

DISSERTATION

EVAPOTRANSPIRATION AND WATER MANAGEMENT OF TURF
CANOPIES IN A SEMI-ARID ENVIRONMENT

Submitted by

Jack Douglas Fry

Department of Horticulture

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR
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Committee on Graduate Work

Joseph J. Wallace
W. H. Smith
Wm E. Mantel
Frank D. Moore III
Jackie A. Butler
Adviser
K. H. Brind
Department Head

ABSTRACT OF DISSERTATION

EVAPOTRANSPIRATION AND WATER MANAGEMENT OF TURF CANOPIES IN A SEMI-ARID ENVIRONMENT

Several investigations were undertaken to better define water requirements of turf canopies in an area of limited precipitation. Potential evapotranspiration (ET) (i.e., ET under conditions where soil water is not limiting) was determined using lysimeters in the field in three studies. When evaluated under putting green conditions, annual bluegrass (Poa annua L.) had a significantly lower water use rate (4.6 mm day⁻¹) than creeping bentgrass (Agrostis palustris Huds.) (4.9 mm day⁻¹) during the summer of 1986, but not 1985. Furthermore, both species had lower water use rates in 1986 when cut at 0.6 cm (4.6 mm day⁻¹) compared to 1.2 cm (4.9 mm day⁻¹).

Evapotranspiration rates of several turf weeds and groundcovers were also evaluated using lysimeters in the field. Results indicated that white clover (Trifolium repens L.), a C₃ dicot, had the highest mean water use rate of all species (6.6 mm day⁻¹). Lowest water use rates were seen with dichondra (Dichondra repens J.R. Forst. and G. Forst.), a C₄ dicot, and barnyardgrass [Echinochloa crusgalli (L.) Beauv.], a C₄ monocot (4.2 and 4.4 mm day⁻¹, respectively). 'Merion' Kentucky bluegrass (Poa pratensis L.), yellow foxtail [Setaria glauca (L.) Beauv.], and crabgrass [Digitaria ischaemum (Schreb.) Muhl.] exhibited intermediate ET rates.

Potential ET rates of 'Merion' Kentucky bluegrass and 'Rebel' tall fescue (Festuca arundinacea Schreb.) were determined during establishment using lysimeters. Over two summers, the mean ET rate for these two species was 5.2 and 5.3 mm day⁻¹, respectively. In 1985, tall fescue began using significantly more water than Kentucky bluegrass twenty days after seeding. Tall fescue, irrigated at 50 and 100% of potential ET of a mature turf, did not achieve satisfactory establishment at the former irrigation level. Preplant soil incorporation of a hydrophilic polymer was also evaluated in greenhouse and field studies for effectiveness in reducing tall fescue drought stress during establishment. When applied at reasonable rates, the polymer was ineffective in enhancing tall fescue establishment.

Mature 'Reliant' hard fescue [Festuca ovina var. duriuscula (L.) Koch.] and 'Rebel' tall fescue were evaluated in field plots under irrigation levels of 50, 75, and 100% of potential ET, applied on 2, 4, 7, or 14 day intervals. Hard fescue had the best quality when irrigated at 75 or 100% of potential ET on 2 or 4 day intervals. Acceptable tall fescue quality resulted when turf was watered once weekly at 50% of potential ET.

These studies have better defined water management requirements and conservation strategies for turf canopies where water supplies are often limited.

Jack Douglas Fry
Horticulture Department
Colorado State University
Fort Collins, Colorado 80523
Summer, 1987

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INTRODUCTION

Of all water present on earth, only one percent is useful for irrigation. That remaining is located in oceans, frozen as ice, etc. (84). Water is a renewable but limited resource. Its quality can be irreversibly altered as it is continually used.

Precipitation does not occur uniformly over space or time. Certain areas of the country may receive more than enough total precipitation for turfgrass growth, while others may receive less than five inches of precipitation annually. Limited precipitation in arid and semi-arid regions necessitates the use of irrigation to maintain most cultivated crops, and turfgrass areas. In humid and subhumid regions, irrigation is of less concern. It is recognized, however, as a valuable way to maintain high quality turf when evapotranspiration (ET) exceeds precipitation.

Eighty percent of the water in the United States is located in aquifers, but they supply only 20% of the water used (99). The Ogallala aquifer in the midwest, and aquifers in the Central Valley of California and southern Arizona, are becoming depleted because water use greatly exceeds recharge. Aquifers serve areas where precipitation is typically quite low; consequently, depletion results. Water removal from these aquifers is increasing at a rate of four percent annually (99).

Usable supplies of underground and surface water are also being reduced continually through contamination by pollutants, and salinization by ocean water on the coasts (84). In the United States, water is often taken for granted. Considering every facet of life, the average American uses 1800 gallons of water daily; whereas, residents of underdeveloped countries use an average of 12 gallons each day (84).

It is clear that water is a valuable resource. On occasions when drought results in water use restrictions, turfgrass areas are usually the first to suffer. Edible crops receive what water is available, for obvious reasons. Water conservation is essential to insure that adequate supplies will be available in the future. Over the past decade, research has focused on identifying methods to improve turfgrass irrigation efficiency in an effort to conserve water.

LITERATURE REVIEW

Water and Its Use

A study in Fort Collins, Colorado in 1978 determined that 35% of water used during the summer was used to water lawns (15). In Logan, Utah (3), it was reported that 61% of the water was used on urban vegetation during the growing season. Throughout the United States, there is great concern that proper amounts of water be applied to maintain acceptable turf quality, primarily in an attempt to conserve. Water cost is a major factor influencing the amount of water applied to home lawns. In general, homeowners who are charged a flat rate for water tend to use more water for lawn irrigation than those who are charged on a volume basis. In Fort Collins, a city where homeowners are charged a flat rate, 13% more water was applied to lawns than required to maintain acceptable turf quality (15). If irrigation had been reduced 13% an annual saving of 7900 acre feet would have resulted for the city. Linaweaver et al. (65) reported that homeowners in the West, whose water use was metered, used approximately 60% of the estimated potential turfgrass requirement.

Scarcity of water during long periods of drought has often led to imposition of restrictions. Restrictions vary in severity, and may simply reduce the amount of water that can be applied to a lawn, or prohibit irrigation completely. In parts of Colorado, lack of water has

resulted in the creation of regulations governing irrigation and turf establishment practices. In Aurora, Colorado (98), the following were some of the lawn irrigation regulations aimed at conserving water:

- Turf surrounding public buildings will receive minimal water applications.
- Grasses selected will be efficient water users appropriate to the site and designated use.
- Irrigation systems will be appropriately designed.
- Non-living groundcovers will be used whenever appropriate to the designated use.

Under the same ordinance, turf establishment and maintenance practices were also addressed. Stipulations were made for reduced fertilizer applications, increased turf mowing height, increased soil cultivation, increased monitoring of irrigation systems, and decreased water application. Furthermore, stipulations were made for size of the landscape, soil amendments before planting, and selection of drought resistant turfgrasses. In Fort Collins, Colorado (15), water conservation efforts were instigated as well. These prohibited runoff water on streets and sidewalks; disallowed watering between 12 and 4 am to avoid all night irrigation; and gave the City Council the power to restrict or prohibit lawn watering upon recommendation of the Water Board. Violation of any of the above rules could have resulted in a \$300 fine, or 90 days in jail.

Most of the water used by the turfgrass plant is transpired. Less than one percent of the water absorbed by the plant is used in metabolism (104). Evapotranspiration (ET) refers to the loss of water from the soil through evaporation, as well as that water transpired by the plant. Turfgrass ET rates are influenced by several factors

including climatic conditions, edaphic factors, species and growth habit, and cultural practices.

Plant Water Absorption and Translocation

Movement of water from the soil, into and through the plant is dependent upon water potential gradients. Water potential is defined as the difference between the chemical potential of pure, free water and the water within the soil-plant system (104). Plant water potential is represented as:

$$\Psi = \Psi_{\pi} + \Psi_m + \Psi_p$$

where: Ψ = total plant water potential.
 Ψ_{π} = osmotic potential.
 Ψ_m = matric potential.
 Ψ_p = pressure potential (104).

Matric potential is usually considered negligible within the plant. Osmotic potential decreases as the concentration of total dissolved solids increases, and is always a negative value. Pressure potential refers to the positive pressure that is exerted on the plant cell wall. It is usually positive, but declines rapidly with the onset of drought (104).

Water always moves from an area of higher potential to lower potential. Costello (24) presented a hypothetical situation to demonstrate water movement into and through a turfgrass plant. Water potentials were assigned as follows:

Water Potential (MPa)

Soil (Field Capacity)	-0.03
Root	-0.40
Stem	-0.55
Leaf	-2.40
Air (20 °C, 50% RH)	-95.00

Thus, water moves from regions of higher to lower potential. The ability of water to travel through the plant is due to its adhesion to the walls of xylem cells, and cohesion of one water molecule to another (104). Transpiration results when water leaves the stomatal cavity in vapor form.

Climatic Factors Affecting Evapotranspiration

Several environmental factors influence turfgrass ET rates. These include temperature (7,8,37), relative humidity (8), solar radiation (35,3,36), and wind (47,45,46,79). Evapotranspiration is an energy dependent process, and the above forms of energy regulate the rate at which it occurs. Beard (8) noted that transpiration is closely linked to the energy balance equation. This is expressed as:

$$R + H + 1E + G + aA = 0$$

where: R = net radiation flux
 H = sensible heat exchange with the atmosphere
 1E = latent heat exchange with the atmosphere
 G = sensible heat exchange with vegetation and soil
 aA = energy used for plant metabolic purposes

Hence, it is clear that as solar radiation is absorbed, energy must be used by the plant or released in the form of heat.

Plant temperature is greatly influenced by the amount of solar radiation absorbed. As plant temperature increases, ET increases (7). When soil water is not limiting, highest turfgrass ET rates occur during the warmest days of summer.

Recently, Feldhake and Boyer (36) studied the effect of soil temperature on turfgrass water use rates. Two C₃ and C₄ grasses were evaluated at soil temperatures of 13, 21, and 29 °C. Generally, all species exhibited higher ET rates with increasing soil temperature. At 13 °C, C₄ grasses averaged 30% lower ET rates than C₃ grasses. At 29 °C, however, the difference was reduced to only 10%.

Relative humidity also influences the rate at which water is lost from a turfgrass plant. As ambient relative humidity decreases, plant water loss increases (7). The rate of water loss is dependent upon the vapor pressure gradient between the stomatal cavity and the atmosphere. For example, if the vapor pressure within the plant is high, but the atmospheric relative humidity is low, water loss will be greater than when a high relative humidity is present. In arid and semi-arid regions, relative humidity may approach 10% or less during summer months. This, coupled with temperatures greater than 32 °C, results in water use rates that are much greater than might be observed in more humid regions.

As discussed previously, solar radiation increases ET by increasing temperature. Feldhake (35) and Aurasteh (3) found a linear relationship between increasing solar radiation and the ET rate of Kentucky bluegrass (Poa pratensis L.). Another study (37) evaluated the possibility of preconditioning 'Merion' Kentucky bluegrass to shade, and thereby reducing its ET rate in full sun. Results indicated that water use rates were not influenced by preconditioning to shade. When turf was removed from the shade and exposed to full sun, ET rates were similar to turf which had been exposed to full sun for the duration of the study. Lower ET rates of turf in shady areas suggests

that irrigation should be adjusted to avoid applying excessive amounts of water.

Wind affects turfgrass ET by changing the vapor pressure gradient between the plant and the atmosphere (45). A narrow layer of water vapor, commonly referred to as the boundary layer, develops above and below the leaf. The presence of this boundary layer minimizes the vapor pressure gradient, and its thickness governs the magnitude of the gradient. Wind increases ET rates by disturbing this layer of high humidity and thereby allowing greater water loss to occur from the leaf to the atmosphere. Grace (45) and Grace and Russell (46) conducted studies to evaluate the influence of wind on plant anatomy and water relations of tall fescue (Festuca arundinacea Schreb.). Grace (45) found that the transpiration rate of 'S170' tall fescue increased as wind speed increased from 1 m s⁻¹ to 3.5 m s⁻¹ above the sward. At lower wind speeds, disruption of the boundary layer resulted in increased water loss. At higher wind speeds, however, stomatal and cuticular resistance decreased, accelerating water loss. Leaf collision at higher wind speeds caused abrasions which accelerated water loss through the plant cuticle. Grace and Russell (46) found that tall fescue plants exposed to wind speeds of 0.5 to 1.0 m s⁻¹ developed more and smaller stomata. In addition, osmotic potential was much lower in wind-treated plants than those not exposed to wind. Wind-grown plants were less able to restrict water loss than plants exposed to drought rather than wind. In Colorado (35), research found that 30% of the water lost by 'Merion' Kentucky bluegrass could be attributed to advective forces.

Plant Factors Affecting Evapotranspiration

Plant factors are just as significant as environmental conditions in influencing plant water use rates. One of the most important plant parameters governing ET is the species, and to a lesser extent, the cultivar. Evapotranspiration rates are quite variable at the inter- and intraspecies levels. Other plant related factors influencing ET include xeromorphic features, such as stomatal characteristics and leaf rolling, growth habit, and canopy configuration. Variability among species and cultivars in ET can usually be directly related to these factors. Extensive research has been conducted to discern differences in ET rates among turfgrass species. Little information is available at the intraspecies level, however. Much of the research that has been done focused on determining ET rates under non-limiting soil moisture conditions (35,72,58). This is commonly referred to as potential ET.

Several studies have been conducted to determine water use rates of warm season (C₄) turfgrass species (31,59,58,60,9). Beard (9), citing research conducted in Texas, ranked water use rates into several categories, and also listed corresponding ET rates of several warm season turfgrasses which are presented in Table 1 on the following page.

Table 1. Potential ET rates of several warm season turfgrass species.

<u>Ranking</u>	<u>Potential ET (mm day⁻¹)</u>	<u>Species</u>
V. Low	< 6.0	Buffalograss [<u>Buchloe dactyloides</u> (Nutt.) Engelm.]
Low	6-7	Bermudagrass (<u>Cynodon dactylon</u> L. Pers.) Centipedegrass [<u>Eremochloa ophiuroides</u> (Munro.) Hack.] Zoysiagrass (<u>Zoysia japonica</u> L.) Blue grama [<u>Bouteloua gracilis</u> (H.B.K.) Lag. ex Steud.]
Medium	7-8.5	'Emerald' zoysiagrass (<u>Zoysia japonica</u> L. x <u>Z. tenuifolia</u> Willd. ex Trin.) St. Augustinegrass [<u>Stenotaphrum secundatum</u> (Walt.) Kuntze] Seashore paspalum (<u>Paspalum vaginatum</u> Swartz.) Bahigrass (<u>Paspalum notatum</u> Flugge.)

Kim (58) studied ET rates of 11 warm season turfgrasses grown in Texas. Results showed that 'Emerald' zoysiagrass exhibited the lowest ET rate (4.8 mm day⁻¹), while 'Texas Common' St. Augustinegrass used the greatest amount of water (6.3 mm day⁻¹). 'Tifgreen' bermudagrass, 'Common' bermudagrass, and 'Meyer' zoysiagrass were intermediate water users. In Arizona (59), bermudagrass and zoysiagrass used similar amounts of water when sub-irrigation was employed. Annual means demonstrated that St. Augustinegrass used significantly more water than bermudagrass and zoysiagrass. In a separate study (60),

water use rates of bermudagrass were determined under three, excessive irrigation regimes. Researchers concluded that ET increased with increasing levels of irrigation. When irrigated at 254, 540, and 808% of water loss from a class A evaporation pan, corresponding bermudagrass ET values were 68, 109, and 119%, respectively, of a class A pan. In Alabama (31), the average ET rate of coastal bermudagrass was 8 mm day⁻¹ the second day following irrigation. Water use decreased to 6 mm day⁻¹, however, when measured 28 days after watering.

Much of the research aimed at determining water used by cool season turfgrass species has been conducted in Colorado (26,35,72). Danielson et al. (26) used lysimeters to determine water use rates of Kentucky bluegrass in two Colorado cities during a summer. Results showed that Kentucky bluegrass had an average ET rate of 5.1 mm day⁻¹ in Fort Collins, and 5.6 mm day⁻¹ in Northglenn. Feldhake (35) found that 'Merion' Kentucky bluegrass used a total of 567 mm of water between 30 June and 18 November, 1979, and 956 mm between 12 March and 11 November, 1980 in Fort Collins, Colorado. In another Colorado study (72), tall fescue used 16% more water than Kentucky bluegrass, 14% more than perennial ryegrass (Lolium perenne L.), and 18% more than fine fescue (Festuca rubra L.) between June and September in one summer. Biran et al. (14) found that 'Alta' tall fescue used significantly more water than 'Pennfine' perennial ryegrass in Israel. Finally, in Nevada (97), a mixture of Kentucky bluegrass, fine fescue, meadow fescue (Festuca elatior L.), chewing fescue (Festuca rubra var. commutata Gaud.) and white clover (Trifolium

repens L.) had an average ET rate of 5.1 mm day⁻¹ between July and September.

Several studies have compared ET rates between warm and cool season turfgrasses (14,38,58). Generally, cool season species exhibited higher water use rates than warm season species. In Texas (58), 'Kentucky 31' tall fescue used 16% more water than 'Texas Common' St. Augustinegrass, and 47% more than 'Emerald' zoysiagrass. Biran et al. (14) found that 'Alta' tall fescue and 'Pennfine' perennial ryegrass had higher ET rates than nine warm season species. In Colorado (38), Kentucky bluegrass and tall fescue, cool season grasses, used over 20% more water than 'Tifway' bermudagrass and buffalograss, warm season species. A paucity of information exists concerning intraspecies differences in ET rates. Shearman (86) evaluated twenty cultivars of Kentucky bluegrass in a growth chamber to determine ET variability. Water use ranged from 3.9 mm day⁻¹ for 'Enoble' Kentucky bluegrass, to 6.3 mm day⁻¹ for 'Birka', 'Sydsport', and 'Merion'. Such studies demonstrate that proper selection of turfgrass species and cultivars is essential to maximize water conservation.

Variability in ET among turfgrass species and cultivars may be related to plant xeromorphic characteristics. These include differences in stomatal density and regulation, and leaf rolling or folding characteristics (7). Results of studies investigating the influence of stomatal characteristics on ET have not been consistent. Shearman and Beard (87) found differences in stomatal density among cultivars of creeping bentgrass (Agrostis palustris Huds.). 'Penncross' creeping bentgrass possessed significantly more stomata (94.3 mm⁻²) than 'Emerald' (77.3 mm⁻²). In a subsequent paper (88), 'Penncross'

stomatal density increased with increasing light intensity.

Furthermore, a positive correlation was reported between stomatal density and water use rate. Results of other studies (29,54) suggested that plant stomatal characteristics have little influence on ET and drought resistance. Dernoeden and Butler (29) evaluated stomatal characteristics of 12 cultivars of field grown Kentucky bluegrass attempting to relate drought resistance to stomata number and size. No correlation was found between stomatal characteristics and drought resistance when data were collected from adaxial and abaxial leaf surfaces. In a controlled environment, Johns et al. (54) found that genetic control of stomatal resistance in St. Augustinegrass would not result in increased water savings. They concluded that ET was two to four times more dependent on factors external to the plant, such as air and canopy resistance. Recently, Shearman (86) found no correlation between stomatal density or index and ET rates of 20 Kentucky bluegrass cultivars in a controlled environment.

Leaf rolling and folding are additional measures which turfgrasses employ to minimize water loss. Decreasing plant water potential results in collapse of bulliform cells, thereby causing the leaf to roll or fold (7). This reduces the amount of leaf surface area and number of stomata exposed to the ambient environment. Other xeromorphic features important in regulating plant water loss include cuticle thickness, presence of surface hairs, and amount of intercellular space. Essentially no research has been conducted with turfgrass to determine the importance of these factors in ET regulation.

In addition to xeromorphic features, turfgrass rooting characteristics also influence ET (7). Water use rates may differ

depending upon root number and depth. Tall fescue, a cool season turfgrass developing a deep, extensive root system, has been shown to use more water than most other species. This could be due to its ability to absorb more water by exploring a greater soil area. Tall fescue, however, also appears to be an exceptionally drought resistant turfgrass. Hence, there is no direct relationship between turfgrass water use rates and drought resistance (8). Species having a low root to shoot ratio generally require more frequent irrigation to prevent wilting. Deep, extensive root systems do not necessarily result in high water use rates, however. Bermudagrass, for example, has a deep root system, but exhibits relatively low ET rates (9,104).

Probably more significant than rooting in affecting turfgrass ET are growth habit and canopy configuration. Species that exhibit a prostrate growth habit tend to have lower ET rates (58). These grasses are low to the ground and are not exposed to turbulent air flow that might be experienced by species with more upright growth habits. Growth rate has also been positively correlated with ET (58,86). In Texas (58), highest ET rates occurred with 'Texas Common' St. Augustinegrass and seashore paspalum which had vertical leaf extension rates of 7.4 and 7.5 mm day⁻¹, respectively. A low ET rate was observed with 'Common' centipedegrass which had a vertical leaf extension rate of 2.5 mm day⁻¹. Shearman (86) found a positive correlation between vertical extension rate and ET of twenty Kentucky bluegrass cultivars. 'Adelphi' Kentucky bluegrass, a relatively low water user, had an average leaf extension rate of 10 mm week⁻¹. 'Sydsport', possessing a high ET rate, exhibited a leaf extension rate of 15 mm week⁻¹.

Plant density has also been shown to have a significant influence upon ET rate (69,58,86). Marlatt (69) evaluated the ET rate of orchardgrass (Dactylis glomerata L.) at 100, 70, 30, and 0% density. Greatest water loss occurred from plots of only 50% density. At 70% density, ET was higher than at full cover. Orchardgrass planted at 30% density, however, exhibited a lower water use rate than full cover plots. Grass growing in plots of 50 and 70% density used more water due to a phenomenon referred to as the "clothesline" effect. An open canopy allowed movement of air around plants, thereby increasing water loss due to advective forces. In addition, temperature measurements indicated that air directly above bare ground was warmer than that above a full cover canopy. The warmth of the air circulating through plots of 50 and 70% cover also contributed to the increased ET rates. Below 50% cover, the plant population was so low that ET losses were most likely due primarily to evaporative water lost from fallow soil. Results of other studies (58,86) have also suggested that increased plant density decreases ET. In Texas (58), low ET rates of twelve warm season turfgrasses were associated with high shoot density. Shearman (86) noted that ET increased with decreasing shoot density and verdure when studying water use rates of 20 Kentucky bluegrass cultivars.

Soil Factors Influencing Evapotranspiration

Because turfgrass growth is greatly dependent upon existing soil characteristics, ET rates are also affected. Soil properties that influence water movement are soil water potential, saturated and unsaturated flow characteristics, and soil moisture content (22).

Therefore, it is primarily the soil physical characteristics that influence turfgrass water use rates. Research evaluating the effects of soil texture (38), soil structure (80,91,1), and soil moisture availability (14,58) on turfgrass water use has been conducted.

In a greenhouse study (80), the water use of 'Derby' perennial ryegrass grown in a silt loam soil was evaluated under moderate and heavy soil compaction. Evapotranspiration was reduced by 21 and 41% for the moderate and heavy compaction treatments, respectively. In addition, water extraction from a 10-25 cm depth decreased 42% when a heavy compaction treatment was applied. This was attributed to decreased root density and poorer turf quality after compaction. Similar results were obtained with 'Pennfine' perennial ryegrass (91) and 'Ram I' Kentucky bluegrass (1) in separate greenhouse studies. The influence of soil compaction on turfgrass root growth and water use suggests that less water is required in compacted areas.

Proper irrigation has been shown to reduce compaction, and, therefore, plant water use. Morgan et al. (75) observed that soil compactibility was greater under set irrigation schedules compared to irrigation done according to tensiometer readings.

Little information is available concerning the effect of soil texture on turfgrass ET rates. In Colorado (38), the water use of 'Merion' Kentucky bluegrass growing on a sand-peat mixture or clay was observed over two seasons. Results showed that during the first year, water use rates were essentially the same on both soil textures. The second year, however, Kentucky bluegrass ET rates were six percent lower on the clay soil than the sand-peat mixture. This may

have been due to reduced rooting in the clay soil which has been observed in other research (34).

Soil water availability has also been shown to influence turfgrass ET rates. Biran et al. (14) found that the water use rates of two cool season and nine warm season grasses declined with decreasing soil water. Similar results were obtained in Texas with warm season turfgrasses (58). Again, ET rates declined as less soil water was available for plant absorption. It is also possible that soil moisture influences turfgrass ET by affecting soil temperature. Feldhake and Boyer (37) found that ET rates of two warm and cool season grasses increased with increasing soil temperature. In general, soils with greater water content tend to be cooler. Hence, in some instances, such as early spring when soils are cold and wet, ET rates may be lower in soil with greater water content.

Essentially no work has been done to evaluate the effect of soil chemical characteristics on turfgrass ET. It is possible that soil salt levels may influence water use rates by decreasing the soil osmotic potential and thereby making water less available to the plant. Research is needed in this area.

Cultural Factors Affecting Evapotranspiration

In addition to edaphic factors, cultural practices have also been shown to have a significant effect upon turfgrass water use rates. Research has been conducted to evaluate the influence of mowing, irrigation, fertility, pests and pesticides, antitranspirants, and plant growth regulators on ET. Because a wealth of information is available on several of these, each will be discussed individually.

Several researchers have reported a relationship between turf mowing height and water use (68,35,14,38). In California (68), 'Merion' Kentucky bluegrass mowed at 1.2 cm used less water than that cut at 5 cm. Plants cut at the lower height also possessed a more shallow root system. Biran et al. (14) found increased vigor and water use when the mowing height of eleven turfgrass species was raised from 3 to 6 cm. In Colorado (38), 'Merion' Kentucky bluegrass used 15% more water when cut at 5 cm compared to 2 cm. A taller canopy subjected the plants to a greater influence by advective energy. These results indicate that water use decreases with decreasing mowing height. However, most researchers agree that a taller cut allows development of a plant which is a more efficient water user (i.e., better turf quality after a given amount of water is transpired), primarily due to a deeper root system. In general, drought resistance is greater when turf is maintained at a taller height (28).

Research in Nebraska (94) evaluated the effect of mower blade sharpness on the water use of a Kentucky bluegrass blend. Turf mowed with a sharp blade used approximately 1.3 times more water than that cut with a dull blade. This was attributed to poor turf quality and reduced vigor of turf in plots where a dull blade was employed.

Irrigation frequencies and amounts appear to influence turfgrass ET rates as much as mowing practices. An earlier discussion cited research focusing on the effects of soil moisture availability on water use rates. As noted, ET decreased with decreasing soil water. Additional work has been done to elucidate turfgrass ET under varying irrigation amounts and frequencies (75,90,43,60). In a greenhouse

study, Morgan et al. (75) found that 'Common' bermudagrass used significantly more water when irrigated with 1.2 cm of water three times weekly compared to irrigation done according to tensiometer readings. Hence, turf grown on wetter soil used more water than that maintained under drier conditions. Silcock and Wilson (90) compared transpiration rates of moisture stressed and non-stressed Festuca spp. after watering the stressed plants well for two days following treatment. Transpiration was greater in plants that had been exposed to moisture stress, and then watered well. In addition, water use efficiency was greatest in plants exposed to prolonged water stress (383 mg shoot dry matter 100 g⁻¹ H₂O), and least in plants suffering intermittent water stress (301 mg shoot dry matter 100 g⁻¹ H₂O). In Texas (43), soil water extraction by bermudagrass was evaluated at several irrigation amounts and frequencies. The authors found that water was extracted 1.5-2 feet deeper by bermudagrass irrigated infrequently (one irrigation between 29 July and 23 September) compared to that watered frequently (four irrigations over the same period) with less water. In addition, soil in plots irrigated with less water frequently was wetted to more shallow depths than that in plots receiving more water on an infrequent basis. Turf irrigated frequently had the poorest quality. In another study involving bermudagrass (60), ET rate increased with increasing water application. Additional literature citing the effects of irrigation frequencies and amounts on turfgrass root growth will be discussed later.

Soil fertility is another cultural practice shown to influence turfgrass ET. Most of the work done in this area has investigated the influence of nitrogen on water use rates (63,91,35,38). In Canada (63),

nitrogen, applied at a total of 211 and 420 kg ha⁻¹ over two years increased the ET rate of a mixture of orchardgrass, smooth brome grass (Bromus inermis Leyss.), and creeping red fescue. Water use efficiency, however, also increased with nitrogen applications. In a greenhouse study evaluating the effects of nitrogen and soil compaction on 'Pennfine' perennial ryegrass, nitrogen applications increased ET rate (91). These researchers also observed increased water use efficiency in turf receiving nitrogen. In Colorado (38), nitrogen-deficient 'Merion' Kentucky bluegrass used 14% less water than turf receiving supplemental nitrogen fertilization. Although nitrogen deficient turf used less water, the authors noted that this grass could be more susceptible to injury with the onset of stress. Research also showed that 'Merion' Kentucky bluegrass deficient in nitrogen exhibited a rapid decline in quality when subjected to moisture stress (35). Well fertilized turf, however, performed more favorably at lower soil moisture levels. Although nitrogen has been shown to influence turfgrass water use rates, essentially no information is available on the effects other elements, such as phosphorus, potassium, and iron, may have on water use.

In addition to soil fertility, pests and pesticides may also influence turfgrass water use. Several pesticides, particularly preemergence herbicides, have been shown to inhibit turfgrass root growth (33,56,40). Although not documented, it is possible that turf that has experienced herbicide-induced inhibition of root growth may use and require less water. This, of course, is not a practical management consideration for conserving water. Little work has been done to determine the effect turfgrass pests have on ET rates. It is

possible that root feeding insects, such as Japanese beetle grubs (Popillia japonica Newm.) reduce turf water use and require that water be applied more frequently due to restricted rooting. Again, much needed information has not been documented through research.

One study was conducted to elucidate the influence of smut diseases [Ustilago striiformis (Westend.) Niessl. and Urocystis agropyri (Preuss) Schroter] on the drought survival of Kentucky bluegrass (77). Infected plants had lower root to shoot ratios and were more susceptible to drought injury than non-infected plants. Information on ET rates of infected plants was not published.

It has been shown that irrigation scheduling can influence pest problems. Fungi, for example, cannot develop and complete their lifecycle without sufficient water. Hence, judicious use of water could contribute to reductions in problems with turf fungal pathogens, as well as other turf pests.

There are certain measures that can be taken to limit transpiration and thereby conserve water. Some research has been conducted to determine the effectiveness of antitranspirants and plant growth regulators in reducing turfgrass transpiration rates (27,53,66). Davenport (27) evaluated two antitranspirants on creeping red fescue for effectiveness in reducing water loss without phytotoxicity. Results showed that phenylmercuric acetate (PMA) gave a 20% reduction in transpiration with no growth inhibition. The chemical was most effective when used under conditions of low soil moisture and cool temperatures. In Maryland (66), several antitranspirants were compared for use on newly transplanted Kentucky bluegrass sod.

Results showed that antitranspirants were not effective in reducing environmental stress experienced by the turf.

Plant growth regulators (PGRs) have been extensively evaluated for use in limiting turfgrass growth and reducing mowing requirements. Little work has been done, however, to determine the effectiveness of PGRs in reducing turfgrass ET rates. In Texas (53), flurprimidol was applied to St. Augustinegrass and data were collected on ET rates. When applied at three rates, water loss in flurprimidol treated plots was 11 to 29% less than untreated controls. Additional work is needed to determine the effectiveness of PGRs in reducing turf water use.

Drought and Turfgrasses

Much of the work done to determine turfgrass ET rates was performed under conditions where soil water was not limiting. In the field, of course, sufficient water is not always present to meet plant requirements. Drought stress occurs when the soil has been depleted of water to the point that the plant begins to suffer. Although a plant may experience the stress that results from lack of water, injury does not result until strain occurs (64). Severe drought strain may result in plant death.

Turfgrasses, as well as other plants, may resist drought through tolerance, avoidance, or escape (64). Plants that tolerate drought experience stress, but adjust to it internally so that injury is minor, or does not occur. Drought avoiders do not experience the stress. For example, tall fescue, with its deep root system, often avoids drought by extracting water from deep in the soil. Some plants escape drought by completing their life cycle before stress begins.

Annual bluegrass (Poa annua L.) is one turfgrass that uses escape to resist drought.

A wealth of information has been presented on the drought resistance of warm and cool season turfgrasses (21,28,89,82,76,73,20). Table 2 lists the relative drought resistance of several cool season turfgrasses.

Table 2. Drought resistance of cool season turfgrass species (20).

<u>Resistance Level</u>	<u>Characteristics of Drought</u>	<u>Species</u>
Excellent	Frequent, Severe	Blue grama Buffalograss Russian wildrye (<u>Elymus junceus</u> Fisch.) Sheep fescue (<u>Festuca ovina</u> var. <u>duriuscula</u> L. Koch) Bermudagrass
Good	Occasional, Long term	Fairway wheatgrass [<u>Agropyron</u> <u>crisatum</u> (L.) Gaertn.] Western wheatgrass (<u>Agropyron smithii</u> Rydb.) Smooth bromegrass Hard Fescue
Medium	Frequent, Moderate	Kentucky bluegrass Tall Fescue Perennial ryegrass Fine fescue Orchardgrass
Poor	Infrequent, Short	Creeping bentgrass Rough bluegrass (<u>Poa trivalis</u> L.) Annual bluegrass

Several studies have been performed to elucidate the drought resistance of cool season turfgrasses at the inter- and intraspecies

levels. In an early study, Carroll (21) compared the atmospheric drought resistance (i.e., drought caused by warm temperatures and wind under adequate soil moisture) of several cool season grasses. Fescues were the least drought resistant, while Kentucky bluegrass was one of the most drought resistant species. In Colorado (28), 25 Kentucky bluegrass cultivars were evaluated under drought. In general, common types were more tolerant to low soil moisture than improved cultivars. 'Code 95', a common type, and 'Merion' exhibited best quality under restricted irrigation. In another Colorado Study (73), cultivars of Kentucky bluegrass, perennial ryegrass, and fine fescue were grown without irrigation for two consecutive summers. 'Majestic' and 'H-7' Kentucky bluegrass showed better drought resistance than other cultivars; whereas, 'Aristocrat', 'Bellatrix', 'Citation', and 'Yorktown' perennial ryegrass performed better during drought than other cultivars of this species. None of the fine fescues provided suitable turf during drought periods or recovery after drought stress. In general, the hard fescues were more drought resistant than other fine fescues. Norris (76) evaluated perennial ryegrass and tall fescue under low soil moisture. Results showed that perennial ryegrass was more sensitive to drought. In Missouri (89), tall fescue was found to have better drought resistance than Kentucky bluegrass or perennial ryegrass. Root samples taken from the field showed that tall fescue had a greater portion of roots at lower soil depths. Consequently, it could absorb more water deeper in the soil profile. Perennial ryegrass exhibited root growth that was intermediate to tall fescue and Kentucky bluegrass.

Information concerning the drought resistance of warm season turfgrasses is limited. Burton et al. (18) compared rooting depth to drought resistance in several warm season turfgrass species. Three months after planting sod plugs, coastal bermudagrass had a root system reaching a depth of eight feet, common bermudagrass-four feet, and common and 'Pensacola' bahiagrass-two feet. The authors concluded that drought susceptible turfgrasses had over 90% of their root system in the top two feet of the soil profile. In general, the ability of most warm season turfgrasses to develop a deep, extensive root system provides a mechanism for drought avoidance.

Some work has been done to identify the turfgrass organs most susceptible to drought stress. Nus and Hodges (78) found that the lateral bud meristems of 'Merion' Kentucky bluegrass were most sensitive to decreasing water potential of the medium. This was suggested as an explanation for decreased tiller and rhizome development under drought stress.

Research using grasses has been conducted to determine the effect of water stress on plant growth (50,57,12,76), photosynthesis (16,57,102), and nitrogen and carbohydrate metabolism (50,102,12,11). Jones et al. (57) observed that drought decreased dry matter accumulation and leaf extension in 'S-24' perennial ryegrass. In England (76), soil moisture deficits reduced crop growth rate, leaf extension rate, and tiller number of perennial ryegrass and tall fescue. Additional research has been reported confirming growth reduction in tall fescue under drought stress (50,102,12).

Plant water deficits have also been shown to reduce photosynthesis in turfgrass. Jones et al. (57) noted that the water

potential within the leaves of well irrigated 'S-24' perennial ryegrass was approximately -1.2 MPa; whereas, plants growing in dry soil had a daytime leaf water potential of -1.6 MPa. This decrease in plant water potential resulted in stomatal closure in stressed plants, and photosynthesis declined approximately 40%. Hence, a decrease in internal CO₂ concentration lead to decreased photosynthesis.

Nonstomatal drought inhibition of photosynthesis has also been demonstrated. Boyer (16) observed that photosynthesis declined in drought stressed sunflower (Helianthus annuus L.) even when internal CO₂ concentration was maintained at an adequate level. This suggested that other plant metabolic processes involved in CO₂ fixation were also inhibited.

Several studies have been done to determine the effects of drought stress on carbohydrate and nitrogen metabolism in tall fescue. Although drought stress decreases plant growth, researchers have observed that tall fescue exhibits rapid growth following a period of drought (50,102,12,11). In Missouri (50), fall growth of 14 tall fescue cultivars that had experienced water stress through the summer was greater than plants that were not stressed. This was attributed to an accumulation of carbohydrates during drought. In a controlled environment, Wolf and Parrish (102) found that tall fescue tillers that experienced short term, severe drought stress displayed rapid elongation after rewatering. Tillers of plants exposed to drought stress for greater than 24 hours, however, were slower to recover after rewatering. Belesky et al. (12) reported that nitrate-nitrogen concentrations increased over 400% in several tall fescue cultivars exposed to drought stress. This may contribute to increased growth

following drought. In the same paper, successive drought cycles were reported to precondition tall fescue to future stress. Results showed that with successive drought, changes in plant water potential were minimized. This resulted in a plant less susceptible to drought injury. In another study, Belesky et al. (11) found that mild drought stress increased the soluble protein fraction of plant nitrogen by about 20%. It was suggested that this was due to decreased protein breakdown during drought stress. Again, this reservoir of nitrogen may contribute to post-stress growth enhancement of tall fescue.

One study (10) investigated the possibility of increasing turfgrass heat tolerance by the imposition of drought stress. Kentucky bluegrass, perennial ryegrass, red fescue, and weeping alkaligrass [*Puccinellia distans* (L.) Parl.] did not show increased heat tolerance under drought stress.

It is clear that drought can greatly affect plant growth. If irrigation is available, drought can be avoided. There are numerous methods employed to estimate turfgrass water use rates.

Measuring and Estimating Evapotranspiration

Several methods have been developed to estimate turfgrass ET losses. These include soil moisture measurement; pan evaporation; estimation of heat flux from the turf canopy; empirical formulae; lysimeters; and infrared thermometers. Youngner et al. (105) compared the quality of two warm and cool season grasses irrigated as follows: 1) By common practice; 2) According to soil moisture level determined with a tensiometer; 3) Based upon pan evaporation. Results showed that most efficient irrigation was done according to tensiometer

readings and an evaporation pan. In another California study (71), warm and cool season turfgrass ET rates were estimated at 70 and 80%, respectively, of a class A evaporation pan.

Johns et al. (55) developed a method for estimating turfgrass ET using equations that predicted resistance to heat flux density from the turf canopy. They found good correlation between estimated and measured ET values.

Several empirical formulae have also been used to estimate turfgrass ET. These are numerous, and include the modified Blaney-Criddle, Jensen-Haise, Penman, and Hargreaves. Each of these uses meteorological data to estimate plant water loss. For example, the Blaney-Criddle equation is represented as:

$$U = 25.4 K \frac{t \times P}{100}$$

where: U = turfgrass consumptive water use in mm month⁻¹
 t = mean temperature in °F
 P = mean percent of daylight hours for the time of year
 K = coefficient derived from a simple calculation

Several researchers have compared actual turfgrass water use rates to those derived from empirical equations (48,81,2,3). In Colorado (48), ET estimates from the Jensen-Haise and Blaney-Criddle formulae were compared to actual turfgrass water use. The Blaney-Criddle method tended to underestimate actual ET, while the Jensen-Haise technique was more accurate. O'Neill et al. (81) attempted to calibrate the Blaney-Criddle formula using actual ET data, to provide a better estimate of lawn water use in the West. In Kuwait (2), ET estimates from the Jensen-Haise and Penman equations were compared

to bermudagrass ET. The correlation between the two empirical methods was 0.97. Both equations slightly underestimated actual water use rates. Aurasteh (3) found a good correlation between the Hargreaves, Penman, Jensen-Haise, and modified Blaney-Criddle methods, and actual water use by Kentucky bluegrass in Utah.

Although empirical formulae provide a reasonably accurate estimate of ET, lysimeters provide actual plant water loss information. Lysimeters are containers holding a medium supporting plant growth, and water application is governed by the researcher. Water loss can be monitored by periodic weighing, such as with small, bucket lysimeters, or with other, non-weighing methods (95). Hence, ET rates can be determined over a short period of time or an entire growing season. Several researchers have employed small, weighing lysimeters to effectively monitor turfgrass ET (34,35,58,72).

Infra-red thermometers may become a valuable tool for use in irrigation scheduling. Researchers have found a relationship between plant water status and canopy temperature (32,38). Infra-red thermometers have been employed to estimate wheat water potential (32). In Colorado (38), the canopy temperature of 'Merion' Kentucky bluegrass increased 1.7 °C for each 10% decrease in irrigation below 100% of potential ET. Further work with infra-red thermometers may someday allow irrigation scheduling to be guided by canopy temperature.

Turfgrass Water Conservation

Several factors influence the amount of water required on a turf area, including type and efficiency of the irrigation system, specific

site characteristics, and turfgrass species and cultivar. Aurasteh et al. (4) evaluated the water management efficiency and sprinkler distribution uniformity on 20 home lawns in Logan, Utah. They found that distribution uniformity was greater with solid-set underground systems than above ground mobile sprinklers. Distribution uniformity was less than 40% for both, however. When uniformity was disregarded, homeowners with solid-set systems applied 38% more water than the grass required, while those with above ground sprinklers applied 16% less than the turf needed. A sprinkler system operating at 60% uniformity must deliver 33% more water than a system at 80% uniformity to achieve the same results (70). Meyer and Camenga (70) also suggested that low application rate sprinklers, soil moisture sensors, rain sensors, wind sensors, drainage check valves, and repeat-cycle and variable-watering programmed controllers can be employed for water savings.

Specific site characteristics, such as soil type and slope, will also influence irrigation practices. Cyclic irrigation, repeated watering at short intervals, or the use of low application rate sprinklers may be required to avoid runoff on steep sites. In addition, water can also be conserved by watering at night, and when there is little or no wind.

As previously discussed, it has been demonstrated that some turfgrass species use more water than others. The use of grasses requiring less water in remote areas can provide significant water savings (19).

Several researchers have conducted studies to determine the effects of deficit irrigation on turfgrass growth (6,3,39,72,44). Deficit irrigation simply refers to water application in some amount less than

the grass would use if it were available. In Colorado, Beach (6) irrigated Kentucky bluegrass on two, four, and seven-day intervals with sprinklers delivering 0.2 to 2 inches of water weekly. Results showed that the interval did not influence turfgrass quality as much as the amount of water applied. Plots receiving 0.5 inches of water weekly did not have acceptable quality. One inch of water weekly was sufficient to maintain quality, but 2 inches was no better than 1. Hence, excessive irrigation did not provide an increase in quality over turf irrigated according to potential ET. In one year of the study, turf irrigated on two-day intervals exhibited better quality than that watered on four, six, or eight-day intervals. Feldhake et al. (39) reported that the quality of 'Merion' Kentucky bluegrass decreased approximately 10% when irrigated at a 27% deficit. Minner (72) irrigated 'Merion' at 100, 75, 50, 25, and 10% of potential ET on two, four, seven, or fourteen day intervals in Colorado. Turf appearance improved as water application amount increased and interval decreased. When watered on two and four day intervals, 73 and 85% of potential ET were required to produce acceptable quality turf, respectively. Hence, little reduction in quality resulted after reducing irrigation by over 25% of what the turf would have used, had it been available. Aurasteh (3) also reported that turf quality increased as irrigation increased between 60 and 100% of potential ET. In California (44), Kentucky bluegrass, perennial ryegrass, and tall fescue exhibited only slightly lower quality when watered at 80%, compared to 100% of potential ET. Poorer quality resulted when turf was irrigated at 60% of potential ET, and a longer period of time was required for recovery.

Concern has been expressed about the effect of irrigation interval on turfgrass root growth. Information is lacking in this area, although some work has been done (6,83). In Colorado (6), Beach found that greatest Kentucky bluegrass root growth between 0-6 inches occurred in plots receiving minimal amounts of water at intervals of seven days or more. In general, as more water was applied, and at shorter intervals, less root growth occurred. In Florida (83), root growth of St. Augustinegrass was unaffected when watered at two, three, four, or six day intervals. Danielson (25) noted that maximum root development should take place under optimum conditions. He further stated that it is possible that reducing the amount of surface water may allow a plant to survive a later drought due to decreased transpiration arising from restricted foliage development. More information is needed on the effects of irrigation on turfgrass root growth.

Chapter I.

EVAPOTRANSPIRATION RATES OF ANNUAL
BLUEGRASS AND CREEPING BENTGRASS

Chapter I. EVAPOTRANSPIRATION RATES OF ANNUAL
BLUEGRASS AND CREEPING BENTGRASS

Several studies over the past decade have focused on determining water use rates of turfgrasses. Information is available on ET rates of cool and warm season turfgrass species (26,35,58,72). Knowledge is lacking, however, on ET rates of creeping bentgrass (Agrostis palustris Huds.) and annual bluegrass (Poa annua L.). Creeping bentgrass is commonly used for putting green surfaces, but its use is increasing on golf course fairways. Annual bluegrass is not usually a desired species, but it often dominates turf stands due to its prolific seed production, preference for moist soil, and ability to withstand a low cutting height and soil compaction. Some work has been done to determine the influence of irrigation on creeping bentgrass growth (67,103,85). Madison (67) noted that frequent irrigation increased density, but decreased rooting of 'Seaside' creeping bentgrass. This study indicated that reducing the cutting height produced similar effects. In California (103), good drought survival was observed with 'Seaside' creeping bentgrass clones having a high root to shoot ratio, but low leaf area. Schmidt and Snyder (85) found that growth and photosynthesis of 'Penncross' creeping bentgrass decreased as soil moisture levels declined, but rooting was unaffected. Additional research (87,88,62,93) has evaluated soil moisture depletion by creeping bentgrass under various cutting heights and environmental conditions. In a controlled environment, Shearman and Beard (88) found drier soil

under 'Penncross' creeping bentgrass cut at 12.5 and 2.5 cm, compared to 0.7 cm.

Some research has been done to determine ET rates of creeping bentgrass. Most of these studies, however, were conducted over short periods of time, or under unique environmental conditions. In Michigan (87), 'Penncross' creeping bentgrass exhibited a mean ET rate of 7.9 mm day⁻¹ when evaluated over a one week period. Stahnke (93) observed that 'Penncross' used an average of 9.7 mm of water daily in a growth chamber over a period of two weeks. In Arizona (62), 'Penncross' had a mean ET rate of approximately 5.0 mm day⁻¹ when subirrigation was employed during summer months.

Little information is available concerning ET rates of creeping bentgrass maintained under putting green conditions over an extended period of time. Furthermore, information is lacking on water requirements of annual bluegrass. Therefore, the objectives of this study were to: 1) Determine the ET rates of creeping bentgrass and annual bluegrass under putting green conditions; and 2) Elucidate the effect of cutting height on water use by these species.

Materials and Methods

This research was conducted during the summers of 1985 and 1986 at the Plant Environmental Research Center in Fort Collins, Colorado. Evapotranspiration was measured using lysimeters described by Feldhake et al. (38) (Fig. 1.1). Twelve lysimeters were filled with sand described in Table 1.1. On 1 April, 1985, a 'Emerald' and 'Penncross' creeping bentgrass blend (1:1) was sodded in six lysimeters, while the remainder were sodded with annual bluegrass

obtained from a fairway at Collindale Golf Course in Fort Collins. Sod was cut to a depth of 2.5 cm, washed free of soil, and placed on the surface of the sand. Lysimeters remained in the greenhouse until placed in the field on 17 May, 1985. Turf in lysimeters was watered well until 5 June, 1985 when data collection began. In 1986, annual bluegrass was resodded in the greenhouse on 21 April. Creeping bentgrass used in 1985 remained in the field until 21 April, 1986 when lysimeters were placed in the greenhouse. All lysimeters were taken to the field on 17 May. Lysimeters were placed in sleeves located on a putting green consisting of a 'Penncross' and 'Emerald' creeping bentgrass blend. Lysimeters were set so that the top of the turf canopy was even with the canopy of the surrounding turf. This was done to provide a uniform microenvironment in and around lysimeter-grown turf.

"Field capacity" weights were determined by removing plugs from the base of lysimeters and watering until drainage occurred. Approximately 24 hours later, drain plugs were replaced, and lysimeters were weighed. A large triple beam balance, capable of weighing to the nearest gram, was employed to determine water loss. Water was applied with a graduated cylinder immediately after weighing. Lysimeters were covered during irrigation and natural precipitation. On occasions when rain occurred, and lysimeters were not covered, precipitation amount was included in ET determination. The area surrounding lysimeters was irrigated four to five days weekly. Lysimeters were weighed daily between 5 June and 3 Sept., 1985, and 4 June and 28 August, 1986.

Two mowing heights were evaluated for influence upon ET rate. Grass in lysimeters was clipped by hand six days weekly at 0.6 or 1.2 cm. The 0.6 cm height represented that of turf on a putting surface; whereas, the higher cut represented that on putting green collars and aprons. Turf surrounding lysimeters was maintained at a height similar to turf in lysimeters using a walk-behind greens mower.

Turf in lysimeters was fertilized with 49 kg N ha⁻¹ from 22N-1.8P-3.3K on 29 April and 23 July, 1985. Ammonium nitrate (33N-0P-0K) was applied at a rate of 25 kg N ha⁻¹ on 4, 8, and 22 June, 2 July, and 13 August, 1985. In 1986, 49 kg N ha⁻¹ from 22N-1.8P-3.3K was applied on 4 June; whereas, ammonium nitrate was applied on 26 April at 49 kg N ha⁻¹, and 24 June, 11 and 25 July, and 12 and 28 August at 25 kg N ha⁻¹. Fertilizer was dissolved in 200 ml water, and the resulting solution was distributed evenly over the surface of each lysimeter. This water application was taken into account when returning lysimeters to reference weight. The area surrounding lysimeters received 49 kg N ha⁻¹ month⁻¹ from ammonium nitrate both years.

Annual bluegrass suffered from melting out (Drechslera spp. and Bipolaris spp.) in July of both years. In 1985, chlorothalonil was applied to the entire study area at 30 kg ha⁻¹ on 10 July, and every five days thereafter until 7 August. To avoid infection in 1986, iprodione was applied preventively at 6.0 kg ha⁻¹ on 21 June, and 3, 7, and 14 July. Severe infection in both years resulted in no data collected on annual bluegrass ET after 10 July, 1985, and 19 July, 1986.

Statistical design was a split-plot with mowing height as the whole plot and species as the sub-plot. Species and mowing height were replicated three times. Weekly and seasonal means were used to identify significant differences in ET. Analysis of variance was performed using the Statistical Package for the Social Sciences (McGraw-Hill Publishing Company).

Results and Discussion

Mean daily ET rates for 1985 and 1986 are presented in Table 1.2. In 1985, there was no significant difference between annual bluegrass and creeping bentgrass in mean daily water use (Table 1.2). When weekly means were analyzed, however, there was a significant difference between species in ET during four weeks in 1985 (Fig. 1.2). During this period, annual bluegrass used an average of 0.3 mm day⁻¹ less water than creeping bentgrass. Figure 1.3 shows the ET rates of creeping bentgrass during the last six weeks of the study in 1985. During this period, ET ranged from 3.8 mm day⁻¹ between 4 and 10 August to 2.4 mm day⁻¹ between 18 and 24 August.

In 1986, creeping bentgrass had a significantly higher ET rate than annual bluegrass when data were averaged between 4 June and 19 July (Table 1.2). Figure 1.4 shows that when ET was calculated weekly, annual bluegrass had a lower water use rate than creeping bentgrass during 5 of 7 weeks. Greater creeping bentgrass ET occurred between late July and then end of August in 1986 than in 1985 (Fig. 1.5). Evapotranspiration ranged from 3.8 mm day⁻¹ to 5.0 mm day⁻¹ during this period.

The effect of mowing height on creeping bentgrass and annual bluegrass ET is presented in Tables 1.3. In 1985, cutting height did not significantly influence ET (Table 1.3). During one week, however, a significant species by mowing height interaction was observed. Between 30 June and 5 July, annual bluegrass exhibited a noticeable increase in water use when cut at 1.2 compared to 0.6 cm; whereas, creeping bentgrass used similar amounts of water at both mowing heights (Table 1.3).

In 1986, annual bluegrass and creeping bentgrass turf used significantly more water when mowed at 1.2 cm compared to 0.6 cm (Table 1.3). This agrees with previous research reporting greater water use of 'Penncross' creeping bentgrass turf maintained at 2.5 cm compared to 0.7 cm (88). After 10 July, 1985 and 27 July, 1986, mowing height had no effect on creeping bentgrass water use rates (Appendix Tables A.1 and A.2).

From these results, it is evident that greater differences in ET due to species and mowing height were observed in 1986 than 1985. This is likely due to very different environmental conditions experienced each year. In 1985, total precipitation between 1 June and 1 Sept. measured 171 mm; whereas, in 1986, 85 mm of rain fell (Appendix Table C.1). Greater periods of cloud cover, and the fact that lysimeters had to be covered during more frequent rainfall, may have contributed to different ET results between 1985 and 1986.

In summary, annual bluegrass exhibited a lower ET rate than creeping bentgrass during several weeks in 1985 and 1986; however, differences were quite small. Hence, irrigation amounts should not vary much between species. Water use rates were quite variable

through study periods. This suggests that water conservation and improved plant vigor will result if ET is monitored and irrigation is adjusted accordingly. Mowing height also influenced ET, and turf cut at 1.2 cm may require more water than that maintained at 0.6 cm. This could necessitate irrigation of putting green collars and aprons separately, and possibly more frequently than playing surfaces. Differences in creeping bentgrass and annual bluegrass water use between mowing heights were small, however, and did not appear to be agronomically significant under the conditions of this study.

Table 1.1. Particle size distribution of sand used in lysimeters for the creeping bentgrass and annual bluegrass study in 1985 and 1986.

Size (mm)	Distribution (% by weight)
> 2.0	7.0
1.0 - 2.0	25.9
0.5 - 1.0	31.4
0.25 - 1.0	23.2
0.125 - 0.25	9.1
< 0.125	2.9

Table 1.2. Mean evapotranspiration (ET) rates of annual bluegrass and creeping bentgrass in 1985 and 1986.

Species	ET ^Z (mm day ⁻¹)	
	1985	1986
Annual bluegrass	4.2	4.6*
Creeping bentgrass	4.2	4.9

^ZNumbers represent means between 6 June and 10 July in 1985, and 4 June and 19 July in 1986.

*Means in a vertical column are significantly different (P = 0.05).

Table 1.3. Mean evapotranspiration (ET) rates of annual bluegrass and creeping bentgrass in 1985 and 1986, and variable response of these species to increasing mowing height during one week in 1985.

Mowing height (cm)	ET (mm day ⁻¹)			
	1985 ^Z	1986	30 June - 5 July, 1985	
			Annual bluegrass	Creeping bentgrass
0.6	4.1	4.6*	3.9	4.4
1.2	4.4	4.9	4.3	4.4

^ZNumbers represent mean ET between 6 June and 10 July in 1985, and 4 June and 19 July in 1986.

*Means in a vertical column are significantly different (P = 0.05).

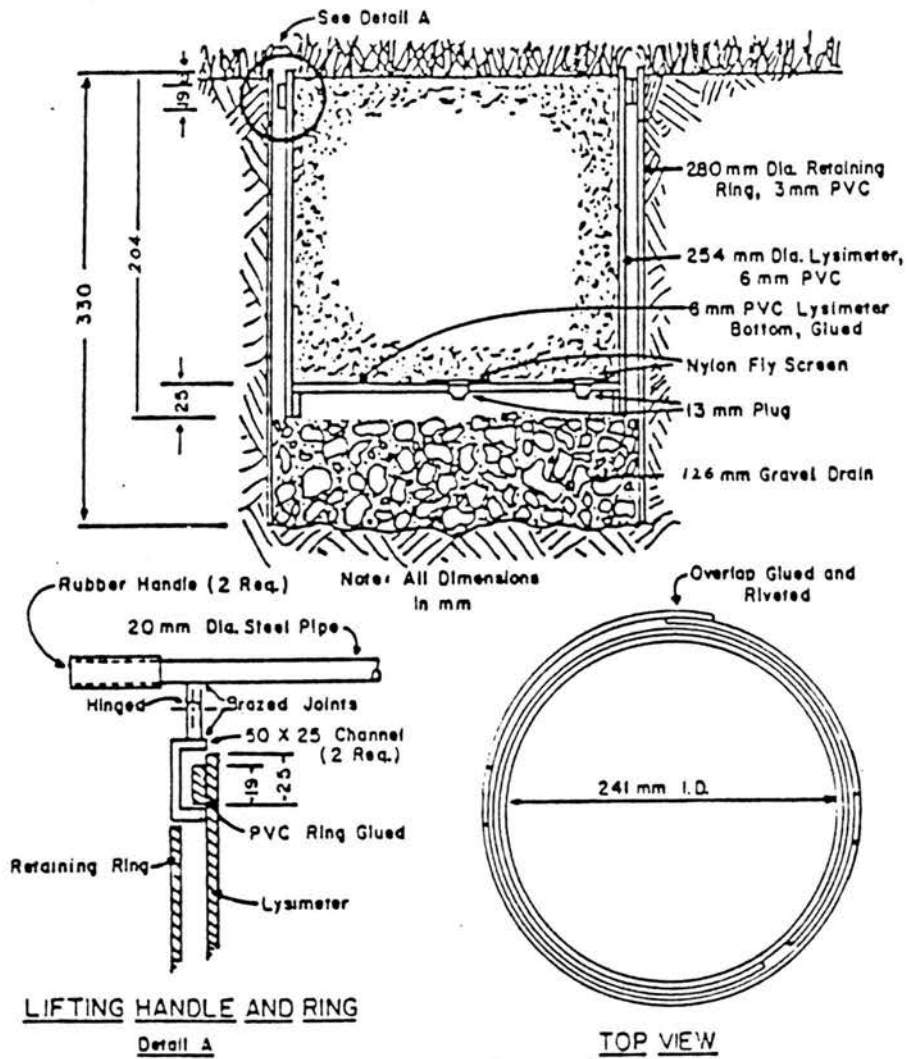


Figure 1.1. Schematic diagram of installed lysimeter and lifting handle.

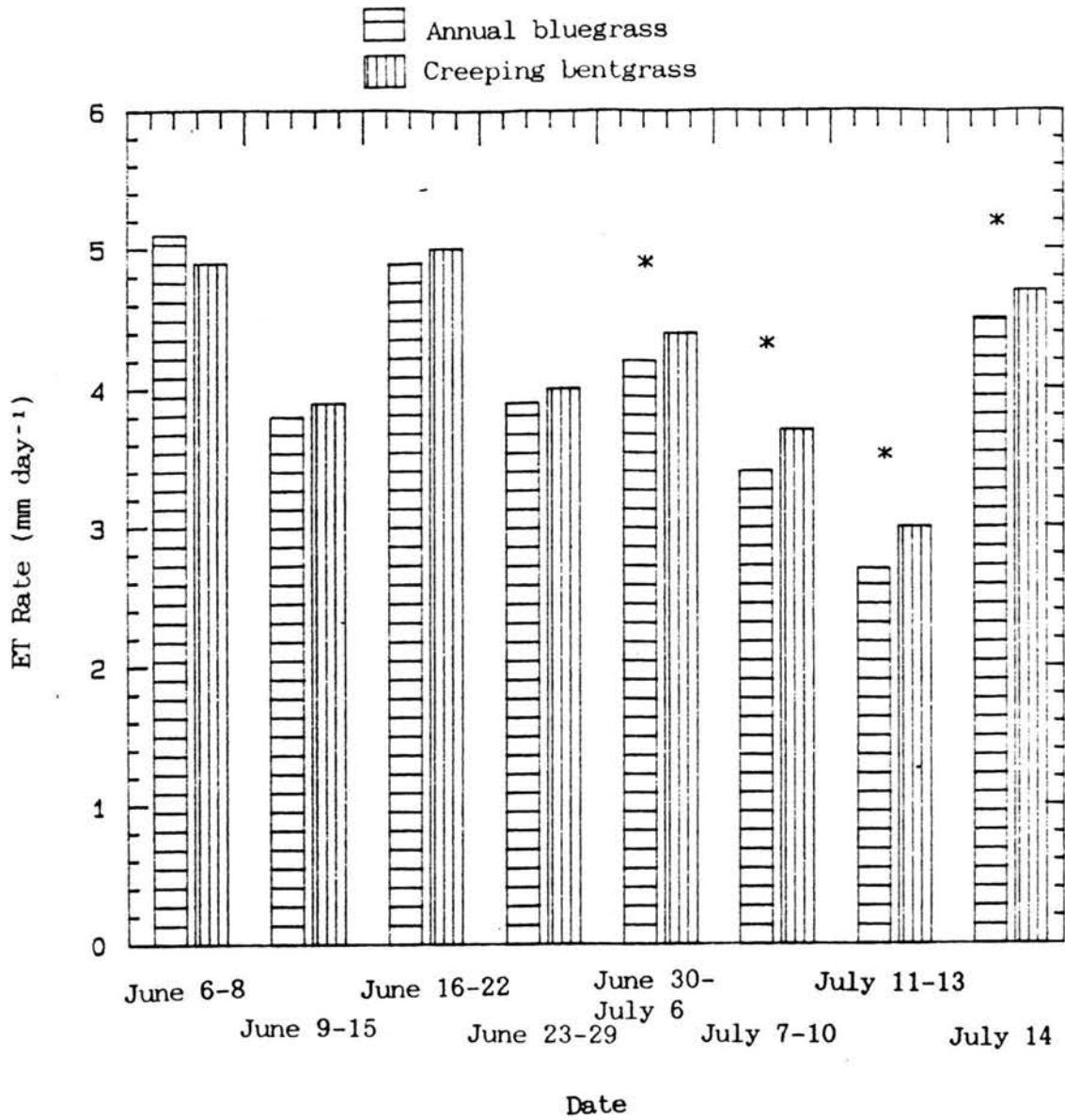


Figure 1.2. Annual bluegrass and creeping bentgrass evapotranspiration (ET) rates between 6 June and 14 July, 1985. A (*) above bars indicates a significant species difference ($P = 0.05$).

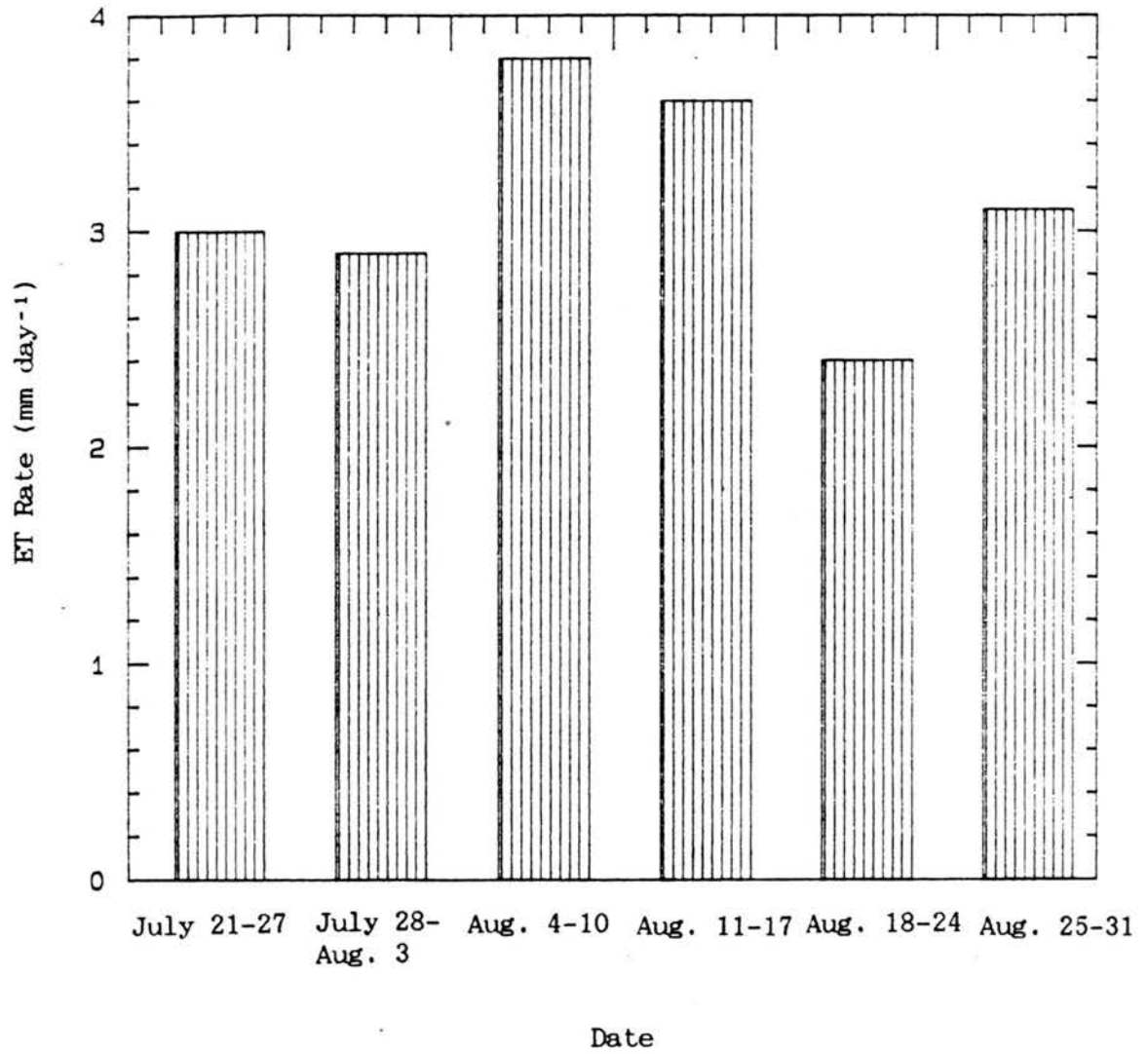


Figure 1.3 Creeping bentgrass evapotranspiration (ET) rates between 21 July and 31 Aug., 1985.

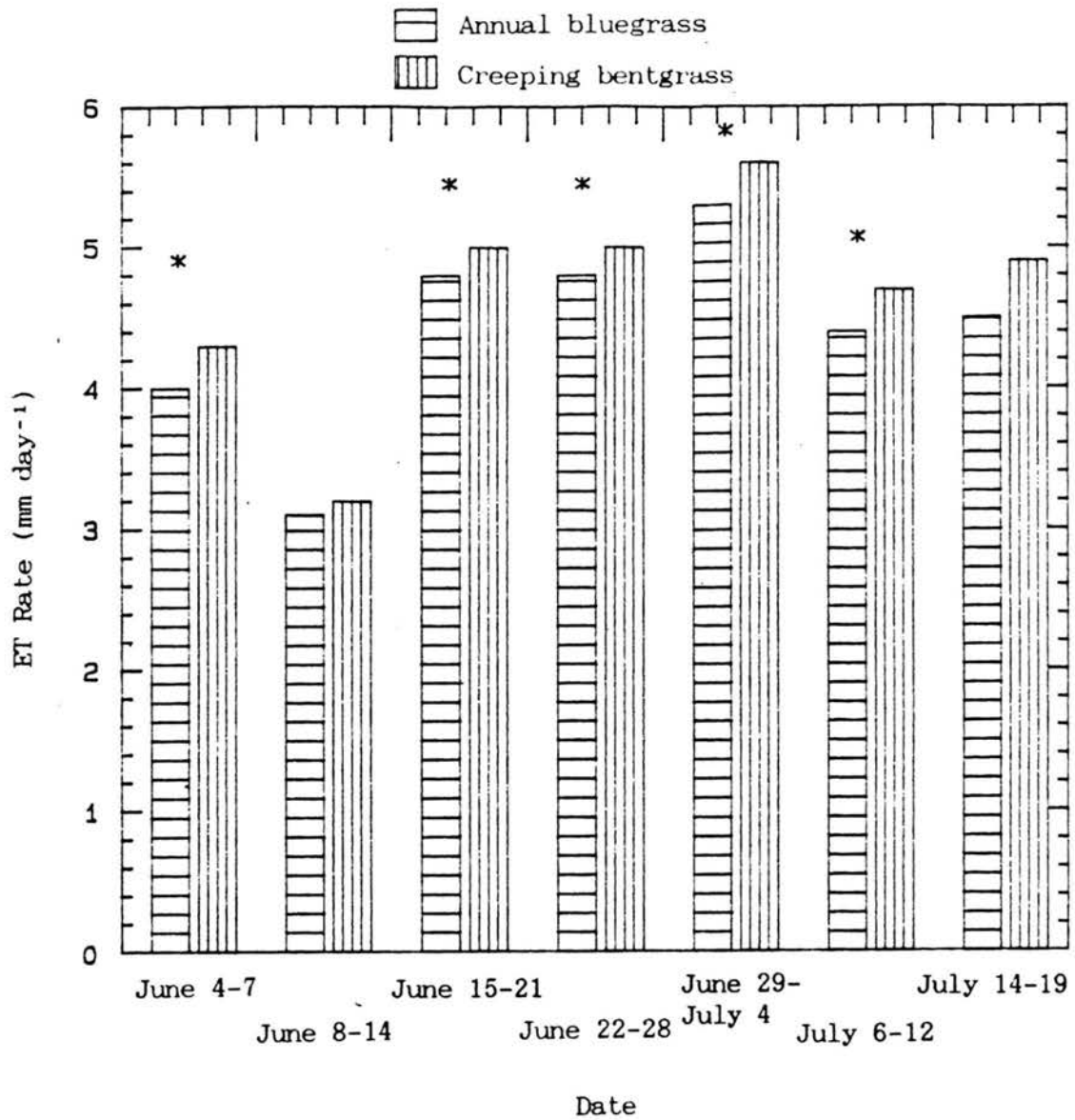


Figure 1.4 Annual bluegrass and creeping bentgrass evapotranspiration (ET) rates between 4 June and 19 July, 1986. A (*) above bars indicates significant species difference ($P=0.05$).

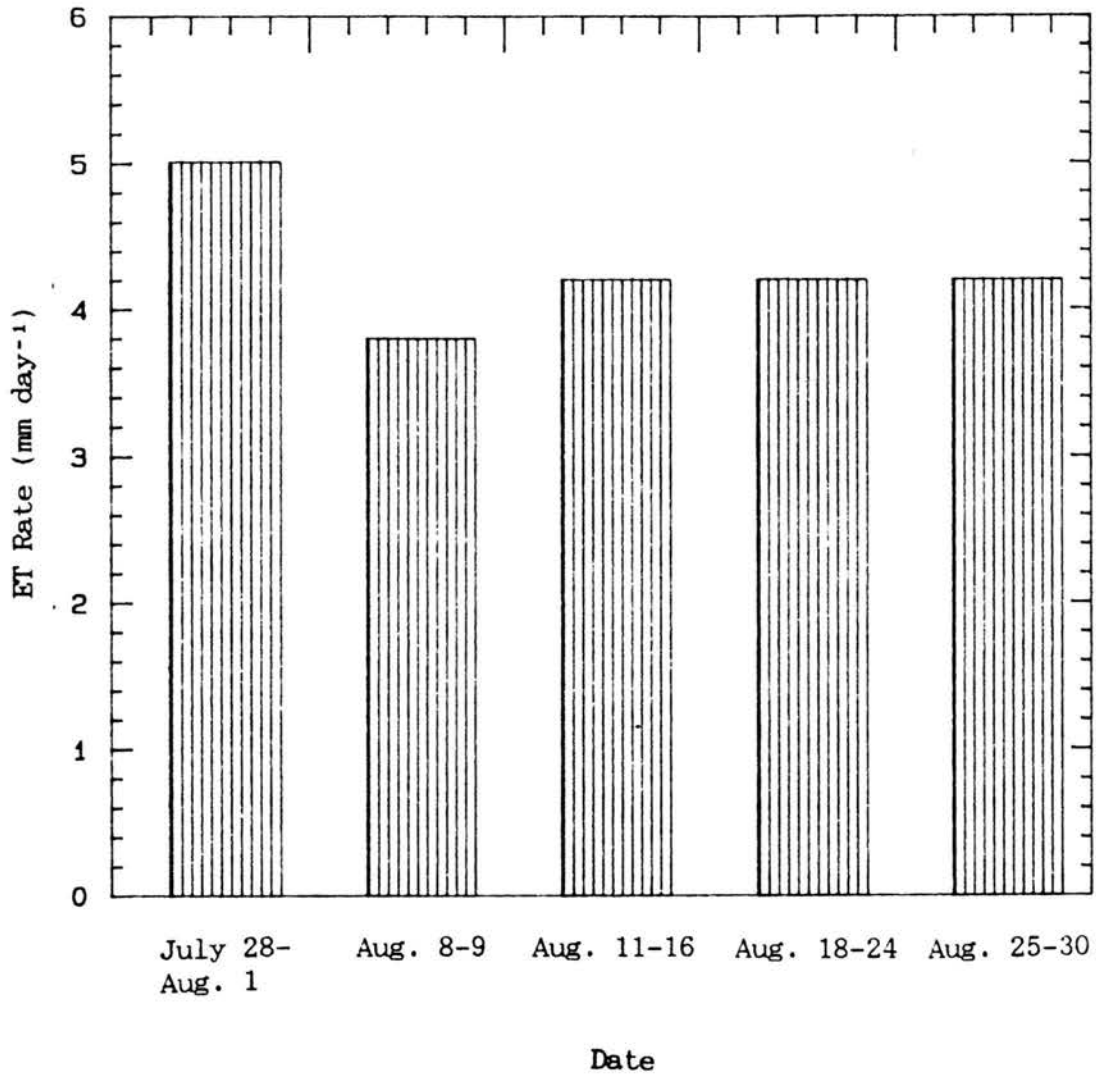


Figure 1.5. Creeping bentgrass evapotranspiration (ET) rates between 28 July and 30 Aug., 1986.

Chapter II.

WATER USE RATES OF TURF WEEDS
AND GROUNDCOVERS

Chapter II. WATER USE RATES OF TURF WEEDS AND GROUNDCOVERS

Irrigation is essential to maintain turfgrass vigor in arid and semi-arid regions of the United States. Research over the past decade has provided valuable information concerning ET rates of warm and cool season turfgrass species (35,58,72). Little is known, however, about the water requirements of weed species that encroach into and occupy large portions of turf areas. Furthermore, planting of groundcovers, such as dichondra (Dichondra repens J.R. Forst. and G. Forst.) and white clover (Trifolium repens L.) has sometimes been recommended in place of grass without knowledge of their water requirements.

Weed encroachment is often favored by frequent irrigation. Excessive water in the spring can encourage the development of crabgrass (Digitaria spp.) (23). Species such as these often exhibit greater drought resistance than the cultivated grasses in which they grow. Consequently, when drought occurs later in the season, growth of undesirable weed species is often favored.

Most of the work on water requirements of groundcovers has emphasized clovers (Trifolium spp.) (42,92). It has been reported (42) that water use by T. subterraneum L. increased as plant population increased. This clover exhibited a relative water content of over 90% down to a soil moisture level of -0.3 MPa. Singh et al. (92) found that berseem clover (T. alexandrium J.) had ET rates of 4.08, 3.77, and

3.60 mm day⁻¹ under wet (0 to -0.025 MPa), moist (0 to -0.05 MPa), and dry (0 to -0.075 MPa) soil moisture regimes, respectively.

This study was done to compare the ET rates of several weed and groundcover species to that of 'Merion' Kentucky bluegrass (Poa pratensis L.), a turfgrass commonly used for home lawns. This information would help to better identify water requirements for low quality turf areas inhabited by weeds.

Materials and Methods

This research was conducted during the summers of 1985 and 1986 at the Plant Environmental Research Center in Fort Collins, Colorado. Evapotranspiration rates were determined using minilysimeters. This procedure is described by Feldhake et al. (38), and was used in the annual bluegrass and creeping bentgrass water use study (p. 36). Evapotranspiration rates were determined for white clover, a C₃ dicot; yellow foxtail [Setaria glauca (L.) Beauv.], barnyardgrass [Echinochloa crusgalli (L.) Beauv.], and smooth crabgrass [Digitaria ischaemum (Schreb.) Muhl.], C₄ grasses; and dichondra, a C₄ dicot. Dichondra has poor low temperature resistance, and is an annual when grown in Colorado. 'Merion' Kentucky bluegrass was included for comparison.

Soil used in the lysimeters during both years was a sandy clay loam. Lysimeters were placed in the greenhouse, and seeded at a rate of 147 kg viable seed ha⁻¹ on 12 April, 1985, and 31 March, 1986.

In 1985, ammonium nitrate (33N-0P-0K) was applied to each lysimeter at a rate of 49 kg N ha⁻¹ on 3 and 25 May. In 1986, 18N-22P-0K was applied at 49 kg N ha⁻¹ to each lysimeter and lightly

incorporated prior to planting. An additional 49 kg N ha⁻¹ from ammonium nitrate was applied on 14 April. Weeds and groundcovers were not fertilized after data collection began in either year.

Lysimeters were placed in the field on 17 May, 1985 and 16 May, 1986. Data collection began on 5 June, 1985 and 4 June, 1986. Studies were terminated on 2 Sept. and 29 August in 1985 and 1986, respectively.

Weeds and groundcovers were mowed three times weekly at a height of 6.4 cm. 'Merion' Kentucky bluegrass, which surrounded lysimeters in the field, was maintained at the same height. In addition, turf surrounding lysimeters was fertilized with 49 kg N ha⁻¹ from ammonium nitrate on 23 May and 9 Sept., 1985. In 1986, a 20N-4.4P-4.2K fertilizer was used to apply 49 kg N ha⁻¹ on 10 March.

Lysimeters were weighed three times weekly using a large triple-beam balance capable of weighing to the nearest gram. Water lost by ET was replaced immediately after weighing using a graduated cylinder. Lysimeters were covered during irrigation and as possible during periods of natural precipitation. On occasions when lysimeters were exposed to rainfall, ET data were adjusted for precipitation amounts.

Density was defined as the percent of the lysimeter soil surface covered by plant material, and was determined in June of each year (Table 2.2). In 1985, density was estimated visually. In 1986, to obtain a more accurate estimate of plant density, photographs were taken above each lysimeter, images were projected onto a grid, and percent coverage was determined graphically.

In the field, lysimeters were arranged in a randomized complete block design with four replications. Weekly and seasonal ET means

were employed in data analyses. Significant species differences ($P = 0.05$) were determined using analysis of variance, and means were separated using the least significant difference multiple comparison test.

Results and Discussion

Mean daily ET rates for 1985 and 1986 are presented in Table 2.1. In both years, dichondra was slow in spreading, and did not exhibit complete coverage of the lysimeter soil surface until mid to late June (Table 2.2). Barnyardgrass did not achieve total groundcover in either year. This species had a very upright growth habit, and it is unlikely that complete groundcover would ever occur when mowed at the height used in this study. Hence, ET losses from barnyardgrass lysimeters may have been due more to evaporative losses from the soil surface, rather than transpiration by the plant. However, this likely parallels the situation that would occur with barnyardgrass when it grows as a weed in mowed turf.

In 1985, ET results were quite variable. Mean daily ET rates are presented in Table 2.1. Because species did not differ in ET through the entire summer, a more accurate representation of weed and groundcover ET rates is given by weekly means presented in Fig. 2.1, 2.2, and 2.3. Significant differences among species were observed during the first five weeks of 1985 (Fig. 2.1 and 2.2). During each of these weeks, white clover exhibited the highest ET rate, while dichondra had the lowest. 'Merion' Kentucky bluegrass had an ET rate significantly lower than that of white clover, but similar to that

of yellow foxtail. Barnyardgrass and crabgrass used intermediate amounts of water when compared to other species (Fig. 2.1 and 2.2).

Table 2.1 shows the seasonal mean daily water use rates for 1986. White clover had a significantly higher ET rate than all other species. Water used by 'Merion' Kentucky bluegrass was similar to amounts used by crabgrass and yellow foxtail. Barnyardgrass and dichondra had the lowest ET rates. Significant species differences were observed throughout the summer of 1986 (Fig. 2.4-2.6). Water use variability among species during 1985 was likely due to climatic conditions experienced in Fort Collins between 1 June and 1 Sept. Rainfall for this period totaled 171 mm (Appendix Table C.1). The frequency of rainfall necessitated that lysimeters often remain covered for lengthy periods. This may have been a contributor to the fact that no differences in ET were observed among species after the fifth week of study in 1985.

In 1986, 85 mm of rain fell between 1 June and 1 Sept., less than 50 percent of that in 1985 (Appendix Table C.1). Therefore, more consistent ET results were observed in 1986.

White clover had a mean ET rate of nearly 10 mm day⁻¹ between 28 July and 1 August, 1986 (Fig. 2.6). White clover has a dark green color and an upright growth habit which likely maximizes the effects of radiant and advective energy resulting in the high ET rates observed for this species. During several study weeks, white clover had a significantly higher ET rate than Kentucky bluegrass. Thus, water savings may result if this species is controlled after encroaching as a weed into turf areas. Furthermore, use of white clover for lawn

areas, rather than Kentucky bluegrass, may require increased irrigation during summer months.

A Texas study (58), evaluating the water use rates of 11 cultivated warm season turfgrasses, found that mean ET rates ranged from 4.8 to 6.3 mm day⁻¹. Herein, yellow foxtail and crabgrass exhibited ET losses similar to 'Merion' Kentucky bluegrass (Table 2.1). However, differences among these species were variable from week to week (Fig. 2.1-2.6). Barnyardgrass had a low ET rate in both years (Table 2.1). This may have been due, in part, to low plant density (Table 2.2). In general C₃ grasses have been found to use greater amounts of water than C₄ grasses, primarily due to differences in photosynthetic efficiency (14,38,58). In this study, 'Merion' Kentucky bluegrass had a significantly higher ET rate than crabgrass, but not yellow foxtail, during the first four weeks in 1985, and the second week in 1986 (Fig. 2.1 and 2.4).

Dichondra is a C₄ dicot that is employed as a groundcover in southern regions of the United States. It is not tolerant to the cold winter temperatures experienced in Colorado. This species, established from seed each year, did not achieve complete cover in lysimeters until mid to late June (Table 2.2). When weekly means were determined, dichondra had the lowest ET rate during the first five weeks in 1985, and all weeks in 1986 (Fig. 2.1-2.6). This species is low growing and stoloniferous, forming a very "tight" canopy. Therefore, advective influences on ET are minimized. Low growing C₄ grasses have also exhibited lower water use rates than those with more upright growth habits (58). In areas where it is adapted,

dichondra may be employed on home lawns to maximize water conservation.

Encroachment of weedy grasses such as crabgrass, yellow foxtail, and barnyardgrass may reduce turf aesthetic appeal, but should not result in increased turf water requirements.

This study showed that white clover, a C₃ dicot, had the highest mean water use rate over two summers (6.6 mm day⁻¹). Dichondra, a low growing C₄ dicot, and barnyardgrass, a C₄ monocot, used the least water (4.4 and 4.2 mm day⁻¹, respectively). 'Merion' Kentucky bluegrass, a C₃ species, and yellow foxtail and crabgrass, two C₄ species, exhibited intermediate ET rates. Water use rates of these species should be considered when recommending groundcovers other than turfgrasses, or controlling weeds in cultivated turf areas where water conservation is of concern.

Table 2.1. Mean evapotranspiration (ET) rates of turf weeds and groundcovers.

Species	ET ^Z (mm day ⁻¹)	
	1985	1986
'Merion' Kentucky bluegrass	5.0 a b	5.1 b c
Yellow foxtail	4.8 b c	4.5 c d
Barnyardgrass	4.2 c	4.1 d
Crabgrass	4.8 b c	5.2 b
Dichondra	4.9 a b	3.9 d
White clover	5.5 a	7.7 a

^ZNumbers represent mean ET between 5 June and 2 September in 1985, and 4 June and 29 August in 1986.

*Means followed by the same letter in a column are not significantly different according to the least significant difference multiple comparison test (P = 0.05).

Table 2.2. Density of turf weeds and groundcovers in lysimeters in 1985 and 1986.

Species	Density ^Z (% cover)					
	1985			1986		
	5 June	12 June	19 June	14 June	24 June	
'Merion' Kentucky bluegrass	100 a ^Y	100 a	100 a	100 a	100 a	
Yellow foxtail	100 a	100 a	100 a	100 a	100 a	
Barnyardgrass	84 b	86 b	84 b	45 c	35 c	
Crabgrass	100 a	100 a	100 a	100 a	100 a	
Dichondra	75 b	94 b	100 a	58 b	93 b	
White clover	100 a	100 a	100 a	100 a	100 a	

^ZDensity in lysimeters was determined visually on a 0 - 100% scale in 1985, and graphically in 1986.

^YMeans followed by the same letter in a column are not significantly different according to the least significant multiple comparison test (P = 0.05).

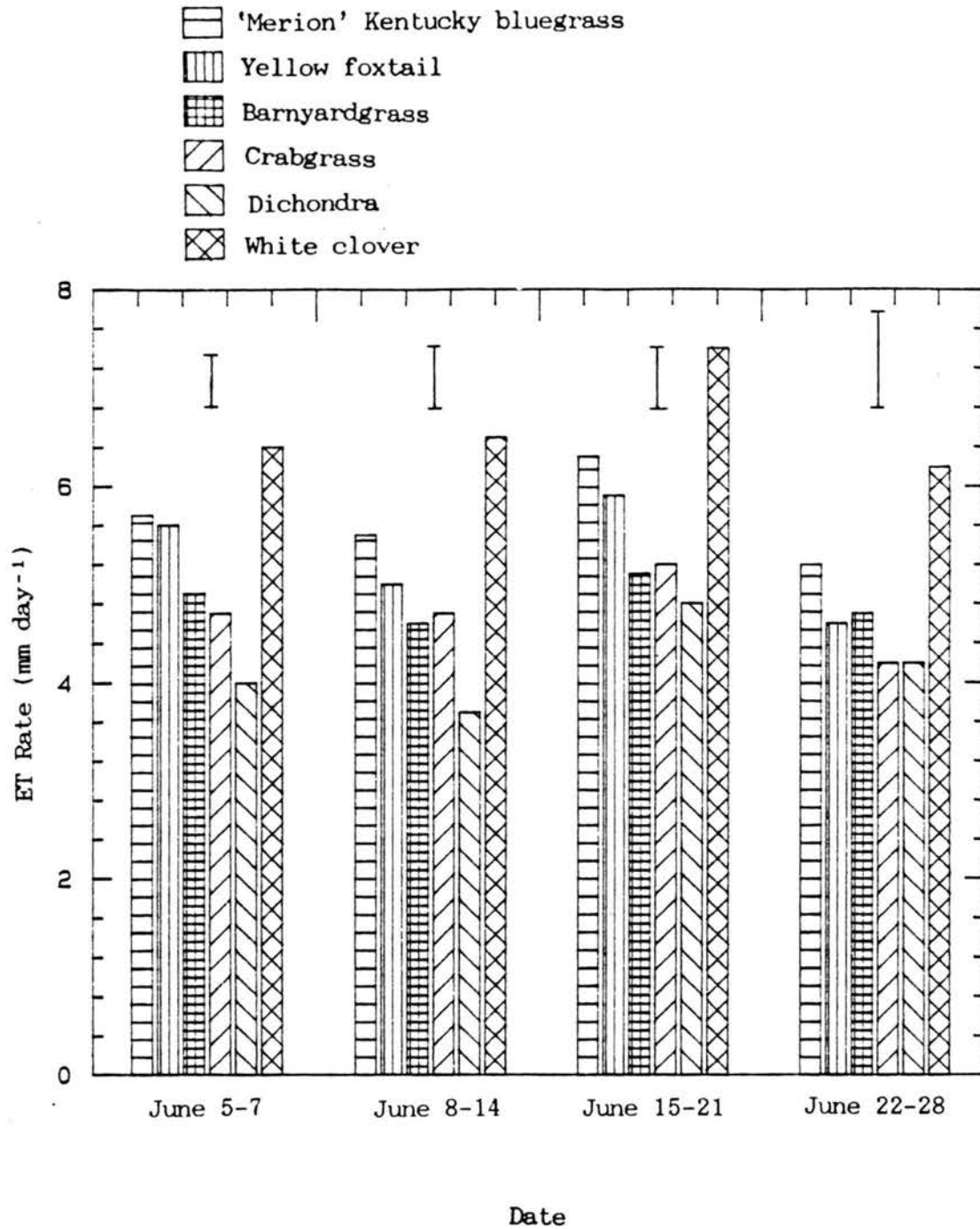


Figure 2.1. Evapotranspiration (ET) rates of turf weeds and groundcovers between 5 and 28 June, 1985. Vertical lines above bars indicate LSD values ($P = 0.05$).

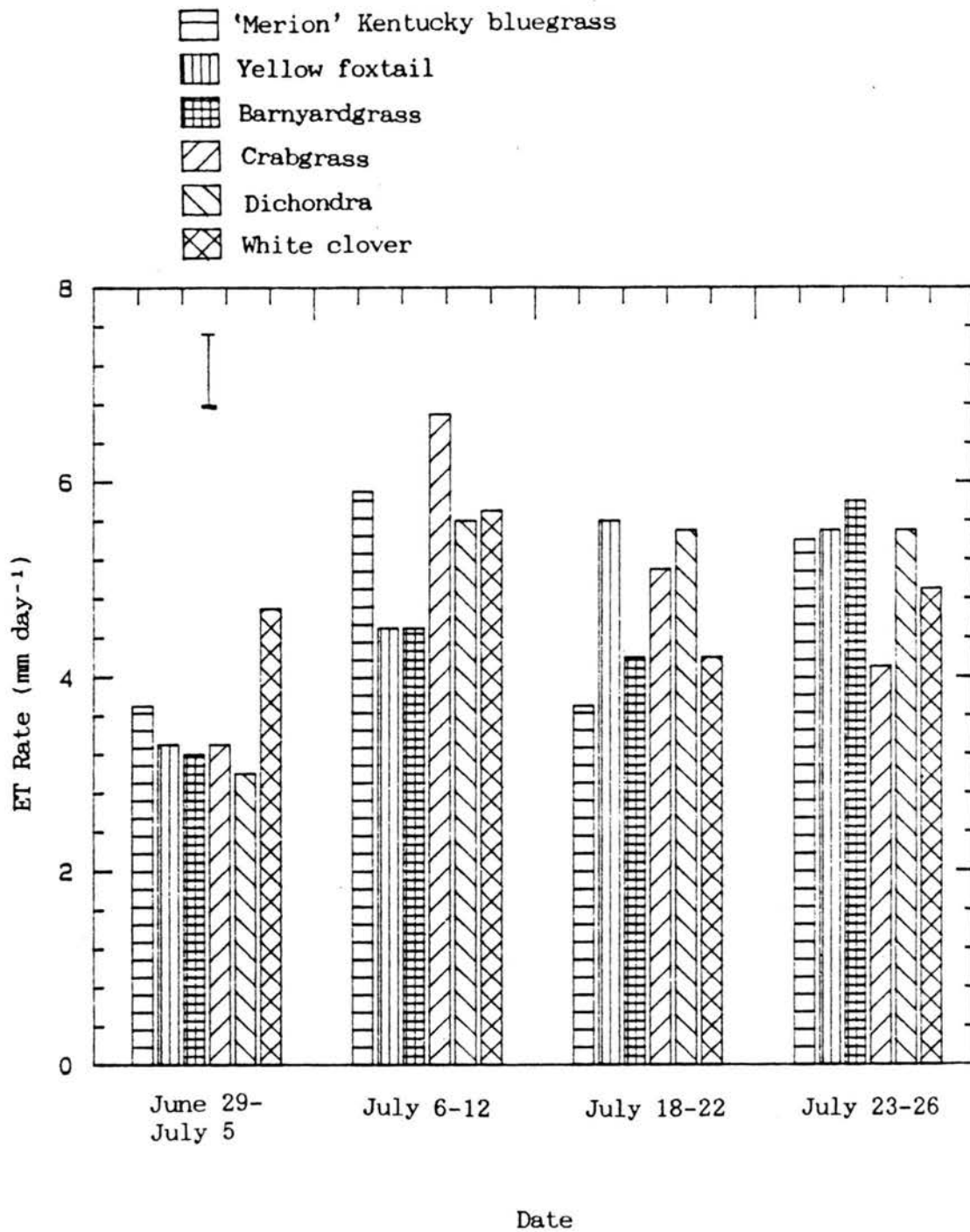


Figure 2.2. Evapotranspiration (ET) rates of turf weeds and groundcovers between 29 June and 26 July, 1985. Vertical lines above bars indicate LSD values ($P = 0.05$).

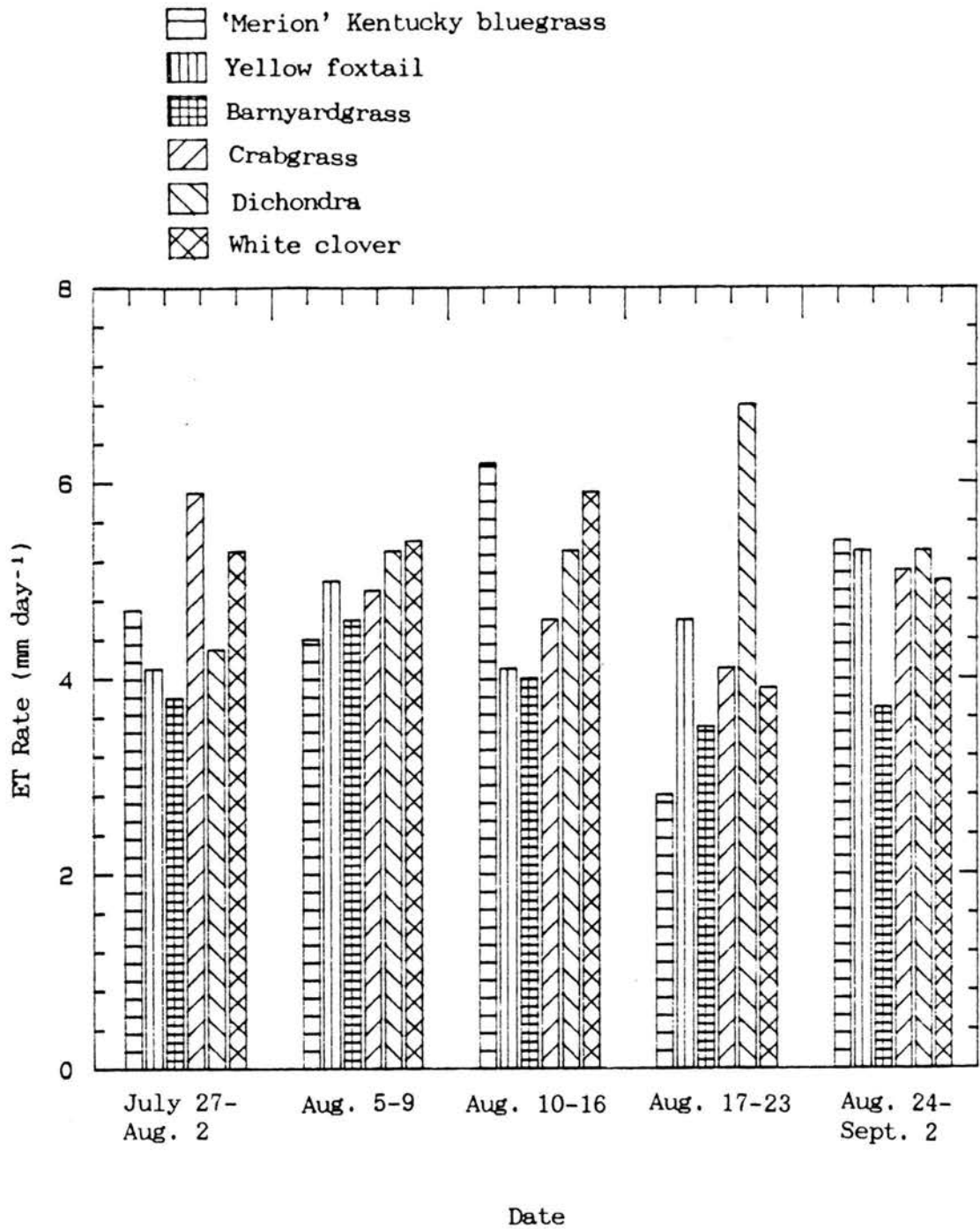


Figure 2.3. Evapotranspiration (ET) rates of turf weeds and groundcovers between 27 July and 2 Sept., 1985. No significant species differences were observed.

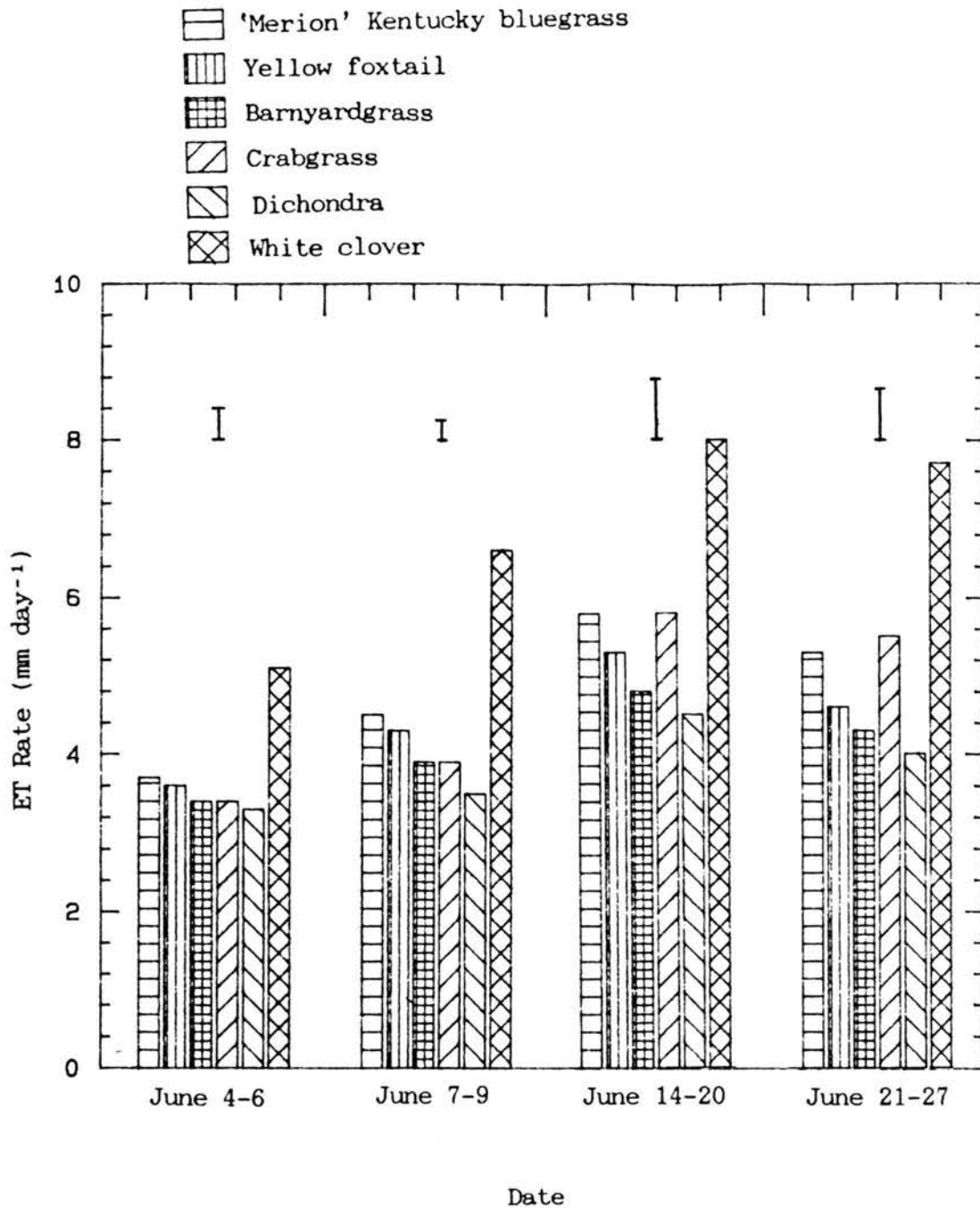


Figure 2.4. Evapotranspiration (ET) rates of turf weeds and groundcovers between 4 and 27 June, 1986. Vertical lines above bars indicate LSD values ($P = 0.05$).

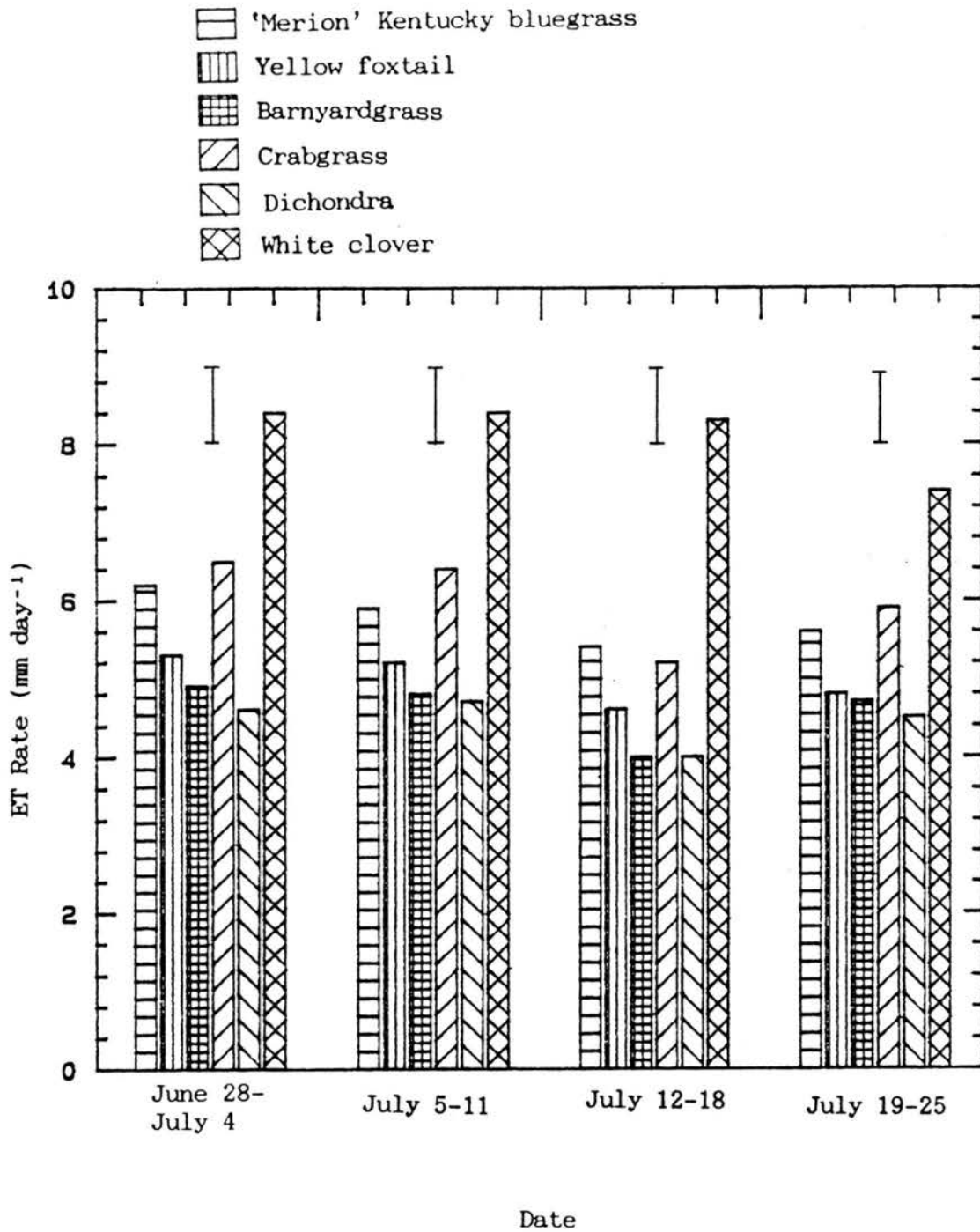


Figure 2.5. Evapotranspiration (ET) rates of turf weeds and groundcovers between 28 June and 25 July, 1986. Vertical lines above bars indicate LSD values ($P = 0.05$).

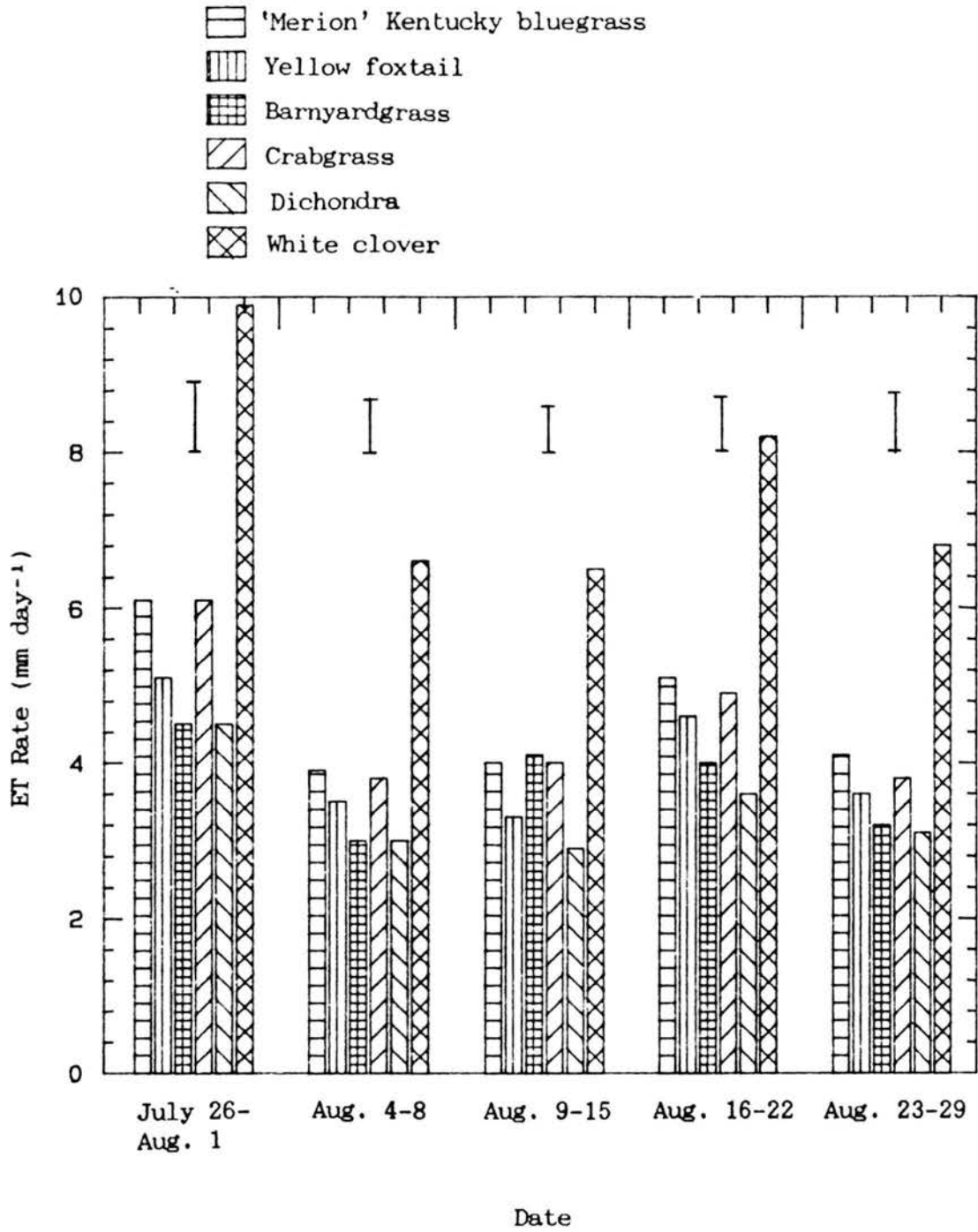


Figure 2.6. Evapotranspiration (ET) rates of turf weeds and groundcovers between 26 July and 29 August, 1986. Vertical lines above bars indicate LSD values ($P = 0.05$).

Chapter III.

WATER MANAGEMENT REQUIREMENTS FOR
TURFGRASS ESTABLISHMENT

Chapter III. WATER MANAGEMENT REQUIREMENTS FOR TURFGRASS ESTABLISHMENT

In arid and semi-arid regions of the United States, irrigation is often required to achieve satisfactory turfgrass seed germination and stand establishment. Extensive work has been done to determine water use rates of mature warm and cool season turfgrass species (58,14,72,38).

Information on water requirements during turf establishment would be a valuable tool for improving stand establishment and conserving water. Essentially no research, however, has been conducted to determine water use rates of turfgrasses as they develop from seed to maturity. Furthermore, although extensive research has been done concerning deficit irrigation of mature turfgrass (39,72,44), very little is known about how deficit irrigation may affect turf establishment. After seeding, new turf areas are frequently over- or under-irrigated. This may result in poor stand development, requiring overseeding at a later date.

Some work has been done to determine the moisture requirements for germination of agricultural crop seed (52). One study (52) found that corn (Zea mays L.), rice (Oryza sativa L.), soybean [Glycine max (L.) Merrill] and sugar beet (Beta vulgaris L.) seeds required internal moisture values of 30.5, 26.5, 50, and 31%, respectively, before germination occurred. When the effect of soil matric potential on

seed germination was evaluated, corn would not germinate at less than -1.25 MPa; rice, -0.79 MPa; soybean, -0.66 MPa; and sugarbeet, -0.35 MPa.

Some research with turfgrass found increased seed germination following exposure to low water potentials (17,101). Wilson (101) observed enhanced germination of 'Nordan' crested wheatgrass [Agropyron desertorum (Fisch. ex Link) Schult.] when exposed to soil water potentials as low as -4.0 MPa and then watered well. Other researchers (17) reported increased germination of 'Guymon' bermudagrass seeds when soaked in solutions with osmotic potentials ranging from -0.6 to -1.8 MPa. Hence, with some species, temporary water stress was not injurious to seed and even favored germination when adequate water supplies became available.

There has been interest in the use of hydrophilic polymers as soil amendments and seed coatings to increase plant water availability. These products are capable of absorbing many times their weight in water, and have been suggested as a means to increase water conservation. One study evaluated effects of amending various soil textures with a hydrolyzed starch polyacrylonitrile (HSPAN) graft polymer on soil water retention (49). Results showed that amended loamy sand and sandy loam soils had higher water contents than unamended, but the polymer had little effect on water retention in a clay loam soil. Other research (61) suggested that high molecular weight polymers could be used as soil amendments to increase soil moisture holding capacity, and reduce evaporation, runoff, and erosion. Most of the work using hydrophilic polymers has been done with species other than turfgrass (30,41,5,96). Results of one study (30)

demonstrated that sugar beet seeds exhibited greater water uptake and emergence when coated with hydrophilic colloids. Baxter and Waters (5) reported enhanced sweet corn (Zea mays L.) establishment when a HSPAN polymer was used as a seedcoat, but cowpea [Vigna unguiculata (L.) Walp.] germination was inhibited. Other studies reported that irrigation was required less frequently when soil was amended with hydrophilic polymers supporting marigold (Tagetes erecta L.) and zinnia (Zinnia elegans Juoq.) (41), and waxtree (Ligustrum lucidum Ait.) (96).

Research on the use of hydrophilic polymers with grasses is very limited. However, Berdahl and Barker (13) did evaluate agar, alginic acid, carragheenan, 'Super Slurper', and 'Viterra 2 Hydrogel' seed coatings, for effectiveness of enhancing germination of Russian wildrye (Elymus junceus Fisch.). When employed over a wide range of matric potentials, none of the materials were effective in improving germination over the untreated controls. Because little information is available concerning turfgrass water needs during establishment, research in this area is badly needed. In addition, the efficacy of hydrophilic polymers in enhancing turfgrass establishment under dry conditions needs further investigation. Therefore, the objectives of this research were to: 1) Determine potential water use rates of 'Merion' Kentucky bluegrass (Poa pratensis L.) and 'Rebel' tall fescue (Festuca arundinacea Schreb.) during establishment; 2) Evaluate the effect of deficit irrigation on Rebel tall fescue establishment; and 3) Determine the effectiveness of amending soil with a hydrophilic polymer to enhance germination and seedling vigor of Merion Kentucky bluegrass and Rebel tall fescue.

Materials and Methods

Field Studies

These studies were conducted at the Colorado State University Plant Environmental Research Center in Fort Collins, Colorado. Mini-lysimeters, as described by Feldhake (38) and used in the creeping bentgrass and annual bluegrass water use study (p. 44), were used to determine ET during turfgrass establishment. Two, separate studies were conducted during the summer of 1985, and again in 1986. Potential ET (i.e., ET under non-limiting soil moisture) during establishment was evaluated in one study. In a separate study, the effect of deficit irrigation on turfgrass establishment was observed.

In all studies, sod was removed from a 1.5 x 1.5 m square. A lysimeter was placed in the center of the square and the entire area within and around the lysimeter was subsequently seeded. The plot area surrounding lysimeters was irrigated at the same time water was added to lysimeters. This was done to provide a similar microenvironment in and around lysimeters as might be experienced when establishing turf in an open field. Density was determined on several dates during both field studies, and defined as the percent of the lysimeter soil surface covered by plant material. In 1985, density was determined by visual estimation. In 1986, to obtain a more accurate estimate of plant density, photographs were taken above each lysimeter, images were projected onto a grid, and percent coverage was determined graphically.

Field Study I. In 1985, to determine potential ET during turfgrass establishment, sod was removed around each lysimeter on 2 May. On 25 May, soil surrounding lysimeters was rototilled to a 7-8 cm depth, and raked until level. Lysimeters were filled with a sandy clay loam soil and placed in sleeves in the center of each plot. A granular, hydrophilic polymer (potassium propenoate-propenamamide copolymers, "Viterra Hydrogel", Nepera, Inc., Harriman, New York) was applied by hand at a rate of 98 kg ha⁻¹ to one-half of the lysimeters, and surrounding soil, on 25 May. The polymer used was capable of absorbing approximately 300 times its weight in water. The polymer was lightly raked in after application. Lysimeters were removed from sleeves and watered to achieve "field capacity" as described in the annual bluegrass and creeping bentgrass study (p. 36). Lysimeters were then returned to sleeves prior to seeding. On 5 June, six of 12 lysimeters were seeded with Merion Kentucky bluegrass at a rate of 74 kg ha⁻¹. Rebel tall fescue was seeded at 245 kg ha⁻¹ to remaining lysimeters. Seeds were covered lightly with moist soil prior to determining "field capacity" weights on 5 June. Evapotranspiration was determined daily until 12 June, and every other day thereafter until 28 July using the water balance method described in the annual bluegrass and creeping bentgrass water use study (p. 36).

On 26 June, 24 kg N ha⁻¹ from ammonium nitrate (33N-0P-0K) were dissolved in approximately 200 ml water and the resulting solution was applied to each lysimeter. This water application was taken into account when returning the lysimeters to "field capacity". Turf was clipped twice weekly at 6.4 cm beginning on 2 July, 1985.

In 1986, Rebel tall fescue and Merion Kentucky bluegrass were seeded on 4 June. Seeding rates, soil, and ET determination methods were the same as 1985. Turf was clipped twice weekly to a height of 6.4 cm beginning on 4 July. Because no significant effect was seen from the hydrophilic polymer in 1985, it was not used in 1986. No fertilizer was applied in 1986, and lysimeters were weighed daily between 4 June and 26 July.

Statistical design in both years was a randomized complete block with four replications of polymer rate and species in 1985, and species in 1986. Seasonal and weekly means were used in data analyses. Statistical significance ($P = 0.05$) was determined using analysis of variance.

Field Study II. In contrast to Field Study I, where potential ET was determined, this research was conducted to evaluate turfgrass establishment under deficit irrigation. After soil in 1.5 x 1.5 m plots was rototilled and leveled, lysimeters were filled with the soil described in Field Study I, and placed in sleeves in the field. A hydrophilic polymer (described in Field Study I) was applied at 98 kg ha⁻¹ to one-half of the lysimeters and surrounding soil area on 15 August. Concurrently, 49 kg N ha⁻¹ from diammonium phosphate (18N-22P-0K) were applied and incorporated in all lysimeters to a 2.5 cm depth. To determine daily soil matric potential, electrical resistance blocks were buried at a depth of 3.8 cm in the center of each lysimeter. Lysimeters were not wetted to "field capacity" before seeding. Rebel tall fescue was seeded at 245 kg ha⁻¹ on 15 August, and lightly raked in.

Irrigation was applied at 50 and 100% of potential ET of a mature turf (50 and 100% IRR). In 1985, water application was based upon potential ET from Merion Kentucky bluegrass growing in lysimeters in an adjacent study. These lysimeters containing mature Kentucky bluegrass were weighed every other day, mean water loss was determined, and half or all of that amount was applied to lysimeters in Field Study II. Lysimeters were weighed daily, and ET was determined by taking the difference between the previous day's lysimeter weight, after water had been added, and the current weight. Turf was clipped at 6.4 cm using scissors on 10 Sept., and twice weekly thereafter. The study ended on 27 Sept., 1985.

In 1986, seedbed preparation was identical to that in 1985. Rebel tall fescue was seeded on 12 August. Irrigation treatments were the same as 1985, but potential ET of mature Rebel tall fescue growing in lysimeters in an adjacent study was used to determine irrigation amounts. Soil moisture and ET were again determined on a daily basis. Turf in 100% IRR lysimeters was clipped at 6.4 cm on 10 Sept., and twice weekly thereafter. Data were collected until 20 Sept.

Field design during both years was a randomized complete block with four replications of irrigation regimes and polymer application rates. Seasonal and weekly means were used in data analyses. Statistical significance ($P = 0.05$) was determined using analysis of variance.

Greenhouse Studies

Two greenhouse studies were conducted during the winter of 1985-1986 to evaluate the efficacy of a hydrophilic polymer on establishment of Rebel tall fescue under moisture limiting conditions. Water use rates were not evaluated in either greenhouse study. A completely randomized design was used in both greenhouse studies. Three and four, replications, respectively, were used in Greenhouse Studies I and II. Significant polymer treatment differences were determined using analysis of variance, and means were separated using the least significant difference multiple comparison test.

Greenhouse Study I. In the first study, lysimeters, as diagramed in the creeping bentgrass water use study (p. 44) were filled with a sandy clay loam soil. A hydrophilic polymer, described in Field Study I, was incorporated to a 2.5 cm depth at rates of 0, 98, and 196 kg ha⁻¹. Also incorporated in each lysimeter were 48 kg N ha⁻¹ from 18N-22P-0K. An electrical resistance block was buried at a depth of 3.8 cm in the center of each lysimeter prior to seeding. Rebel tall fescue was seeded by hand on 31 Jan., 1986, and lightly covered with soil. Lysimeters were fully watered until 18 Feb., when drought began. One lysimeter at each polymer application level was fully watered to allow determination of Relative Whole Plant Water Content (RWPWC). This was defined as:

$$\text{RWPWC (\%)} = \frac{\text{Mass of H}_2\text{O in stressed plants}}{\text{Mass of H}_2\text{O in unstressed plants}} \times 100$$

This procedure was used to observe effects of preplant hydrophilic polymer application on plant water status. Water content of stressed plants is expressed as a percentage of unstressed seedlings. It should be noted that RWPWC differs from the traditional relative water content which is determined using leaf discs soaked in water for a given time period.

To determine mass of water in seedlings, 10 plants were randomly harvested from each lysimeter, weighed collectively, dried at 70 °C for 48 hours, and weighed again.

After first sampling on 28 Feb., lysimeters were returned to the greenhouse, and each received 150 ml of water daily until 8 March when a second drought treatment began. Plants were again sampled on 17 March to determine RWPWC. Turf was clipped at 6.4 cm using scissors on 6 and 13 March, 1986.

Greenhouse Study II. This study was initiated to evaluate the effect of higher polymer application rates on Rebel tall fescue establishment. In this study, 15.2 cm diam. plastic pots were employed. A sandy clay loam soil was mixed in a tumbler with a hydrophilic polymer (described in Field Study I) to obtain soil mixtures containing 0, 0.1, 1.0, and 5.0% polymer on a volume basis. Pots were then filled with the soil-polymer mixtures, and an electrical resistance block was buried at a 7.6 cm depth in each container. Fertilization and seeding were done, as in Greenhouse Study I, on 19 March, 1986. Pots were watered well until 10 April when drought began. Relative Whole Plant Water Content, as described in Greenhouse Study I, was determined on 18 April. Pots were returned to the greenhouse, and no additional water

was applied until 28 April. Plants were watered well until 8 May when the number of living plants per pot was determined. Turf was clipped at a 6.4 cm height on 7 April.

Results and Discussion

Field Study I. Mean daily ET rates for Rebel tall fescue and Merion Kentucky bluegrass in 1985 and 1986 are presented in Table 3.1. In 1985, tall fescue had a significantly higher ET rate when data were averaged over the entire establishment period. Figure 3.1 illustrates species water use rates on a weekly basis in 1985. Kentucky bluegrass used significantly less water than tall fescue after 30 June, 20 days after seeding. Water loss early in establishment was almost exclusively due to water evaporating from the soil surface, not transpiration. Therefore, ET may be a misnomer, at least prior to seedling emergence.

In 1986, Kentucky bluegrass and tall fescue had statistically similar ET rates when data were analyzed for the entire study period (Table 3.1), or weekly (Fig. 3.2).

Differences between species ET in 1985, but not 1986, may have been due to reduced Kentucky bluegrass vigor in the former year. In 1985, there was some soil settling in lysimeters after the study began, creating less soil volume. Addition of water to return lysimeters to "field capacity" sometimes resulted in an excess of water. Tall fescue growth did not appear to be inhibited, but Kentucky bluegrass may have suffered from excessive water in the rootzone. In 1986, less settling occurred, and Kentucky bluegrass vigor was better than in 1985.

Water lost from lysimeters prior to germination was similar to that lost from mature Merion Kentucky bluegrass in an adjacent study conducted concurrently. This was likely due to the fact that frequent water application provided surface water that was readily available for evaporation. Hence, evaporation losses approached values that were observed for an open pan during the same period (Appendix Table C.1). Under field conditions, where surface water may not always be present, lower water losses may be observed.

Turf density was determined on several dates in 1985 and 1986 (Table 3.2). Some researchers have observed a significant relationship between plant density and ET (69,58,86). Marlatt (69) reported greater water use by orchardgrass (Dactylis glomerata L.) at 50 and 70% density, compared to 100% density. This was primarily due to greater air movement around plants in stands where density was less than 100%. Lower ET rates have also been reported as shoot density of warm (58) and cool season (86) turfgrasses increased. In our studies, no significant correlation was found between Kentucky bluegrass and tall fescue density, and ET rate. The studies cited earlier (69,58,86) were conducted with mature turfgrasses. It is possible that density has a greater influence on ET of a mature stand, where leaf and root morphology may be quite different from that observed in an immature turf.

Field Study II. In this study, Rebel tall fescue was seeded and irrigated daily with an equivalent amount of water as used by a mature turf, or half of that amount. In contrast to Field Study I, lysimeters were not maintained at "field capacity".

The effect of water application amount on ET during tall fescue establishment is presented in Table 3.3 and Fig. 3.3 and 3.4. Turf in lysimeters receiving 50% of potential ET (50% IRR) had significantly lower ET rates than that receiving 100% IRR when weekly and seasonal means were analyzed in both years. This was primarily due to the fact that 50% IRR lysimeters had less water available for ET than those receiving 100% IRR. Furthermore, lysimeters receiving 50% IRR had such poor density that water was lost primarily from evaporation. Evapotranspiration rates for tall fescue at 100% IRR were lower than those reported in Field Study I. In that study, soil in lysimeters was maintained at "field capacity", and a greater amount of water was available for ET. In addition, this study was conducted during a later, cooler part of the season. Other researchers have reported decreasing ET of mature turfgrasses with declining soil moisture (75,72).

Effects of irrigation amount on turf establishment are presented in Table 3.4. Results showed that unsatisfactory tall fescue establishment occurred when irrigated at 50% IRR of a mature turf. Deficit irrigation resulted in a significantly lower plant number in 1985, and poor density in 1985 and 1986. In general, water applied to lysimeters receiving 50% IRR was just enough to wet the soil surface. During warm days with low humidity, this was not enough water to achieve adequate stand development. Lysimeters where tall fescue received 100% IRR exhibited good germination and stand development in both years.

Percent IRR had no influence on soil matric potential (Table 3.3). This was likely because data were collected in the morning prior to

weighing lysimeters. Soil in lysimeters of both irrigation treatments was relatively dry at this time. In addition, because poor establishment resulted in 50% IRR lysimeters, there were few plants present to withdraw moisture from below the soil surface with developing roots. Hence, soil matric potentials were similar to those in 100% IRR lysimeters where greater plant growth led to greater water extraction on a daily basis.

Preplant soil incorporation of a hydrophilic polymer at 98 kg ha⁻¹ did not increase plant number or density in 50% IRR lysimeters in either year (Appendix Table A.3). However, the polymer had a significant effect on Rebel tall fescue ET during establishment in 1985, but not 1986 (Table 3.5). In 1985, less water loss occurred in lysimeters where the polymer had been applied. Another study (61) reported decreased evaporation from soil where a hydrophilic polymer was used. This was thought to be due to a diffusion barrier developing on the surface of soil where the polymer had been applied, reducing water loss to the atmosphere. In our study, although ET rates were lower on polymer-treated soil, the difference was only 0.1 mm day⁻¹ compared to untreated soil. It is unlikely, based upon this work, that this hydrophilic polymer could be used to greatly reduce soil evaporative losses.

When 1985 means were analyzed, there was a significant polymer x irrigation level interaction for ET (Table 3.6). Evapotranspiration at 50% IRR was essentially the same at both polymer application rates. At 100% IRR, however, greater water loss resulted from lysimeters where no polymer was applied. Between 31 Aug. and 14 Sept., 1985, ET losses were greater in 50% IRR lysimeters where polymer was used,

but 100% IRR lysimeters again had higher ET rates where no polymer was applied (Appendix Table A.4). Hence, the polymer increased water use at the low irrigation regime, but reduced ET when lysimeters were watered at 100% IRR during these two weeks in 1985.

Greenhouse Study I. In this study, polymer was applied at 98 and 196 kg ha⁻¹, two and four times the recommended rate, respectively. At these rates, the polymer had no significant effect upon soil matric potential during drought when evaluated on four dates (Fig. 3.5).

Plants were harvested to determine RWPWC following two separate drought periods in February and March. Results showed that preplant polymer application at 98 and 196 kg ha⁻¹ had no significant effect on plant water content (Table 3.7).

Greenhouse Study II. Study II was done to evaluate higher rates of hydrophilic polymer application on establishment of Rebel tall fescue during drought. Seedlings received adequate moisture until 10 April when the drought treatment began. Soil that contained 5.0% polymer by volume exhibited a significantly lower soil matric potential 12 days after seeding, before drought was imposed (Fig. 3.6). This was likely due to effects the high concentration of polymer had on soil moisture movement. Absorption of water by the polymer may have prevented the electrical resistance block from reaching equilibrium with soil water. Hence, the polymer was likely holding the majority of water, preventing flow into the resistance block. Twenty-eight days after seeding, soil where polymer was 1.0% of the soil volume had a significantly higher matric potential than the 0.1% treatment and the

control. Thirty-four days after seeding, soil matric potential in all treatments had reached -1.50 MPa or below.

Plant harvest 8 days after seeding showed that tall fescue in treatments where the polymer was 1.0 and 5.0% of the soil volume had a higher RWPWC than plants growing in pots where no polymer was applied (Table 3.8). At these rates, the polymer appeared to be effective in reducing plant water stress. Approximately 20 days after drought began, data indicated that a significantly greater number of plants survived in pots where polymer was 5.0% of the soil volume (Table 3.8).

Other researchers (100) reported increased growth of tomato (Lycopersicon esculentum Mill.) when seedlings were grown in soil amended with 0.25-0.5% "Viterra hydrogel". Unfortunately, polymer applications needed to increase plant water content herein, 1.0 and 5.0% of the soil volume, are equivalent to soil surface application rates of 4,098 and 22,003 kg ha⁻¹, respectively. Recommended application rate is 49 kg ha⁻¹. Therefore, use of this polymer to decrease drought stress of tall fescue during establishment would require excessive rates of application.

In conclusion, field and greenhouse studies were conducted to determine water requirements of Merion Kentucky bluegrass and Rebel tall fescue during establishment. When lysimeters were used to determine potential ET during establishment in the field, Merion Kentucky bluegrass and Rebel tall fescue had water use rates of 5.2 and 5.3 mm day⁻¹, respectively, when data were averaged over two years. During one year, Rebel began using significantly more water than Merion 20 days after seeding. In a separate field study,

establishment of Rebel tall fescue was evaluated under deficit irrigation. Results showed that successful tall fescue establishment did not occur when irrigation was done at 50% of the potential ET of mature Merion Kentucky bluegrass in 1985, or Rebel tall fescue in 1986. Greenhouse and field studies were also conducted to evaluate the effectiveness of preplant incorporation of a hydrophilic polymer in improving Rebel tall fescue establishment during drought. Application of the polymer at reasonable rates to reduce plant drought stress did not increase drought survival of seedlings.

Table 3.1. Mean evapotranspiration (ET) rates of 'Rebel' tall fescue and 'Merion' Kentucky bluegrass in 1985 and 1986.

Species	ET ^Z (mm day ⁻¹)	
	1985	1986
'Rebel' tall fescue	5.5*	5.1
'Merion' Kentucky bluegrass	4.9	5.4

^ZNumbers represent mean ET between 5 June and 28 July in 1985, and 5 June and 26 July in 1986.

*Means in a vertical column are significantly different (P = 0.05).

Table 3.2. Density of 'Rebel' tall fescue and 'Merion' Kentucky bluegrass in Seeding Study I in 1985 and 1986.

Species	Density ^z (% cover)							
	1985			1986				
	2 July	10 July	20 July	1 July	8 July	16 July	26 July	
Tall fescue	74*	83	98	64	91	91	92	
Kentucky bluegrass	45	60	66	44	63	75	86	

*Density in lysimeters was estimated visually on a scale of 0 - 100% groundcover in 1985, and graphically in 1986.

^zMeans in a column are significantly different (P = 0.05).

Table 3.3. Influence of irrigation on mean evapotranspiration (ET) of 'Rebel' tall fescue, and soil matric potential during establishment in 1985 and 1986.

Irrigation amount	ET ^Z (mm day ⁻¹)		Soil matric potential ^Z (MPa)	
	1985	1986	1985	1986
50 percent IRR	2.3*	1.9*	-0.09	-0.42
100 percent IRR	4.0	3.6	-0.20	-0.42

^ZNumbers represent mean ET between 17 August and 27 September in 1985, and 13 August and 20 September in 1986.

*Means in a column are significantly different (P = 0.05).

Table 3.4. Influence of irrigation amount on 'Rebel' tall fescue plant number and density during establishment in 1985 and 1986.

Irrigation amount	1985	Density (% cover) ^y					
	Plant number ^z	1985				1986	
	21 Aug.	7 Sept.	11 Sept.	18 Sept.	25 Sept.	2 Sept.	11 Sept.
50 percent IRR	14*	7*	16*	31*	17*	1*	1*
100 percent IRR	40	57	76	89	98	14	64

^zNumbers represent plants in lysimeters.

^yDensity in lysimeters was estimated visually on a scale of 0-100% in 1985, and graphically in 1986.

*Means in a column are significantly different (P = 0.05).

Table 3.5. Influence of a hydrophilic polymer on 'Rebel' tall fescue evapotranspiration (ET) rate during establishment in 1985 and 1986.

Polymer application rate (kg ha ⁻¹)	ET ^Z (mm day ⁻¹)	
	1985	1986
0	3.2*	2.7
98	3.1	2.7

^ZNumbers represent mean ET between 17 August and 27 September in 1985 and 13 August and 20 September in 1986.

*Means in a column are significantly different (P = 0.05).

Table 3.6. Evapotranspiration (ET) rate of 'Rebel' tall fescue at two irrigation regimes and polymer application rates during establishment in 1985.

Irrigation amount	ET ^Z (mm day ⁻¹)	
	Polymer application rate (kg ha ⁻¹)	
	0	98
50 percent IRR	2.3	2.3
100 percent IRR	4.1	3.9

^ZNumbers represent means between 17 August and 27 September.

Table 3.7. Influence of a hydrophilic polymer on 'Rebel' tall fescue water content during establishment in the greenhouse.

Polymer application rate (kg ha ⁻¹)	Relative whole plant water content (% of fully watered)	
	10 days after initial drought began	9 days after second drought began
0	49.8 a ^Y	11.1 a
98	59.0 a	14.9 a
196	58.7 a	12.7 a

88

^ZTen seedlings were randomly sampled from each lysimeter, fresh and dry weights were determined, and Relative Whole Plant Water Content (RWPWC) was defined as:

$$\frac{\text{Mass of H}_2\text{O in stressed plants}}{\text{Mass of H}_2\text{O in fully watered plants}} \times 100$$

^YMeans followed by the same letter in a column are not significantly different according to the least significant difference multiple comparison test (P = 0.05).

Table. 3.8. Influence of a hydrophilic polymer on 'Rebel' tall fescue water content and number of living plants during establishment in the greenhouse.

Polymer application rate (% of soil volume)	Relative Whole Plant Water Content (% of fully watered)		Number of living plants	
	8 days after drought began		20 days after drought began	
0	30.4	b ^Y	0	b
0.1	41.1	a b	0	b
1.0	53.6	a	3	b
5.0	48.8	a	34	a

^ZTen seedlings were randomly sampled from each pot, fresh and dry weights were determined, and Relative Whole Plant Water Content (RWPWC) was defined as:

$$\frac{\text{Mass of H}_2\text{O in stressed plants}}{\text{Mass of H}_2\text{O in fully watered plants}} \times 100$$

^YMeans followed by the same letter in a column are not significantly different according to the least significant difference multiple comparison test (P = 0.05).

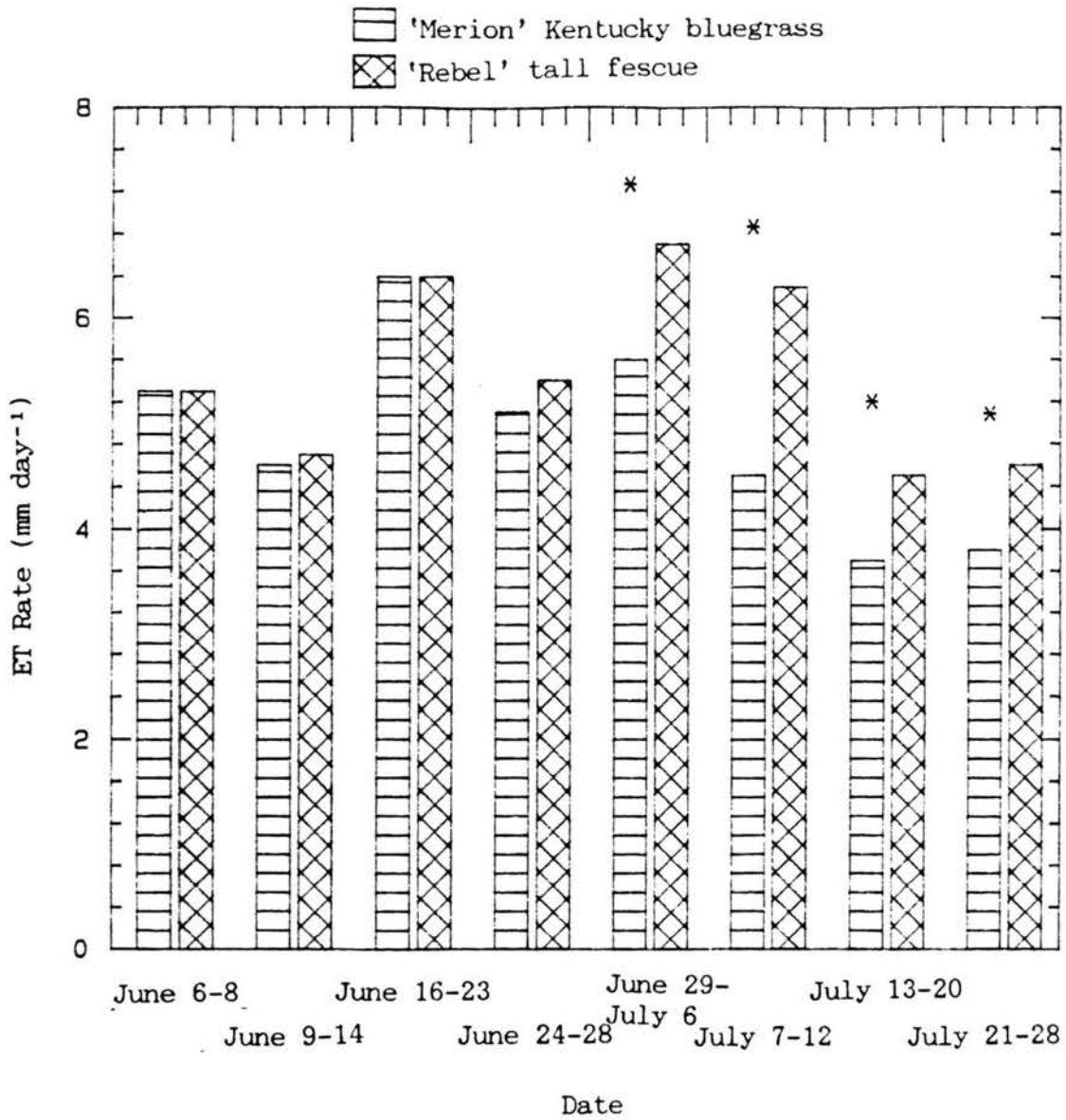


Figure 3.1. Evapotranspiration (ET) rates of 'Merion' Kentucky bluegrass and 'Rebel' tall fescue during establishment in 1985. A (*) above bars indicates a significant species difference ($P = 0.05$).

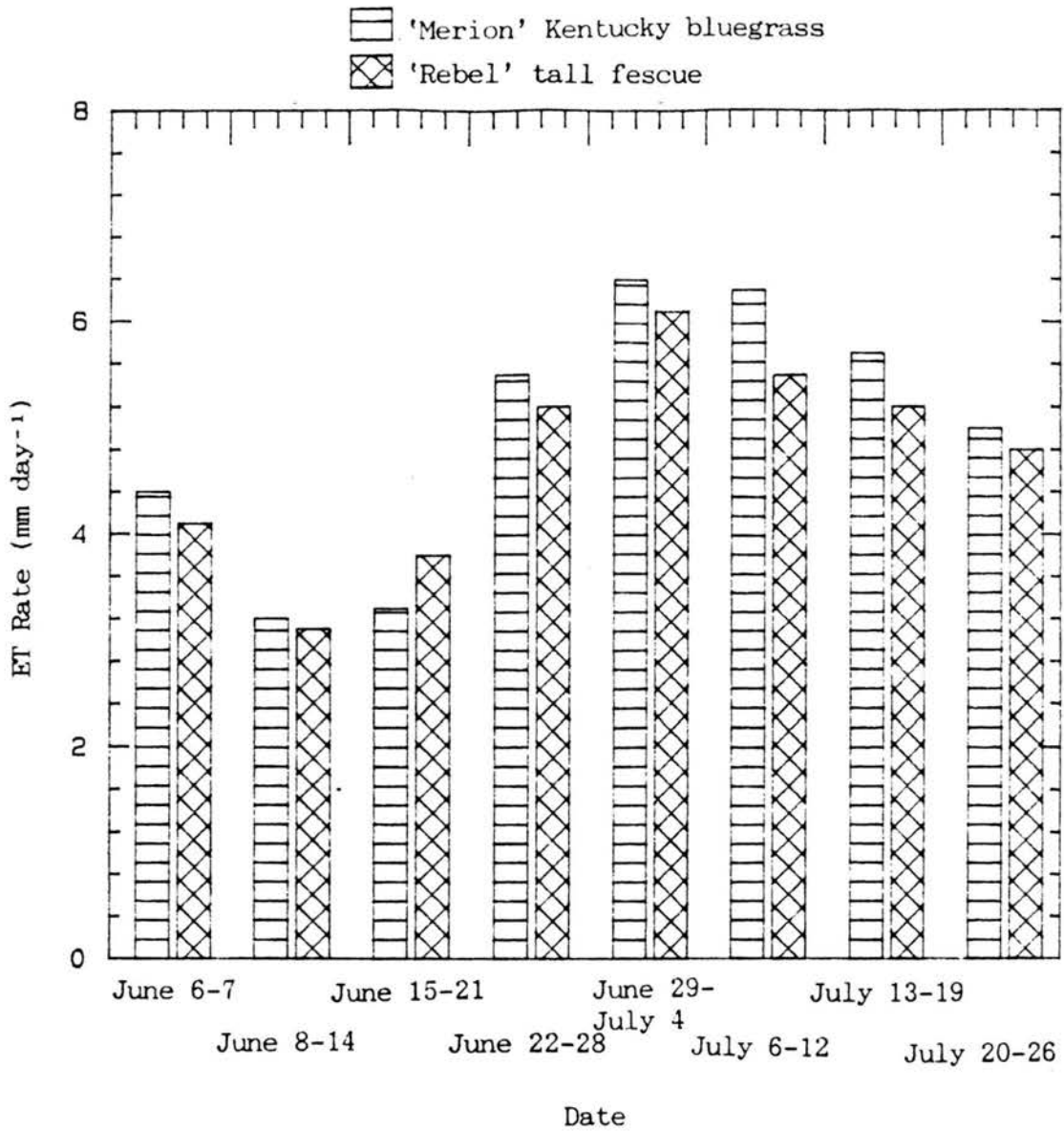


Figure 3.2. Evapotranspiration (ET) rates of 'Merion' Kentucky bluegrass and 'Rebel' tall fescue during establishment in 1986. No significant species differences were observed.

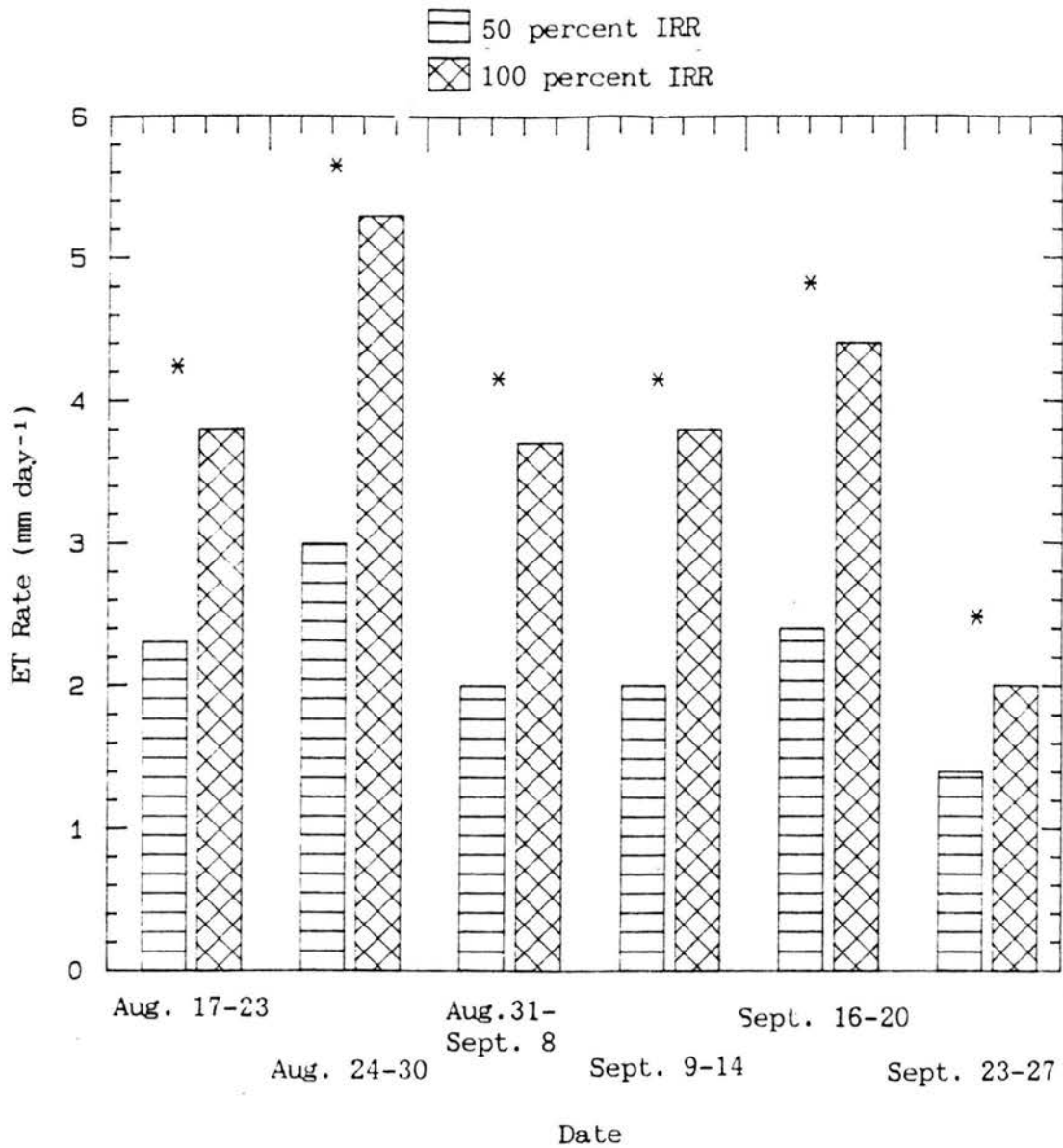


Figure 3.3. Influence of irrigation amount on evapotranspiration (ET) of 'Rebel' tall fescue during establishment in 1985. A (*) above bars indicates a significant treatment difference ($P = 0.05$).

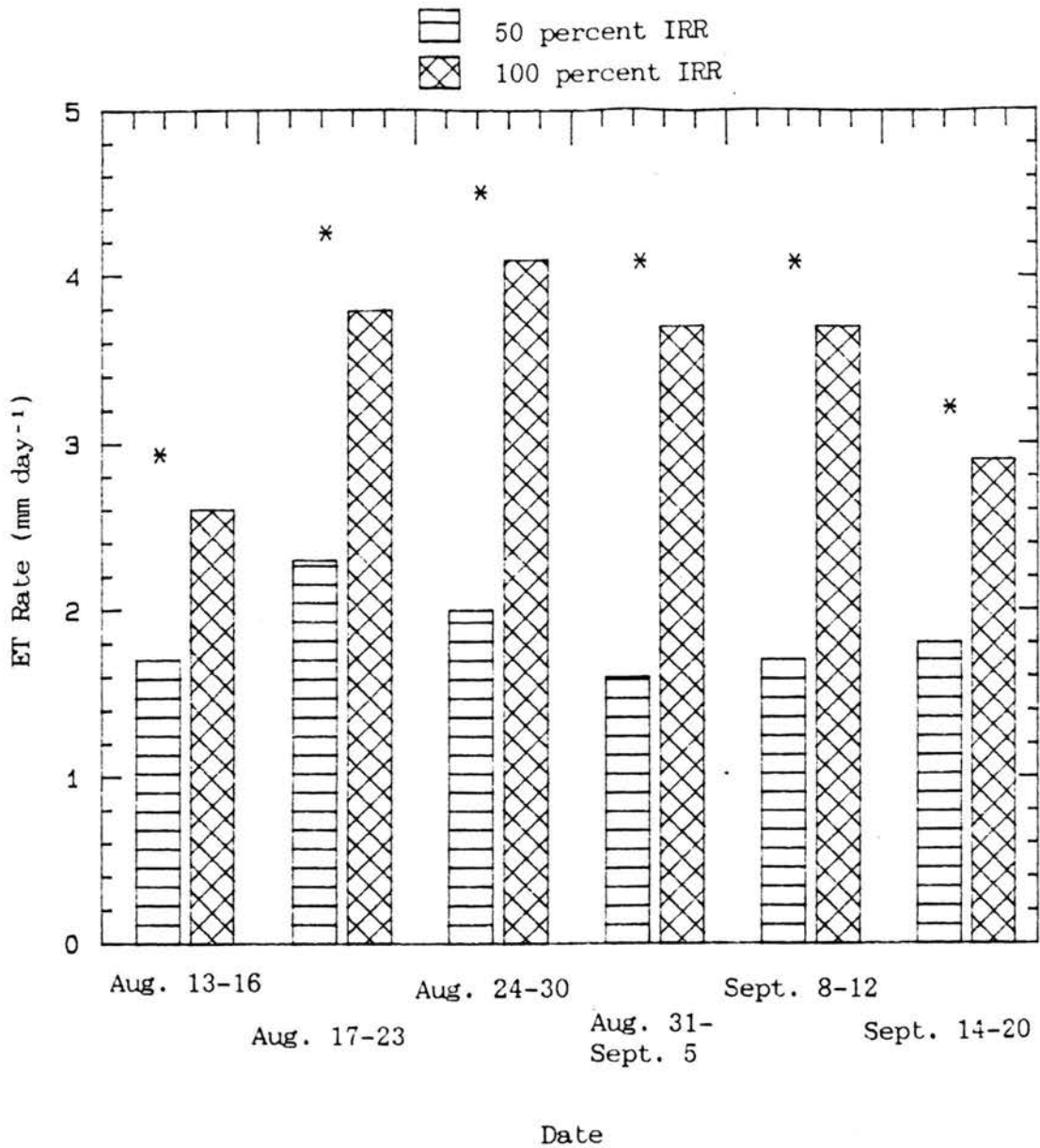


Figure 3.4. Influence of irrigation amount on evapotranspiration (ET) of 'Rebel' tall fescue during establishment in 1986. A (*) above bars indicates a significant treatment difference ($P = 0.05$).

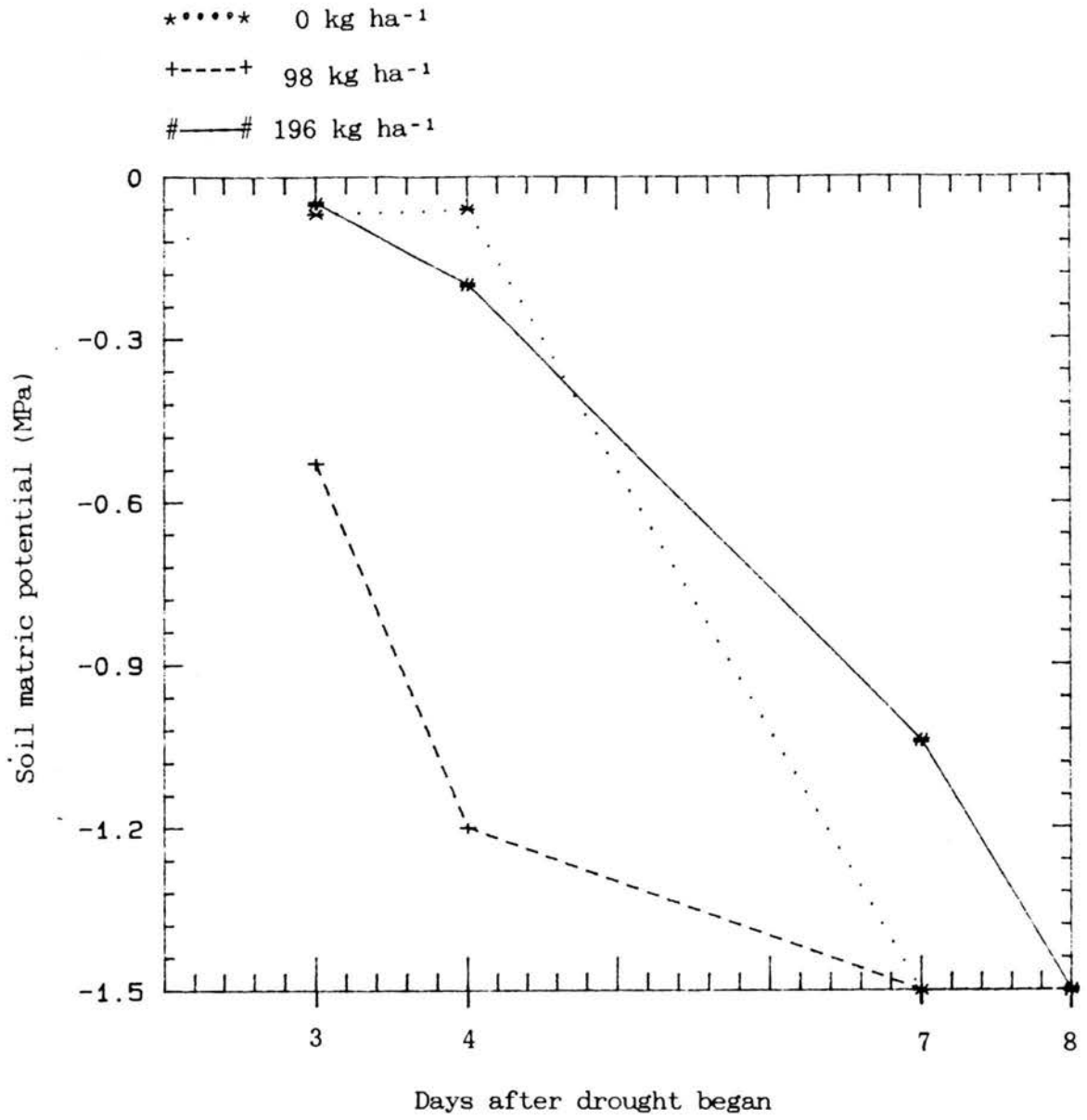


Figure 3.5. Effect of a hydrophilic polymer, applied at rates of 0, 98, and 196 kg ha⁻¹, on soil matric potential. No significant treatment differences were observed.

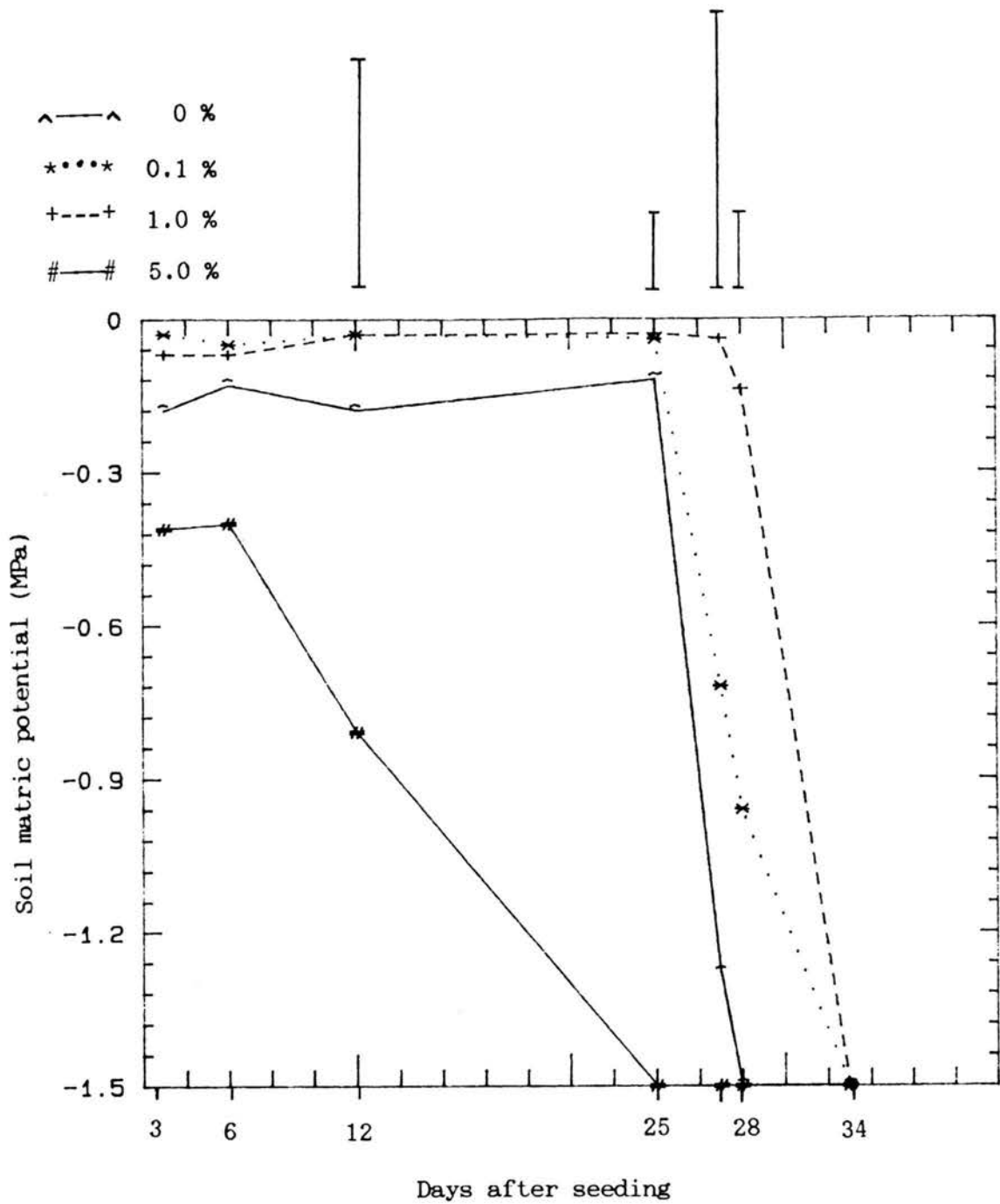


Figure 3.6. Effect of a hydrophilic polymer, mixed with soil to obtain 0, 0.1, 1.0, and 5.0 percent by volume, on soil matric potential. Drought treatment began 22 days after seeding. Bars represent LSD values ($P = 0.05$).

Chapter IV.

EFFECT OF DEFICIT IRRIGATION

ON FESTUCA SPP.

Chapter IV. EFFECT OF DEFICIT IRRIGATION ON
FESTUCA SPP.

Until recently, little information was available concerning turfgrass water requirements. The potential ET of many turfgrass species has now been determined. However, the influence of irrigation frequency and possible water savings when water is applied in amounts less than potential ET has received limited research attention.

It has been noted that Kentucky bluegrass (Poa pratensis L.) irrigation could be reduced by up to 25% of potential ET while maintaining acceptable quality (72,39). With the exception of Kentucky bluegrass, little work has been done with deficit irrigation of turfgrasses. Feldhake et al. (39) did find that 'Rebel' tall fescue (Festuca arundinacea Schreb.) exhibited a similar response to deficit irrigation as 'Merion' Kentucky bluegrass. This study was conducted using a sandy soil in lysimeters. However, the possibility that different results would result in heavy field soils in a lawn setting did exist. In a California Study (44), 'K-31' tall fescue had the highest quality rating at 100% of potential ET, and significantly poorer quality at 60%. Turf irrigated at 80% of potential ET had a quality rating similar to that watered at 60% and 100% of potential ET. Turf performance was relatively poor at all irrigation regimes for the duration of this study.

Little is known about the water requirements of hard fescue [Festuca ovina var. duriuscula (L.) Koch], a species often used in seed

mixtures for lawns in cool regions of the United States. Minner (72) found that 'Biljart' hard fescue had an ET rate similar to Kentucky bluegrass and perennial ryegrass. In a separate study (73), the quality of several fine fescues was evaluated under severe drought. Results indicated that none of the fine fescues performed well, but hard fescues generally had better quality during drought than other fine fescue species observed.

Irrigation at various intervals with similar amounts of water has been shown to influence turfgrass quality. Traditional recommendations for lawn maintenance have been to water deeply and infrequently. This was reported to promote rooting and drought resistance. In Colorado, however, research showed that Kentucky bluegrass had the best quality when irrigation was done on a two or four day interval (6,72).

Much more information is needed on water management requirements for tall and hard fescue turf. These studies were conducted to provide additional knowledge in this important aspect of fescue turf management.

Materials and Methods

Studies were conducted at the Plant Environmental Research Center in Ft. Collins, Colorado. Rebel tall fescue and 'Reliant' hard fescue were seeded in two separate study areas in June, 1985. Soil in both areas was a sandy clay loam (Aridic Argiustoll). Three irrigation levels were investigated: Water application at 100% of potential ET (100% IRR), 75% IRR, and 50% IRR. In addition, plots were irrigated on a 2, 4, 7, or 14 day interval (ΔT 2, 4, 7, or 14). Irrigation

intervals and amounts in each study were arranged factorially in a randomized complete block design with three replications. Individual plots measured 2.1 x 1.5 m.

Potential ET was determined every two days by weighing three lysimeters adjacent to each study area and containing the appropriate fescue species. Lysimeters were similar to those described in the creeping bentgrass and annual bluegrass water use study, (p. 44) but were approximately 50 mm taller to allow a deeper soil profile for root development. Tall fescue and hard fescue were sodded in lysimeters on 7 and 21 April, 1986, respectively. Turf surrounding lysimeters was the same species as that growing in lysimeters. Soil in lysimeters was similar to surrounding field soil. Plots receiving irrigation at 100% IRR received the same amount of water on an area basis as was lost by lysimeters. Seventy-five and 50% IRR treatments received the respective fraction of that water applied to 100% IRR plots. Plots within an irrigation treatment received the same amount of water regardless of the irrigation interval. Plots irrigated every 2 days received small amounts of water frequently; whereas, those watered every 14 days received large amounts of water infrequently. Irrigation treatments were applied using a hand-held garden hose with a fan type sprinkler attached. Water application amount on each plot was determined using a flowmeter (Rockwell Mfg. Co., 1.6 cm connection) which was directly attached to the garden hose and allowed accurate metering of water flow.

Plots were protected during irrigation and precipitation by employing a large plastic tarp, and lysimeters were covered individually

with metal lids. On the six occasions when precipitation occurred, and plots were not covered, irrigation amounts were adjusted accordingly.

Treatments began on 4 June and ended on 27 August, 1986. A recovery period began on 30 August when all plots were returned to a routine watering schedule. On 18 Sept., 49 kg N ha⁻¹ from 33N-0P-0K were applied.

Electrical resistance blocks were buried in the center of each plot at a depth of 10 cm before data collection began. Soil matric potential was determined every two days during the stress period. A Barnes 14-220 infrared thermometer was used to measure mid-day canopy temperature on several dates. Turf quality was determined visually every two days using a 1-10 scale where 1 = brown, open turf; 7 = acceptable turf for a home lawn; and 10 = optimum color, density, and uniformity.

Weekly means were subjected to analysis of variance, and significant treatment means were separated using the least significant difference multiple comparison test.

Results and Discussion

Reliant Hard Fescue

Tables 4.1 and 4.2 show the influence of irrigation amount and interval on the quality of Reliant hard fescue when data were analyzed over two summer periods. When irrigation amount was averaged over all intervals, turf irrigated at 50% IRR had significantly lower, unacceptable quality ratings than that at 75 and 100% IRR during both periods (Table 4.1). Turf irrigated at 75% IRR had a similar quality as that at 100% IRR. When the influence of interval was observed over

all irrigation amounts, turf quality declined as interval increased (Table 4.2). Hard fescue watered every two days had a similar quality as that watered on a four-day interval during both summer periods. Figures 4.1, 4.2, 4.3, and 4.4 show turf quality when irrigated at 100, 75, and 50% IRR on 2, 4, 7, or 14 day intervals. When watered at ΔT 2, turf quality in plots receiving 100 and 75% IRR was significantly better than that of turf watered at 50% IRR during all but the first and last two weeks of the study (Fig. 4.1). Turf quality was less than acceptable (i.e., quality = 7) at 50% IRR during 9 of 12 weeks of the stress period. Minner (72) observed that Merion Kentucky bluegrass had unacceptable quality when irrigated every two days at 50% IRR during summer months in Colorado.

When watered at ΔT 4, hard fescue receiving 75% IRR exhibited a higher, but statistically similar, quality as turf in the 100% IRR plots during five weeks of the study (Fig. 4.2). Turf irrigated at 50% IRR every four days had unacceptable quality during six weeks of the stress period. Other research (72) found that Merion Kentucky bluegrass had quality ratings that were unacceptable when irrigated at 75 and 50% IRR on four day intervals. Reliant hard fescue appeared to maintain better quality than Merion Kentucky bluegrass under these conditions.

Reliant hard fescue watered every seven days had acceptable quality at 100 and 75% IRR throughout the stress period (Fig. 4.3). Again, turf in plots receiving 75% IRR possessed better quality throughout the stress period, but the difference was not statistically significant. Merion Kentucky bluegrass did not exhibit acceptable quality in another Colorado study when watered at 100 or 75% IRR

every seven days (72). Unacceptable Reliant hard fescue quality resulted at the 50% IRR regime during most of the stress period.

When irrigated at ΔT 14, Reliant hard fescue had poor quality during most of the stress period when watered at 75 and 50% IRR (Fig. 4.4). At 100% IRR, quality was unacceptable during two weeks of the stress period. Again, although quality was usually poor when turf was watered biweekly, turf performance was better than that reported for Merion Kentucky bluegrass (72).

Although turf quality declined below an acceptable level under some irrigation treatments, all plots exhibited excellent quality by the end of the four week recovery period when turf was fertilized once, and watered well (Fig. 4.1-4.4).

Mean soil matric potentials during two summer periods under Reliant hard fescue were not significantly different when percent IRR and irrigation interval were evaluated (Tables 4.1 and 4.2). Lowest soil matric potentials were observed in plots irrigated at 50% IRR biweekly. Weekly soil moisture data are shown in Fig. 4.5-4.8. Data were not collected between 8 and 22 July. Soil in plots irrigated at ΔT 2 and 100% IRR generally had a higher (less negative) soil water potential than soil in plots receiving 50 and 75% IRR (Fig. 4.5). This was not true, however, between 11 and 23 August when soil in 100% IRR plots had a lower matric potential than that in 75% IRR plots. This appeared to be due to error in electrical resistance block readings rather than actual soil moisture conditions.

In general, soil matric potential declined as irrigation interval increased between four and fourteen days (Fig. 4.6-4.8). Furthermore, soil matric potential decreased with decreasing percent IRR. Lowest

soil matric potentials were observed when plots were watered on a 14 day interval (Fig. 4.8). Soil in plots receiving 100% IRR had the lowest matric potential during the last week of stress when watered at ΔT 14. This may have been due to greater ET in these plots as corroborated by higher turf quality ratings observed concurrently (Fig. 4.4).

Turf canopy temperature was determined on three dates in 1986 using an infrared thermometer. On 29 July, Reliant hard fescue in 100% IRR plots had a significantly cooler canopy temperature than turf in 50% IRR plots (Table 4.3). In addition, on 29 July and 8 August, turf watered every two weeks had a higher canopy temperature than that irrigated on 2, 4, or 7 day intervals (Table 4.4). An increase in canopy temperature with decreasing irrigation amount was also reported by Feldhake (39) with Merion Kentucky bluegrass. In that study, however, canopy temperature increased approximately 2 °C with every 10% drop in irrigation below 100% of potential ET. Temperature increases with decreasing irrigation with Reliant hard fescue were not so dramatic in this study. Nevertheless, irrigation applied to maintain acceptable turf quality may result in cooler, more comfortable, ambient air temperatures in urban areas.

Unsuccessful attempts were made to obtain an equation whereby turf quality could be predicted at various irrigation and soil moisture levels. A better correlation between these variables may have resulted if additional irrigation regimes, such as 25 and 10% IRR, were investigated.

This study suggests that best Reliant hard fescue results when irrigation is done on a 2 or 4 day interval at 100 or 75% of potential

ET. Acceptable quality resulted, however, when turf was watered once weekly at 75 or 100% of potential water use. Application of small amounts of water frequently (i.e., 50% of potential ET every 2 days) resulted in quality similar to turf receiving intermediate irrigation infrequently (i.e., 75% of potential ET every 14 days).

Rebel Tall Fescue

Rebel tall fescue exhibited exceptional drought resistance throughout the summer. Percent IRR had no significant effect upon turf quality when means were analyzed over two summer periods (Table 4.5). When averaged over all percent IRR treatments, turf quality in plots irrigated every two days was superior to that watered once every 14 days between 2 and 27 August (Table 4.6). Weekly tall fescue quality at all irrigation intervals and amounts is presented in Fig. 4.9-4.12. Turf irrigated every two days exhibited acceptable quality throughout the summer at all percent IRR regimes (Fig. 4.9). Hence, water application at 50% IRR allowed reduction in water application by half of potential ET, while acceptable quality was maintained. Furthermore, during only three study weeks did turf in 100% IRR plots possess significantly better quality than that in plots receiving 50% IRR when water was applied every two days.

When Rebel tall fescue was watered every four days, acceptable quality resulted at 50% IRR during all but one week (Fig. 4.10). Between 6 and 18 July, turf in 100% IRR plots had better quality than that in 75% IRR plots. During all other weeks, however, statistically similar quality was observed between these treatments.

As with the ΔT 4 day treatments, tall fescue watered once weekly at 50% IRR also had acceptable quality during all but one week (Fig. 4.11). Hence, reduced irrigation on an infrequent basis did not greatly reduce tall fescue vigor.

Tall fescue irrigated biweekly at 50% IRR had poor quality during several summer weeks (Fig. 4.12). However, 75 and 100% IRR treatments had acceptable quality throughout the stress period.

Turf in all irrigation treatments exhibited excellent quality following a four week recovery period when plots were irrigated on a routine basis (Fig. 4.9-4.12).

Irrigation amount and interval had no significant effect on soil matric potential under Rebel tall fescue when seasonal means were analyzed over the two summer periods (Tables 4.5 and 4.6). Soil in plots watered every two days remained relatively moist at all irrigation regimes throughout the summer (Fig. 4.13). Soil matric potential at ΔT 4 and ΔT 7 day irrigation intervals remained high at 100 and 75% IRR, and fluctuated at 50% IRR (Fig. 4.14 and 4.15). When water was applied biweekly, soil matric potentials fluctuated with soil wetting and drying cycles (Fig. 4.16).

Tall fescue canopy temperature was not affected by percent IRR treatments (Table 4.7). This is supported by the fact that no differences were observed in turf quality among irrigation treatments when seasonal means were compared (Table 4.5). Irrigation interval affected turf canopy temperature on only one of three dates. On 20 July, turf in plots irrigated biweekly had a significantly higher canopy temperature than that watered every two days (Table 4.8).

Although canopy temperatures between Reliant hard fescue and Rebel tall fescue could not be compared statistically, it is interesting to note that Rebel was up to 15 °C cooler than Reliant under similar irrigation treatments (Tables 4.3 and 4.7). Hence, species selection could influence ambient air temperatures in the urban environment.

Regression analysis was employed to predict Rebel tall fescue quality using soil matric potential, irrigation amount and interval, and turf canopy temperature. Variability in turf quality was not successfully predicted by any of these variables.

These results with Rebel tall fescue suggest that it is a species that can be employed to achieve significant water savings while maintaining acceptable turf quality. Furthermore, water can be applied rather infrequently (i.e., every 7 or 14 days) to maintain quality. Kentucky bluegrass has exhibited poor quality under irrigation regimes similar to these (6,72). Tall fescue may, therefore, be a species to consider when limitations or restrictions are placed on irrigation.

In summary, Reliant hard fescue and Rebel tall fescue were evaluated at deficit irrigation levels of 50, 75, and 100% of potential ET, applied on 2, 4, 7, or 14 day intervals. Reliant hard fescue exhibited the best quality when watered at 75 or 100% of potential ET on 2 or 4 day intervals. Unacceptable turf quality resulted from irrigation at 50% of potential ET at all intervals. Rebel tall fescue exhibited excellent drought resistance throughout the study. Best Rebel quality occurred as irrigation amount increased and interval decreased. Acceptable quality resulted, however, when turf was watered once weekly at 50% of potential ET. Irrigation amount and interval did not significantly affect Rebel canopy temperature.

However, Reliant hard fescue possessed a significantly higher canopy temperature when irrigated every 14 days compared to every 2, 4, or 7 days. Results of these studies suggest that Rebel tall fescue may be employed to greatly reduce irrigation requirements with minimal effects on turf quality.

Table 4.1. Influence of deficit irrigation, averaged over intervals, on 'Reliant' hard fescue quality, and soil matric potential in 1986.

Irrigation amount	Quality ^Z		Soil matric potential (MPa)	
	3 June-1 Aug.	2 Aug.-27 Aug.	3 June-1 Aug.	2 Aug.-27 Aug.
100 percent IRR	8.0 a ^Y	8.3 a	-0.21 a	-0.14 a
75 percent IRR	7.9 a	8.1 a	-0.22 a	-0.04 a
50 percent IRR	6.2 b	6.5 b	-0.44 a	-0.13 a

^ZQuality ratings were based upon a 1-10 scale where 1 = brown, open turf; 7 = acceptable turf for a homelawn; and 10 = optimum color, density, and uniformity.

^YMeans followed by the same letter in a column are not significantly different according to the least significant difference multiple comparison test (P = 0.05).

Table 4.2. Influence of irrigation interval, averaged over deficit irrigation amounts, on 'Reliant' hard fescue quality, and soil matric potential in 1986.

Irrigation interval	Quality ^Z		Soil matric potential (MPa)	
	3 June-1 Aug.	2 Aug.-27 Aug.	3 June-1 Aug.	2 Aug.-27 Aug.
2 day	8.4 a ^Y	8.6 a	-0.13 a	-0.11 a
4 day	7.6 a b	7.7 a b	-0.14 a	-0.05 a
7 day	7.2 b c	7.5 a b	-0.34 a	-0.05 a
14 day	6.3 c	6.7 b	-0.61 a	-0.20 a

^ZQuality ratings were based upon a 1-10 scale where 1 = brown, open turf; 7 = acceptable turf for a homelawn; and 10 = optimum color, density, and uniformity.

^YMeans followed by the same letter in a column are not significantly different according to the least significant difference multiple comparison test (P = 0.05).

Table 4.3. Influence of deficit irrigation, averaged over intervals, on 'Reliant' hard fescue canopy temperature in 1986.

Irrigation amount	Canopy temperature (°C)		
	20 July	29 July	8 August
100 percent IRR	34.2 a ^Z	34.5 b	38.7 a
75 percent IRR	34.7 a	35.5 a b	38.3 a
50 percent IRR	35.9 a	37.8 a	40.1 a

^ZMeans followed by the same letter in a column are not significantly different according to the least significant difference multiple comparison test (P = 0.05).

4.4. Influence of irrigation interval, averaged over deficit irrigation levels, on 'Reliant' hard fescue canopy temperature in 1986.

Irrigation interval	Canopy temperature (°C)		
	20 July	29 July	8 August
2 day	35.0 a ^Z	34.1 b	38.1 b
4 day	34.9 a	35.4 b	39.4 b
7 day	34.0 a	35.6 b	38.2 b
14 day	35.8 a	38.5 a	40.2 a

^ZMeans followed by the same letter in a column are not significantly different according to the least significant difference multiple comparison test (P = 0.05).

Table 4.5 Influence of deficit irrigation, averaged over intervals, on 'Rebel' tall fescue quality, and soil matric potential in 1986.

Irrigation amount	Quality ^Z		Soil matric potential (MPa)	
	3 June-1 Aug.	2 Aug.-27 Aug.	3 June-1 Aug.	2 Aug.-27 Aug.
100 percent IRR	9.4 a ^Y	8.9 a	-0.18 a	-0.06 a
75 percent IRR	9.2 a	9.0 a	-0.17 a	-0.08 a
50 percent IRR	8.7 a	7.3 a	-0.30 a	-0.31 a

^ZQuality ratings were based upon a 1-10 scale where 1 = brown, open turf; 7 = acceptable turf for a homelawn; and 10 = optimum color, density, and uniformity.

^YMeans followed by the same letter in a column are not significantly different according to the least significant difference multiple comparison test (P = 0.05).

Table 4.6. Influence of irrigation interval, averaged over deficit irrigation levels, on 'Rebel' tall fescue quality, and soil matric potential in 1986.

Irrigation interval	Quality ^Z		Soil matric potential (MPa)	
	3 June-1 Aug.	2 Aug.-27 Aug.	3 June-1 Aug.	2 Aug.-27 Aug.
2 day	9.6 a ^Y	9.9 a	-0.06 a	-0.04 a
4 day	9.2 a	8.4 a b	-0.16 a	-0.03 a
7 day	8.9 a	8.0 a b	-0.22 a	-0.33 a
14 day	8.6 a	7.3 b	-0.43 a	-0.20 a

^ZQuality ratings were based upon a 1-10 scale where 1 = brown, open turf; 7 = acceptable turf for a homelawn; and 10 = optimum color, density, and uniformity.

^YMeans followed by the same letter in a column are not significantly different according to the least significant difference multiple comparison test (P = 0.05).

Table 4.7. Influence of deficit irrigation, averaged over intervals, on 'Rebel' tall fescue canopy temperature in 1986.

Irrigation amount	Canopy temperature (°C)		
	20 July	29 July	8 August
100 percent IRR	26.0 a ^Z	23.5 a	30.0 a
75 percent IRR	26.0 a	23.3 a	29.6 a
50 percent IRR	25.7 a	23.9 a	31.0 a

^ZMeans followed by the same letter in a column are not significantly different according to the least significant difference multiple comparison test (P = 0.05).

Table 4.8. Influence of irrigation interval, averaged over deficit irrigation levels, on 'Rebel' tall fescue canopy temperature in 1986.

Irrigation interval	Canopy temperature (°C)		
	20 July	29 July	8 August
2 day	25.3 b ^Z	23.3 a	29.4 a
4 day	25.8 a b	23.2 a	29.9 a
7 day	25.9 a b	23.4 a	30.9 a
14 day	26.5 a	24.1 a	30.4 a

^ZMeans followed by the same letter in a column are not significantly different according to the least significant difference multiple comparison test (P = 0.05).

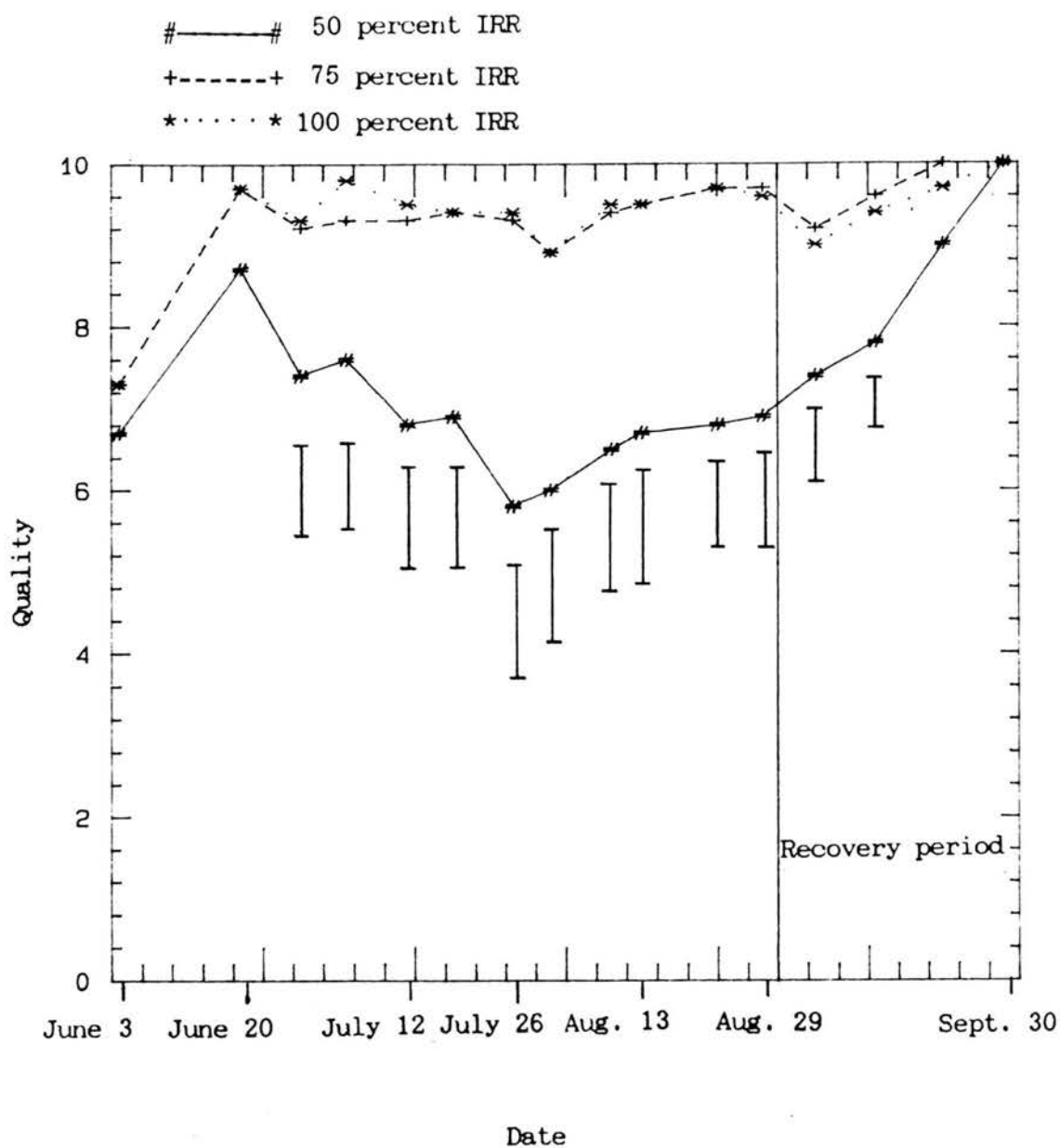


Figure 4.1. Quality of 'Reliant' hard fescue irrigated every two days at 50, 75, and 100 percent of potential ET. Points represent weekly means. Vertical bars below points indicate LSD values ($P = 0.05$).

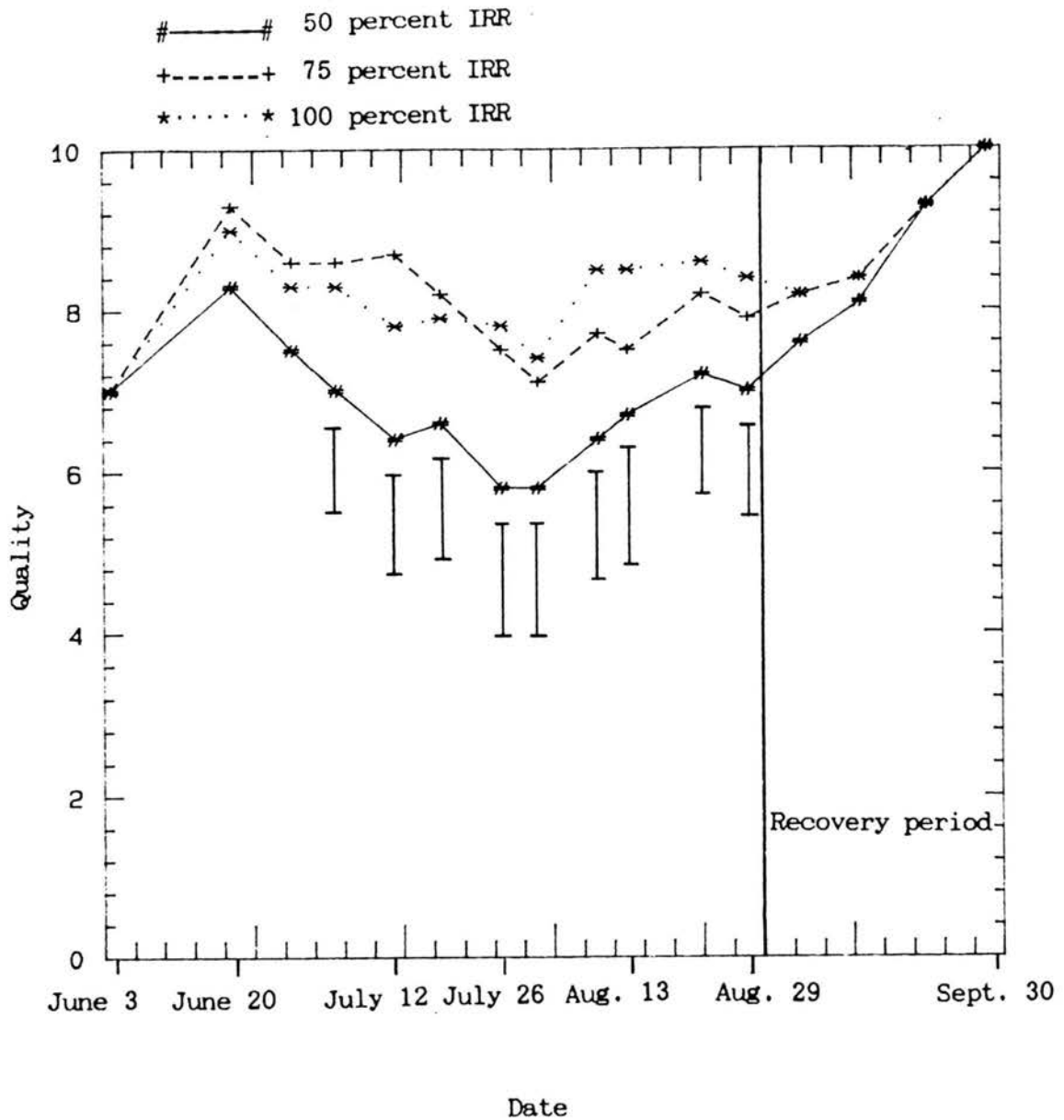


Figure 4.2. Quality of 'Reliant' hard fescue irrigated every four days at 50, 75, and 100 percent of potential ET. Points represent weekly means. Vertical bars below points indicate LSD values ($P = 0.05$).

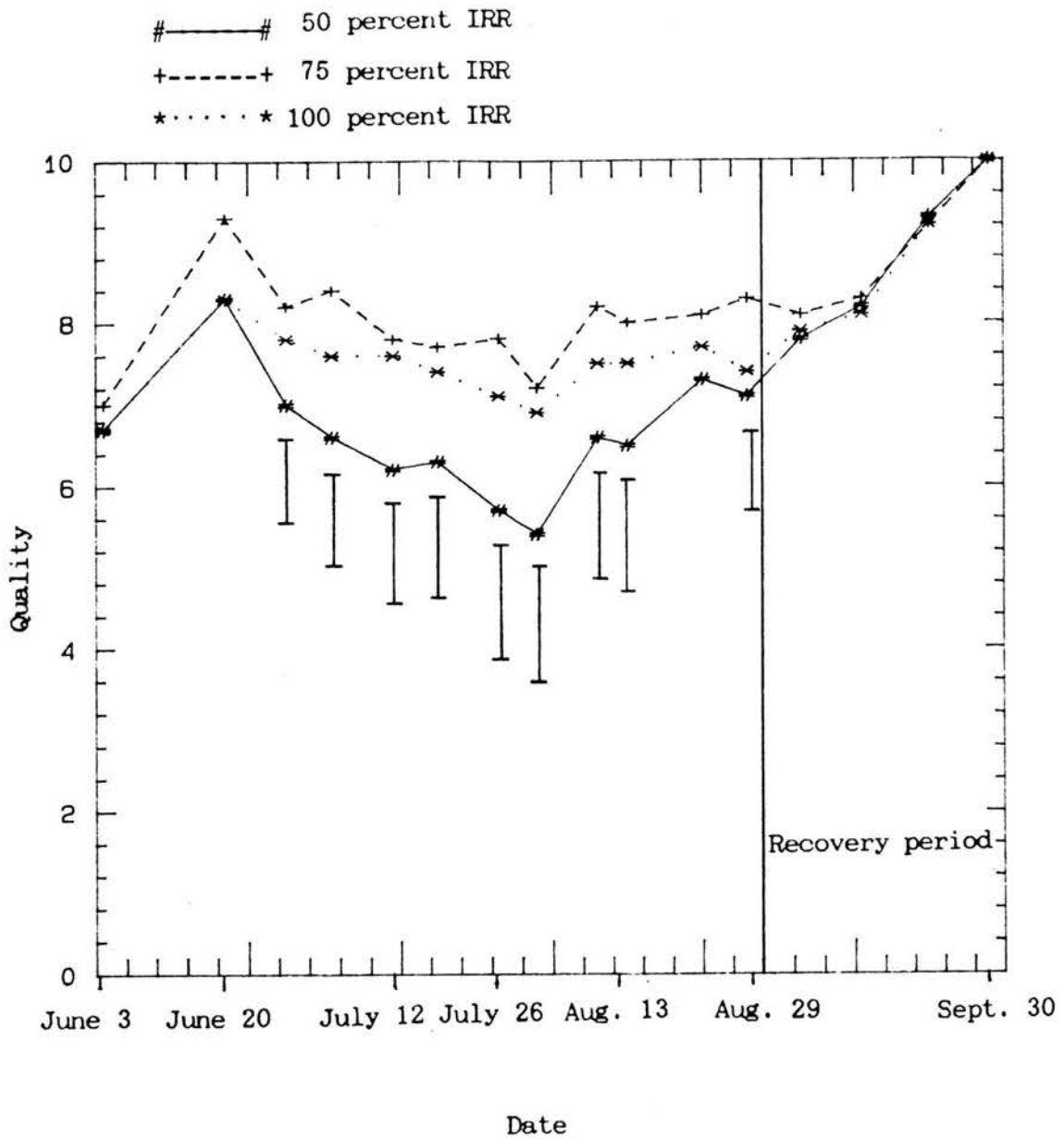


Figure 4.3. Quality of 'Reliant' hard fescue irrigated every seven days at 50, 75, and 100 percent of potential ET. Points represent weekly means. Vertical bars below points indicate LSD values ($P = 0.05$).

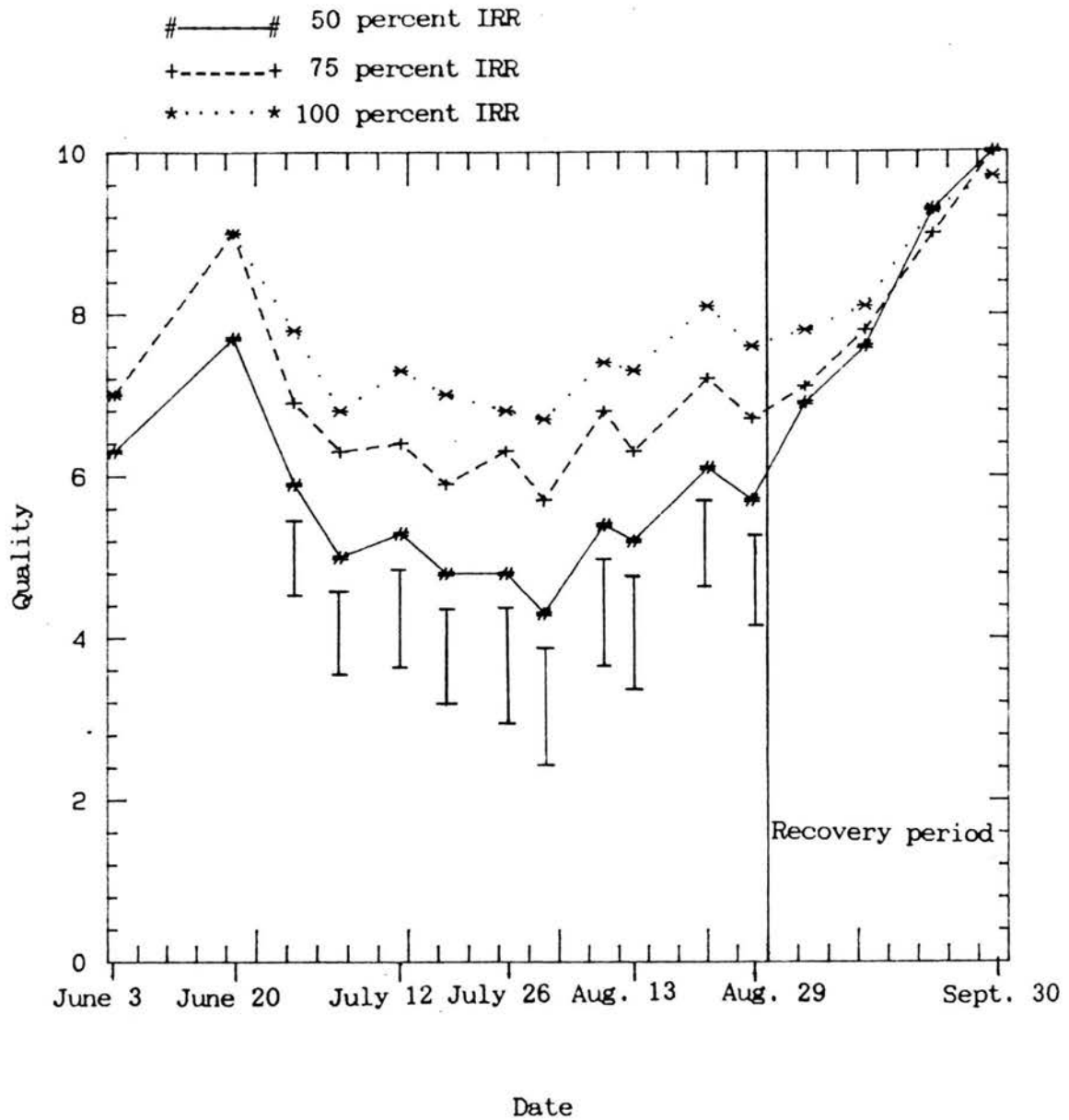


Figure 4.4. Quality of 'Reliant' hard fescue irrigated every 14 days at 50, 75, and 100 percent of potential ET. Points represent weekly means. Vertical bars below points indicate LSD values ($P = 0.05$).

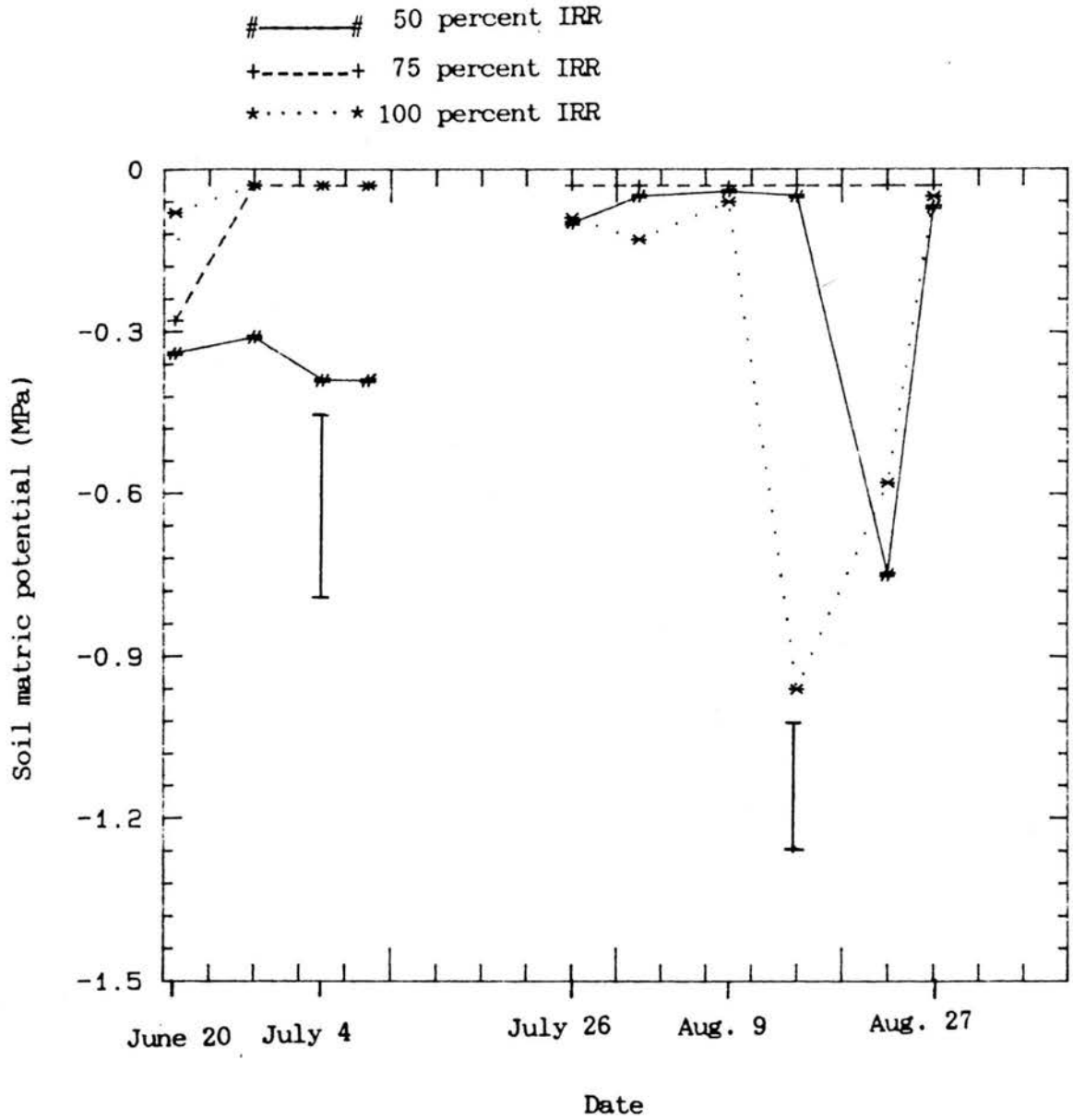


Figure 4.5. Soil matric potential under a 'Reliant' hard fescue turf irrigated every two days at 50, 75, and 100 percent of potential ET. Points represent weekly means. Vertical bars below points indicate LSD values ($P = 0.05$).

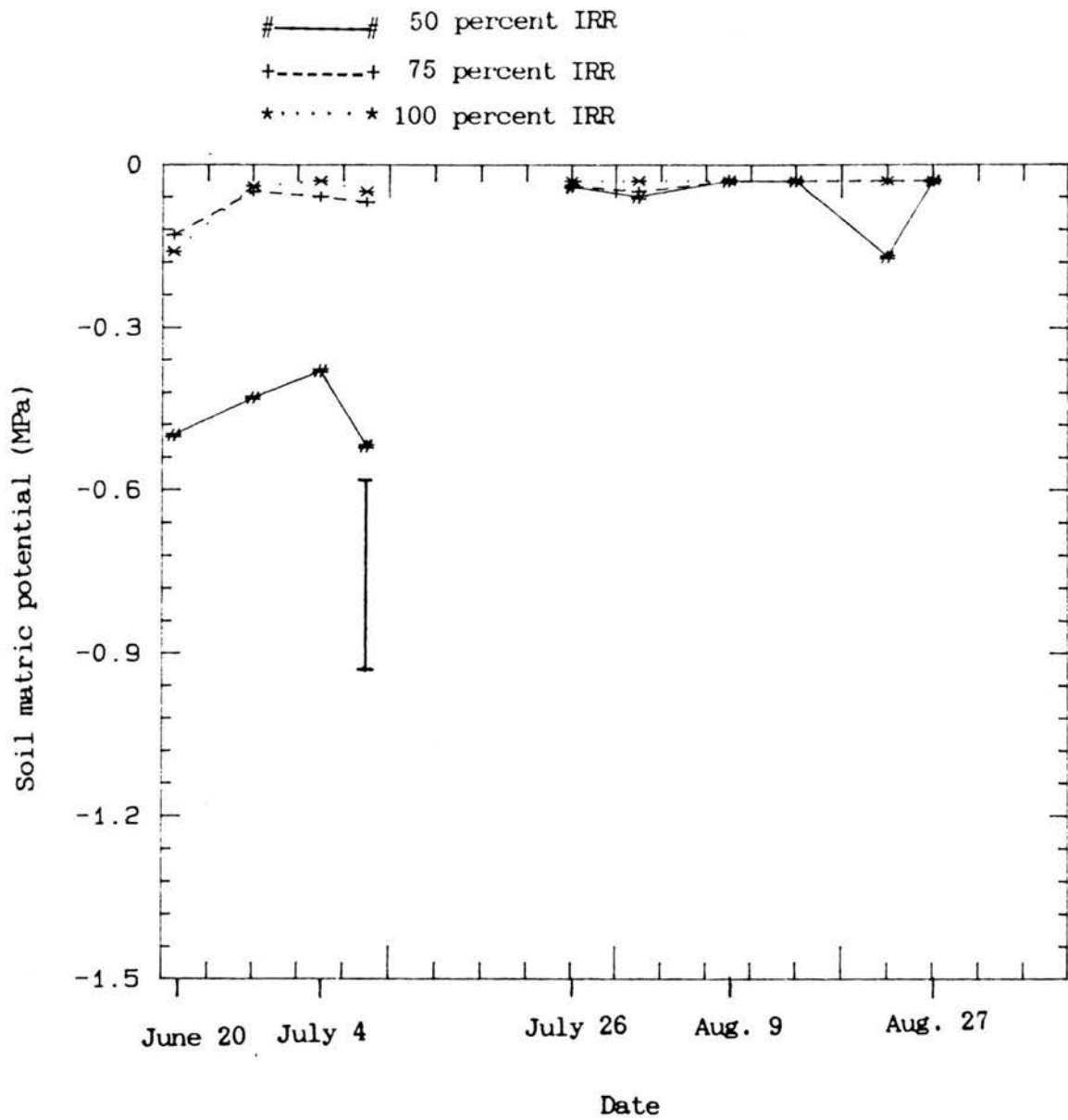


Figure 4.6. Soil matric potential under a 'Reliant' hard fescue turf irrigated every four days at 50, 75, and 100 percent of potential ET. Points represent weekly means. Vertical bars below points indicate LSD values ($P = 0.05$).

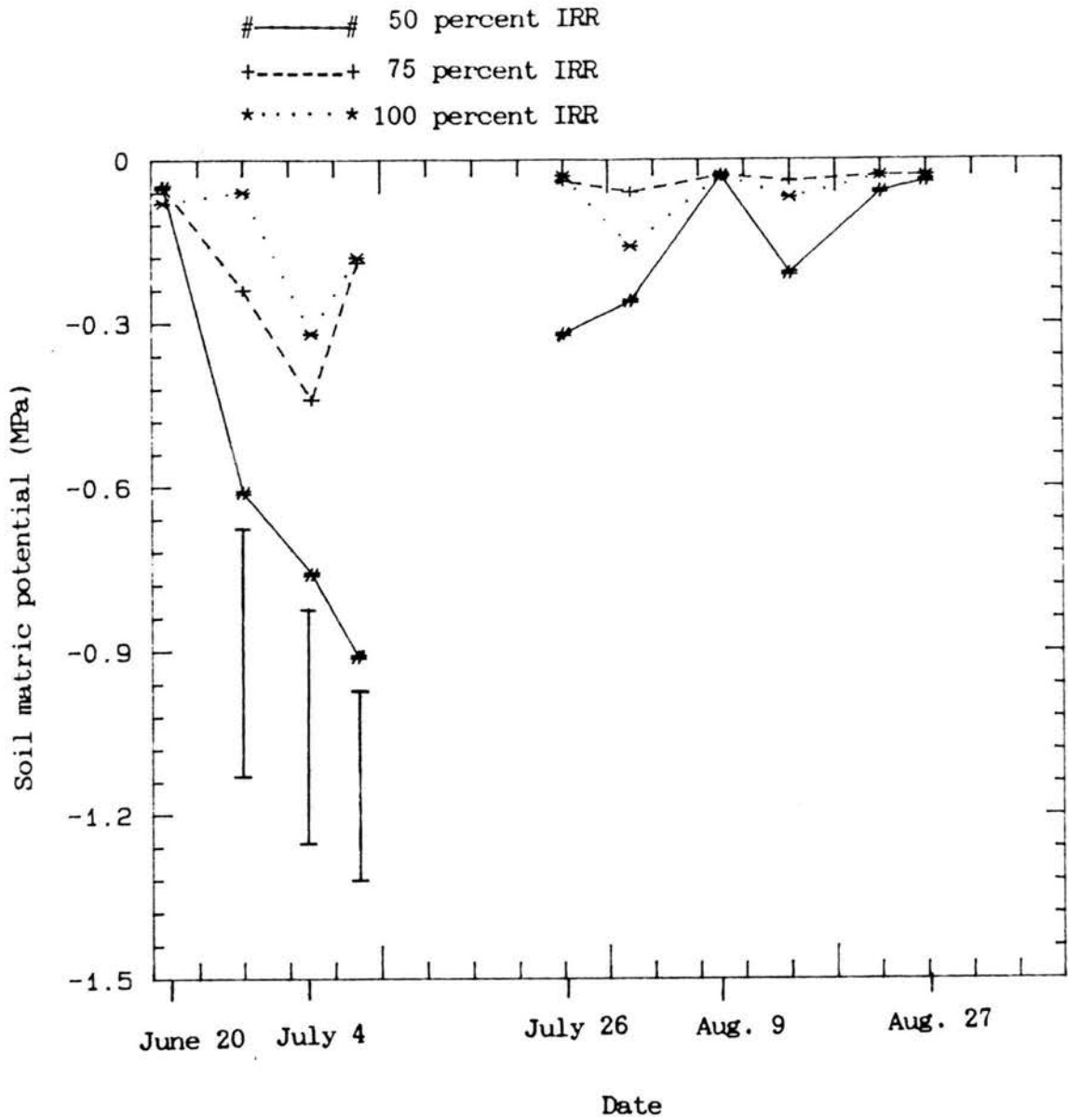


Figure 4.7. Soil matric potential under a 'Reliant' hard fescue turf irrigated every seven days at 50, 75, and 100 percent of potential ET. Points represent weekly means. Vertical bars below points indicate LSD values ($P = 0.05$).

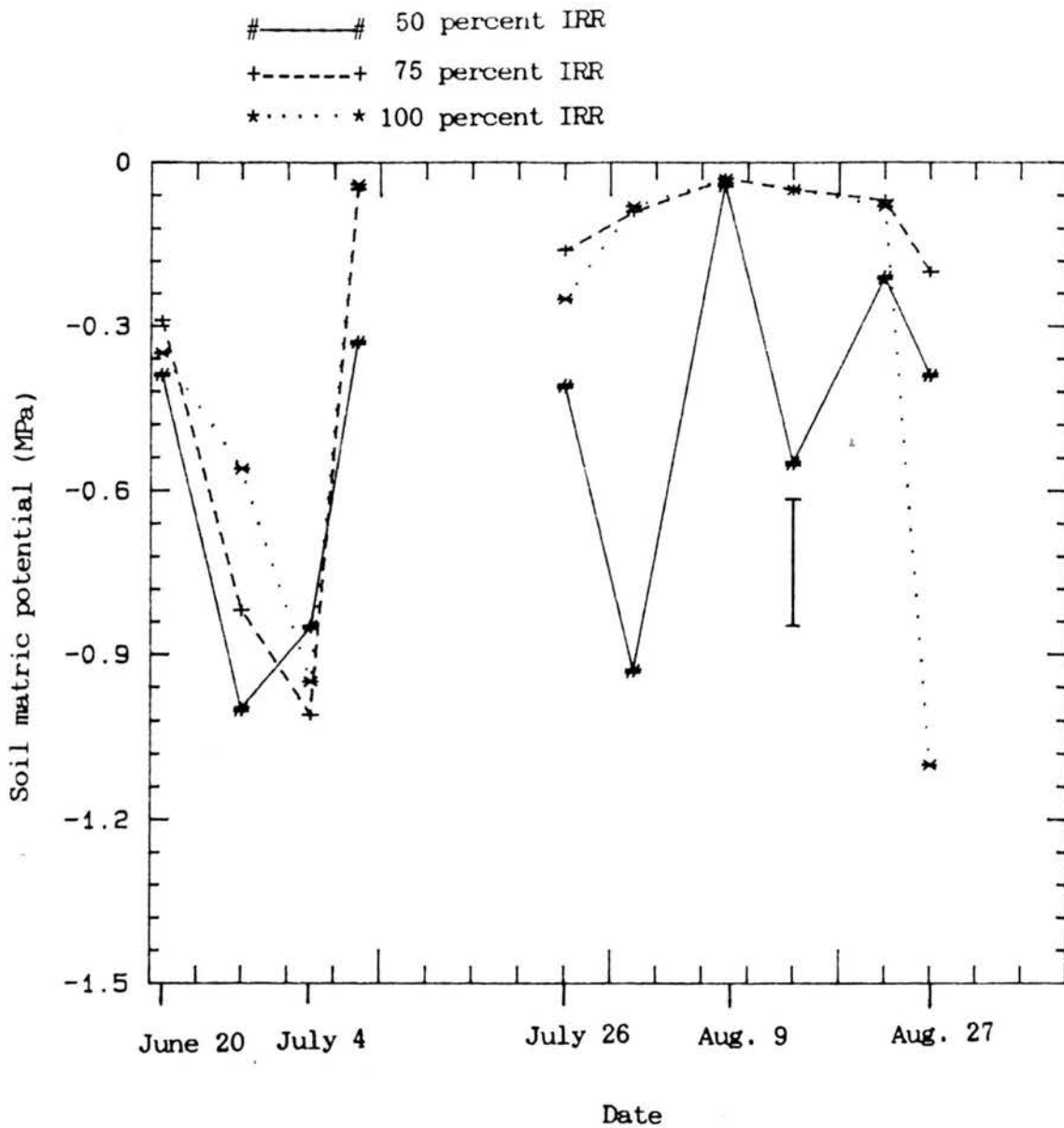


Figure 4.8. Soil matric potential under a 'Reliant' hard fescue turf irrigated every 14 days at 50, 75, and 100 percent of potential ET. Points represent weekly means. Vertical vars below points indicate LSD values ($P = 0.05$).

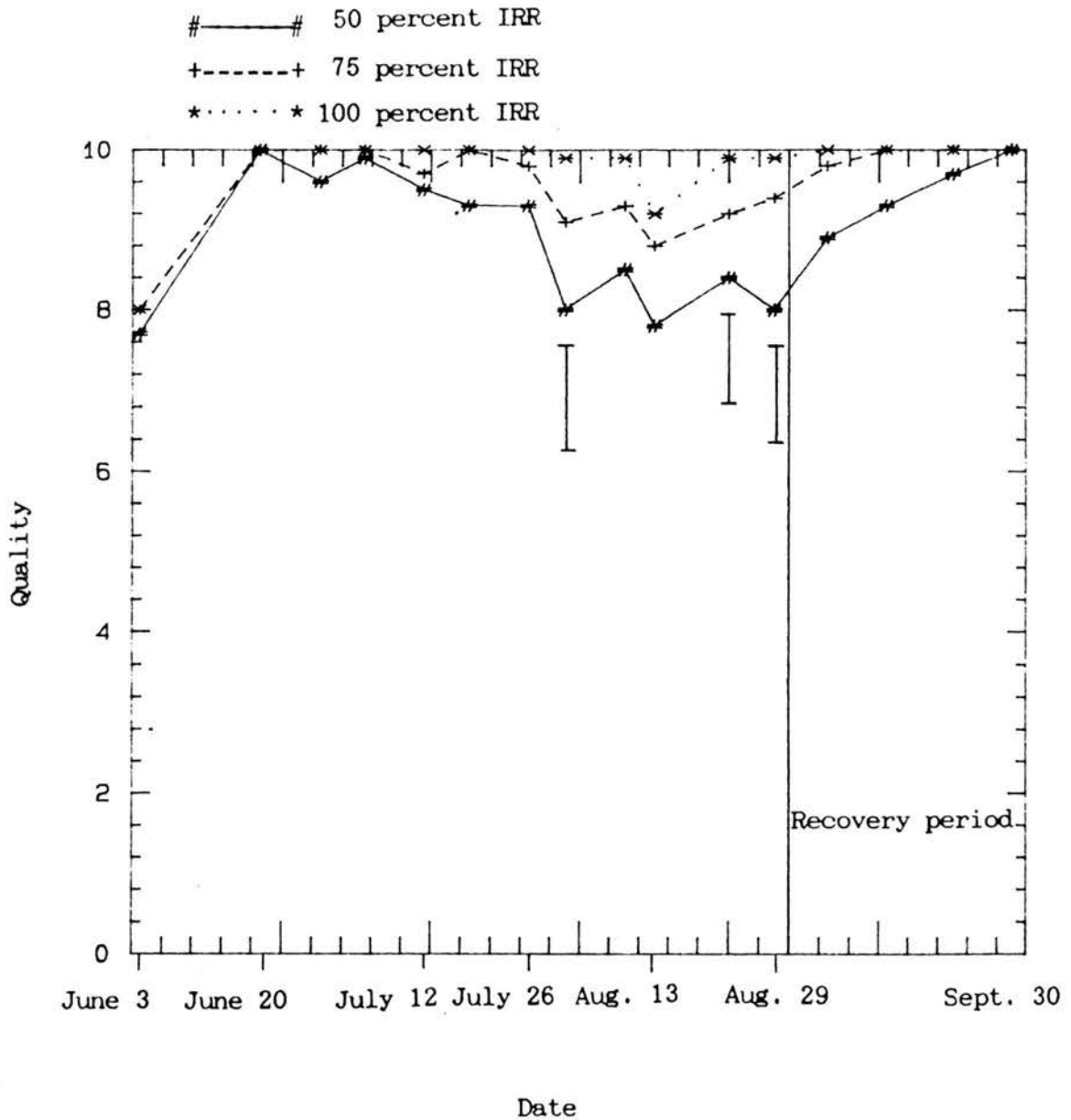


Figure 4.9. Quality of 'Rebel' tall fescue irrigated every two days at 50, 75, and 100 percent of potential ET. Points represent weekly means. Vertical bars below points indicate LSD values ($P = 0.05$).

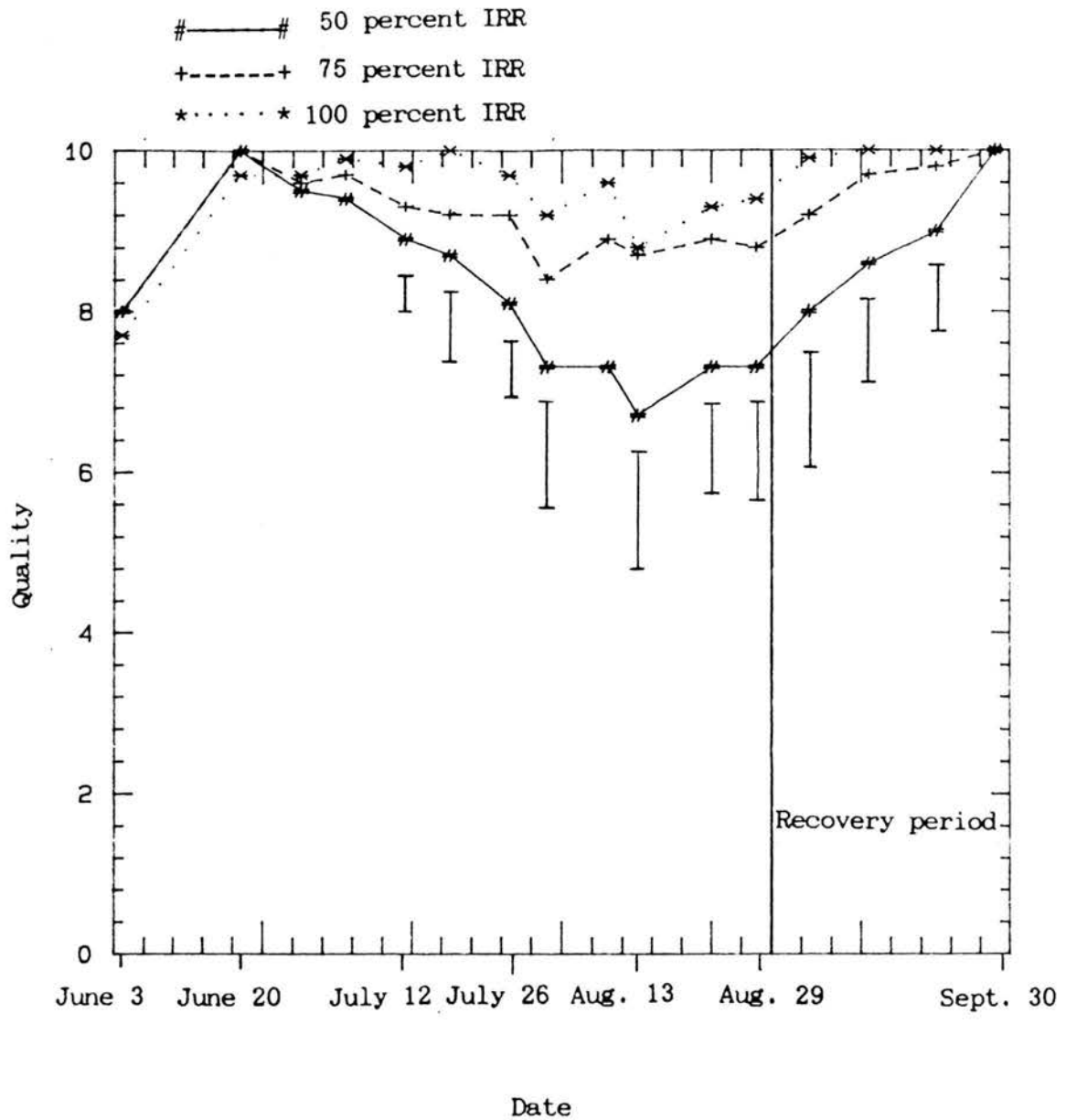


Figure 4.10. Quality of 'Rebel' tall fescue irrigated every four days at 50, 75, and 100 percent of potential ET. Points represent weekly means. Vertical bars below points indicate LSD values ($P = 0.05$).

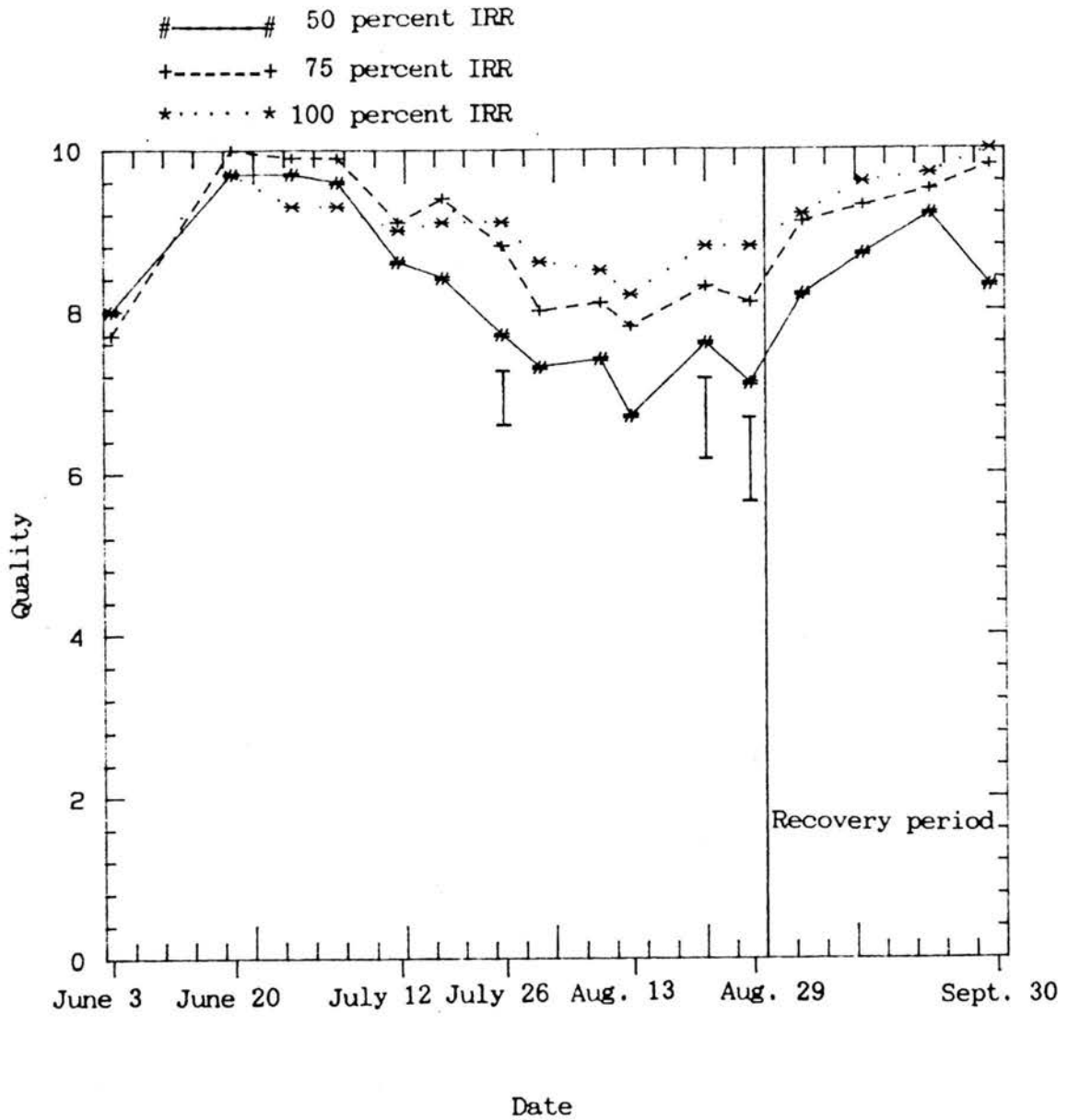


Figure 4.11. Quality of 'Rebel' tall fescue irrigated every seven days at 50, 75, and 100 percent of potential ET. Points represent weekly means. Vertical bars below points represent LSD values ($P = 0.05$).

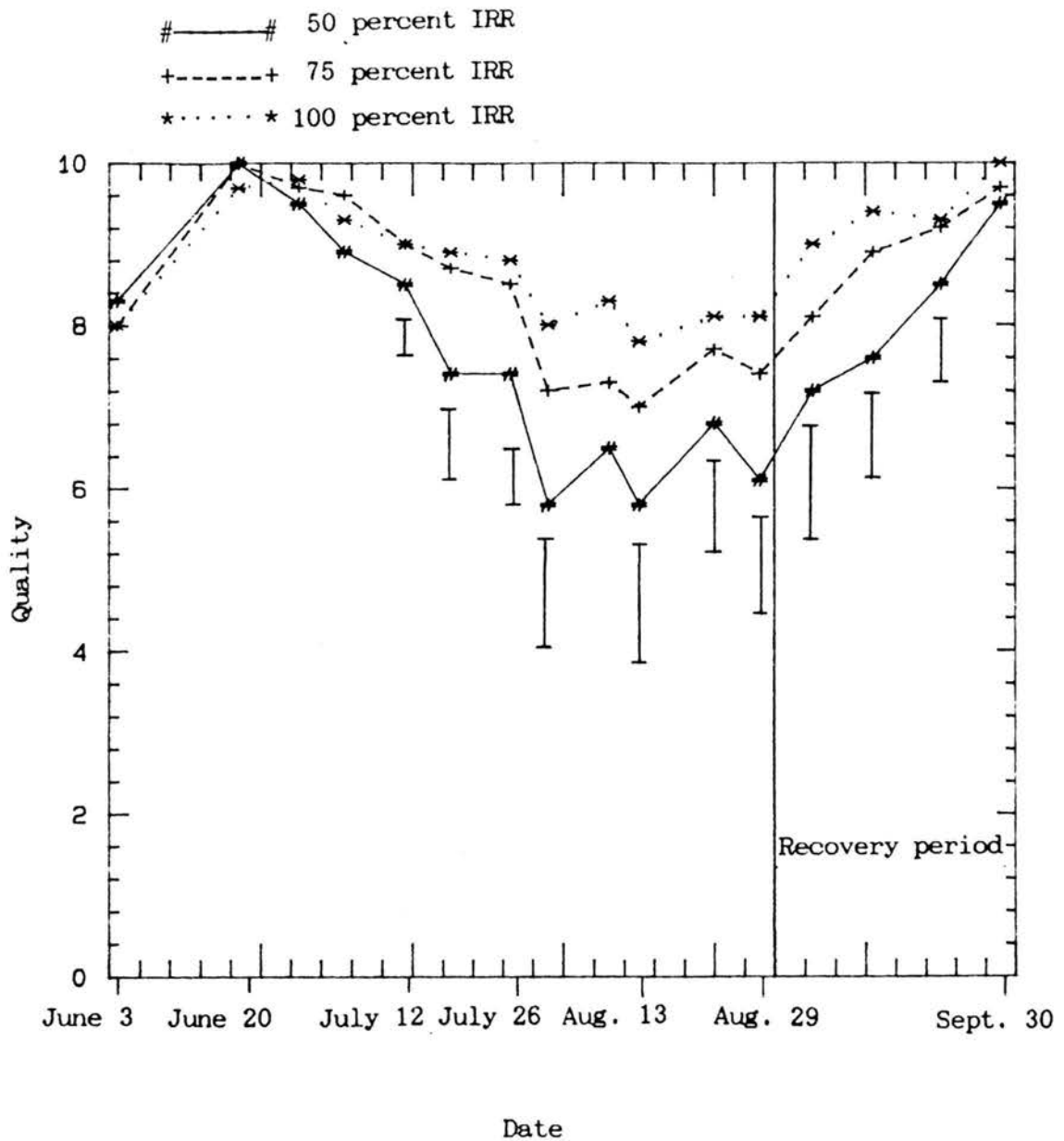


Figure 4.12. Quality of 'Rebel' tall fescue irrigated every 14 days at 50, 75, and 100 percent of potential ET. Points represent weekly means. Vertical bars below points indicate LSD values ($P = 0.05$).

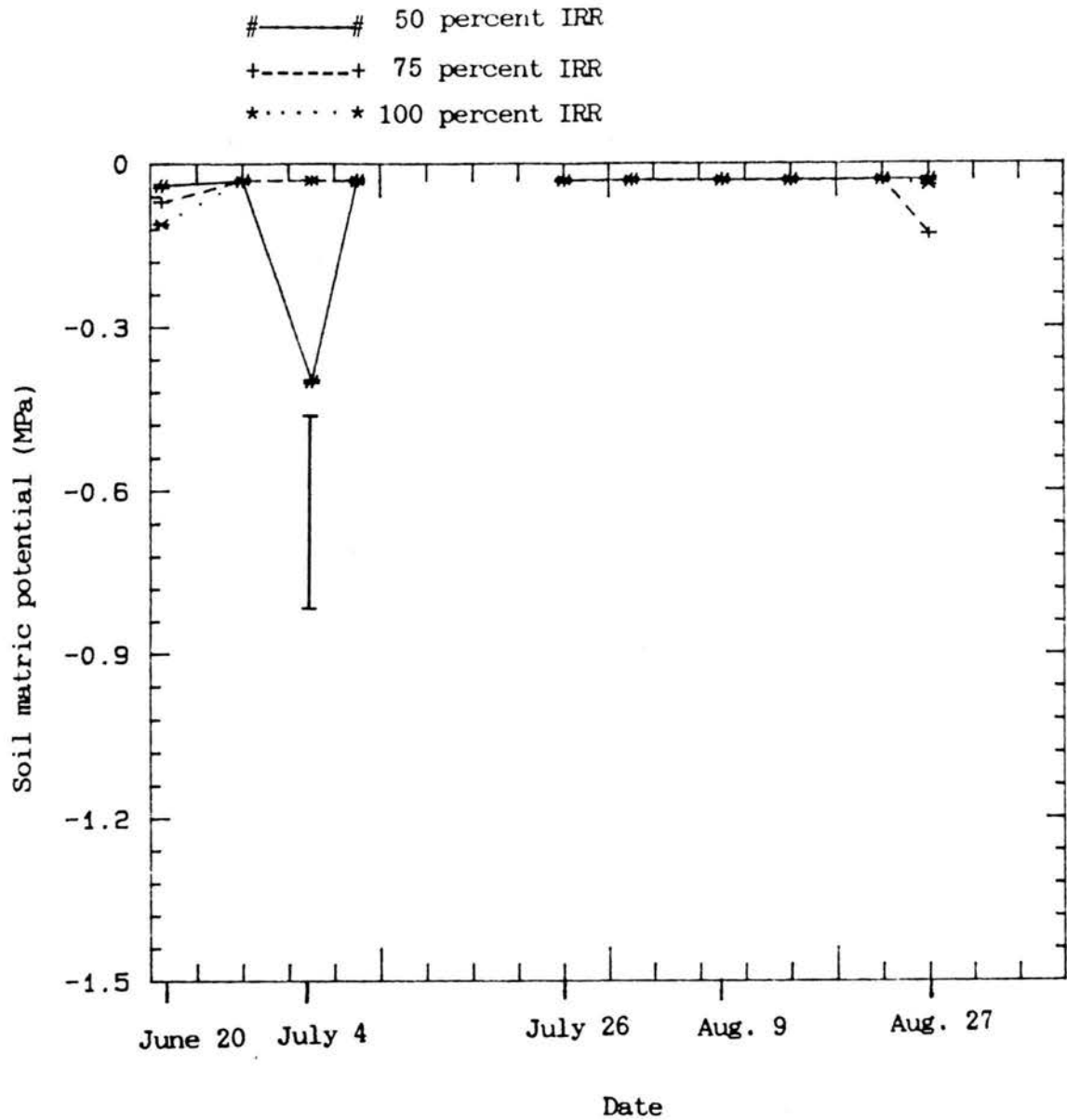


Figure 4.13. Soil matric potential under a 'Rebel' tall fescue turf irrigated every two days at 50, 75, and 100 percent of potential ET. Points represent weekly means. Vertical bars below points indicate LSD values ($P = 0.05$).

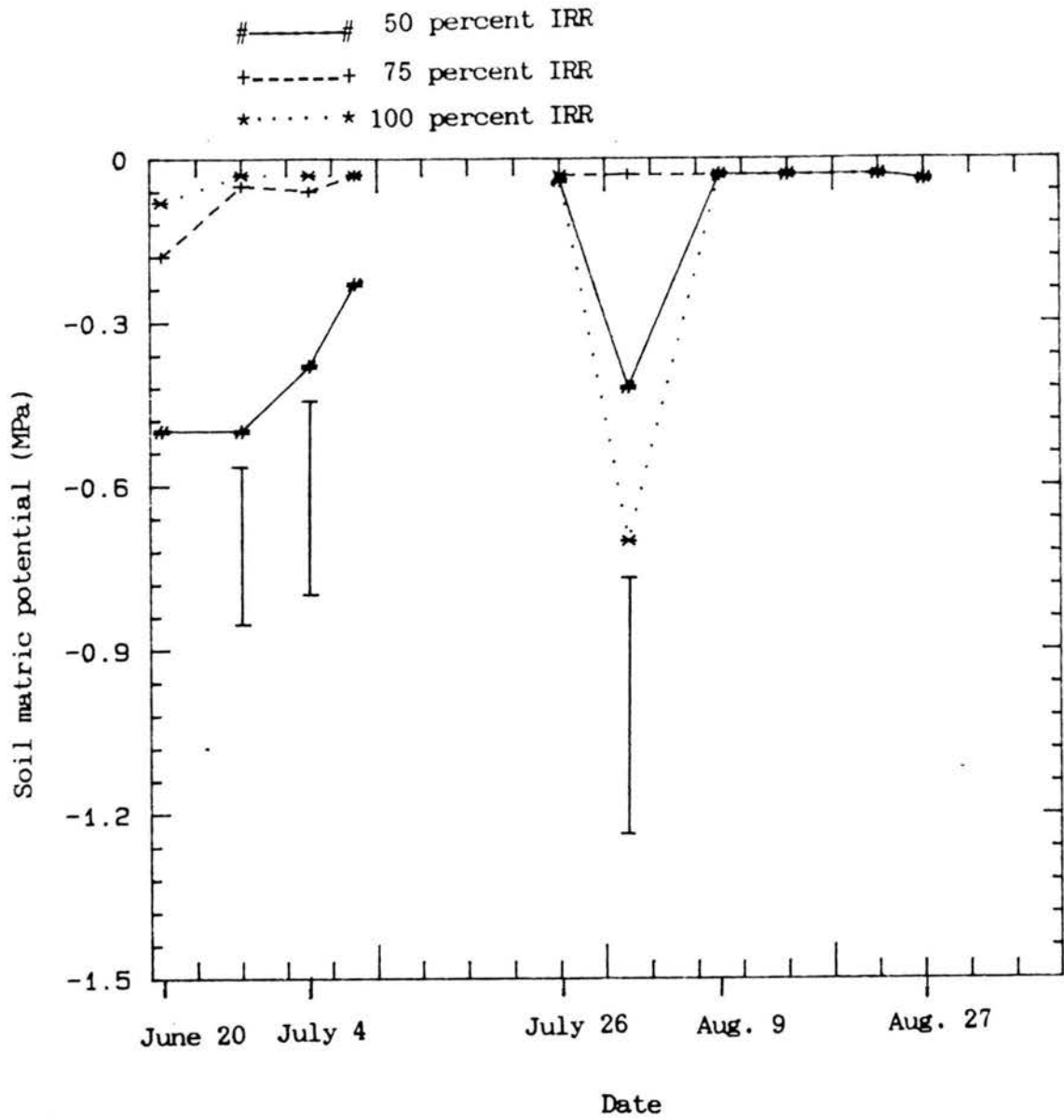


Figure 4.14. Soil matric potential under a 'Rebel' tall fescue turf irrigated every four days at 50, 75, and 100 percent of potential ET. Points represent weekly means. Vertical bars below points indicate LSD values ($P = 0.05$).

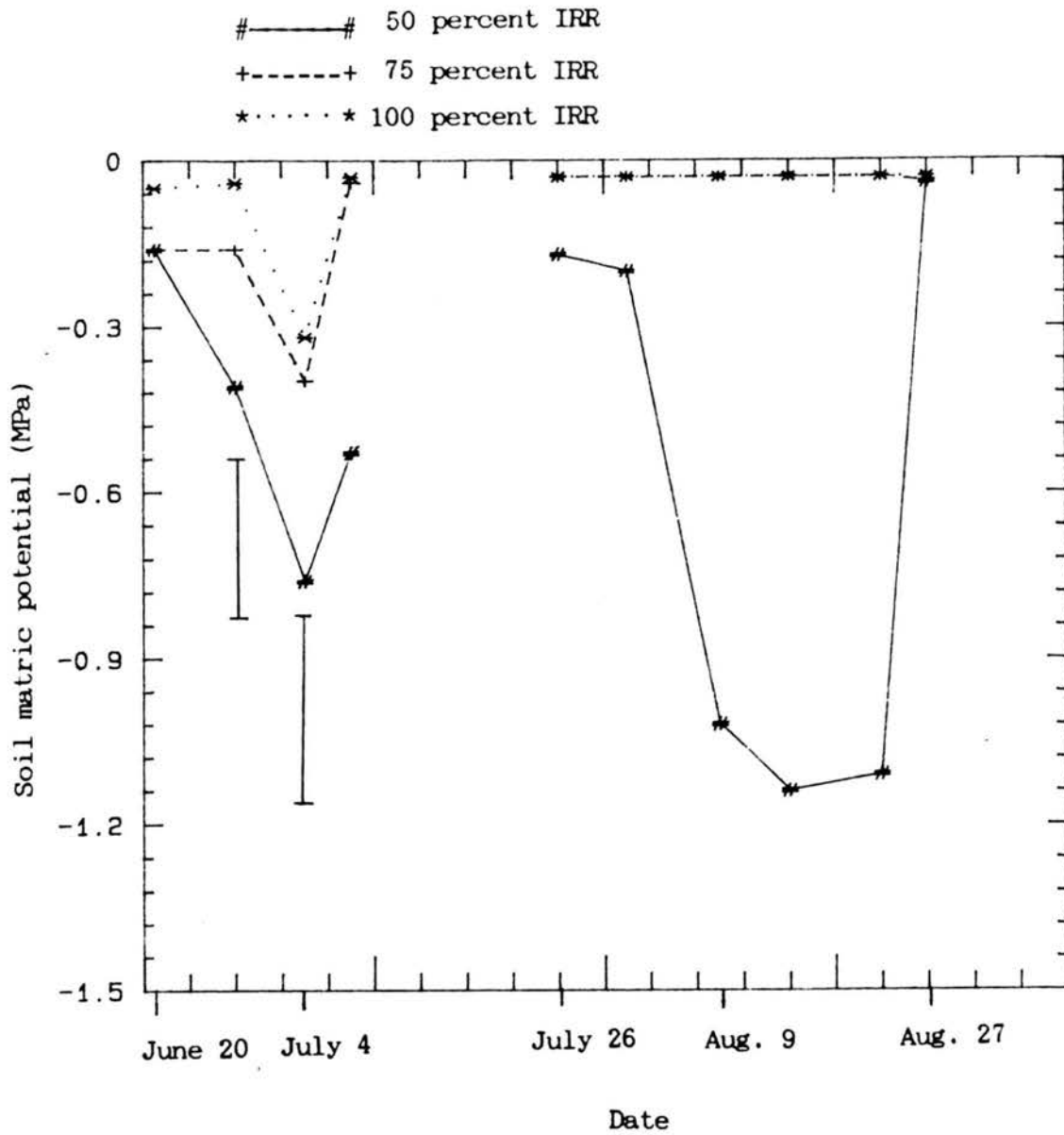


Figure 4.15. Soil matric potential under a 'Rebel' tall fescue turf irrigated every seven days at 50, 75, and 100 percent of potential ET. Points represent weekly means. Vertical bars below points indicate LSD values ($P = 0.05$).

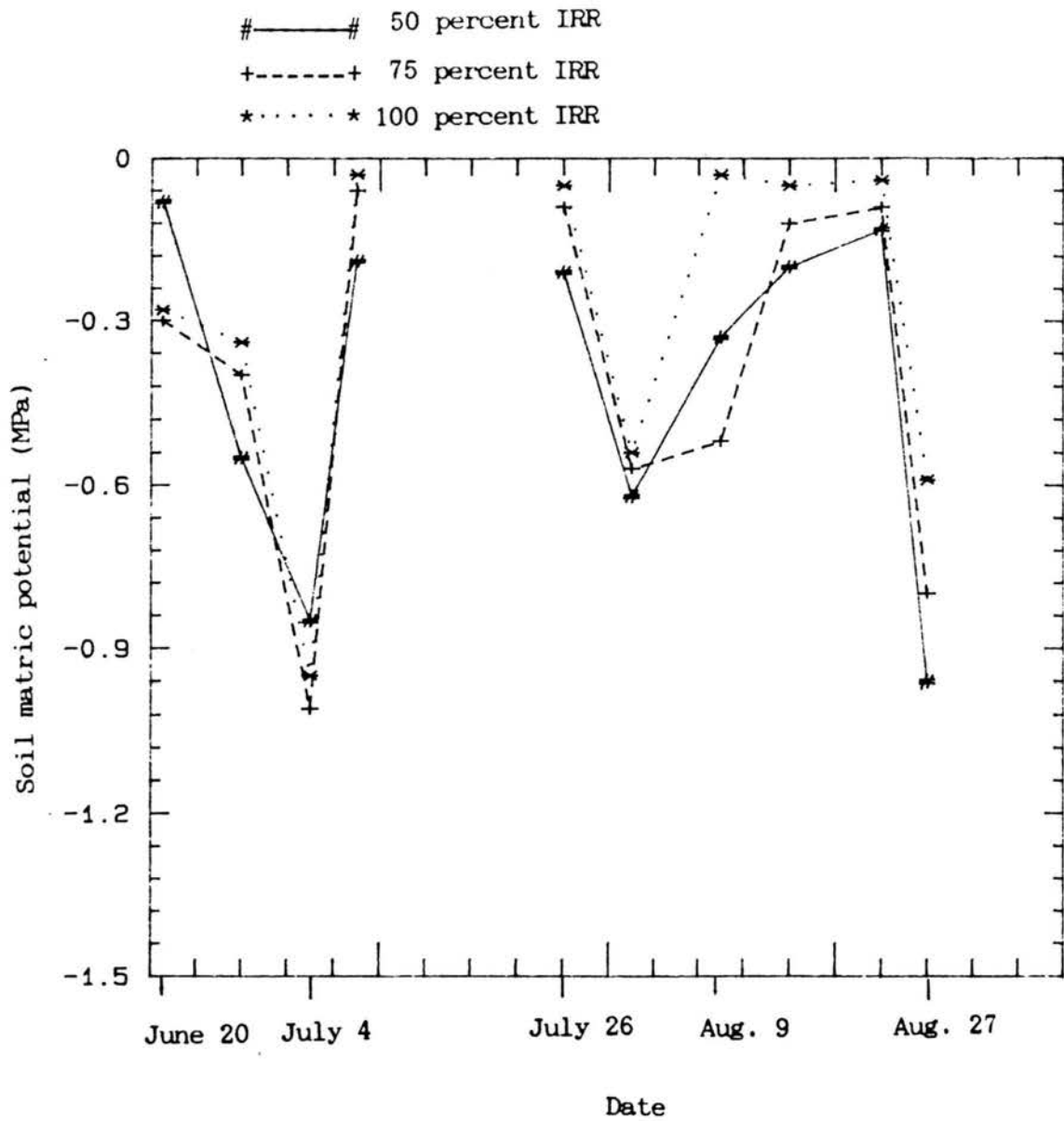


Figure 4.16. Soil matric potential under a 'Rebel' tall fescue turf irrigated every 14 days at 50, 75, and 100 percent of potential ET. Points represent weekly means.

LITERATURE CITED

1. Agnew, M.L., and R.N. Carrow. 1985. Soil compaction and moisture stress preconditioning in Kentucky bluegrass. I. Soil aeration, water use, and root responses. *Agron. J.* 77: 872-877.
2. Al-Nakshabandi, G.A. 1983. The potential evapotranspiration of short grass (*Cynodon dactylon*) as related to the estimated potential evaporation and evapotranspiration from meteorological data in the coastal region of Kuwait. *J. of Arid Environ.* 6:33-38.
3. Aurasteh, R.M. 1983. A model for estimating lawn grass water requirement considering deficit irrigation, shading and application efficiency. Ph. D. Dissertation. Utah State Univ., Logan, Utah. 241 p.
4. Aurasteh, R., M. Jafari, and L.S. Willardson. 1984. Residential lawn irrigation management. *Trans. of the Am. Soc. of Agric. Eng.* 27:470-472.
5. Baxter, L., and L. Waters, Jr. 1986. Effect of a hydrophilic polymer seed coating on the field performance of sweet corn and cowpea. *J. Am. Soc. Hort. Sci.* 111:31-34.
6. Beach, G. 1958. Irrigation of lawns, results of tests, 1953-1957. *Colo. St. Exp. Stn. Gen. Series, No. 684.* 11 p.
7. Beard, J.B. 1973. *Turfgrass: Science and Culture.* Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 658 p.
8. Beard, J.B. 1985. An assessment of water use by turfgrasses. *In* V.A. Gibeault and S.T. Cockerham (eds.) *Turfgrass Water Conservation.* Univ. of Calif. Pub. 21405. p. 45-62.
9. Beard, J.B. 1986. Turfgrass water use rates. *Grounds Maintenance, January.* p. 60-62.
10. Becwar, M.R., S.J. Wallner, and J.D. Butler. 1983. Effect of water stress on *in vitro* heat tolerance of turfgrass leaves. *Hort. Sci.* 18:93-95.
11. Belesky, D.P., M.L. Fishman, and S.R. Wilkinson. 1984. Effect of nitrogen fertilization and mild water stress on the distribution of nitrogen in tall fescue. *Plant and Soil* 77:295-303.

12. Belesky, D.P., S.R. Wilkinson, and J.E. Pallas, Jr. 1982. Response of four tall fescue cultivars grown at two nitrogen levels to low soil water availability. *Crop Sci.* 22:93-97.
13. Berdahl, J.D., and R.E. Barker. 1980. Germination and emergence of Russian wildrye seeds coated with hydrophilic materials. *Agron. J.* 72:1006-1008.
14. Biran, I., B. Bravado, I. Bushkin-Harav, and E. Rawitz. 1981. Water consumption and growth rate of 11 turfgrasses as affected by mowing height, irrigation frequency, and soil moisture. *Agron. J.* 73:85-90.
15. Bode, D.A., and S.L. Olson. 1980. Informational report on metering and conservation in Fort Collins, Colorado. Water Utilities Dept., Ft. Collins, Colorado. 35 p.
16. Boyer, J.S. 1971. Nonstomatal inhibition of photosynthesis in sunflower at low leaf water potentials and high light intensities. *Plant Physiol.* 48:532-536.
17. Brede, J.L., and A.D. Brede. 1986. Seed priming effects on 'Guymon' bermudagrass. *Agron. Abst.* p. 131.
18. Burton, G.W., E.H. DeVane, and R.L. Carter. 1954. Root penetration, distribution, and activity in southern grasses measured by yields, drought symptoms, and ^{32}P uptake. *Agron. J.* 46:229-233.
19. Butler, J.D., and C.M. Feldhake. 1981. Drought tolerant grasses for golf courses. *Proc. of the Golf Course Supt. Inst.* p. 98-101.
20. Butler, J.D., and J.D. Fry. 1987. Search for drought tolerant turfgrasses. *Proc of the New Jersey Turf Conf.* In Press.
21. Carroll, J.C. 1943. Atmospheric drought tests of some pasture and turf grasses. *J. Am. Soc. Agron.* 35:77-79.
22. Carrow, R.N. 1985. Soil/water relationships in turfgrass. In V.A. Gibeault and S.T. Cockerham (eds.) *Turfgrass Water Conservation.* Univ. of Calif. Pub. 21405. p. 85-102.
23. Colbaugh, P.F., and C.L. Elmore. 1985. Influence of water on pest activity. In V.A. Gibeault and S.T. Cockerham (eds.) *Turfgrass Water Conservation.* Univ. of Calif. Pub. 21405. p. 113-130.
24. Costello, L. 1981. Water absorption, translocation, and transpiration in the turfgrass plant. *Proc. of the California Golf Course Supt. Institute.* p. 10-13.

25. Danielson, R.E. 1967. Root systems in relation to irrigation. In R.M. Hagan, H.R. Haise, and T.W. Edminster (eds.). Irrigation of Agricultural Land. Publication of the American Society of Agronomy, Madison, Wisconsin. p. 390-424.
26. Danielson, R.E., W.E. Hart, C.M. Feldhake, and P.M. Haw. 1979. Water requirements for urban lawns. Colorado completion report to OWRT Project B-035-WYO. 90 p.
27. Davenport, D.C. 1966. Effects of chemical antitranspirants on transpiration and growth of grass. J. of Exp. Botany 18:332-347.
28. Dernoeden, P.H., and J.D. Butler. 1978. Drought resistance of Kentucky bluegrass cultivars. Hort. Sci. 13:667-668.
29. Dernoeden, P.H., and J.D. Butler. 1979. Relation of various plant characters to drought resistance of Kentucky bluegrass. Hort. Sci. 14:511-512.
30. Dexter, S.T., and T. Miyamoto. 1959. Acceleration of water uptake and germination of sugarbeet seedballs by surface coatings of hydrophilic colloids. Agron. J. 51:388-389.
31. Doss, B.D., and H.M. Taylor. 1970. Evapotranspiration and drainage from the root zone of irrigated coastal bermudagrass (*Cynodon dactylon* L. Pers.) on coastal plains soils. Trans. of the Am. Soc. of Agric. Eng. 13:426-429.
32. Ehrler, W.L., S.B. Idso, R.D. Jackson, and R.J. Reginato. 1978. Wheat canopy temperature: Relation to plant water potential. Agron. J. 70:251-256.
33. Engel, R.E. and L.M. Callahan. 1967. Merion Kentucky bluegrass response to soil residue of preemergence herbicides. Weeds 15:128-130.
34. Feldhake, C.M. 1979. Measuring evapotranspiration of turfgrass. M.S. thesis, Colorado State Univ., Fort Collins, Colorado. 56 p.
35. Feldhake, C.M. 1981. Turfgrass evapotranspiration and microenvironment interaction. Ph.D. dissertation, Colorado State Univ., Fort Collins, Colorado. 147 p.
36. Feldhake, C.M., and D.G. Boyer. 1986. Effect of soil temperature on evapotranspiration by C₃ and C₄ grasses. Agric. and Forest Meteorology. 37:309-318.
37. Feldhake, C.M., J.D. Butler, and R.E. Danielson. 1985. Turfgrass evapotranspiration. Responses to shade preconditioning. Irrigation Sci. 6:265-270.

38. Feldhake, C.M., R.E. Danielson, and J.D. Butler. 1983. Turfgrass evapotranspiration. I. Factors influencing rate in urban environments. *Agron. J.* 75:824-830.
39. Feldhake, C.M., R.E. Danielson, and J.D. Butler. 1985. Turfgrass evapotranspiration. II. Responses to deficit irrigation. *Agron. J.* 76:85-89.
40. Fry, J.D., P.H. Dernoeden, and J.J. Murray. 1986. Establishment and rooting of zoysiagrass (*Zoysia japonica*) as affected by preemergence herbicides. *Weed Sci.* 34:413-418.
41. Gehring, J.M., and H.J. Lewis III. 1980. Effect of hydrogel on wilting and moisture stress of bedding plants. *J. Am. Soc. Hort. Sci.* 105:511-513.
42. Gerakis, P.A., F.P. Guerrero, and W. Williams. 1975. Growth, water relations and nutrition of three grassland annuals as affected by drought. *J. of Appl. Ecology* 12:125-135.
43. Gerst, M.D., and C.W. Wendt. 1983. Effect of irrigation frequency on turf water requirements. *Texas Turfgrass Research.* p. 41-53.
44. Gibeault, V.A., J.L. Meyer, V.B. Youngner, and S.T. Cockerham. 1985. Irrigation of turfgrass below replacement of evapotranspiration as a means of water conservation: performance of commonly used turfgrasses. *Proceedings of the Fifth International Turfgrass Research Conf.* p. 347-356.
45. Grace, J. 1974. The effect of wind on grasses. I. Cuticular and stomatal transpiration. *J. of Exp. Botany* 25:542-551.
46. Grace, J., and G. Russell. 1977. The effect of wind on grasses. III. Influence of continuous drought or wind on anatomy and water relations in *Festuca arundinacea* Schreb. *J. of Exp. Botany* 28:268-278.
47. Grace, J., and J.R. Thompson. 1973. The after-effect of wind on the photosynthesis and transpiration of *Festuca arundinacea*. *Physiol. Plant.* 28:541-547.
48. Haw, P.M. 1978. Irrigation of urban lawns. M.S. thesis, Colorado State Univ., Fort Collins, Colorado. 80 p.
49. Hemyari, P., and D.L. Nofziger. 1981. Super slurper effects on crust strength, water retention, and water infiltration of soils. *Soil Sci. Soc. Am. J.* 45:799-801.
50. Horst, G.L., and C.J. Nelson. 1979. Compensatory growth of tall fescue following drought. *Agron. J.* 71:559-563.

51. Hsiao, T.C. 1973. Plant responses to water stress. *Ann. Rev. Plant Physiol.* 24:519-570.
52. Hunter, J.R., and A.E. Erickson. 1952. Relation of seed germination to soil moisture tension. *Agron. J.* 44:107-109.
53. Johns, D., and J.B. Beard. 1981. Reducing turfgrass transpiration using a growth inhibitor. *Agron. Abst.* p. 126.
54. Johns, D., J.B. Beard, and C.H.M. van Bavel. 1983. Resistance to evaporation from a St. Augustinegrass turf canopy. *Agron. J.* 75:419-422.
55. Johns, D., C.H.M. van Bavel, and J.B. Beard. 1981. Determination of the resistance to sensible heat flux density from turfgrass for estimation of its evapotranspiration rate. *Agric. Meteorology* 25:15-25.
56. Johnson, B.J. 1980. Root growth of southern turf cultivars as affected by herbicides. *Weed Sci.* 28:526-528.
57. Jones, M.B., E.L. Leafe, and W. Stiles. 1980. Water stress in field-grown perennial ryegrass. I. Its effect on growth, canopy photosynthesis and transpiration. *Ann. Appl. Biol.* 96:87-101.
58. Kim, K.S. 1983. Comparative evapotranspiration rates of thirteen turfgrasses grown under both non-limiting soil moisture and progressive water stress conditions. M.S. thesis, Texas A and M Univ., College Station, Texas. 64 p.
59. Kneebone, W.R., and I.L. Pepper. 1982. Consumptive water use by sub-irrigated turfgrasses under desert conditions. *Agron. J.* 74:419-423.
60. Kneebone, W.R., and I.L. Pepper. 1984. Luxury water use by bermudagrass turf. *Agron. J.* 76:999-1002.
61. Koslow, E.E. 1981. High-molecular weight poly (ethyleneoxide) polymers as soil amendments. Ph.D. dissertation, Cornell Univ., Ithaca, New York. 200 p.
62. Krans, J.V., and G.V. Johnson. 1974. Subirrigation and fertilization of bentgrass during prolonged heat stress. *Proc. of the Second International Turfgrass Research Conf.* p. 527-533.
63. Krogman, K.K. 1967. Evapotranspiration by irrigated grass as related to fertilizer. *Canadian J. of Plant Sci.* 47:281-287.

64. Levitt, J. 1980. Responses of plants to environmental stresses. Vol. II. Water, radiation, salt, and other stresses. Academic Press, New York, New York. 607 p.
65. Linaweaver, F.P., Jr., J.C. Geyer, and J.B. Wolff. 1967. A study of residential water use. U.S. Dept. of Housing and Urban Development. U.S. Government Printing Office, Washington, D.C.
66. Lipscomb, S.H., and M.S. Welterlen. 1986. Effects of wetting agents and antitranspirants on rooting of Kentucky bluegrass. Agron. Abst. p. 136.
67. Madison, J.H. 1962. Turfgrass ecology. Effects of mowing, irrigation, and nitrogen treatments of Agrostis palustris Huds., 'Seaside' and Agrostis tenuis Sibth., 'Highland' on population, yield, rooting, and cover. Agron. J. 54:407-412.
68. Madison, J.H., and R.M. Hagan. 1962. Extraction of soil moisture by 'Merion' bluegrass (Poa pratensis 'Merion') turf, as affected by irrigation frequency, mowing height, and other cultural operations. Agron. J. 54:157-160.
69. Marlatt, W.E. 1961. The interactions of microclimate, plant cover, and soil moisture content affecting evapotranspiration rates. Atmospheric Sci. Tech. Paper No. 23, Colorado State Univ., Fort Collins, Colorado. 8 p.
70. Meyer, J.L., and B.C. Camenga. 1985. Irrigation systems for water conservation. In V.A. Gibeault and S.T. Cockerham (eds.) Turfgrass Water Conservation. p. 103-112.
71. Meyer, J.L., V.A. Gibeault, and V.B. Youngner. 1985. Irrigation of turfgrass below replacement of evapotranspiration as a means of water conservation: Determining crop coefficients of turfgrasses. Proceedings of the Fifth International Turfgrass Research Conf. p. 357-364.
72. Minner, D.D. 1984. Cool season turfgrass quality as related to evapotranspiration and drought. Ph.D. dissertation. Colorado State Univ., Fort Collins, Colorado. 133 p.
73. Minner, D.D., and J.D. Butler. 1985. Drought tolerance of cool season turfgrasses. Proceedings of the Fifth International Turfgrass Research Conf. p. 199-112.
74. Mitchell, K.J., and J.R. Kerr. 1966. Differences in rate of use of soil moisture by stands of perennial ryegrass and white clover. Agron. J. 58:5-8.

75. Morgan, W.C., J. Letey, S.J. Richards, and N. Valoras. 1966. Physical soil amendments, soil compaction, irrigation, and wetting agents in turfgrass management. I. Effects on compactibility, water infiltration rates, evapotranspiration, and number of irrigations. *Agron. J.* 58:525-535.
76. Norris, I.B. 1982. Soil moisture and growth of contrasting varieties of Lolium, Dactylis and Festuca species. *Grass and Forage Sci.* 37:273-283.
77. Nus, J.L., and C.F. Hodges. 1985. Leaf and root growth of water stressed Kentucky bluegrass infected by Ustilago striiformis or Urocystis agropyri. *Crop Sci.* 25:97-100.
78. Nus, J.L., and C.F. Hodges. 1986. Differential sensitivity of turfgrass organs to water stress. *Hort. Sci.* 21:1014-1015.
79. Oke, T.R. 1979. Advectively-assisted evapotranspiration from irrigated urban vegetation. *Boundary Layer Meteorology* 17:167-173.
80. O'Neil, K.J., and R.N. Carrow. 1982. Kentucky bluegrass growth and water use under different soil compaction and irrigation regimes. *Agron. J.* 74:933-936.
81. O'Neill, P., L. Pochop, and J. Borrelli. 1979. Urban lawn evapotranspiration-measurement and prediction. *Trans. of the Am. Soc. of Agric. Eng.* 22:1050-1053.
82. Pande, H., and J.S. Singh. 1981. Comparative biomass and water status of four range grasses grown under two soil water conditions. *J. of Range Mgt.* 34:480-484.
83. Peacock, C.H., and A.E. Dudeck. 1985. Effect of irrigation interval on St. Augustinegrass rooting. *Agron. J.* 77:813-815.
84. Rossillon, J.P. 1985. Water: Whose is it, and who gets it? In V.A. Gibeault and S.T. Cockerham (eds.) *Turfgrass Water Conservation*. Univ. of Calif. Pub. 21405. p. 13-19.
85. Schmidt, R.E., and V. Snyder. 1984. Effects of N, temperature, and moisture stress on the growth and physiology of creeping bentgrass and response to chelated iron. *Agron. J.* 76:590-594.
86. Shearman, R.C. 1986. Kentucky bluegrass cultivar evapotranspiration rates. *Hort. Sci.* 21:455-457.
87. Shearman, R.C., and J.B. Beard. 1972. Stomatal density and distribution as influenced by species, cultivar, leaf blade surface and position. *Crop Sci.* 12:822-823.

88. Shearman, R.C., and J.B. Beard. 1973. Environmental and cultural preconditioning effects on the water use rate of Agrostis palustris Huds., cultivar Penncross. *Crop Sci.* 13:424-427
89. Sheffer, K.M. 1980. Responses of three cool season turfgrass species to heat and moisture stress. *Dissertation Abst. International* 40:4058.
90. Silcock, R.G., and D. Wilson. 1981. Effect of watering regime on yield, water use, and leaf conductance of seven Festuca species with contrasting leaf ridging. *New Phytologist* 89:569-580.
91. Sills, M.J., and R.N. Carrow. 1983. Turfgrass growth, N use, and water use under soil compaction and N fertilization. *Agron. J.* 75:488-492.
92. Singh, S.P., R.P. Singh, and S.R.P. Giri. 1973. Effect of soil moisture on water use by Berseem (Trifolium alexandrium J.). *Indian J. of Agron.* 18:333-337.
93. Stahnke, G.K. 1981. Evaluation of antitranspirants on creeping bentgrass (Agrostis palustris Huds., cv. 'Penncross') and bermudagrass [Cynodon dactylon (L.) Pers. x Cynodon transvaalensis Burt-Davy, cv. 'Tifway']. M.S. Thesis, Texas A and M Univ., College Station, Texas. 70 p.
94. Steinegger, D.H., R.C. Shearman, T.P. Riordan, and E.J. Kinbacher. 1983. Mower blade sharpness effects on turf. *Agron J.* 75:479-480.
95. Tanner, C.B. 1967. Measurement of evapotranspiration. In R.M. Hagan, A.R. Haise, and T.W. Edminster (eds.) *Irrigation of Agricultural Land*. Publication of the American Society of Agronomy, Madison, Wisconsin. p. 534-574.
96. Taylor, K.C., and R.G. Halfacre. 1986. The effect of a hydrophilic polymer on media water retention and nutrient availability to Ligustrum lucidum. *Hort. Sci.* 21:1159-1161.
97. Tovey, R., J.S. Spencer, and D.C. Muckel. 1969. Water requirements of lawngrass. *Trans. of the Am. Soc. of Ag. Eng.* 12:356-358.
98. Waldo, B.S. 1981. Water conservation report for the Department of Parks, Recreation, and Public Properties. Aurora Parks and Recreation, Aurora, Colorado.
99. Watson, J.R. 1985. Water resources in the United States. In V.A. Gibeault and S.T. Cockerham (eds.) *Turfgrass Water Conservation*. Univ. of Calif. Pub. 21405. p. 19-36.

100. Willingham, J.E., and D.L. Coffey. 1981. Influence of hydrophilic polymer amended soil on growth of tomato transplants. Hort. Sci. 16:289 (Abst.).
101. Wilson, A.M. 1973. Responses of crested wheatgrass seeds to environment. J. of Range Mgt. 26:43-46.
102. Wolf, D.D., and D.J. Parrish. 1982. Short-term growth responses of tall fescue to changes in soil water potential and to defoliation. Crop Sci. 22:996-999.
103. Wu, L., and D.R. Huff. 1983. Characteristics of creeping bentgrass clones (Agrostis stolonifera L.) from a salinity-tolerant population after surviving drought stress. Hort. Sci. 18:883-885.
104. Youngner, V.B. 1985. Physiology of water use and water stress. In V.A. Gibeault and S.T. Cockerham (eds.) Turfgrass Water Conservation. p. 37-43.
105. Youngner, V.B., A.W. Marsh, R.A. Strohman, V.A. Gibeault, and S. Spaulding. 1980. Water use and turf quality of warm and cool season turfgrasses. Proc. of the Fourth International Turfgrass Research Conf. p. 251-257.

APPENDIX A

Additional Tables Not Included In Text

Appendix Table A.1. Influence of mowing height on creeping bentgrass evapotranspiration (ET) between 11 July and 2 September, 1985.

Mowing Height	ET (mm day ⁻¹)								
	7/11-13	7/14	7/21-27	7/28-8/3	8/4-10	8/11-17	8/18-24	8/25-31	9/2
0.6	3.0 a ^Z	4.5 a	3.0 a	2.9 a	3.8 a	2.5 a	2.3 a	3.0 a	1.3 a
1.2	3.1 a	4.8 a	2.9 a	3.0 a	3.9 a	3.7 a	2.4 a	3.3 a	1.4 a

^ZMeans followed by the same letter in a column are not significantly different (P = 0.05).

Appendix Table A.2. Creeping bentgrass and annual bluegrass evapotranspiration (ET) rates at different mowing heights between 28 July and 30 August, 1986.

Species	Mowing height (cm)	ET (mm day ⁻¹)				
		28 July-1 Aug.	8-9 Aug.	11-16 Aug.	18-24 Aug.	25-30 Aug.
Annual bluegrass	1.2	4.8 a ^Z	NE ^Y	NE	NE	NE
Creeping bentgrass	0.6	4.9 a	3.8 a	4.0 a	4.1 a	4.2 a
Creeping bentgrass	1.2	5.1 a	3.8 a	4.3 a	4.2 a	4.2 a

^ZMeans followed by the same letter in a vertical column are not significantly different (P = 0.05).

^YAnnual bluegrass was not evaluated.

Appendix Table A.3. Influence of a hydrophilic polymer on plant number and density in 50 percent IRR lysimeters in 1985 and 1986.

Polymer application rate (kg ha ⁻¹)	1985		Density ^Z (% cover)				
	Plant number		1985			1986	
	27 Aug.	7 Sept.	11 Sept.	18 Sept.	25 Sept.	2 Sept.	11 Sept.
0	9 a ^Y	8 a	22 a	37 a	62 a	1 a	1 a
98	18 a	5 a	10 a	24 a	32 a	1 a	1 a

^ZDensity in lysimeters was estimated visually on a scale of 0-100% in 1985, and graphically in 1986.

^YMeans followed by the same letter in a column are not significantly different (P = 0.05).

Appendix Table A.4. Evapotranspiration (ET) rate of 'Rebel' tall fescue at two irrigation regimes and hydrophilic polymer application rates during establishment in 1985.

Irrigation amount	ET (mm day ⁻¹)			
	31 Aug.-8 Sept.		9-14 Sept.	
	Rate (Kg ha ⁻¹)			
	98	0	98	0
50 percent IRR	2.1	1.8	2.0	1.9
100 percent IRR	3.4	3.9	3.6	4.0

Appendix Table A.5. Water applied to lysimeters in Seeding Study II according to 'Merion' Kentucky bluegrass ET in 1985, and 'Rebel' tall fescue ET in 1986.

Date	Water applied (mm)	
	100 percent IRR	50 percent IRR
1985 8/17	7.5	3.8
8/18	4.8	2.4
8/19	1.3	0.7
8/20	3.4	1.7
8/21	5.0	2.5
8/22	4.8	2.4
8/23	3.4	1.7
8/24	5.9	3.0
8/25	4.7	2.4
8/26	4.8	2.4
8/27	7.3	3.6
8/28	2.3	1.2
8/29	4.4	2.2
8/30	3.1	1.5
8/31	6.6	3.3
9/2	3.0	1.5
9/4	3.2	1.6
9/7	3.4	1.7
9/8	3.8	1.9
9/9	4.1	2.1
9/10	2.4	1.2
9/11	3.0	1.5
9/12	3.7	1.9
9/14	5.7	2.9
9/16	10.4	5.2
9/18	6.0	3.0
9/20	4.5	2.2
9/23	6.8	3.4
9/25	4.4	2.2
9/27	3.0	1.5
1986 8/13	3.0	1.5
8/14	5.0	2.5
8/15	1.4	0.7
8/16	5.9	2.9
8/17	6.7	3.4
8/18	4.3	2.2
8/19	6.4	3.2
8/20	3.4	1.7
(Cont.)		

Appendix Table A.5. (Cont.).

Date	Water applied (mm)	
	100 percent IRR	50 percent IRR
1986 8/21	2.2	1.1
8/22	2.4	1.2
8/23	3.8	1.9
8/24	3.7	1.8
8/25	4.4	2.2
8/26	3.5	1.8
8/27	3.7	1.9
8/28	4.7	2.4
8/29	4.1	2.1
8/30	3.7	1.9
8/31	2.5	1.3
9/1	2.9	1.4
9/2	1.0	0.5
9/3	2.2	1.1
9/4	7.2	3.6
9/5	3.2	1.6
9/8	3.7	1.8
9/9	4.0	2.0
9/10	2.8	1.4
9/11	3.9	1.9
9/12	5.0	2.5
9/14	2.2	1.1
9/17	1.8	0.9
9/20	2.0	1.0

Appendix Table A.6. Weekly evapotranspiration (ET) means of 'Rebel' tall fescue and 'Reliant' hard fescue in 1986.

		ET (mm day ⁻¹)	
Date		'Rebel' tall fescue	'Reliant' hard fescue
1986	6/4-6/6	4.7	4.6
	6/7-6/14	4.5	4.5
	6/15-6/20	5.9	5.3
	6/21-6/28	5.4	5.2
	6/29-7/4	6.1	5.9
	7/5-7/12	5.9	5.4
	7/13-7/18	5.4	5.3
	7/19-7/26	4.5	5.0
	7/27-8/1	5.5	5.8
	8/2-8/7	3.7	3.9
	8/11-8/15	4.0	3.9
	8/16-8/23	4.8	4.4
	8/24-8/30	4.0	4.0

APPENDIX B

Analysis Of Variance Summaries

Appendix Table B.1. Analysis of variance summaries for the creeping bentgrass and annual bluegrass study during 1985 and 1986. A significant ($P=0.05$) effect is represented by a (*).

Date	SOV: DF:	ET				
		Mow ht. 1	Error 1 2	Spec. 1	Mow. ht.x Spec. 1	Error 2 4
		-----mean squares-----				
1985	6/6-6/8	0.998	0.875	0.127	0.001	0.242
	6/9-6/15	0.199	0.486	0.034	0.051	0.038
	6/16-6/22	0.405	0.149	0.026	0.006	0.005
	6/23-6/29	0.385	0.388	0.041	0.185	0.113
	6/30-7/6	0.286	0.114	0.083*	0.125*	0.006
	7/7-7/10	0.116	0.055	0.173	0.004	0.027
	7/11-7/13	0.040	0.088	0.397*	0.003	0.023
	7/14	0.496	0.106	0.053	0.030	0.040
	7/21-7/27	0.047	0.005	0.657*	0.017	0.007
	7/28-8/3	0.032	0.054	0.154	0.001	0.037
	8/4-8/10	0.115	0.024	0.208*	0.014	0.004
	8/11-8/17	0.397	0.037	0.003	0.049	0.021
	8/18-8/24	0.119	0.026	0.027	0.029	0.020
	8/25-8/31	0.200	0.037	0.091*	0.001	0.010
	9/2	0.018	0.014	0.001	0.012	0.047
Total	6/6-7/10	0.327	0.235	0.034	0.051	0.020
1986	6/4-6/7	0.137	0.010	0.386*	0.038	0.013
	6/8-6/14	0.024	0.059	0.025	0.043	0.031
	6/15-6/21	0.018*	0.004	0.157*	0.001	0.017
	6/22-6/28	0.179	0.022	0.129*	0.004	0.009
	6/29-7/4	0.694*	0.013	0.205*	0.035	0.027
	7/6-7/12	0.133	0.012	0.315*	0.228	0.038
	7/14-7/19	0.688*	0.021	0.475	0.272	0.078
Total	6/14-7/4	0.245*	0.010	0.158*	0.001	0.009
Total	7/6-7/19	0.336*	0.016	0.385*	0.247	0.052

Appendix Table B.2. Analysis of variance summaries for creeping bentgrass (0.6 and 1.2 cm mowing ht.) and annual bluegrass (1.2 cm) evapotranspiration (ET) between 28 July and 1 August, 1986, and for creeping bentgrass (0.6 and 1.2 cm) after 1 August, 1986. A significant effect ($P = 0.05$) is represented by a (*).

		ET	
Date	SOV: DF:	TRT 2	Error 4
-----mean squares-----			
1986 7/28-8/1		.299	.057
	DF:	1	2
1986 8/8-8/9		.003	.051
8/11-8/16		.161	.026
8/18-8/24		.009	.076
8/25-8/30		.007	.046

Appendix Table B.3. Analysis of variance summaries for turf weed and groundcover evapotranspiration (ET) in 1985 and 1986. A significant species difference is represented by a (*).

Date	SOV: DF:	Species 5	Error 15
-----mean squares-----			
1985	6/5-6/7	2.94*	0.119
	6/8-6/14	3.53*	0.156
	6/15-6/21	3.69*	0.145
	6/22-6/28	2.31*	0.322
	6/29-7/5	1.58*	0.244
	7/6-7/12	2.81	2.640
	7/18-7/22	2.58	2.140
	7/23-7/26	1.53	2.970
	7/27-8/2	2.60	2.740
	8/5-8/9	0.54	3.570
	8/10-8/16	3.68	4.080
	8/17-8/23	7.50	3.120
	8/24-9/2	1.62	1.390
Total	6/5-9-2	0.596*	0.142
1986	6/4-6/6	1.91*	0.053
	6/7-6/9	4.81*	0.040
	6/14-6/20	6.40*	0.282
	6/21-6/27	6.94*	0.210
	6/28-7/4	7.82*	0.340
	7/5-7/11	7.72*	0.368
	7/12-7/18	10.27*	0.345
	7/19-7/25	4.77*	0.273
	7/27-8/1	16.37*	0.348
	8/4-8/8	7.13*	0.215
	8/9-8/15	6.92*	0.146
	8/16-8/22	10.72*	0.219
	8/23-8/29	7.76*	0.273
Total	6/4-8/29	7.53*	0.160

Appendix Table B.4. Analysis of variance summaries for turf weed and groundcover density in 1985 and 1986. A significant effect is represented by a (*).

Date	SOV: DF:	Density	
		Species 5	Error 15
-----means squares-----			
1985 6/5		484.38*	33.26
6/12		128.04*	8.71
6/19		175.00*	1.11
1986 6/14		2566.38*	63.29
6/24		2708.87*	16.62

Appendix Table B.5. Analysis of variance summaries for Seeding Study I evapotranspiration (ET) in 1985 and 1986. A significant ($P = 0.05$) effect is represented by a (*).

		ET			
1985 Date	SOV: DF:	Species 1	Polymer 1	Spec. x Pol. 1	Error 6
-----mean squares-----					
6/6-6/8		0.002	0.016	0.467	0.180
6/9-6/14		0.093	0.027	0.031	0.065
6/16-6/23		0.008	0.009	0.223	0.133
6/24-6/28		0.229	0.040	0.001	0.276
6/29-7/6		3.39*	0.085	0.001	0.362
7/7-7/12		9.30*	0.105	0.021	0.365
7/13-7/20		1.94*	0.074	0.092	0.313
7/21-7/28		2.15*	0.225	0.001	0.278
Total 6/6-7/28		1.05*	0.059	0.001	0.132
<hr/>					
1986 Date	DF:	1	(Not Tested)	(Not Tested)	3
<hr/>					
6/6-6/7		0.195	-	-	0.630
6/8-6/14		0.001	-	-	0.039
6/15-6/21		36.000	-	-	14.700
6/22-6/28		0.174	-	-	1.540
6/29-7/4		0.191	-	-	3.060
7/6-7/12		1.330	-	-	1.870
7/13-7/19		0.490	-	-	0.173
7/20-7/26		0.061	-	-	1.840
Total 6/6-7/12		0.071	-	-	3.110
Total 7/13-7/26		0.241	-	-	0.084

Appendix Table B.6. Analysis of variance summaries for Seeding Study I density in 1985 and 1986. A significant ($P = 0.05$) is represented by a (*).

Date 1985	SOV: DF:	Density			Error 6
		Species 1	Polymer 1	Spec. x Pol. 1	
-----mean squares-----					
7/2		2640.33*	85.33	147.00	214.64
7/10		1728.00	96.33	481.33	444.81
7/20		2133.33	8.33	33.33	44.67
7/26		4370.08*	140.08	126.75	315.89
1986		1	Not Tested	Not Tested	3
7/1		800.00	-	-	596.33
7/8		1485.13	-	-	816.79
7/16		544.50	-	-	662.17
7/26		60.50	-	-	94.83

Appendix Table B.7. Analysis of variance summaries for Seeding Study II evapotranspiration (ET) in 1985 and 1986. A significant ($P = 0.05$) effect is represented by a (*).

Date	SOV: DF:	ET			
		IRR 1	Polymer 1	IRR x Pol. 1	Error 6
-----mean squares-----					
1985	8/17-8/23	6.24*	0.002	0.001	0.033
	8/24-8/30	16.10*	0.167	0.002	0.018
	8/31-9/8	8.58*	0.059	0.599*	0.020
	9/9-9/14	9.92*	0.012	0.251*	0.040
	9/16-9/20	11.70*	0.015	0.125	0.351
	9/23-9/27	0.83*	0.067	0.130	0.154
	Total 8/17-9/27	8.61*	0.053*	0.044*	0.006
1986	8/13-8/16	2.31*	0.038*	0.018	0.004
	8/17-8/23	6.61*	0.014	0.001	0.020
	8/24-8/30	13.30*	0.001	0.005	0.007
	8/31-9/5	13.20*	0.027	0.026	0.006
	9/8-9/12	12.30*	0.000	0.008	0.007
	9/14-9/20	4.00*	0.001	0.001	0.001
	Total 8/13-9/20	8.79*	0.001	0.005	0.002

Appendix Table B.8. Analysis of variance summaries for turf density in lysimeters in Seeding Study II in 1985 and 1986. A significant ($P = 0.05$) effect is represented by a (*).

Date	SOV: DF:	Density			
		IRR 1	Polymer 1	IRR x Pol. 1	Error 6
-----mean squares-----					
1985	8/27 (Plant No.)	2106.8*	60.8	60.8	70.1
	9/7	7650.8*	126.8	24.1	63.5
	9/11	10920.3*	280.3	12.0	183.8
	9/18	10092.0*	192.0	85.3	437.5
	9/25	7650.8	816.8	546.8	1830.4
1986	9/2	552.2*	0.3	1.5	1.2
	9/11	12096.8*	10.8	6.2	23.0

Appendix Table B.9. Analysis of variance summaries for Seeding Study II soil matric potential in 1985 and 1986. A significant ($P = 0.05$) effect is represented by a (*).

Date	SOV: IRR DF: 1	Polymer 1	IRR x Polymer 1	Error 6
	-----mean squares-----			
1985 8/17	5.33	5.33	0.08	3.02
8/18	9.19*	0.61	0.61	0.14
8/19	4.20*	0.14	0.14	0.83
8/20	2.80*	0.08	0.08	0.21
8/21	1.84*	0.001	0.001	0.001
8/22	4.44*	0.02	0.02	0.02
8/23	2.17*	0.008	0.008	0.03
8/24	1.33*	0.003	0.003	0.003
8/25	1.76*	0.003	0.003	0.003
8/26	1.69*	0.41*	0.007	0.004
8/27	1.61*	0.13	0.0	0.19
8/28	1.20*	0.03	0.003	0.006
8/29	1.33*	0.13	0.0	0.012
8/30	1.33*	0.013	0.0	0.012
8/31	1.33*	0.013	0.0	0.009
9/2	1.20*	0.03	0.003	0.006
9/4	1.33*	0.05	0.013	0.03
9/7	1.47*	0.003	0.003	0.01
9/10	2.17*	0.008	0.141	0.165
9/11	3.10*	0.008	0.141	0.178
9/12	2.00*	0.188	0.608	0.124
9/14	2.08	1.76	9.72	5.30
9/16	5.74	5.20	242.1*	39.88
9/17	5.74	5.20	242.1*	39.88
9/18	50.84	71.54	262.27*	16.66
9/20	19.51	22.14	22.14	48.17
9/23	79.05	0.03	0.05	23.41
9/25	41.44	6.31	7.84	15.26
Total 8/17-9/27	3.45	0.127	2.21	0.977
1986 8/21-8/23	11.87	15.71	4.98	13.69
8/24-8/30	13.59	36.55	2.48	20.95
8/31-9/5	5.97	53.48	2.87	21.02
9/8-9/12	1.94	61.77	7.72	75.51
9/14-9/20	238.22*	5.51	8.67	13.33
Total 8/21-9/20	0.002	0.001	0.109	20.73

Appendix Table B.10. Analysis of variance summaries for Greenhouse Seeding Studies I and II. A significant ($P = 0.05$) effect is represented by a (*).

Date	Variable	SOV: DF:	Polymer 2	Error 6
---mean squares---				
1986	2/28 RWPWC		82.3	56.5
	3/17 RWPWC		10.9	18.9
	2/21 Soil matric pot.		22.1	23.8
	2/22 Soil matric pot.		75.4	28.1
	2/24 Soil matric pot.		21.2	21.2
	2/25 Soil matric pot.		0	0
	2/26 Soil matric pot.		0	0
	2/28 Soil matric pot.		0	0
Study II Date	Variable	SOV: DF:	Polymer 3	Error 12
1986	3/22 Soil matric pot.		11.6	15.5
	3/25 Soil matric pot.		15.8	13.0
	3/31 Soil matric pot.		55.7*	8.6
	4/13 Soil matric pot.		207.6*	283.9
	4/16 Soil matric pot.		170.9*	12.2
	4/17 Soil matric pot.		165.8*	10.3
	4/22 Soil matric pot.		0	0
	4/18 RWPWC		408.9*	116.3
	5/8 No. of living plants		1064.3*	32.3

Appendix Table B.11. Analysis of variance summaries for 'Reliant' hard fescue quality during deficit irrigation in 1986. A significant ($P = 0.05$) effect is represented by a (*).

		Quality			
Date	SOV: DF:	IRR 2	INTERV 3	IRR x INTERV 6	Error 22
-----mean squares-----					
1986	6/3	0.583*	0.250	0.139	0.151
	6/20	3.69*	1.06	0.287	0.558
	6/22-6/28	6.81*	5.02*	0.446	0.392
	6/30-7/4	10.39*	12.72*	0.376	0.356
	7/6-7/12	14.06*	7.52*	0.648	0.534
	7/14-7/18	12.11*	11.25*	0.662	0.511
	7/20-7/26	20.10*	7.51*	0.931	0.675
	7/28-8/1	15.53*	8.55*	0.647	0.691
	8/3-8/9	14.38*	5.69*	0.895	0.594
	8/11-8/13	12.97*	7.86*	0.956	0.719
	8/19-8/23	9.62*	3.78*	1.21*	0.380
	8/25-8/29	9.37*	6.49*	1.17*	0.456
	9/1-9/5	2.43*	2.54*	0.519	0.255
	9/8-9/13	1.57*	1.83*	0.621*	0.143
	9/15-9/22	0.063	0.222	0.285	0.134
	9/25-9/30	0.028	0.028	0.028	0.028
Total	6/3-8/1	11.44*	7.16*	0.456	0.382
	8/3-8/27	11.67*	5.65*	0.988	0.478

Appendix Table B.12. Analysis of variance summaries for soil matric potential and canopy temperature during deficit irrigation of 'Reliant' hard fescue in 1986. A significant ($P = 0.05$) effect is represented by a (*).

Soil matric potential					
Date	SOV: DF:	IRR 2	INTERV 3	IRR x INTERV 6	Error 22
-----mean squares-----					
1986	6/16-6/20	8.05	12.88	3.54	7.13
	6/22-6/28	54.53*	85.09*	1.86	6.46
	6/30-7/4	23.37*	124.12*	6.25	4.24
	7/6-7/8	85.13*	15.63*	3.82	6.74
	7/22-7/26	7.41	9.66*	1.87	2.40
	7/28-8/1	2458.07	2347.98	2466.19	2472.37
	8/5-8/9	0.02	0.04	0.02	6.03
	8/11-8/15	10.66*	5.82	5.64*	2.06
	8/17-8/23	6.00	6.04	8.72	8.51
	8/25-8/27	17.18*	62.31*	16.86*	4.94
Total	6/16-8/1	50.87	116.50	69.81	77.22
Total	8/5-8/27	3.16	4.31	1.55	1.55
Canopy temperature					
	7/20	8.56*	5.06	0.39	2.13
	7/29	35.87*	30.77*	6.44*	2.50
	8/8	11.08*	9.26*	3.68*	2.01

Appendix Table B.13. Analysis of variance summaries for 'Rebel' tall fescue quality in 1986. A significant effect ($P = 0.05$) is represented by a (*).

Date	SOV: DF:	Quality			
		IRR 2	INTERV 3	IRR x INTERV 6	Error 22
-----mean squares-----					
1986	6/3	0.028	0.111	0.139	0.088
	6/20	0.194	0.074	0.046	0.104
	6/22-6/28	0.158	0.145	0.142	0.195
	6/30-7/4	0.336	0.752*	0.135	0.168
	7/6-7/12	1.06*	1.59*	0.076	0.068
	7/14-7/18	3.65*	3.29*	0.244	0.304
	7/20-7/26	5.32*	3.68*	0.112	0.182
	7/28-8/1	9.91*	6.27*	0.145	0.552
	8/3-8/9	21.78	29.41	11.20	11.85
	8/11-8/13	10.03*	4.83*	0.222	0.747
	8/19-8/23	7.00*	4.29*	0.136	0.458
	8/25-8/29	11.50*	5.78*	0.046	0.538
	9/1-9/5	6.51*	3.22*	0.184	0.663
	9/8-9/13	4.93*	2.08*	0.235	0.373
	9/15-9/22	1.51*	1.25*	0.081	0.211
	9/25-9/30	0.965	0.759	0.586	0.702
Total	6/3-8/1	1.76*	1.57*	0.051	0.080
	8/3-8/27	11.57*	11.02*	1.53	1.80

Appendix Table B.14. Analysis of variance summaries for soil matrix potential and canopy temperature during deficit irrigation of 'Rebel' tall fescue in 1986. A significant ($P = 0.05$) effect is represented by a (*).

		Soil matrix potential			
Date	SOV: DF:	IRR 2	INTERV 3	IRR x INTERV 6	Error 22
-----mean squares-----					
1986	6/16-6/20	0.93	7.04	9.01	6.51
	6/22-6/28	22.51*	24.34	3.72	3.00
	6/30-7/4	23.94*	123.69*	6.33	4.20
	7/6-7/8	17.34	4.35	4.28	7.16
	7/22-7/26	2.19	1.50	0.65	0.73
	7/28-8/1	7.87	54.57*	12.96	7.80
	8/5-8/9	24.13	24.09	24.64	24.41
	8/11-8/15	37.74	27.46	28.86	30.11
	8/17-8/23	32.63	27.00	28.15	28.35
	8/25-8/27	2.96	122.94*	2.71	7.62
Total	6/16-8/1	6.77*	21.59*	1.12	1.33
Total	8/5-8/27	7.18*	5.41*	0.43	0.61
		Canopy temperature			
1986	7/20	0.47	2.06*	1.38*	0.49
	7/29	1.19	1.42	0.80	2.41
	8/8	5.51*	3.51	1.03	1.36

APPENDIX C

Climatic Data During Study Periods

Appendix Table C.1. Temperature, precipitation, evaporation, and solar radiation data collected between 1 June and 30 Sept., 1985 and 1986 in Fort Collins, Colorado.

Date	Temperature(°C)			Precipitation(mm)		Evap.	Solar rad.
	Max.	Min.	Mean	Total	Mean(day ⁻¹)	(mm day ⁻¹)	(Mj m ⁻²)
June, 1985							
2-8	27	11	19	5.1	0.7	5.8	22.2
9-15	26	11	19	44.7	7.5	5.6	23.3
16-22	28	12	20	2.0	0.3	7.6	27.18
23-29	27	10	19	21.6	3.0	5.8	23.08
July, 1985							
30-6	31	13	22	0.3	1.03	6.9	25.92
7-13	33	15	24	9.4	1.3	6.1	19.47
14-20	28	14	26	76.2	10.7	4.1	17.03
21-27	27	14	21	3.0	.3	4.8	22.59
28-3	27	14	21	9.1	1.3	4.3	19.74
Aug., 1985							
4-10	31	12	22	0.0	0.0	6.1	23.27
11-17	27	11	19	0.0	0.0	6.4	22.46
18-24	28	11	20	0.8	0.1	4.6	18.62
25-31	32	12	22	7.6	1.0	5.1	18.84
Sept., 1985							
1-7	28	12	20	10.7	1.5	4.6	17.34
8-14	23	9	16	7.6	1.0	4.1	18.68
15-21	26	8	17	1.5	0.2	4.3	16.25
22-28	15	1	8	14.7	2.0	3.3	11.62
29-30	2	-7	-3	0.3	0.1		11.74
June 1986							
1-7	26	12	19	3.3	0.3	5.3	22.54
8-14	24	9	17	24.6	3.3	4.6	21.73
15-21	31	12	22	1.5	0.2	7.1	26.35
22-28	31	13	22	0.5	0.05	7.6	23.79
29-5	31	15	23	0.3	0.03	7.1	23.65
July 1986							
6-12	28	13	21	4.3	0.5	5.6	21.95
13-19	31	14	23	0.3	0.03	5.6	21.09
20-26	27	13	20	19.3	2.5	5.3	22.65
27-2	29	14	22	11.2	1.5	8.1	25.17
Aug., 1986							
3-9	28	12	20	9.1	1.3	6.9	20.27
10-16	29	12	21	0.5	0.1	5.3	21.61
17-23	28	14	21	8.9	1.3	4.8	18.20
24-30	28	13	21	1.0	0.1	4.8	18.81
31-6	24	9	17	1.8	0.3	3.8	16.76

(Cont.)

Appendix Table C.1. (cont.)

	Temperature(°C)			Precip.(mm)		Evap.	Solar rad.
	Max.	Min.	Mean	Total	Mean(day ⁻¹)	(mm day ⁻¹)	(Mj m ⁻²)
Sept., 1986							
7-13	22	9	16	7.6	1.0	3.3	14.00
14-20	23	8	16	1.3	0.2	3.3	14.50
21-27	19	7	13	3.6	0.5	3.0	14.97
28-30	17	4	11	4.6	1.5	2.8	13.43