Tall Fescue Performance Influenced by Irrigation Scheduling, Cultivar, and Mowing Height

W. E. Richie, R. L. Green,* G. J. Klein, and J. S. Hartin

ABSTRACT

Prudent water management on turfgrass is an important issue. There is a need to define best management practices (BMPs), including optimal irrigation frequency for tall fescue (*Festuca arundinacea* Schreb.) when irrigated at a level that would be less than a typical industry practice of ET_{crop}/irrigation uniformity, where ET_{crop} = crop evapotranspiration = reference evapotranspiration (ET_o) × crop coefficient (K_c). A 2-yr field study was conducted in Riverside, CA, to determine if the visual quality of tall fescue could be improved during the warm season by altering irrigation frequency (two, three, or four irrigation events per week), cultivar selection (a dwarf cultivar, 'Shortstop' or a turf-type cultivar, 'Jaguar III'), and mowing height (3.8 or 6.4 cm) when irrigated at 80% ET_{crop}/irrigation uniformity. Volumetric soil water content at the 30-, 61-, and 91-cm depths was also measured on each Jaguar III sub-subplot. During the first year, visual quality was significantly higher for Jaguar III and the lower mowing height. During the second year, overall visual turfgrass quality was significantly highest for plots irrigated twice per week. Visual turfgrass quality was significantly correlated with soil water content. In summary, data from this study support recommendations for deeper, less frequent irrigation of established tall fescue grown on sandy loam soils in southern California interior valleys with an irrigation budget of 80% ET_{crop}/irrigation uniformity.

WATER FOR LANDSCAPE IRRIGATION is a precious commodity, particularly in the arid southwestern USA. Growing population and industrialization have increased water requirements in many areas, but affordable water supplies have not increased as readily. The Metropolitan Water District of Southern California (MWD), for example, is the largest water wholesaler in California and provides water to ≈16 million people. Of the water MWD delivers, ≈90% is used for nonagricultural purposes, and of this percentage, the split between indoor and outdoor (including landscape) uses is ≈70%:30%, respectively (Metropolitan Water District of Southern California, 1996). The MWD predicts that southern California water demand will increase ≈36% more than current demands during the next 20 yr (Metropolitan Water District of Southern California, 1996). While prepared for increased water demands through 2020, the MWD also is committed to reducing its draw from the Colorado River and other imported water sources. Statistics like these highlight the need for research focused on efficient application of irrigation water.

California drought years in the mid-1970s resulted in the imposition of water restrictions. During this time, many turf managers realized that acceptable turfgrass quality could be maintained with reduced, or even deficit irrigation; an irrigation level below ET_{crop} (Doorenbos and Pruitt, 1984) divided by uniformity of the irrigation system. Subsequent research at the University of California sought to provide guidelines for minimum irrigation levels for turfgrass. Meyer et al. (1985) determined accurate monthly K_c for warm- and cool-season turfgrasses and stated water conservation effectively saves 20 to 40% of water needs when 60 to 80% of ET_{crop} is applied. This research, in part, led to the Model Water Efficient Landscape Ordinance, AB325, which recommended an annual maximum applied water allowance of 80% ET_o per square foot of landscape. Current BMPs recommend an annual maximum applied water allowance of up to 100% ET_o per square foot of landscape, regardless of plant material.

Though these BMPs focus on water conservation with a reduced amount of water, there is no recommendation about irrigation scheduling or application frequency. Turfgrass managers have taught and research has shown that light, frequent irrigation encourages shallow rooting and weed growth (Madison and Hagan, 1962; Shearman and Beard, 1973). The recommendation for many years has been to water just often enough to maintain acceptable visual turfgrass quality, that is, infrequent, yet deep watering (Grau and Ferguson, 1948). Youngner (1985) stated that less-frequent irrigation scheduling may improve turfgrass drought avoidance mechanisms, such as deeper rooting. Gibeault et al. (1991) stated that it is desirable to irrigate turfgrass as infrequently as possible. Hagan (1955) and Butler and Feldhake (1979) recommended irrigating only when turfgrass needs water or shows signs of water stress, then watering deeply to bring the root zone to field capacity. Tovey et al. (1969) stated that less-frequent irrigation, depending on soil type, is adequate to maintain good quality turfgrass if sufficient water is applied to bring the root zone to field capacity at each irrigation. The use of poor quality water, however, may require that additional water be used to leach salts below the root zone. Fry and Butler (1989) found that when 'Rebel' tall fescue was irrigated at 75 or 100% potential evapotranspiration (ET_p), best turfgrass quality was observed when the irrigation interval was 2 or 4 d vs. 7 or 14 d, though the 7-d interval was acceptable. They also reported that when Rebel tall fescue was irrigated at 50% ET_p, best turfgrass quality was observed when the irrigation interval was 2 d.

Research has shown a correlation between plant rooting patterns and drought avoidance mechanisms. Crop drought avoidance mechanisms are largely due to expansive root systems (May and Milthorpe, 1962), and

---

W.E. Richie, R.L. Green, and G.J. Klein, Dep. of Botany and Plant Sciences, Univ. of California, Riverside, CA 92521; and J.S. Hartin, Univ. of California Coop. Ext., San Bernardino County, 777 E. Rialto Ave., San Bernardino, CA 92415. Received 7 July 2001. *Corresponding author (robert.green@ucr.edu).

Published in Crop Sci. 42:2011–2017 (2002).

Abbreviations: BMP, best management practices; MWD, Metropolitan Water District of Southern California.

tall fescue is reported to possess extensive rooting and drought avoidance characteristics (Sheffer, et al., 1987; Qian et al., 1997; Ervin and Koski, 1998). White et al. (1993) concluded that deep prolific rooting contributes to drought avoidance characteristics of tall fescue cultivars. Research findings by Carrow (1996) showed that reduced wilt and leaf firing of tall fescue cultivars was correlated with higher root length density in the deeper root zone (20- to 60-cm depth). His study showed that high root length density in the surface 3 to 10 cm of soil actually enhanced wilt, possibly due to rapid depletion of the surface soil water.

Effects of irrigation frequency and soil water status on turfgrass rooting have been reported as well. Madison and Hagan (1962) found that Kentucky bluegrass (*Poa pratensis* L.) maintained at a higher mowing height had a deeper root system and they stated that this may improve drought tolerance. They found that frequent irrigation resulted in sparser and shallower rooting in Kentucky bluegrass. Doss et al. (1960) found that rooting depth for warm-season grasses increased as the interval between irrigation events increased. Bennett and Doss (1960), working with tall fescue, showed that reducing irrigation frequency allowed soil to dry more between irrigation events and resulted in increased root length. Mantell (1966) found deeper root extension within infrequently irrigated kikuyugrass (*Pennisetum clandestinum* Hochst. ex Chiov) field plots. Qian and Fry (1996) found that deep, infrequent irrigation of 'Meyer' zoysiagrass (*Zoysia japonica* Steud.) resulted in reduced shoot growth rates, increased root elongation, and reduced drought symptoms during drydown periods.

Irrigation frequency also has been shown to influence turfgrass evapotranspiration. A field evaluation by Doss et al. (1964) showed that ET_{crop} was highest when water was unlimited and surmised that if irrigation interval was increased, ET_{crop} would be reduced. Mantell (1966) found ET_{crop} of field-grown kikuyugrass was higher when irrigated more frequently. Morgan et al. (1966) found that common bermudagrass [*Cynodon dactylon* (L.) Pers.] evapotranspiration was higher under a set irrigation schedule, and surmised this was due to soil surfaces remaining wetter compared with tensiometer-guided irrigation. Shearman and Beard (1973) found that container-grown bentgrass {*Agrostis palustris* Huds. [= *A. stolonifera* var. *palustris* (Huds.) Farw.]} water use declined when irrigated less frequently. Reduction in water use, however, was strongly correlated with a decline in vegetative cover. Biran et al. (1981) found that lowering irrigation frequency reduced water consumption of container-grown, warm- and cool-season turfgrasses. They concluded that reduced water consumption was due to moderate water stress. Peacock and Dudeck (1984) found that irrigating St. Augustinegrass [*Stenotaphrum secundatum* (Walter) Kuntze] less frequently resulted in reduced evapotranspiration without a significant reduction in visual turfgrass quality.

There is a need to define the optimal irrigation frequency for tall fescue when irrigated at a level that would be less than a typical industry practice of ET_{crop}/irrigation uniformity. The objective of this study was to determine if tall fescue performance during the warm season could be improved, when irrigated with 80% ET_{crop}/irrigation uniformity, by altering irrigation frequency, cultivar, and mowing height. Such information might help turfgrass managers improve tall fescue quality via cultural practice and prudent use of irrigation water.

MATERIALS AND METHODS

The study was conducted at the University of California-Riverside turfgrass research facility on a Hanford fine sandy loam (coarse-loamy, mixed, superactive, nonacid, thermic Typic Xerorthents) with a deep profile (i.e., no barriers to deep rooting). Soil texture and water release characteristics of this soil are presented for five depths in Table 1. Four cores from each soil depth were used to develop this information.

Two cultivars of tall fescue, Jaguar III and Shortstop, were seeded at a rate of 391 kg ha^{-1}. The study was conducted at the University of California-Riverside turfgrass research facility on a Hanford fine sandy loam on 13 Jan. 1994. These cultivars were selected as being representative of standard turf-type and dwarf cultivars, respectively, and were in common industry use at the time of the study. The experimental design was a split-strip design with four replications of each treatment combination. Irrigation treatments (two, three, and four irrigation events per week) formed 12 main plots which measured 6.1 by 6.1 m. Tall fescue cultivars formed 6.1- by 3.0-m subplots. Two mowing heights (6.4 cm and 3.8 cm) were stripped across the subplots, forming 3.0- by 3.0-m subsubplots. Each main plot was irrigated with pop-up spray heads which were spaced 3.0 m apart and adjusted for maximum application uniformity. Main plots were zoned and controlled separately from one another.

Irrigation frequency treatments were applied from 27 July to 10 Dec. 1994 and from 24 May to 15 Nov. 1995. Treatments were not begun until July 1994 to allow time for the tall fescue to become established. During the period between the 2 yr, the plots were irrigated to prevent visual drought symptoms. Irrigation treatments consisted of an equivalent amount of irrigation water, applied in three different weekly frequencies.

Table 1. Soil texture and water release information of the Hanford fine sandy loam soil. Values in parenthesis are standard error of the mean.

	Soil texture					Soil water content at applied pressures, KPa					
Soil depth	Sand	Silt	Clay	Organic matter	Bulk density	0	−5	−10	−50	−100	−500
cm	% (w/w)				g cm^{-3}	% (v/v)					
0–15	70.5(0.50)	19.8(0.25)	9.8(0.25)	0.6(0.08)	1.78(0.06)	30.0(1.78)	21.4(0.45)	20.3(0.58)	19.2(0.77)	17.8(0.79)	15.1(1.18)
15–30	70.3(0.25)	19.5(0.50)	10.3(0.63)	0.4(0.03)	1.75(0.05)	28.9(0.70)	21.5(0.45)	20.4(0.38)	19.7(0.48)	18.2(0.55)	15.6(0.99)
30–60	69.3(1.55)	19.3(0.95)	11.5(0.64)	0.2(0.02)	1.78(0.02)	29.8(1.10)	22.0(0.46)	21.5(0.36)	20.8(0.37)	19.8(0.29)	16.5(0.42)
60–90	77.3(2.14)	14.3(1.49)	8.5(0.64)	0.1(0.03)	1.67(0.09)	31.6(3.70)	20.6(4.69)	19.3(4.58)	17.9(4.53)	16.7(4.63)	13.7(4.79)
90–120	82.8(2.87)	9.8(2.43)	7.5(0.50)	0.1(0.02)	1.60(0.01)	31.1(1.55)	14.7(2.42)	12.7(2.55)	11.2(2.51)	10.5(2.66)	7.7(2.30)
0–120 average	74.0(1.39)	16.5(1.05)	9.5(0.39)	0.3(0.05)	1.72(0.03)						

Table 2. Comparison of study time period, reference evapotranspiration (ET_o), applied irrigation, days in daily ET_o range, rainfall, and maximum, minimum, and mean air temperature during 1994 and 1995. Values in brackets are standard error of the mean.

	27 July–10 Dec. 1994		24 May–15 Nov. 1995	
Study duration, d	**137**		**176**	
12-mo ET_o, mm	**1406**		**1436**	
ET_o during study, mm	**536**		**895**	
Water applied, mm	**424 (79% ET_o)**		**757 (85% ET_o)**	
	d in daily ET_o range			
ET_o range, mm d^{-1}	**Number of days, 1994**	**% of total days**	**Number of days, 1995**	**% of total days**
$ET_o \geq 7$	**0**	**0**	**10**	**5.7**
$6 \leq ET_o < 7$	**16**	**11.7**	**69**	**39.2**
$5 \leq ET_o < 6$	**29**	**21.2**	**25**	**14.2**
$4 \leq ET_o < 5$	**21**	**15.3**	**22**	**12.5**
$3 \leq ET_o < 4$	**25**	**18.2**	**21**	**11.9**
$2 \leq ET_o < 3$	**34**	**24.8**	**21**	**11.9**
$1 \leq ET_o < 2$	**11**	**8.0**	**7**	**4.0**
$ET_o < 1$	**1**	**<1**	**1**	**<1**
Rainfall: 1 Jan. until study initiation, mm		**181**	**401**	
Rainfall during study, mm		**18**	**25**	
Avg. daily maximum air temp., °C	**27[0.6]**	**31[0.4]**		
Avg. daily minimum air temp., °C	**12[0.5]**	**15[0.2]**		
Avg. daily mean air temp., °C	**19[0.5]**	**22[0.3]**		

Weekly irrigation quantity was calculated for each plot as ($ET_o \times$ monthly cool-season $K_c \times 0.8$)/CvU, with CvU representing coefficient of variation uniformity, based on the previous 7-d cumulative ET_o. The CvU was commonly used at the time of the study and was calculated as 1 − coefficient of variation (standard deviation of mean/overall mean) (1994 average CvU = 0.83; 1995 average CvU = 0.81). Monthly crop coefficients utilized in this study were developed in Irvine, CA, which is ≈45 km from Riverside, CA (Meyer et al., 1985). Weekly irrigation quantity was then divided by the number of irrigation events per week. Irrigation events were cycled to prevent runoff and maximize infiltration. Reference evapotranspiration was obtained from an on-site California Irrigation Management and Information Service station (Doorenbos and Pruitt, 1984; Snyder, 1986) located ≈50 m from the research plot. Weekly rainfall was subtracted from the quantity of irrigation applied to each plot; however, it should be noted that rainfall occurred very infrequently during the studies each year and was 4% and 3% of applied irrigation water for 1994 and 1995, respectively (Table 2).

Mowing height treatments were initiated 17 May 1994 and continued to 15 Nov. 1995. The turfgrass was mowed twice per week with a rotary mower with clippings removed. During this same time period, the turfgrass was fertilized with a 16–2.6–6.6 (NPK) granular fertilizer at a N rate of 24 kg^{-1} ha^{-1} 3 wk^{-1}.

Visual turfgrass quality was measured during both years using a 1 to 9 scale, with 1 = poorest and 9 = best tall fescue quality. Quality ratings were influenced by the turf's density, texture, uniformity, and color, including leaf browning due to drought, and to a lesser extent, leaf wilting and rolling. Visual ratings began on 2 Sept. 1994 when drought symptoms began to appear on the plots. No disease symptoms were observed in either year of the study and were not a factor in the visual ratings. Soil water content was measured weekly at the 30-, 61-, and 91-cm soil depths using neutron scattering (CPN Model 503 Hydroprobe, Boart Longyear Company, Martinez, CA). One neutron probe access tube, made of Class 200 PVC pipe, was installed in each mowing height sub-subplot of Jaguar III in June 1994. A calibration curve was developed for this particular meter and soil type using gravimetric samples extracted during access tube installation [mm water mm^{-1} soil (Θ_v) = 40.86 × neutron scattering ratio −14.95; $r^2 = 0.89$; $n = 30$].

The experiment consisted of three treatment factors: three irrigation frequencies (main plots), two tall fescue cultivars (split-plot), and two mowing heights (stripped across each block), with four replications. Treatment effects on visual turfgrass quality were tested by a split-strip ANOVA according to the general linear models procedure of SAS (SAS Institute Inc., Cary, NC). Variation was partitioned into irrigation frequency, cultivar, mowing height, and their corresponding interactions. A repeated measures ANOVA also was performed for visual quality measurements with date as the repeated measures factor. Because soil water content data were measured in one cultivar only, the data were analyzed by each depth with a strip-plot ANOVA. Variation was partitioned into irrigation frequency and mowing height. These data also were tested with a repeated measures ANOVA with date as the repeated measures factor. Means of irrigation frequency, cultivar, and mowing height treatments were compared with a Fisher's protected LSD test, $P = 0.05$. A Pearson product-moment correlation analysis (SAS Institute Inc., Cary, NC) was performed to test for relationship between visual turfgrass quality and soil water content at three depths. The correlation was performed on means (calculated for each plot and depth) across all 1995 treatment and measurement dates, for a sample size equal to 12 for each depth.

RESULTS AND DISCUSSION

Irrigation treatments were initiated in July 1994 after a 6-mo establishment period. The research plots were irrigated with 79% ET_o (424 mm) between 27 July and 10 Dec. 1994 and 85% ET_o (757 mm) between 24 May and 15 Nov. 1995 (Table 2). Visual appearance and density indicated the turfgrass was mature and representative by July 1994 (7 mo after seeding), although tillering and root development most likely continued the remainder of the year. During the longer 1995 study, which included more peak summer months, there was a larger window for irrigation frequency treatment effects to manifest themselves.

Mean squares for the effects of irrigation frequency, cultivar, mowing height, and their interactions on visual turfgrass quality showed that visual turfgrass quality was primarily significantly affected by cultivar and mowing height in 1994 (Table 3). The I × C, I × M, C × M, and I × C × M interactions were nonsignificant except

Table 3. Analysis of variance for the effects of irrigation frequency, cultivar, and mowing height treatments on visual turfgrass quality for each rating date and overall effect during 1994.

		Date								
Source	df	2 Sept.	15 Sept.	30 Sept.	13 Oct.	28 Oct.	11 Nov.	25 Nov.	9 Dec.	Overall
		Mean square								
Replication (R)	3	0.09	0.92	0.34*	0.51*	0.17	0.09	4.45**	0.34	1.85
Irrigation frequency (I)	2	0.69	0.40	0.52**	0.07	0.04	0.04	0.01	0.27	1.12
R × I (Error a)	6	0.23	0.31	0.05	0.10	0.20	0.06	0.24	0.17	0.49
Cultivar (C)	1	1.17**	0.63*	1.27***	1.02**	0.88***	0.63**	2.76**	2.30***	9.96***
I × C	2	0.11	0.15	0.04	0.01	0.19*	0.04	0.07	0.00	0.09
R × C (I) (Error b)	9	0.12	0.10	0.02	0.07	0.03	0.05	0.20	0.06	0.16
Mowing height (M)	1	0.26	0.42	0.11	0.75**	3.80**	6.38**	6.38**	8.76***	18.89**
R × M (Error c)	3	0.19	0.10	0.01	0.01	0.10	0.24	0.23	0.06	0.34
I × M	2	0.01	0.06	0.05	0.05	0.02	0.04	0.04	0.02	0.07
R × I × M (Error d)	6	0.06	0.08	0.04	0.08	0.03	0.04	0.05	0.01	0.01
C × M	1	0.01	0.01	0.00	0.02	0.01	0.05	0.13	0.01	0.04
I × C × M	2	0.01	0.02	0.02	0.01	0.07	0.02	0.10	0.02	0.08
R × C × M (I) (Error e)	9	0.05	0.03	0.01	0.04	0.02	0.01	0.12	0.03	0.05
Date (D)	7									10.54***
R × D (Error f)	21									0.71
I × D	14									0.13
R × I × D (Error g)	42									0.12
C × D	7									0.10
I × C × D	14									0.07
R × C × D (I) (Error h)	63									0.07
M × D	7									1.02
R × M × D (Error i)	20									0.09
I × M × D	14									0.03
R × I × M × D (Error j)	40									0.05
C × M × D	7									0.03
I × C × M × D	14									0.02
R × C × M × D (I) (Error k)	60									0.04

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.

on 29 October for the I × C interaction. The visual turfgrass quality of Jaguar III, the turf-type cultivar, was significantly ($P = 0.05$) higher than Shortstop, the dwarf cultivar, on all rating dates and the overall mean (data not shown). The overall visual turfgrass quality for Jaguar III and Shortstop was 6.5 and 6.1, respectively, (data not shown). This may be consistent with research by Huang and Fry (1998), Huang et al. (1998), Carrow (1996), and White et al. (1993), who found that turf-type tall fescue cultivars were more drought resistant than dwarf-type cultivars. The 1994 data also showed that the 3.8-cm mowing height resulted in significantly ($P = 0.05$) higher visual turfgrass quality than the 6.4-cm mowing height between 13 Oct. and 9 Dec. 1994 and the overall mean (data not shown). The overall visual turfgrass quality for the 3.8- and 6.4-cm mowing heights was 6.5 and 6.1, respectively (data not shown). Irrigation frequency affected visual turfgrass quality only on 30 September with plots irrigated three and four events per week having significantly ($P = 0.05$) higher quality than plots irrigated twice per week. The overall irrigation frequency effect was not significant (data not shown). During 1994, mowing height and irrigation frequency treatments did not significantly affect volumetric soil water content on all measurement dates nor the overall statistical effect for the 30-, 61-, and 91-cm depths (data not shown).

In comparison with 1994, data from 1995 showed that visual turfgrass quality was significantly affected less by cultivar and mowing height, and more by irrigation frequency (Table 4). The I × C interaction was significant on one date, and the I × M and I × C × M interactions were nonsignificant. The C × M interaction was significant on three dates and the overall statistical effect, suggesting that the cultivars differed in their response to the mowing treatments. In terms of visual turfgrass quality, there were few dates when there were significant differences between the two cultivars; the exceptions being 28 June, 18 October, 15 November, and the overall mean when the visual turfgrass quality of Jaguar III was significantly ($P = 0.05$) higher than that of Shortstop (data not shown). The overall visual turfgrass quality for Jaguar III and Shortstop was 5.1 and 5.0, respectively (data not shown). Similarly, visual turfgrass quality was higher for the 3.8-cm mowing height compared with the 6.4-cm mowing height; however, this difference was significant ($P = 0.05$) only on 28 June and 15 November (data not shown). Though statistically significant differences for these measurements were fewer than in 1994, the trend for improved visual turfgrass quality with Jaguar III and the lower mowing height was consistent between the 2 yr.

Irrigation frequency significantly affected visual turfgrass quality on 27 July through 18 Oct. 1995 and the overall statistical effect (Table 4, Fig. 1). During this period (176 d), plots irrigated with two irrigation events per week visually rated significantly ($P = 0.05$) higher than plots irrigated with three events per week on all rating dates when the irrigation treatment effect was significant. Plots irrigated twice per week rated significantly ($P = 0.05$) higher than plots irrigated with four events per week on 71% of rating dates when the irrigation treatment effect was significant. The overall visual turfgrass quality of each irrigation frequency treatment

Table 4. Analysis of variance for the effects of irrigation frequency, cultivar, and mowing height treatments on visual turfgrass quality for each rating date and overall effect during 1995.

		Date												
Source	**df**	**14 June**	**28 June**	**12 July**	**27 July**	**9 Aug.**	**24 Aug.**	**6 Sept.**	**20 Sept.**	**4 Oct.**	**18 Oct.**	**1 Nov.**	**15 Nov.**	**Overall**
		Mean square												
Replication (R)	3	0.25	0.20	0.50	0.55	0.44*	2.88***	1.19***	2.01**	2.60**	1.12	2.24*	0.97	9.15***
Irrigation frequency (I)	2	0.15	0.02	0.32	1.51*	4.13***	1.83***	1.61***	1.90**	4.32**	3.56**	1.44	0.88	13.16***
R × I (Error a)	6	0.23	0.53	0.57	0.26	0.08	0.08	0.05	0.18	0.25	0.38	0.33	0.41	0.28
Cultivar (C)	1	0.33	1.33**	0.02	0.01	0.05	0.08	0.08	0.08	0.13	1.51***	0.02	1.69***	2.78*
I × C	2	0.27	0.02	0.19	0.07	0.42**	0.26	0.04	0.02	0.04	0.02	0.04	0.05	0.26
R × C (I) (Error b)	9	0.07	0.11	0.19	0.09	0.06	0.13	0.08	0.18	0.10	0.07	0.03	0.08	0.33
Mowing height (M)	1	3.00	0.75*	1.02	2.30	0.26	0.33	0.08	0.02	0.26	0.42	1.02	3.52*	9.51
R × M (Error c)	3	0.50	0.07	0.52	0.37	0.09	0.10	0.14	0.40	0.37	0.31	0.35	0.24	1.69
I × M	2	0.44	0.06	0.22	0.02	0.04	0.07	0.07	0.15	0.07	0.06	0.04	0.13	0.07
R × I × M (Error d)	6	0.19	0.09	0.10	0.09	0.06	0.12	0.04	0.08	0.10	0.20	0.12	0.08	0.22
C × M	1	0.75**	0.19*	0.00	0.05	0.01	0.00	0.00	0.02	0.26**	0.01	0.02	0.00	0.50*
I × C × M	2	0.06	0.06	0.02	0.02	0.04	0.02	0.02	0.02	0.04	0.02	0.01	0.05	0.07
R × C × M (I) (Error e)	9	0.07	0.03	0.07	0.01	0.04	0.02	0.04	0.05	0.03	0.04	0.01	0.02	0.08
Date (D)	11													7.33***
R × D (Error f)	33													0.53
I × D	22													0.77***
R × I × D (Error g)	66													0.28
C × D	11													0.23**
I × C × D	22													0.11
R × C × D (I) (Error h)	99													0.08
M × D	11													0.32
R × M × D (Error i)	33													0.16
I × M × D	22													0.12
R × I × M × D (Error j)	66													0.09
C × M × D	11													0.07*
I × C × M × D	22													0.03
R × C × M × D (I) (Error k)	99													0.03

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.

was significantly ($P = 0.05$) different and was 5.3, 4.8, and 5.1 for two, three, and four irrigation events per week, respectively (data not shown). Visual turfgrass quality of plots irrigated twice per week remained >5.0 (minimally acceptable) for the duration of the 1995 study, with the exception of 6 September, when visual turfgrass quality dropped to 4.9. Ratings for plots irrigated three or four events per week were below minimum acceptability between 9 Aug. and 18 Oct. It should be noted that visual turfgrass quality for all irrigation treatments was <6.0 between 14 June and 1 November, indicating that 85% ET_o (80% ET_{crop}/irrigation uniformity) is insufficient to maintain quality tall fescue that is subjected to the conditions of 1995 in Riverside, CA. These data suggest, however, that when irrigating tall fescue at 85% ET_o, a less-frequent irrigation schedule may help maintain higher visual turfgrass quality compared with more frequent irrigation scheduling. Fry and Butler (1989) evaluated the effects of irrigation quantity and frequency on tall fescue visual quality. Their data showed that when tall fescue was irrigated at a considerable deficit (50% ET_p), best turfgrass quality was maintained when the irrigation interval was shortest (2 d vs. 4, 7, and 14 d). However, when tall fescue was irrigated more heavily (75 or 100% ET_p), the irrigation interval could be extended to 7 d, though better turfgrass quality was maintained when the irrigation interval was 2 or 4 d. The authors suggest that when tall fescue is irrigated heavily (75 or 100% ET_p), the irrigation can be deep and infrequent (7-d irrigation interval) because tall fescue is relatively deep rooted. Data from our study support this concept of deeper and less frequent irrigations when tall fescue is irrigated at 80% ET_{crop}/irrigation uniformity. Conversely, the data of Fry and Butler (1989) show that shallower and more frequent irrigations are needed for tall fescue when the irrigation level is at a considerable deficit (50% ET_p).

During 1995, mowing height treatments did not significantly affect volumetric soil water content on all measurement dates nor the overall statistical effect for the 30-, 61-, and 91-cm depths (data not shown). Irrigation frequency treatments did significantly affect volumetric soil water content on selected dates for all depths (Fig. 2).

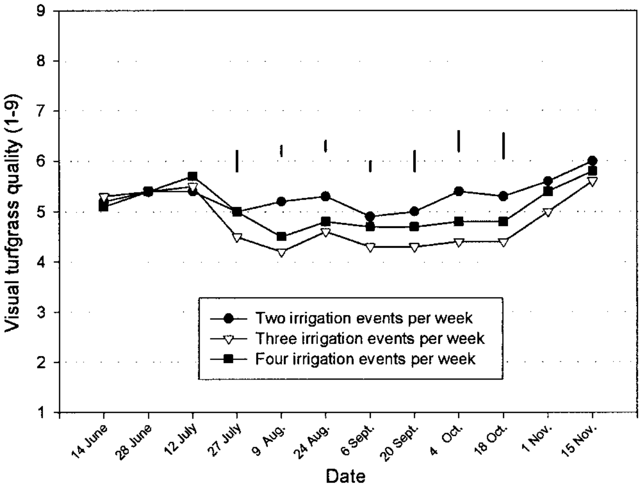

Fig. 1. Visual turfgrass quality of tall fescue when irrigated with 80% ET_{crop}/irrigation uniformity in two, three, and four irrigation events per week during 1995. Bars above curves represent significant differences ($P = 0.05$) according to Fisher's protected LSD test.

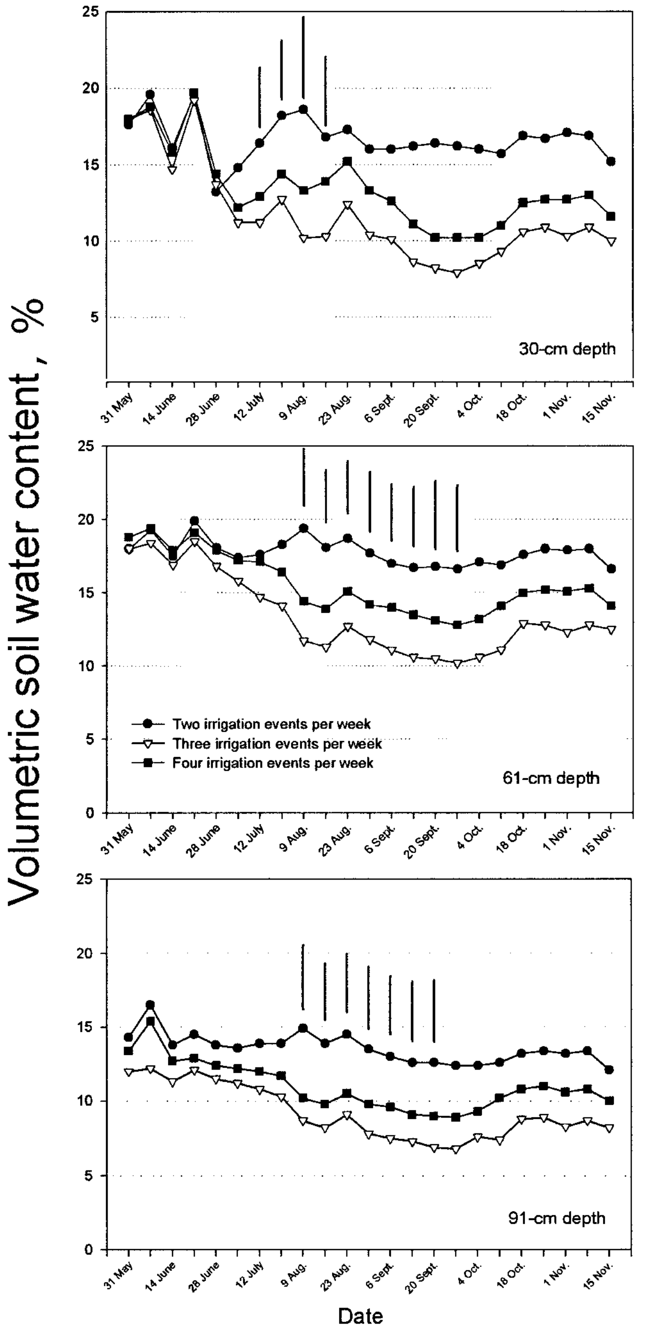

Fig. 2. Volumetric soil water content measured with neutron probe at three soil depths for three irrigation frequency treatments during 1995. Bars above curves represent significant differences ($P = 0.05$) according to Fisher's protected LSD test.

However, the overall irrigation frequency treatment effect was not significant for all three depths (data not shown).

Volumetric soil water content at the 30-cm depth was significantly ($P = 0.05$) higher in plots irrigated twice per week compared with plots irrigated with three events per week between 12 July and 16 Aug. Similarly, volumetric soil water content at the 61- and 91-cm depths was significantly ($P = 0.05$) higher in plots irrigated twice per week compared with plots irrigated with three events per week between 9 August and 20 September. There was a consistent, although nonsignificant trend for higher soil water content as follows: two irrigation events per week > four irrigation events per week > three irrigation events per week. Though this order is difficult to explain, it is consistent with visual turfgrass quality ratings. Soil water content was correlated with visual turfgrass quality ratings at the 30-cm depth ($r = 0.69$; $P = 0.013$), 61-cm depth ($r = 0.77$; $P = 0.004$), and the 91-cm depth ($r = 0.53$; $P = 0.079$). Data from this research has shown a relationship between irrigation frequency, visual turfgrass quality, and volumetric soil water content. Other investigators have shown a relationship between less frequent irrigation and deeper root development, plant stress conditioning, moderate plant water stress, and reduced evapotranspiration (Bennett and Doss, 1960; Mantell, 1966; Biran et al.,1981; Peacock and Dudeck, 1984; Youngner, 1985).

In summary, data from this 2-yr study indicated that a lower mowing height and selection of a turf-type cultivar may improve visual tall fescue quality during a limited establishment period, or under the climatic conditions seen during the 1994 study. After this, or during a more extended period involving more summer months and an irrigation level set at 80% ET_{crop}/irrigation uniformity, visual differences due to mowing height or cultivar became less apparent. Data from this study showed that when irrigated with an amount less than the typical industry practice of $ET_o \times K_c$/irrigation uniformity in southern California interior valleys, well-established tall fescue visual quality was better when irrigated twice per week compared with three and four events per week. These improved visual quality ratings correlated significantly with higher soil water content. The data support recommendations for deeper, less frequent irrigation of established tall fescue when an irrigation water budget of 80% ET_{crop}/irrigation uniformity.

ACKNOWLEDGMENTS

Partial funding for this research was provided by the Metropolitan Water District of Southern California and The Toro Company.

REFERENCES

Bennett, O.L., and B.D. Doss. 1960. Effect of soil moisture level on root distribution of cool-season forage species. Agron. J. 52: 204–207.

Biran, I., B. Bravdo, 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.

Butler, J.D., and C.M. Feldhake. 1979. Drought tolerance and water relationships of turfgrasses. California Turf. Cult. 29:3–5.

Carrow, R.N. 1996. Drought avoidance characteristics of diverse tall fescue cultivars. Crop Sci. 36:371–377.

Doorenbos, J., and W.O. Pruitt. 1984. Guidelines for predicting crop water requirements. Environmental Assessment Office, Irrigation and Drainage Paper 24. United Nations, Rome, Italy.

Doss, B.D., D.A. Ashley, and O.L. Bennett. 1960. Effect of soil moisture regime on root distribution of warm season forage species. Agron. J. 52:569–572.

Doss, B.D., O.L. Bennett, and D.A. Ashley. 1964. Moisture use by forage species as related to pan evaporation and net radiation. Soil Sci. 98:322–327.

Ervin, E.H., and A.J. Koski. 1998. Drought avoidance aspects and crop coefficients of Kentucky bluegrass and tall fescue turfs in the semiarid west. Crop Sci. 38:788–795.

Fry, J.D., and J.D. Butler. 1989. Responses of tall and hard fescue to deficit irrigation. Crop Sci. 29:1536–1541.

Gibeault, V.A., J. Meyer., M.A. Harivandi, M. Henry, and S.T. Cockerham. 1991. Managing turfgrasses during drought. Leaflet 21499. Univ. of California, Div. Agric. and Nat. Resources, Oakland, CA.

Grau, F.V., and M.H. Ferguson. 1948. Pointers on making good lawns. p. 302–307. *In* A. Stefferud (ed.) Grass: The yearbook of agriculture. U.S. Gov. Print. Office, Washington, DC.

Hagan, R.M. 1955. Watering lawns and turf and otherwise caring for them. p. 462–467. *In* A. Stefferud (ed.) Water: The yearbook of agriculture. U.S. Gov. Print. Office, Washington, DC.

Huang, B., and J.D. Fry. 1998. Root anatomical, physiological, and morphological responses to drought stress for tall fescue cultivars. Crop Sci. 38:1017–1022.

Huang, B., J. Fry, and B. Wang. 1998. Water relations and canopy characteristics of tall fescue cultivars during and after drought stress. HortSci. 33:837–840.

Madison, J.H., and R.M. Hagan. 1962. Extraction of soil moisture by Merion bluegrass (*Poa pratensis* L. ‘Merion’) turf, as affected by irrigation frequency, mowing height, and other cultural operations. Agron. J. 54:157–160.

Mantell, A. 1966. Effect of irrigation frequency and nitrogen fertilization on growth and water use of a kikuyugrass lawn (*Pennisetum clandestinum* Hochst.). Agron. J. 58:559–561.

May, L.H., and F.L. Milthorpe. 1962. Drought resistance of crop plants. Field Crop Abstr. 15:171–179.

Metropolitan Water District of Southern California. 1996. Projected demands and existing supplies. p. 2-5–2-9. *In* Southern California’s integrated water resources plan. Volume 1: The long-term resources plan. MWD Rep. no. 1107. MWD of Southern California, Los Angeles.

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 coefficient of turfgrasses. p. 357–364. *In* F. Lemaire (ed.) Proc. Int. Turfgrass Res. conf., 5th, Avignon, France. 1–5 July 1985. Institut National del la Recherche Agronomique and International Turfgrass Society, Paris.

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 compactability, water infiltration rates, evapotranspiration, and number of irrigations. Agron. J. 58:525–535.

Peacock, C.H., and A.E. Dudeck. 1984. Physiological response of St. Augustinegrass to irrigation scheduling. Agron. J. 76:275–279.

Qian, Y.L., and J.D. Fry. 1996. Irrigation frequency affects zoysiagrass rooting and plant water status. HortSci. 31:234–237.

Qian, Y.L., J.D. Fry, and W.S. Upham. 1997. Rooting and drought avoidance of warm-season turfgrasses and tall fescue in Kansas. Crop Sci. 37:905–910.

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.

Sheffer, K.M, J.H. Dunn, and D.D. Minner. 1987. Summer drought response and rooting depth of three cool-season turfgrasses. HortSci. 22:296–297.

Snyder, R.L. 1986. Evapotranspiration-based irrigation scheduling—The CIMIS experience. Tech. Conf. Proc.—Irrig. Assoc. 245–263.

Tovey, R., J.S. Spencer, and D.C. Muckel. 1969. Turfgrass evapotranspiration. Agron J. 61:863–867.

White, R.H., A.H. Bruneau, and T.J. Cowett. 1993. Drought resistance of diverse tall fescue cultivars. Int. Turf. Soc. Res. J. 7:607–613.

Youngner, V.B. 1985. Physiology of water use and water stress, p. 37–43. *In* V.A. Gibeault and S.T. Cockerham (ed.) Turfgrass water conservation. Publ. 21405. Univ. of California, Div. Agric. and Nat. Resources, Oakland, CA.