, but still resulted in acceptable quality turf during July and August was 75 percent IRR applied every 2 or 4 days.

3. When the interval between irrigations was increased more water was required at each irrigation to maintain acceptable quality turf during July and August. Calculated values from regression analysis indicated that acceptable turf during July and August required 73 percent IRR every 2 days or 85 percent IRR every 4 days or 106 percent IRR every 7 days.

4. Calculated values also indicated that grass irrigated every 2 days at 27 percent IRR or 4 days at 30 percent IRR or 7 days at 44 percent IRR or 14 days at 75 percent IRR resulted in poor turf quality during July and August, but this turf was able to recover to an acceptable level of quality following a well irrigated recovery period in September.

5. Turf quality remained acceptable during July and August when average soil moisture tension at the 10 cm depth was between 4.5 and 1.4 bars.

SPECIES AND CULTIVAR DROUGHT EVALUATION

Materials and Methods

The objectives of this study were to determine which species and cultivars of Kentucky bluegrass, perennial ryegrass, and fine fescue could: 1) produce the best turf when water was severely restricted during the summer and, 2) recover from severe drought after late summer watering.

Drought conditions were imposed on 55 Kentucky bluegrass, 34 perennial ryegrass, and 42 fine fescue cultivars that had previously been evaluated in Western Regional Trials (Western Regional Coordinating Committee, 1983). In the Western Regional trials these grasses were grown on a clay loam soil, fertilized, and supplied with water to prevent wilt over a three year period.

In the fall of 1981 intensive maintenance of the Trials was terminated and the drought study began. From the fall of 1981 until the fall of 1983 the grasses received natural rainfall (Fig. 6a and 6b) with one thorough irrigation in early May of 1983. Also, during September 1982 and 1983 water was applied as needed to support regrowth and recovery of the drought stressed grasses. During the recovery period grass was fertilized with 96 kg N/ha from a 3:2:1 fertilizer.

During the summer months of 1982 and 1983 severe drought conditions existed as evident from rainfall and temperature data (Fig. 6a and 6b), soil moisture levels (Table 4), and turf quality (Tables 5 - 10).

Table 4. Soil moisture conditions on July 13 and August 31, 1983, when water was withheld during the species and cultivar drought tolerance study.

Field[z] location	July 13		Aug. 31	
	Percent soil[y] moisture	Soil moisture[x] tension	Percent soil[y] moisture	Soil moisture[x] tension
	% by weight	bars	% by weight	bars
1	9	46	7	70
2	8	59	7	70
3	8	59	8	59
4	12	25	8	59
5	13	21	9	46
6	10	36	9	46
7	10	36	7	70
8	12	25	7	70
9	11	28	7	70
10	10	36	8	59
11	9	46	7	70
12	10	36	7	70
13	9	46	8	59
14	10	36	9	46
15	10	36	9	46
16	8	59	8	59
17	8	59	7	70
18	9	46	11	28
19	10	36	8	59
20	11	28	7	70
21	9	46	8	59

z Field location numbers are found in Fig. 19.

y Soil was oven dried at 108 C for 24 hours.

x Soil moisture tension was read from the moisture release curve prepared by Dernoeden (1976). The soil in Dernoeden's study was the same texture as in this study and was located 100 meters from the drought tolerance plots.

Table 5. Quality comparisons in 1981 and 1982 for 55 cultivars of Kentucky bluegrass when irrigation was withheld except for a recovery period during September. Data are the average of 3 replications.

		1981	1982						
			Stress Period						Recovery Period
	Cultivar	10/5	5/28	6/11	6/25	7/19	8/4	8/31	10/5
1.	A-20-6	8.7	8.3^z a	6.7^z a	7.3^z a	6.7^z a	6.3^z a	4.3^z a	7.3^z a
2.	A-34	8.0	7.7 a	4.0 c	4.7 b	3.7 c	2.7 c	2.0 b	4.3 b
3.	Adelphi	8.7	6.7 a	4.7 c	6.0 b	4.0 c	4.0 b	3.0 b	6.0 a
4.	Aquila	8.3	7.7 a	6.0 b	6.3 b	4.3 c	5.0 a	4.0 a	6.7 a
5.	Baron	8.0	6.7 a	5.3 c	7.0 a	4.7 c	4.3 b	3.0 b	6.0 a
6.	BFB-35	8.0	8.0 a	6.0 b	6.3 b	6.7 a	2.3 c	2.7 b	4.3 b
7.	Birka	8.0	6.7 a	4.7 c	6.0 b	4.0 c	2.7 c	2.7 b	4.3 b
8.	Bluebell	8.3	6.3 b	5.0 c	6.3 b	4.3 c	4.0 b	3.3 b	6.3 a
9.	Bonnieblue	8.3	7.7 a	6.0 b	7.0 a	4.7 c	5.0 a	3.7 a	7.7 a
10.	Bristol	8.7	7.7 a	6.3 b	7.3 a	5.7 b	4.3 b	3.3 b	6.3 a
11.	Brunswick	8.3	6.3 b	5.3 c	6.0 b	5.0 b	4.3 b	3.3 b	6.0 a
12.	Cello	8.3	8.0 a	5.0 c	6.0 b	4.7 c	3.7 c	2.7 b	6.0 a
13.	Charlotte	8.0	6.7 a	5.0 c	6.7 a	4.0 c	5.0 a	3.3 b	6.7 a
14.	Cheri	8.0	8.3 a	6.7 a	7.0 a	5.0 b	4.7 b	3.3 b	6.7 a
15.	Cleopatra	8.3	6.7 a	5.0 c	5.7 b	3.7 c	3.3 c	3.0 b	4.0 b
16.	Columbia	8.0	7.3 a	5.7 b	6.0 b	5.3 b	4.3 b	3.0 b	5.7 a
17.	Dormie	8.0	7.3 a	6.3 b	7.0 a	5.0 b	4.7 b	3.0 b	5.3 b
18.	Enaldo	8.3	6.0 b	4.3 c	5.3 b	3.7 c	2.7 c	2.3 b	4.0 b
19.	Enmundi	8.0	6.7 a	4.0 c	5.0 b	3.0 c	3.0 c	2.3 b	3.7 b
20.	Enoble	8.3	7.3 a	6.0 b	7.0 a	4.3 c	5.0 a	3.7 a	7.0 a
21.	Entensa	8.0	8.7 a	5.7 b	7.0 a	5.7 b	5.0 a	3.7 a	7.7 a
22.	Entopper	8.0	5.3 b	4.7 c	5.0 b	3.7 c	3.7 c	2.3 b	4.7 b
23.	Fylking	8.0	5.3 b	4.0 c	5.7 b	3.7 c	2.7 c	2.3 b	6.0 a
24.	Geronimo	8.3	7.6 a	4.7 c	5.7 b	3.3 c	4.3 b	3.0 b	6.3 a
25.	Glade	8.3	6.0 b	4.3 c	5.0 b	3.0 c	2.3 c	2.7 b	4.0 b
26.	H-7	8.0	8.7 a	7.0 a	7.7 a	7.0 a	7.3 a	5.0 a	8.3 a
27.	Haga	8.0	8.0 a	6.7 a	8.0 a	4.7 c	4.7 b	3.3 b	6.7 a
28.	Harmony	8.3	6.7 a	5.7 b	6.3 b	4.0 c	4.3 b	3.0 b	6.3 a
29.	Hekla	8.0	4.0 c	4.7 c	6.0 b	4.0 c	4.0 b	2.7 b	5.0 b
30.	Holiday	9.0	7.3 a	6.0 b	7.0 a	4.0 c	4.3 b	3.3 b	6.3 a
31.	ISI-128	8.0	7.7 a	6.0 b	7.3 a	4.7 c	4.3 b	3.0 b	7.0 a
32.	America	8.7	8.0 a	7.0 a	7.0 a	6.3 a	5.7 a	4.7 a	7.3 a
33.	Kimono	8.3	5.7 b	5.3 c	6.0 b	4.0 c	3.3 c	2.7 b	5.0 b
34.	Majestic	8.7	8.3 a	7.3 a	7.7 a	6.0 a	5.7 a	4.0 a	8.3 a
35.	Merion	8.3	7.7 a	5.7 b	7.0 a	5.3 b	5.3 a	4.0 a	7.3 a
36.	Merit	8.0	7.0 a	6.0 b	7.0 a	5.3 b	5.0 a	3.0 b	6.3 a
37.	Mosa	8.7	7.0 a	5.7 b	6.3 b	4.0 c	3.3 c	3.0 b	5.3 b
38.	Obelisk	8.3	7.3 a	4.3 c	5.0 b	3.7 c	2.7 c	3.0 b	5.3 b
39.	Orna	7.7	5.0 b	4.3 c	5.3 b	3.7 c	2.7 c	2.3 b	4.7 b
40.	D-164	8.7	7.3 a	5.7 b	7.0 a	4.7 c	3.3 c	2.7 b	6.7 a
41.	Parade	8.3	6.7 a	7.0 a	7.0 a	4.7 c	4.0 b	2.3 b	5.3 b
42.	Pion	8.0	9.0 a	6.0 b	7.0 a	5.3 b	5.7 a	4.0 a	7.7 a
43.	Plush	8.0	7.0 a	6.0 b	7.0 a	5.0 b	4.7 b	3.7 a	6.7 a
44.	Ram I	9.0	7.3 a	6.0 b	7.7 a	4.3 c	4.0 b	3.3 b	6.3 a
45.	Rugby	9.0	8.0 a	6.0 b	6.7 a	4.7 c	4.0 b	3.0 b	5.3 b
46.	Scenic	8.3	7.7 a	5.3 c	6.3 b	3.7 c	4.3 b	3.0 b	5.3 b
47.	Sherpa	7.3	4.0 c	4.0 c	5.3 b	3.7 c	3.7 c	2.7 b	4.0 b
48.	Sving	8.3	7.3 a	7.3 a	8.0 a	6.7 a	5.3 a	3.7 a	6.3 a
49.	Svdsport	7.0	8.0 a	6.0 b	7.0 a	5.3 b	5.0 a	3.7 a	6.7 a
50.	Touchdown	8.3	7.0 a	4.3 c	5.3 a	6.7 c	2.3 c	2.7 b	3.6 b
53.	Victa	8.0	6.7 a	5.7 b	6.3 b	3.7 c	3.3 c	2.7 b	5.3 b
54.	Welcome	7.7	5.7 b	4.0 c	6.0 b	3.7 c	4.0 b	3.0 b	5.3 b
55.	WWAG 480	9.0	7.7 a	6.3 b	6.7 a	5.0 b	4.3 b	3.0 b	6.3 a

^{z}Mean separation by Scott-Knott multiple comparison test, 5% level.

Table 6. Quality comparisons in 1983 for 55 cultivars of Kentucky bluegrass when irrigation was withheld except for a recovery period during September. Data are the average of 3 replications.

	1983									
	Stress Period						Recovery Period			
Cultivar	6/8	6/23	7/11	7/26	8/11	8/30	9/15	9/23	9/30	10/12
1. A-20-6	7.3	6.3	4.3[z] a	2.3	2.0	2.7[z] a	4.0[z] a	4.7	5.0	5.3
2. A-34	7.3	5.3	4.3 a	2.0	2.7	2.7 a	3.7 a	4.3	4.7	5.7
3. Adelphi	6.0	4.7	4.0 b	2.7	2.7	3.0 a	4.0 a	4.7	5.0	5.3
4. Aquila	7.0	5.0	3.7 b	3.0	2.7	2.3 b	3.3 b	4.3	5.0	5.7
5. Baron	7.0	5.0	3.7 b	2.7	2.3	2.3 b	3.7 a	4.0	4.7	5.7
6. BFB-35	5.7	5.0	4.0 b	3.0	2.3	2.3 b	3.0 b	3.3	5.0	5.7
7. Birka	6.7	5.3	4.7 a	3.3	2.7	2.7 a	3.0 b	4.3	5.0	5.7
8. Bluebell	6.3	4.7	5.0 a	2.0	1.7	1.7 b	2.7 b	3.3	4.7	5.0
9. Blunnieblue	7.3	6.7	3.7 b	2.3	2.0	1.7 b	2.3 b	3.7	4.0	5.3
10. Bristol	6.3	5.7	4.7 a	3.0	2.7	2.7 a	4.0 a	5.0	5.3	6.3
11. Brunswick	5.7	4.3	3.0 b	2.0	2.0	2.3 b	4.0 a	4.7	4.3	5.7
12. Cello	6.7	5.7	4.0 b	1.3	2.0	1.7 b	3.3 b	3.7	4.0	5.0
13. Charlotte	6.7	5.0	4.0 b	2.7	2.0	2.3 b	4.0 a	4.7	4.7	5.7
14. Cheri	7.0	5.3	4.0 b	2.3	2.0	2.3 b	2.3 b	4.0	3.7	4.7
15. Cleopatra	5.7	4.3	3.7 b	2.0	2.7	2.3 b	3.7 a	4.3	4.3	6.3
16. Columbia	6.7	5.7	4.7 a	3.7	2.7	3.3 a	5.0 a	6.0	6.3	7.0
17. Dormie	7.0	5.7	4.7 a	3.3	2.3	2.3 b	4.0 a	4.7	4.7	6.0
18. Enaldo	6.0	5.0	3.3 b	1.7	2.3	2.7 a	3.7 a	4.0	4.7	6.0
19. Enmundi	7.0	5.3	4.7 a	2.7	2.3	3.0 a	3.7 a	4.7	5.0	5.7
20. Enoble	6.7	5.0	3.7 b	2.3	2.0	2.0 b	3.3 b	4.0	4.0	4.7
21. Entensa	7.3	6.7	4.3 a	2.7	1.7	1.7 b	4.0 a	4.3	4.3	5.3
22. Entopper	6.3	5.7	5.3 a	3.0	2.3	3.0 a	3.3 b	3.7	4.7	5.7
23. Fylking	5.7	4.7	3.0 b	2.3	1.7	1.7 b	3.3 b	4.3	5.0	5.3
24. Geronimo	7.0	6.0	3.7 b	2.7	2.0	2.3 b	4.3 a	4.7	5.3	6.7
25. Glade	8.0	4.7	4.3 a	2.3	2.3	2.7 a	4.3 a	4.3	5.3	6.0
26. H-7	7.0	7.7	6.0 a	3.7	3.3	2.7 a	4.3 a	4.3	5.3	6.0
27. Haga	6.0	6.7	5.0 a	3.7	3.0	3.3 a	5.3 a	5.7	6.3	7.3
28. Harmony	6.7	5.0	4.0 b	3.3	3.0	3.0 a	4.7 a	5.3	6.0	6.3
29. Hekla	6.7	5.0	4.3 a	2.7	2.3	2.7 a	3.7 a	4.7	5.0	5.3
30. Holiday	6.7	5.3	3.3 b	2.0	2.0	2.3 b	3.0 b	3.7	3.7	5.0
31. ISI-128	7.0	5.3	4.7 a	3.3	2.7	2.7 a	4.0 a	4.7	5.0	5.7
32. America	7.3	5.7	4.0 b	2.3	2.0	2.3 b	3.7 a	4.0	4.0	4.7
33. Kimono	7.0	5.0	4.7 a	2.7	2.7	3.0 a	3.3 b	3.7	4.0	4.3
34. Majestic	7.0	6.3	4.3 a	2.3	2.3	2.0 b	3.7 a	4.3	4.7	6.0
35. Merion	6.7	6.3	4.0 b	2.3	2.0	2.0 b	3.7 a	4.3	4.7	5.3
36. Merit	6.3	5.3	4.7 a	2.3	2.3	2.3 b	3.0 b	3.7	4.0	4.7
37. Mosa	6.0	5.3	4.0 b	2.0	2.3	2.3 b	3.3 b	4.0	4.7	5.3
38. Obelisk	5.7	5.3	4.3 a	2.7	3.0	3.7 a	4.3 a	5.3	5.7	6.0
39. Orna	6.0	4.7	3.3 b	3.0	2.3	2.7 a	4.0 a	3.0	5.3	6.0
40. D-164	7.0	4.7	3.3 b	2.3	2.0	2.3 b	3.0 b	3.3	4.7	5.7
41. Parade	6.7	6.0	5.0 a	2.7	2.3	2.0 b	3.3 b	3.7	4.7	6.0
42. Pion	6.0	5.3	3.7 b	2.3	2.0	2.0 b	3.0 b	3.3	4.0	5.3
43. Plush	6.3	5.0	3.3 b	2.0	1.7	1.7 b	3.0 b	3.7	4.0	5.0
44. Ram I	6.3	5.0	3.3 b	1.7	2.0	2.3 b	2.7 b	2.7	3.0	3.7
45. Rugby	6.3	5.0	3.7 b	2.7	2.0	2.0 b	4.0 a	5.0	5.0	6.3
46. Scenic	6.0	5.0	4.0 b	3.0	3.0	2.7 a	5.0 a	4.7	5.7	6.3
47. Sherpa	6.7	4.7	3.3 b	3.0	2.7	2.3 b	3.7 a	4.0	4.3	4.7
48. Sving	6.7	5.3	3.3 b	1.0	1.0	1.3 b	2.0 b	2.3	1.7	2.3
49. Svdsport	5.7	5.3	3.7 b	1.7	2.0	1.7 b	2.0 b	2.3	2.0	3.0
50. Touchdown	6.3	4.0	3.0 b	1.7	2.0	2.0 b	3.0 b	3.7	4.7	5.3
51. Trenton	7.0	4.7	3.7 b	2.7	2.3	2.3 b	3.7 a	4.7	5.0	6.3
52. Vanessa	6.3	5.3	4.0 b	2.3	2.7	2.0 b	3.7 a	4.0	4.3	5.3
53. Victa	6.3	5.0	4.0 b	2.3	2.3	2.0 b	3.0 b	1.7	4.3	4.3
54. Welcome	7.3	4.3	2.7 b	2.0	2.0	1.7 b	3.0 b	3.7	4.7	4.7
55. WWAG 480	6.3	5.7	2.7 b	2.0	2.3	1.7 b	2.3 b	2.3	2.7	2.7

[z]Mean separation by Scott-Knott multiple comparison test, 5% level.

Table 7. Quality comparison in 1981 and 1982 for 34 cultivars of perennial ryegrass when irrigation was withheld except for a recovery period during September. Data are the average of 3 replications.

	1981	1982						Recovery Period
		Stress Period						
Cultivar	10/5	5/25	6/11	6/25	7/19	8/4	8/31	10/5
1. Acclaim	9.0^z a	8.7	7.0^z a	7.3^z a	6.7^z a	3.7	2.3	5.3
2. Aristocrat	9.0 a	7.7	8.0 a	7.7 a	7.0 a	5.7	3.7	7.0
3. Arno	8.3 b	7.7	8.3 a	7.3 a	7.0 a	5.0	2.7	5.7
4. Bellatrix	8.7 a	7.0	8.7 a	8.0 a	7.3 a	7.0	5.7	7.3
5. Birdie	8.3 b	6.3	7.3 a	7.0 a	7.0 a	4.7	3.0	6.3
6. Blazer	9.0 a	8.0	8.0 a	7.7 a	7.3 a	5.0	2.7	6.0
7. Caravelle	7.3 b	6.0	6.0 b	6.0 b	6.3 b	5.3	3.7	6.0
8. Citation	8.7 a	6.7	8.3 a	7.0 a	7.3 a	6.7	3.7	7.3
9. Compas	8.0 b	5.0	5.7 b	6.0 b	6.0 b	4.0	2.0	3.7
10. Derby	8.7 a	6.0	7.7 a	7.3 a	6.7 a	5.0	2.7	6.0
11. Diplomat	9.0 a	6.3	6.7 b	6.7 b	7.0 a	3.3	2.0	4.3
12. Elka	9.0 a	6.7	7.7 a	8.3 a	8.0 a	4.3	2.3	6.0
13. Ensporta	8.0 b	5.0	5.0 b	6.0 b	5.3 b	3.7	2.3	3.7
14. Fiesta	8.0 b	6.0	8.0 a	7.0 a	6.3 b	4.3	2.7	5.7
15. Goalie	8.3 b	6.3	7.3 a	6.0 b	5.7 b	4.3	3.3	5.7
16. Hunter	8.0 b	5.7	7.3 a	7.7 a	6.7 a	3.3	2.0	3.7
17. Loretta	8.7 a	7.7	8.3 a	8.0 a	7.3 a	4.7	2.7	6.3
18. Manhatten	8.0 b	6.7	8.0 a	7.3 a	7.0 a	3.3	1.3	4.0
19. MOM - LP20	9.0 a	6.7	7.7 a	7.7 a	7.0 a	3.0	2.3	5.7
20. Omega	8.0 b	5.3	8.0 a	7.0 a	6.3 b	3.7	1.7	4.0
21. Pennant	9.0 a	7.3	8.0 a	8.3 a	7.0 a	5.0	2.7	6.7
22. Pennfine	8.7 a	7.0	7.3 a	7.3 a	6.7 a	4.0	2.3	5.0
23. Pippin	8.0 b	7.3	7.3 a	7.0 a	6.3 b	5.0	3.3	6.0
24. Player	8.0 b	6.7	7.3 a	8.0 a	6.7 a	4.7	2.3	4.7
25. Pleno	8.0 b	5.7	6.7 b	6.3 b	5.7 b	3.3	2.0	3.7
26. Regal	8.7 a	7.0	7.0 a	7.0 a	6.3 b	4.7	2.3	5.7
27. Runner	8.0 b	7.0	7.3 a	7.3 a	6.7 a	4.7	3.3	5.3
28. Score	8.0 b	6.3	7.3 a	7.3 a	6.3 b	5.3	2.3	4.3
29. Servo	7.0 b	6.3	5.7 b	5.7 b	6.0 b	3.7	1.7	4.0
30. Sportiva	8.0 b	7.3	7.7 a	7.0 a	7.0 a	5.3	3.3	6.7
31. Sprinter	7.7 b	7.7	8.0 a	7.0 a	7.0 a	5.7	3.3	6.0
32. Venlona	8.0 b	6.7	6.7 b	6.3 b	6.3 b	5.0	2.3	6.0
33. Yorktown	8.3 b	7.6	7.7 a	7.0 a	6.3 b	5.3	3.7	7.0
34. Yorktown II	8.7 a	6.0	6.7 b	6.7 b	6.7 a	4.0	3.0	5.3

^{z} Mean separation by Scott-Knott multiple comparison test, 5% level.

Table 8. Quality comparisons in 1983 for 34 cultivars of perennial ryegrass when irrigation was withheld except for a recovery period during September. Data are the average of 3 replications.

	1983									
	Stress Period						Recovery Period			
Cultivar	6/8	6/23	7/11	7/26	8/11	8/30	9/15	9/23	9/30	10/12
1. Acclaim	6.0	6.0	4.3	3.0	3.0	2.0	6.7	7.3	6.7	7.7
2. Aristocrat	8.0	8.0	2.0	3.7	3.0	2.0	8.0	8.7	8.0	9.0
3. Arno	6.0	6.3	4.7	3.3	2.7	2.0	5.7	6.0	6.0	7.3
4. Bellatrix	7.0	6.7	6.0	4.0	3.0	2.0	5.7	6.7	6.3	7.3
5. Birdie	7.0	6.0	4.3	2.3	2.3	1.3	6.0	6.7	6.3	7.3
6. Blazer	6.3	6.7	4.7	3.7	2.7	1.7	6.7	7.3	7.0	7.7
7. Caravelle	6.7	6.7	4.7	3.7	2.7	1.7	6.3	7.0	6.7	8.0
8. Citation	8.0	7.7	5.3	3.7	2.3	1.7	7.7	8.0	7.7	8.7
9. Compas	4.7	5.0	3.3	2.7	2.0	1.3	4.0	4.7	5.3	5.7
10. Derby	6.0	5.7	4.3	3.3	2.3	1.3	6.0	6.0	6.7	7.7
11. Diplomat	4.7	4.3	4.0	3.3	2.0	1.3	4.7	5.0	5.3	6.3
12. Elka	6.0	6.3	5.3	3.7	3.0	1.7	5.3	6.3	6.7	7.0
13. Ensporta	3.0	3.3	2.3	3.0	2.0	1.0	3.3	4.0	4.7	5.0
14. Fiesta	6.0	6.0	3.7	2.3	2.0	1.0	4.3	5.3	6.0	6.3
15. Goalie	6.0	5.7	4.3	3.3	2.3	1.3	5.7	5.3	6.3	6.7
16. Hunter	5.0	4.7	3.3	2.7	2.0	1.3	3.7	4.7	5.0	5.7
17. Loretta	7.0	7.3	5.3	2.7	2.3	1.7	5.3	6.0	6.3	7.3
18. Manhatten	4.7	5.0	3.3	2.3	2.0	1.0	4.0	4.7	5.3	6.3
19. MOM - LP20	6.0	6.0	4.7	3.3	2.3	1.7	5.7	6.3	6.0	7.0
20. Omega	5.0	5.3	4.0	3.0	2.0	1.0	4.7	5.3	5.7	6.7
21. Pennant	7.3	7.0	4.7	3.3	2.7	2.0	7.0	7.7	7.3	8.0
22. Pennfine	5.7	6.0	3.7	2.7	2.0	1.3	5.3	5.7	6.0	7.0
23. Pippin	6.7	6.7	5.3	3.7	2.7	2.3	6.7	7.3	7.0	8.0
24. Player	5.3	5.3	4.0	3.0	2.3	1.3	4.7	4.7	5.7	6.7
25. Pleno	5.0	4.7	3.3	2.7	2.0	1.3	4.0	4.3	5.0	6.3
26. Regal	5.3	5.7	3.0	3.0	2.3	1.3	5.3	6.7	6.7	7.0
27. Runner	6.3	6.3	4.3	3.3	2.3	1.7	6.3	6.7	6.3	7.3
28. Score	6.0	6.3	4.7	4.0	2.0	1.7	6.3	6.7	6.7	8.0
29. Servo	4.0	4.7	3.3	3.0	2.0	1.3	4.7	5.3	5.3	6.3
30. Sportiva	7.3	7.0	5.7	3.7	3.0	2.0	6.7	7.0	7.7	8.3
31. Sprinter	6.3	6.3	5.7	4.7	2.7	2.7	6.3	7.0	7.0	8.0
32. Venlona	6.3	6.0	4.3	3.3	2.7	2.0	6.7	6.7	7.0	7.7
33. Yortktown	7.7	7.0	5.3	3.3	2.3	2.0	7.0	7.3	7.3	8.3
34. Yorktown II	3.3	5.3	3.7	3.0	2.3	1.3	5.7	6.3	6.0	6.7

Table 9. Quality comparisons in 1981 and 1982 for 42 cultivars of fine fescue when irrigation was withheld except for a recovery period during September. Data are the average of 3 replications.

	1981	1982						
		Stress Period						Recovery Period
Cultivar	10/5	5/25	6/11	6/25	7/19	8/4	8/31	10/5
1. Adonis	8.0^z a	6.5	6.0^z a	6.0	5.0^z a	3.0	2.5^z b	3.5^z b
2. Agram	8.0 a	7.0	5.5 a	5.5	4.0 b	4.0	2.0 c	4.5 a
3. Atlanta	8.0 a	7.5	4.5 b	5.5	3.5 b	4.0	2.0 c	4.5 a
4. Balmoral	7.5 b	6.5	5.5 a	5.5	5.5 a	3.0	2.5 b	4.5 a
5. Banner	8.5 a	5.5	3.5 b	4.5	3.0 b	3.0	1.5 c	2.5 b
6. Biljart	7.5 b	5.0	6.0 a	5.5	5.0 a	3.5	3.0 b	5.5 a
7. Bingo	8.5 a	5.5	5.5 a	4.5	3.5 b	2.5	1.5 c	3.0 b
8. Checker	8.0 a	5.0	3.5 b	4.0	2.5 b	2.0	1.5 c	2.5 b
9. Corona	7.0 b	5.5	5.0 a	4.0	4.0 b	3.0	1.5 c	2.5 b
10. Dawson	8.5 a	4.5	4.5 b	3.5	3.0 b	2.5	1.5 c	2.5 b
11. Engina	7.5 b	4.0	5.0 a	5.5	4.0 b	4.0	3.0 b	4.5 a
12. Ensylva	8.0 a	3.5	4.0 b	3.5	2.5 b	2.5	1.0 c	2.5 b
13. Envira	8.0 a	4.5	5.0 a	4.5	3.0 b	3.0	1.5 c	3.5 b
14. Enzet	7.0 b	5.0	4.5 b	5.0	3.5 b	3.0	2.0 c	4.0 a
15. Fortress	8.5 a	6.0	4.5 b	5.0	3.0 b	3.0	2.0 c	4.0 a
16. Frida	8.5 a	7.0	3.5 b	4.0	3.0 b	3.0	1.5 c	3.0 b
17. Gracia	7.5 b	4.5	4.0 b	4.0	3.5 b	2.0	1.5 c	3.0 b
18. Grelo	8.5 a	5.0	3.0 b	3.5	3.0 b	2.0	1.0 c	1.5 b
19. Jade	8.0 a	6.5	3.5 b	2.5	5.0 a	3.0	2.0 c	4.0 a
20. Ilona	8.0 a	7.5	3.5 b	6.0	5.5 a	3.5	2.0 c	3.5 b
21. Jamestown	8.0 a	6.5	7.0 a	7.0	6.5 a	4.0	4.0 a	6.0 a
22. Koket	8.5 a	5.5	2.5 b	3.5	3.0 b	2.0	1.5 c	3.0 b
23. Luster	8.5 a	5.5	3.5 b	4.0	2.5 b	2.0	0.5 c	2.0 b
24. Menuet	8.0 a	5.5	2.0 b	2.5	2.0 b	2.5	1.0 c	2.0 b
25. Monocorde	7.5 b	4.5	3.5 b	3.5	3.0 b	2.5	1.5 c	2.5 b
26. Oase	8.0 a	5.0	4.5 b	3.5	3.0 b	2.5	1.5 c	2.0 b
27. Pernille	8.5 a	5.5	3.0 b	3.5	2.0 b	2.0	1.0 c	2.0 b
28. Polar	7.5 b	6.5	5.5 a	5.0	3.5 b	2.0	1.0 c	2.5 b
29. Rolax	8.5 a	4.0	5.5 a	5.0	3.5 b	3.5	2.0 c	3.0 b
30. Satin	8.0 a	6.0	6.0 a	6.0	5.0 a	3.0	2.0 c	3.5 b
31. Scaldis	8.0 a	6.0	5.5 a	6.0	4.5 a	4.5	3.5 a	5.5 a
32. Silvana	7.5 b	6.0	6.0 a	6.0	4.5 a	4.0	3.0 b	4.5 a
33. Sonnet	8.0 a	5.5	4.5 b	5.0	3.0 b	2.5	1.5 b	2.0 b
34. Starlight	7.5 b	6.5	5.5 a	6.0	4.5 a	5.0	2.5 b	3.5 b
35. Shadow	9.0 a	6.0	4.5 b	6.0	4.0 b	3.5	2.0 c	3.0 b
36. Tamara	8.0 a	6.0	5.0 a	5.0	3.5 b	2.0	1.0 c	3.0 b
37. Tatjana	8.0 a	5.0	3.0 b	4.0	2.5 b	2.0	1.5 c	3.0 b
38. Tournament	6.5 b	5.0	5.5 a	2.5	5.0 a	3.0	4.5 a	5.5 a
39. Waldorf	9.0 a	6.5	6.5 a	6.5	5.0 a	3.5	2.5 b	4.5 a
40. Waldena	7.0 b	7.0	7.0 a	6.0	5.5 a	5.5	3.0 b	4.0 a
41. Wilton	8.0 a	5.0	6.5 a	5.5	4.0 b	3.0	2.5 b	4.5 a
42. Wintergreen	8.0 a	4.0	4.0 b	4.5	2.5 b	2.0	1.0 c	2.0 b

^{z} Mean separation by Scott-Knott multiple comparison test, 5% level.

Table 10. Quality comparisons in 1983 for 42 cultivars of fine fescue when irrigation was withheld except for a recovery period during September. Data are the average of 3 replications.

	1983									
	Stress Period						Recovery Period			
Cultivar	6/8	6/23	7/11	7/26	8/11	8/30	9/15	9/23	9/30	10/12
1. Adonis	5.5	6.0[z] a	4.5[z] a	2.5	1.5	1.5[z] b	2.5	3.5	5.5	5.0
2. Agram	6.5	6.0 a	4.5 a	2.5	2.0	2.0 a	3.5	4.0	3.5	5.0
3. Atlanta	6.0	6.0 a	4.0 a	2.0	1.5	1.5 b	3.0	4.0	4.5	5.0
4. Balmoral	6.5	6.0 a	5.0 a	2.5	2.5	2.0 a	3.0	3.5	5.0	4.5
5. Banner	5.5	5.0 a	4.5 a	2.0	2.0	2.0 a	4.0	3.5	4.5	4.5
6. Biljart	6.5	7.0 a	5.0 a	3.0	2.5	2.5 a	4.0	4.5	5.5	5.5
7. Bingo	4.5	5.0 a	3.5 b	2.0	1.5	1.5 b	3.0	3.0	4.0	4.5
8. Checker	5.0	4.5 b	3.0 b	2.0	2.0	1.5 b	2.5	3.0	4.5	4.0
9. Corona	3.0	2.5 b	2.0 b	2.0	1.0	1.0 b	2.0	2.5	3.5	4.0
10. Dawson	3.0	3.5 b	2.5 b	2.0	1.0	1.0 b	2.5	3.5	4.0	4.5
11. Engina	7.5	4.0 b	3.0 b	2.5	1.5	1.0 b	3.5	4.0	5.0	5.0
12. Ensylva	4.5	5.5 a	4.0 a	3.0	2.0	1.0 b	3.5	4.0	5.0	5.5
13. Envira	5.0	5.5 a	4.0 a	2.5	1.5	1.0 b	3.0	3.0	4.0	3.5
14. Enzet	5.0	5.0 a	3.5 b	2.0	1.0	1.0 b	3.0	3.0	4.5	3.5
15. Fortress	4.0	5.0 a	4.0 a	2.0	2.0	1.0 b	3.0	3.0	4.0	4.5
16. Frida	4.5	4.5 b	3.0 b	2.0	2.0	1.0 b	2.5	3.5	4.0	4.5
17. Gracia	4.0	3.5 b	2.5 b	2.5	2.0	1.0 b	3.0	3.5	4.0	4.0
18. Grelo	2.5	2.5 b	2.0 b	2.0	1.0	1.0 b	2.5	2.5	3.5	2.0
19. Jade	6.0	6.0 a	4.0 a	2.0	2.5	2.0 a	4.5	4.5	5.0	5.0
20. Ilona	5.5	5.5 a	3.5 b	2.0	1.5	2.0 a	4.0	4.0	4.0	4.0
21. Jamestown	7.0	7.0 a	5.0 a	2.0	2.0	2.0 a	3.0	3.5	5.5	5.5
22. Koket	4.0	3.5 b	3.0 b	1.5	1.0	1.5 b	3.0	3.0	4.5	4.5
23. Luster	4.0	3.5 b	3.0 b	1.5	1.5	1.5 b	3.0	3.5	4.5	4.0
24. Menuet	4.0	3.0 b	3.5 b	1.5	1.0	1.0 b	3.5	3.5	4.5	4.0
25. Moncorde	5.5	4.5 b	4.0 a	2.5	2.0	1.0 b	3.0	3.0	4.0	4.0
26. Oase	5.0	5.0 a	4.0 a	2.0	2.0	1.5 b	3.5	4.0	5.0	5.0
27. Pernille	4.5	4.5 b	4.0 a	2.0	2.0	1.0 b	3.0	3.0	4.5	4.5
28. Polar	4.5	5.0 a	4.0 a	2.0	1.5	1.5 b	3.0	3.0	3.5	4.5
29. Rolax	5.5	5.5 a	4.5 a	2.5	2.5	2.0 a	3.5	4.5	5.5	6.0
30. Satin	6.0	5.5 a	4.5 a	2.5	2.0	1.5 b	2.5	2.5	4.5	4.5
31. Scaldis	7.0	6.5 a	5.0 a	3.0	2.5	2.5 a	3.0	3.5	4.5	5.5
32. Silvana	6.0	6.0 a	4.5 a	2.5	2.5	2.5 a	3.5	4.0	5.0	5.5
33. Sonnet	4.5	4.0 b	3.5 b	2.0	1.5	1.5 b	2.0	2.5	4.0	3.5
34. Starlight	6.0	5.5 a	4.5 a	3.0	2.0	1.5 b	2.0	2.5	4.5	4.5
35. Shadow	5.5	5.5 a	4.5 a	2.5	2.5	2.0 a	4.0	4.5	5.5	6.0
36. Tamara	5.5	5.0 a	4.0 a	2.0	2.0	1.5 b	3.0	3.0	4.0	4.0
37. Tatjana	5.0	4.5 b	3.0 b	2.5	1.5	1.5 b	2.5	2.5	4.5	5.0
38. Tournament	7.0	6.0 a	4.5 a	2.5	3.0	2.5 a	2.5	3.0	4.5	4.0
39. Waldorf	6.0	6.0 a	4.0 a	2.0	2.0	2.5 a	2.5	2.5	5.0	5.0
40. Waldena	7.0	6.5 a	5.0 a	2.5	2.0	2.0 a	2.0	3.0	4.0	4.5
41. Wilton	6.5	6.0 a	5.5 a	3.0	2.5	1.5 b	2.5	3.5	5.0	5.0
42. Wintergreen	4.2	4.5 b	3.0 b	2.5	1.5	1.5 b	3.0	3.5	5.0	5.0

[z] Mean separation by Scott-Knott multiple comparison test, 5% level.

Turf quality, on a scale of one to nine (one = brown turf appearing dormant or dead, seven = lowest acceptable quality, and nine = green, dense living turf), was evaluated approximately every two weeks from June to October in 1982 and 1983.

Soil moisture tension was determined using gypsum blocks at the 10 cm depth in 1982. Since soil moisture levels were often below the detection limits of the gypsum blocks, a different determination of soil moisture was necessary. In 1983 six 2 x 5 cm soil cores were removed from the plots (Fig. 19). The cores were sealed in cans as they were removed. Soil samples were weighed, then immediately oven dried for 24 h. at 108 C and then weighed again to determine percent soil moisture.

The responses of the grass species in this study were analyzed as three separate experiments. The cultivars of each species were arranged in a randomized complete block with three replications for Kentucky bluegrass and perennial ryegrass, and two for the fine fescues (Fig. 19). All three experiments were situated side by side and treated the same.

Results and Discussion

Kentucky bluegrass, perennial ryegrass, and fine fescue are three cool season grasses that can provide excellent turf when soil moisture, temperature, and fertility are optimum. Irrigation, proper fertilization, and mowing allow these grasses to produce high quality turf in semi-arid climates. Efforts to conserve water have caused the use of these grasses to be questioned under conditions of limited rainfall and low relative humidity. This study was directed at identifying cultivars of Kentucky bluegrass, perennial ryegrass, and fine fescue that are suitable for dry climates.

REPLICATION

II	II	II	I	I	III	III	II	II	I	I	III	III	III	III	II	II	I	I	I	I
7	32	22	18	17	12	1	27	16	18	17	28	6	22	16	27	5	52	51	18	17
28	4	37	19	16	18	3	11	29	19	16	51	37	19	7	36	33	53	50	19	16
9 [21]	39	11	20 [20]	15	22	29 [19]	34	22	20 [18]	15	2	45 [17]	42	13	21	54 [16]	54	49	20	15 [15]
19	21	2	21	14	24	25	26	20	21	14	55	50	14	15	41	4	55	48	21	14
27	6	33	22	13	32	33	5	17	22	13	31	17	29	32	15	1	11	47	22	13
18	5	3	23	12	15	13	25	18	23	12	23	26	35	10	25	52	8	46	23	12
14	24	31	24	11	16	19	31	6	24	11	8	44	20	27	32	34	13	45	24	11
35	15	10	25	10	10	9	13	4	25	10	48	11	38	46	3	6	20	44	25	10
8 [8]	38	12	26 [9]	9	34	5 [10]	14	9	26 [11]	9	39	43 [12]	18	40	16	28 [13]	35	43	26	9 [14]
42	17	42	27	8	14	20	3	30	27	8	41	47	33	53	29	45	7	42	27	8
36	41	41	28	7	11	4	1	24	28	7	53	12	36	46	43	31	10	41	28	7
23	1	40	29	6	8	21	32	7	29	6	3	24	49	44	37	51	49	40	29	6
13	26	39	30	5	30	2	19	10	30	5	X	9	4	48	9	23	38	39	30	5
16	29	38	31	4	28	17	33	12	31	4	X	1	5	2	40	50	30	38	31	4
40	34	37	32	3	31	7	23	8	32	3	X	30	52	39	14	12	17	37	32	3
25 [7]	30	36	33 [6]	2	26	23 [5]	2	15	33 [4]	2	X	34 [3]	54	55	18	24 [2]	47	36	33	2 [1]
X	20	35	34	1	6	27	21	28	34	1	X	21	25	19	26	22	42	35	34	1

FINE FESCUE | PERENNIAL RYEGRASS | KENTUCKY BLUEGRASS

Fig. 19. Plot plan of the species and cultivar drought tolerance study. Plot numbers correspond to the cultivars listed in Tables 5 thru 10. Bold face numbers, 1 thru 20, in the upper right corner of some plots correspond to the plots that were sampled for soil moisture content in 1983 (Table 4).

Drought tolerance is a vague term that is subject to different meanings. With respect to grasses it can mean the avoidance, tolerance, or escape of drought conditions. Survival could mean the ability of only a few plants to live. From a turfgrass standpoint, where complete vegetative cover is usually desired, survival of only a few plants would be generally unacceptable. In this study turf quality was evaluated over an extended drought period and then through a well irrigated recovery period. The rating scale was: one = completely brown grass, seven or higher = acceptable turf, and nine = completely green, high quality turf. In this study drought tolerance was measured by the amount of green living turf that was present at any time during the stress or recovery periods. For example, if 50 percent of the plants were green and actively growing this grass plot would receive a quality rating of five. This level of drought tolerance, because it would not provide enough cover to qualify as a functional turf, would not be considered satisfactory. Thus, drought tolerance was defined as the ability of a large number of grass plants, at least 70 percent, to regrow within a specified time.

Rainfall and temperature data in Fig. 6a and 6b indicate the drought conditions that these grasses were exposed to during the summer of 1982 and 1983. Soil moisture values reported on July 12 and August 31, 1983 indicated extreme soil drought (Table 4).

Kentucky Bluegrass

Tables 5 and 6 show the quality ratings of the Kentucky bluegrasses during the stress and recovery periods in 1982 and 1983. In October, 1981 there were no significant differences among the Kentucky bluegrass cultivars and all cultivars displayed an acceptable level of quality

(quality value of seven or greater). Turf quality during the stress period and following a recovery period was cultivar dependent (Table 5). The large number of cultivars within a species made it desirable to group the cultivars according to their relative drought tolerance. The Scott-Knott method of mean separation was used because it ranks many cultivars into definite groups with non-overlapping means (Gates and Bilbro, 1978). This method was very useful in data analysis since identification of the best cultivars was of greatest concern in this study. Turf quality was observed seven times during the stress and recovery periods in 1982. The following cultivars ranked in the best group on all 7 dates that turf quality was observed: A-20-6, H-7, America, Majestic, and Sving. These grasses had the best appearance during the stress period and following the recovery period in 1982. Cultivars that were not always in the top ranking during the stress period, but were able to recover to an acceptable level of quality after a 5 week irrigated recovery period included: Bonnieblue, Enoble, Entensa, ISI-128, Merion, Pion, and Vanessa.

In 1983 significant differences were found on only 3 of the 10 dates that turf quality was observed (Table 6). On October 12, 1983 turf quality values ranged between 2.7 and 7.3 on a scale of 1 to 9. This produced a significant F value but mean separation by the Scott-Knott cluster analysis did not show any significant group separations. The inability of the Scott-Knott method of mean separation to find differences between obviously diverse data is one factor that must be weighed against the benefit of non-overlapping means. In this case ranking the cultivars into groups that had non-overlapping means, even though mean separation was not always present, was more important than finding significant differences that resulted in many overlapping means.

During the early part of the stress period, July 8, 1983, 18 of the 55 Kentucky bluegrass cultivars were above the lowest acceptable quality level of 7. Two weeks later on July 23, only H-7 displayed an acceptable level of turf quality. For the rest of the stress period many of the Kentucky bluegrass cultivars appeared dormant or dead, as evident by the very low turf quality ratings (Table 6). A-20-6 and H-7 were among the best cultivars on all 3 dates in 1983 when significant differences were evident. These cultivars also ranked high in drought tolerance in 1982. At the end of the recovery period two cultivars, Columbia and Haga, provided acceptable turf quality. These cultivars were not among the most drought tolerant cultivars mentioned in 1982 (Table 5). 'Majestic' and 'H-7' recovered to a quality level of 6 in 1983, whereas 'Sving' almost completely died (quality value of 2.3). Majestic, H-7, and Svins were among the most drought tolerant cultivars in 1982. This indicates that several years of drought stress should be considered before a cultivar is labeled drought tolerant. Also, it reveals the variability in drought tolerance that may occur from one year to the next.

Perennial Ryegrass

Tables 7 and 8 show the appearance of perennial ryegrass during the stress and recovery periods in 1982 and 1983. In October 1981, before irrigation was restricted, all cultivars of perennial ryegrass provided acceptable quality turf. Significant mean separation occurred on only three of the seven weeks that turf quality was observed in 1982

(Table 7). Cultivars that provided the best quality during the stress period and also recovered to an acceptable level of quality following irrigation in September included: Aristocrat, Bellatrix, Citation, and Yorktown. In 1983 mean separations were not evident on any of the days when turf quality was observed (Table 8). On October 12, 1983, following a well irrigated recovery period, 22 of the 34 perennial ryegrass cultivars recovered to an acceptable level of turf quality. These results indicate that most of the perennial ryegrass cultivars in this study had the ability to avoid and/or tolerate summer drought conditions. This was evident by the large number of cultivars that quickly returned to an acceptable level of turf quality when grass was irrigated following a period of severe moisture depletion (Table 8).

The Western Regional Study (Western Regional Coordinating Committee, 1983) was mainly concerned with cultivar evaluations within a species. The design of the experiment treated each species as a separate experiment. Since this drought study used the same field plots employed in the Western Regional study, they were not conducive to comparisons between the species, however, the three species in this study were arranged side by side (Fig. 19), grown on the same soil and treated with the same amount of water and fertilizer. For these reasons a general and non-statistical comparison between species could be made. The perennial ryegrasses generally produced better quality turf longer into the stress period than either Kentucky bluegrass or fine fescue. This was evident from higher quality values for the perennial ryegrasses on June 11 and 25 and July 19, 1982 (Tables 5, 7, and 9). In 1983 there was no clear evidence that the perennial ryegrasses remained actively growing longer into the drought period, however, the 6 weeks of observation during the recovery period indicated that perennial ryegrass recovered faster (turf quality values on September 15, 1983, Tables 6, 8, and 10) and to an ultimately better level of quality (turf quality values on October 12, 1983, Tables 6, 8, and 10) than Kentucky bluegrass or fine fescue.

These results indicate that as drought conditions develop perennial ryegrass may remain viable for a longer period than Kentucky bluegrass or fine fescue. Also, when water becomes available following a soil drought, perennial ryegrass may break dormancy and recover faster than Kentucky bluegrass or fine fescue. These results are derived from general observations of several cultivars within a species. It should be realized that specific cultivars of both perennial ryegrass (ie. Aristocrat, Citation, and Yorktown) and Kentucky bluegrass (ie. Majestic and H-7) show promise for turf use under drought conditions.

Fine Fescue

Fine fescue has been used as a general term that encompasses the narrow leaved, turf-type fescues. In this study the fine fescues were represented by chewings fescue (*Festuca rubra* subsp. *commutata* Gaud.), slender creeping fescue (*Festuca rubra* subsp. *trichlophylla* Gaud.), spreader creeping fescue (*Festuca rubra* subsp. *rubra* Hack.), and hard fescue (*Festuca longifolia* Thuill). The fine fescues as a group did not perform as well as the Kentucky bluegrasses or perennial ryegrasses. This was most evident at the end of the recovery period on October 5, 1982 (Tables 5, 7, and 9) and October 12, 1983 (Tables 6, 8, and 10). On these dates no fine fescue cultivars had recovered to an acceptable level of quality when a well irrigated recovery period followed an unirrigated stress period (Tables 9 and 10), however, cultivars of perennial ryegrass and Kentucky bluegrass were able to recover to an acceptable level of turf quality. On October 5, 1982, 4 of 34 perennial ryegrass cultivars (Table 7) and 9 of 55 Kentucky bluegrass cultivars (Table 5) were able to recover to an acceptable level of quality (turf quality value > 7). On October 12, 1983 no cultivars of fine fescue appeared acceptable whereas 22 of 34 perennial ryegrass cultivars and 2 of 55 Kentucky bluegrass cultivars appeared acceptable.

Even though the appearance of the fine fescues was unacceptable on 15 of the 17 dates that turf quality was observed in 1982 and 1983 (Tables 9 and 10), there were some cultivars that tolerated drought better than others. The best performers were 'Balmoral', 'Biljart', 'Jamestown', 'Scaldis', 'Silvansa', 'Tournament', 'Waldorf', and 'Waldena'. Of these cultivars Waldorf and Jamestown are chewings fescues and the rest are hard fescues. These grasses were considered to be more drought tolerant than many of the other cultivars because they received a significantly higher ranking (6 or 7) on the dates when mean separation occurred.

As drought conditions developed in this study the fine fescues displayed a brown patchy appearance rather than a uniform dormancy as noted for the perennial ryegrasses and the Kentucky bluegrasses. Eventually the brown areas died and the remaining grass appeared to be dormant rather than dead. During the irrigated and fertilized recovery periods of this study the dead areas of fine fescue turf never filled in with new growth. This resulted in a very rough turf that was difficult to mow. Thus, while some fine fescue plants survived the overall appearance of the turf was very undesirable.

Conclusions

The observations in this study pertain to field grown cultivars of Kentucky bluegrass, perennial ryegrass, and fine fescue. Drought conditions were imposed by withholding irrigation except for a recovery period in September.

1. Along the Front Range of Colorado Kentucky bluegrass, perennial ryegrass, and fine fescue require supplemental irrigation to provide acceptable quality.

2. Some Kentucky bluegrass cultivars such as: A-20-6, H-7, America and Majestic, have improved drought tolerance. Of these cultivars H-7 and Majestic had superior drought tolerance.

3. Some perennial ryegrass cultivars including Arisocrat, Bellatrix, Citation, and Yorktown have improved drought tolerance.

4. No fine fescues provided acceptable turf under the drought conditions in this study. Some hard fescues, 'Balmoral', 'Biljart', 'Scaldis', 'Silvana', 'Tournament', and 'Waldena', were more drought tolerant than other fine fescues tested.

5. An overall evaluation from several cultivars within a species indicated that as drought conditions develop perennial ryegrass remains green and viable longer than Kentucky bluegrass or fine fescue. When water becomes available in late summer, perennial ryegrass recovers faster than Kentucky bluegrass or fine fescue. The relative drought tolerance of these three species was perennial ryegrass $\geq$ Kentucky bluegrass > fine fescue.

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APPENDIX

Appendix Table 1. Summary of analyses of variance for the Kentucky Bluegrass Lysimeter Study. Data represent mean square values associated with five sources of variation (SOV). Illustrative data for evapotranspiration is in Fig. 4a, 4b, 4c, 4d and in fig. 5a, 5b, 5c and 5d for quality. Denotes significance at the 5% level (*).

		Evapotranspiration					Quality				
	Date / SOV DF	% IRR 4	Error 1 8	ΔT 1	% IRR X ΔT 4	Error 2 10	% IRR 4	Error 1 8	ΔT 1	% IRR X ΔT 4	Error 2 10
		mean squares									
1982	7/12 - 18	11.492*	.201	2.181*	.251	.269	57.425*	.165	2.700*	.907	.449
	7/19 - 25	48.010*	.396	25.810*	2.350*	.276	85.067*	.563	18.565*	5.572*	.391
	7/26 - 8/1	11.675*	.117	1.045*	.541*	.102	89.584*	.604	24.843*	6.851*	.465
	8/2 - 9	25.748*	.117	2.352*	.144	.057	92.203*	.469	13.200*	3.608*	.658
	8/9 - 15	17.496*	.181	.222	.039	.033	91.093*	.578	3.136*	1.445*	.572
	8/16 - 22	16.280*	.169	.120	.118	.125	91.746*	.824	1.976	1.026	.466
	8/23 - 29	15.664*	.081	.021	.049	.062	86.189*	.571	1.496	.713	.318
	8/30 - 9/5						80.105*	.765	1.240*	.535*	.116
	9/6 - 12						84.720*	.392	1.776*	.601*	.085
	9/20 - 26						86.094*	.394	1.680*	.214	.207
	7/1 - 8/31	130379*	1148	8178*	196	133					
1983	6/20 - 26	32.487*	.637	12.805*	3.289*	.582	81.283*	.983	10.800*	4.050	2.200
	7/4 - 10	26.286*	1.239	12.046*	3.436*	1.728	69.283*	1.733	43.200*	15.283*	.767
	7/11 - 17	30.477*	.446	28.277*	2.612*	.289	72.883*	1.133	58.800*	16.050*	.400
	7/18 - 24	22.624*	.144	11.212*	2.596*	.102	87.700*	.225	36.300*	10.800*	.200
	7/25 - 31	16.464*	.104	8.501*	1.436*	.045	88.800*	.250	26.133*	7.967*	.200
	8/1 - 7	21.749*	.047	3.516*	.286	.350	91.117*	.367	22.533*	5.783*	.433
	8/8 - 14	29.165*	.210	5.967*	.199	.127	92.800*	.350	13.333*	3.667*	.300
	8/15 - 21	17.956*	.153	1.501*	.219	.194	88.533*	.158	10.800*	4.133*	.067
	8/22 - 28	21.188*	.111	.156	.294	.104	86.966*	.467	7.500*	2.833*	.067
	8/29 - 9/4						85.054*	.379	9.633*	3.029*	.175
	9/5 - 11						84.450*	.325	17.633*	5.216*	.400
	9/12 - 18						84.617*	.467	28.033*	11.117*	.800
	9/19 - 25						87.133*	.633	24.300*	8.800*	.800
	9/26 - 10/2						84.633*	.533	28.033*	9.533*	.833
	10/10 - 16						75.617*	.492	32.033*	7.283*	.733
	6/1 - 8/31	330512*	618	111562*	7257*	797					

APPENDIX TABLE 2. Summary analyses of variance for the Lysimeter Study With Four Cool Season Grasses. Illustrative data for these statistics are in Fig. 10a, 10b, 10c, 11a, 11b and 11c. Denotes significance at the 5% level (*).

		QUALITY			
SOV	%IRR	Error[1]	SP	%IRRxSP	Error[2]
DF	2	4	3	6	18
	mean squares				
1982 6/28 - 7/4	.361	.069	12.259*	.176	.120
7/5 - 11	.194*	.028	.444*	.194*	.028
7/12 - 18	10.990*	.385	1.308*	.475	.187
7/19 - 25	119.621*	.273	2.838*	1.632*	.291
7/26 - 8/1	156.363*	.453	3.864*	4.810*	.826
8/2 - 8	157.111*	.177	4.072*	3.295*	.917
8/23 - 29	163.448*	.850	1.523*	.639	.367
8/30 - 9/5	145.450*	.894	3.197*	1.190*	.344
9/6 - 12	114.145*	.860	2.200*	1.143*	.348
9/20 - 26	104.333*	.667	2.111*	1.889*	.435
1983 7/4 - 10	38.694*	1.778	8.917*	4.806*	.926
7/11 - 17	150.861*	.694	11.963*	8.268*	.694
7/18 - 24	152.528*	.444	3.361*	2.639*	.602
8/15 - 21	151.694*	.069	.629*	.657*	.092
8/22 - 28	179.861*	.153	3.435*	2.935*	.407
8/29 - 9/4	156.361*	.069	1.518*	.991*	.222
9/5 - 11	127.444*	.153	1.518*	1.296*	.314
9/19 - 25	184.056*	.778	1.815*	1.731*	.565
9/26 - 10/2	79.528*	.944	2.250*	2.750*	.667
10/10 - 16	90.250*	.250	.917*	9.17*	.139

APPENDIX TABLE 3. Summary analyses of variance for the Lysimeter Study With Four Cool Season Grasses. Illustrative data for these statistics are in Fig. 10a, 10b, and 10c. Denotes significance at the 5% level (*).

		SOV	EVAPOTRANSPIRATION				
		SOV	%IRR	Error[1]	SP	%IRRxSP	Error[2]
Date		DF	2	4	3	6	18
			mean squares				
1982	6/28 - 7/4		.2636	.0737	6.0924*	.5260	.2489
	7/5 - 11		.1392	.848	4.9264*	.7226*	.1360
	7/12 - 18		3.5134*	.1719	2.9637*	.4207	.1754
	7/19 - 25		49.4812*	.4825	3.4294*	2.4253*	.4010
	8/2 - 8		21.7507*	.0338	4.2599*	.6180	.2926
	8/9 - 15		21.7348*	.0316	2.4285*	.0578	.2773
	8/16 - 22		13.6963*	.0076	1.4631*	.2006	.2040
	8/23 - 29		13.5794*	.2522	2.7740*	.1634	.1762

APPENDIX TABLE 4. Summary analyses of variance for the Lysimeter Study with Four Cool Season Grasses. Denotes significance at the 5% level (*).

		SOV	EVAPOTRANSPIRATION	
Date		DF	SP 3	Error 6
			mean squares	
1982	7/1 - 8/31		9339*	2105
1983	6/1 - 8/31		8463*	1725
(Data in Table 3)				
1983				
(Data in Fig. 11a)				
	6/13 - 19		.7624*	.1614
	6/20 - 26		.2148*	.0142
	7/4 - 10		2.3410*	.4829

Appendix Table 5. Summary analyses of variance for the Kentucky Bluegrass Field Irrigation Study. Illustrative data for these statistics are in Fig. 12a, 12b, 14a, 14b, 14c and 14d. Denotes significance at the 5% level(*).

				QUALITY			
Date		SOV DF	%IRR (4)	Error[1] (8)	ΔT (1)	%IRRxΔT (4)	Error[2] (10)
			mean squares				
1982	7/19 - 25		12.987*	.200	25.208*	2.354*	.175
	7/26 - 8/1		22.659*	.488	6.627*	1.272*	.164
	8/2 - 8		21.279*	.535	4.408*	.179	.275
	8/9 - 15		21.200*	1.225	20.833*	.667	.400
	8/16 - 22		31.729*	1.854	26.133*	.696	.733
	8/23 - 29		39.533*	.596	20.833*	.375	.192
	9/6 - 12		18.646*	.640	5.208*	.104	.100
	9/20 - 26		5.533*	.733	2.700*	.533	.167
		DF	(4)	(8)	(3)	(12)	(30)
			mean squares				
1983	7/11 - 17		8.495*	.218	29.260*	1.871*	.178
	7/18 - 24		23.652*	.280	25.449*	2.480*	.194
	7/25 - 31		25.828*	1.121	17.916*	2.148*	.313
	8/1 - 7		69.200*	.404	14.633*	2.442*	.272
	8/8 - 14		69.048*	.213	13.967*	2.803*	.269
	9/15 - 21		75.390*	.746	12.404*	2.623*	.183
	8/22 - 28		72.442*	.485	6.415*	2.630*	.221
	8/29 - 9/4		69.417*	.217	6.000*	2.639*	.261
	9/5 - 11		75.642*	.567	8.017*	1.475*	.267
	9/12 - 18		55.392*	1.192	8.778*	.625	.339
	9/19 - 25		50.733*	1.358	11.044*	.211	.261
	9/26 - 10/2		38.875*	.638	7.217*	.342	.350
	10/10 - 16		23.183*	.971	8.194*	.194	.194

Appendix Table 6. Summary analyses of variance for all regression parameters. Denotes significance at the 5% level (*).

Figure	ΔT (days)	Sov	DF	Mean Squares
7	2	regression	1	70.714*
		residual	8	0.840
	7	regression	1	63.845*
		residual	8	1.694
8	2	regression	1	104.983*
		residual	8	1.805
	7	regression	1	104.186*
		residual	8	1.150
9	2	regression	1	50.446*
		residual	3	4.106
	7	regression	1	50.989*
		residual	3	1.989
13	2	regression	1	62.852*
		residual	13	.428
	7	regression	1	29.922*
		residual	13	.346
15	2	regression	1	99.997*
		residual	13	.234
	4	regression	1	68.976*
		residual	13	.149
	7	regression	1	42.041*
		residual	13	.260
	14	regression	1	9.121*
		residual	13	.247
16	2	regression	1	19.542*
		residual	13	.476
	4	regression	1	21.476*
		residual	13	.533
	7	regression	1	27.656*
		residual	13	.437
	14	regression	1	15.760*
		residual	13	.552
18	2	regression	1	89.793*
		residual	13	1.018
	4	regression	1	42.257*
		residual	13	2.204
	7	regression	1	32.737*
		residual	13	.976
	14	regressiona	1	7.469*
		residual	13	.374

Appendix Table 7. Summary analyses of variance for the Species and Cultivar Evaluation to Drought Study. Only the dates with a significant F ratio (5% level) are presented.

Experiment	Date	SOV	DF	MS	F ratio
Kentucky bluegrass	5/28/82	Block	2	1.654	
(Data in Tables 5 and		Cultivar	54	3.401	3.798
6 of text)	6/11/82	Block	2	5.387	
		Cultivar	54	2.562	5.133
	6/25/82	Block	2	1.527	
		Cultivar	54	2.116	2.799
	7/19/82	Block	2	1.170	
		Cultivar	54	2.116	2.799
	8/4/82	Block	2		
		Cultivar	54		
	8/31/82	Block	2	8.406	
		Cultivar	54	1.180	2.255
	10/5/82	Block	2	11.660	
		Cultivar	54	4.418	2.660
	6/23/83	Block	2	0.891	
		Cultivar	54	1.405	1.588
	7/11/83	Block	2	0.806	
		Cultivar	54	1.259	1.734
	8/30/83	Block	2	9.696	
		Cultivar	54	0.734	1.805
	9/15/83	Block	2	22.927	
		Cultivar	54	1.461	1.751
	10/12/83	Block	2	55.587	
		Cultivar	54	2.701	1.916
Perennial ryegrass	10/15/81	Block	2	0.559	
(Data in Tables 7		Cultivar	33	0.777	3.787
and 8 of text)	6/11/82	Block	2	1.098	
		Cultivar	33	2.111	2.622
	6/25/82	Block	2	2.069	
		Cultivar	33	1.425	3.375
	7/19/82	Block	2	0.068	
		Cultivar	33	0.948	1.812
	8/31/82	Block	2	0.657	
		Cultivar	33	1.989	1.840
Fine fescue	10/5/81	Block	1	0.964	
(Data in Tables		Cultivar	41	0.570	2.740
	6/11/82	Block	1	0.107	
		Cultivar	41	3.020	2.196
	7/19/82	Block	1	0.298	
		Cultivar	41	2.348	2.587
	8/31/82	Block	1	0.012	
		Cultivar	41	1.468	3.651
	6/23/83	Block	1	5.250	
		Cultivar	41	2.546	2.119
	7/11/83	Block	1	7.440	
		Cultivar	41	1.440	2.182
	8/30/83	Block	1	0.762	
		Cultivar	41	0.502	2.226
	10/12/83	Block	1	1.190	
		Cultivar	41	1.136	2.238