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Full Length Article

Irrigation Level and Nitrogen Rate Affect Evapotranspiration and Quality of Perennial Ryegrass (*Lolium perenne*)

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Abstract

This study examined the effects of different irrigation levels and nitrogen rates on perennial ryegrass (*Lolium perenne* L.) evapotranspiration and quality in a sub-humid climate over a two-year period (2007–2008). Nitrogen treatment (25 kg N ha^{-1}; N_1 and 50 kg N ha^{-1}; N_2) varied among main plots and irrigation levels (25%; I_1, 50%; I_2, 75%; I_3, 100%; I_4 and 125%; I_5 of the Class A pan evaporation) by subplot. Irrigation was performed at 3-day intervals during May-September using a pop-up sprinkler irrigation system, and N applied as a monthly rate during the irrigation period. Seasonal turfgrass evapotranspiration was found to vary by treatment from 309-1178 mm in 2007 and from 379-1097 mm in 2008. Turfgrass visual color, quality and clipping yield were shown to decrease significantly with decreases in irrigation water and N fertilizer. The study findings demonstrated that under a non-limiting water supply, irrigation could be decreased by adjusting N fertilizer rates according to turfgrass visual color and quality and that N_1I_4 or N_2I_3 treatments can maintain acceptable turfgrass visual color and quality under sub-humid climatic conditions.

Keywords: Cool-season turf grass; Deficit irrigation; Fertilization; Water use; Visual quality

Introduction

Turf grasses are recreational vegetation surface for outdoor sports and leisure activities and aesthetic components for physical health of participants. In addition, turfgrass has several functional benefits including soil erosion control and dust stabilization, reducing air temperature, noise, and visual pollution problems (Beard, 1973; King and Balogh, 2008).

Parks, lawns, and sport fields are largely based on cool-season grasses and perennial ryegrass is widely used in the turf mixtures (Beard, 1973; Jiang and Huang, 2001). Perennial ryegrass is best adapted to cool, moist regions that have mild winters and cool summers. In regions with a sub-humid climate, the frequency and amount of rainfall during the summer season are often quite variable. Thus, drought stress is considered as the primary environmental factor limiting cool-season turfgrass growth under these conditions (Beard, 1973; Huang *et al*., 1998a, b), and well-scheduled irrigation is necessary to sustain acceptable turfgrass quality. The institution of some type of water conservation program on turfgrass sites is of utmost importance (Kirda and Kanber, 1999; Carrow and Duncan, 2000). The scientists and turfgrass managers should develop strategies for maintaining acceptable levels of turfgrass quality, while considerably reducing irrigation input (Ervin and Koski, 1998).

In order to maintain turf quality and performance, it is important to maintain a favourable soil water level through well-scheduled irrigation together with other appropriate inputs, such as fertilizer (Kneebone *et al*., 1992). Bastug and Buyuktas (2003) reported improvements in the quality of turfgrass [a mixture of Kentucky bluegrass (*Poa pratensis* L., 40%), red fescue (*Festuca rubra*, 30%) and perennial ryegrass (30%)] with an irrigation schedule amounting to 75% of Class A pan evaporation. This schedule achieved a 15% reduction in water use, with seasonal ET and applied irrigation water calculated at 711 mm and 587.5 mm, respectively. A study by Gibeault *et al*. (1985) conducted in Southern California found that a 20% reduction in irrigation based on calculated potential ET resulted in only a slight decline in the quality of turf blends of bluegrass, perennial ryegrass cultivars and 'Kentucky 31'. Aronson *et al*. (1987) stated that perennial ryegrass did not maintain acceptable turf quality (a score of 6.5 or above) once soil water potential declined to -60 kPa.

Fertilizers used to maintain turfgrass are comprised mainly of nitrogen (N). Application of nitrogen fertilizer has been shown to significantly improve turfgrass color, uniformity and density and limit the amount of weeds (Beard, 1973). Moreover, adequately fertilized turfgrass has been shown to withstand moisture stress better than nitrogen-deficient turf (Feldhake, 1981). In fact, the use of N management as a water-conservation tool is often overlooked, even though increases in N application have

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been found to typically lead to increased water usage (Brown *et al*., 2004).

Water conservation is of considerable interest to turfgrass managers and decision makers, especially given the expense involved in securing the functional and aesthetic properties required by recreational sites and sporting areas. This study aimed to: (i) investigate the responses of perennial ryegrass to different irrigation and nitrogen levels in terms of growth and quality; and (ii) to determine the effects of reduced N fertilizer levels on water use of perennial ryegrass needed to maintain turfgrass visual color and quality under a continuous water supply in a sub-humid climate.

Materials and Methods

Experimental Site

Field experiments were conducted at the Agricultural Training and Research Centre (ATRC) of the Uludag University Faculty of Agriculture located in Bursa (40° 13' 36" N latitude, 28° 51' 35" E longitude, 112 m altitude) in northwestern Turkey during May-September of 2007 and 2008. The region has a sub-humid climate (Candogan and Yazgan, 2010; Candogan *et al*., 2013). Daily meteorological data were collected from an automated meteorological station (Watch Dog, Spectrum Technologies, Inc., Plainfield, IL, USA) near the trial site and is shown in Figs. 1a (2007) and 1b (2008).

Experimental Design

The study was conducted on plots of 'Esquire' perennial ryegrass (DLF-TRIFOLIUM Group) with clay soil (23.8% sand, 26.2% silt, 50.0% clay), a gravimetrically average field capacity of 39.1% and a wilting point of 27.1% for a 0-60 cm soil profile. Field capacity and wilting point were measured in laboratory condition by using undisturbed and disturbed soil samples, respectively. For this purpose, analyses were carried out according to methods given by Cassel and Nielsen (1986) and Tuzuner (1990). Average bulk density and total available moisture (TAM) were 1.36 g cm^{-3} and 98.0 mm, respectively.

Soil was tilled, leveled and rolled during the summer of 2006, and P (20 g m^{-2}) and K (10 g m^{-2}) were incorporated prior to seeding. Turfgrass seeds were sown on October 17, 2006 at a rate of 40 g m^{-2}. Seeds were broadcast and top-dressed with a mixture of soil and peat, and irrigation was performed as needed to maintain a moist soil surface until emergence was complete.

The study was conducted using a split-plot design with four replications per treatment, with nitrogen rates in the main plots and irrigation levels in subplots (1×2 m). Irrigation levels were determined according to US Weather Bureau Class A pan evaporation (E_{pan}). Nitrogen and irrigation treatments are listed in Table 1. Nitrogen was applied as a monthly rate during May-September. The experimental area was irrigated using a pop-up sprinkler irrigation system at 3-day intervals during the same period. Sprinkler heads were located in the 4 corners of each plot that was 4×4 m in size to form a 90° wetting pattern, and sprinkling was conducted at a rate of 7.5 mm h^{-1}, which was below the soil infiltration rate (8.0 mm h^{-1}).

Soil Water Content (SWC) Measurements and Evapotranspiration (ET) Calculations

SWC was measured in the centre of each plot prior to irrigation at depths of 0.15 m and 0.45 m using a neutron probe (503 DR Hydroprobe, CPN International, Inc., Martinez, CA, USA). In addition, SWC at 0.15 m was monitored using tension meters. Turfgrass ET was calculated as the residual of the soil water balance for the time period between two successive soil water measurement dates. ET was calculated separately for each irrigation treatment (Allen *et al*., 1998) using the formula:

$$ET = I + P - RO - DP + CR \pm \Delta SF \pm \Delta SW$$

Where, I is the depth of irrigation water (mm), P is precipitation (mm), ΔSF is water transferred in or out of the root zone horizontally by subsurface flow, ΔSW is the change in SWC (mm), RO is the depth of runoff (mm), DP is the deep percolation below the root zone (mm) and CR is capillary rise. Irrigation water was measured using water meters, and P was determined from meteorological station data. Because the sprinkling rate was below the infiltration rate, no runoff occured. Given the difficulties involved in assessing ΔSF, DP and CR from a water table over short periods of time (Allen *et al*., 1998), ΔSF and CR were assumed to be zero. In order to account for percolation, soil-water balance was calculated using moisture measurements for the 0.6 m soil profile. Doty *et al*. (1990) noted that a large portion of grass water uptake occurs at the 0-25 cm soil profile; therefore, effective rooting depth was assumed to be 0.3 m.

Growth and Quality Parameters

Clipping yields were evaluated by month for each year. After reaching a height of 6-8 cm (18 May, 15 June, 12 July, 20 August and 18 September in 2007 and 14 May, 10 June, 17 July, 26 August and September 24 in 2008), a 0.5 m × 1.0 m strip of turfgrass at the centre of each subplot was clipped to a height of 4 cm. The clipped turfgrass was removed and dried at 70°C for 24 h and then weighed according to Bilgili *et al*. (2011b). On each clipping date, prior to mowing, turfgrass color ratings were visually assessed on a scale from 1-9 (1=completely yellow; 9=dark green) (Mehall *et al*., 1983; Frank *et al*., 2004; Bilgili and Acıkgoz, 2005). Turfgrass quality was also visually assessed on each clipping date prior to mowing using a scale of 1-9 (1=poorest; 9=best) based primarily on turf color, texture, uniformity and density. Leaf wilting, rolling and browning due to drought were also taken into

Table 1: Nitrogen and irrigation treatments

Nitrogen Rates	Irrigation Levels (% Class A pan evaporation)				
(kg ha^{-1})	25 (I_1)	50 (I_2)	75 (I_3)	100 (I_4)	125 (I_5)
25 (N_1)	N_1I_1	N_1I_2	N_1I_3	N_1I_4	N_1I_5
50 (N_2)	N_2I_1	N_2I_2	N_2I_3	N_2I_4	N_2I_5

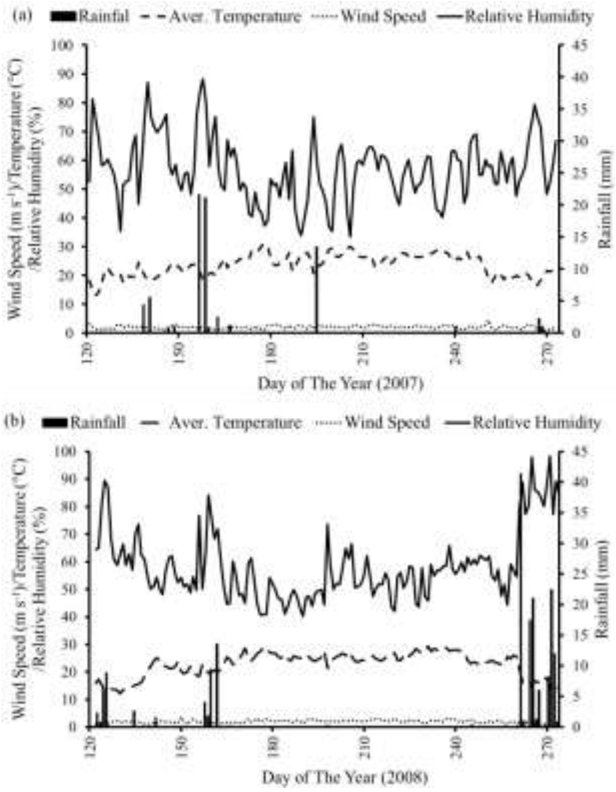

Fig. 1: Weather parameters recorded during 2007 (a) and 2008 (b) experimental seasons

consideration in rating turfgrass quality, with a rating of 6.0 or above considered acceptable. No symptoms of disease were observed in either year of the study and were thus not included in quality assessment.

Statistical Analysis

Color, quality and clipping yield data for each sampling date was subjected to analysis of variance (ANOVA). In cases where N rate, irrigation level or N×irrigation interaction were found to be significant at either 0.05 or 0.01 probability levels, means were separated using Fisher's Least Significant Difference (LSD) test at the 0.05 level.

Results

Effects of Irrigation on ET

Monthly and total amounts of irrigation water and rainfall (mm) for 2007 and 2008 are given in Table 2. Total amounts of irrigation water varied from 204.8-1023.8 mm in 2007 and from 175.9-879.4 mm in 2008, whereas total amounts of rainfall during the 2007 and 2008 experimental seasons were 77.1 mm and 180.3 mm, respectively.

Monthly and seasonal ET rates for each treatment group are given in Table 3. Seasonal ET increased with increases in N rates and irrigation levels, with the highest seasonal ET values found for the N_2I_5 treatment in both 2007 (1178 mm) and 2008 (1097 mm) and the highest monthly ET values found for the N_2I_5 treatment in both July of 2007 (313 mm) and July of 2008 (284 mm).

Turfgrass Growth and Quality

The results of ANOVA for the effects of N rates and irrigation levels on turfgrass color, quality and clipping yields are given in Table 4 (2007) and 5 (2008). Data was analyzed separately for each year. Turfgrass color, quality and clipping yields were all significantly affected by both N rates and irrigation levels throughout the study. With the exception of visual color in May 2007, the interaction between N rates × irrigation levels also had a significant effect on turfgrass color, quality and clipping yields throughout the study period.

In general, a rate of N_2 (50 kg N ha^{-1}) resulted in more uniform turf visual color and higher visual quality and clipping yields (Table 4 and 5). The lowest irrigation level (I_1) resulted in the poorest color, quality and clipping yields throughout the experiment. In general, full (I_4) and excessive (I_5) irrigation treatments resulted in high values for color, quality and clipping yields. As the amount of applied irrigation water decreased, the seasonal mean values for color, quality and clipping yields tended to decrease (Table 4 and 5). Acceptable turfgrass visual color and quality were sustained under I_3 irrigation treatment through the each experimental season (with the exception of June 2008, for which quality ratings fell slightly below acceptable levels) (Table 4 and 5).

Analysis of the interaction between N rates × irrigation levels showed that clipping yields decreased significantly with decreases in both N rates and irrigation levels (Table 6), with the lowest seasonal average clipping yields obtained from the N_1I_1 treatments in both 2007 (4.0 g m^{-2}) and 2008 (5.9 g m^{-2}) and the highest seasonal averages obtained from the N_2I_5 treatment in both 2007 (43.6 g m^{-2}) and 2008 (34.4 g m^{-2}).

Seasonal visual color ratings by irrigation level and N rate were plotted for 2007and 2008 (Fig. 2). Additionally, seasonal visual quality ratings by irrigation level and N rate were plotted for 2007 and 2008 (Fig. 3). Both turfgrass color and quality were sustained with the N_1I_4 and N_2I_3 treatments through both the 2007 and 2008 experimental seasons. In addition, acceptable turf color was maintained throughout the season with N_1I_4 in 2007, with N_1I_3 in 2008 and with N_2I_2 in both 2007 and 2008, while acceptable turf quality was maintained with N_1I_4 and N_2I_3 treatments through both study years.

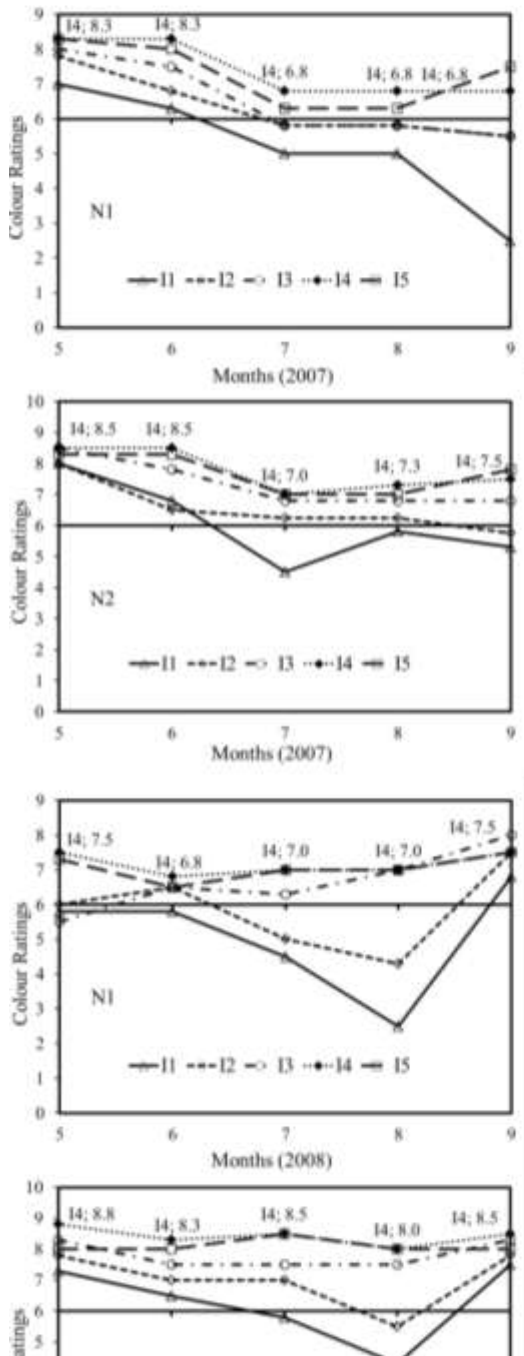

Fig. 2: Color rating of perennial ryegrass as a function of N application rates and irrigation levels in 2007 and 2008. The horizontal line at a color rating of 6 denotes the minimum acceptable color

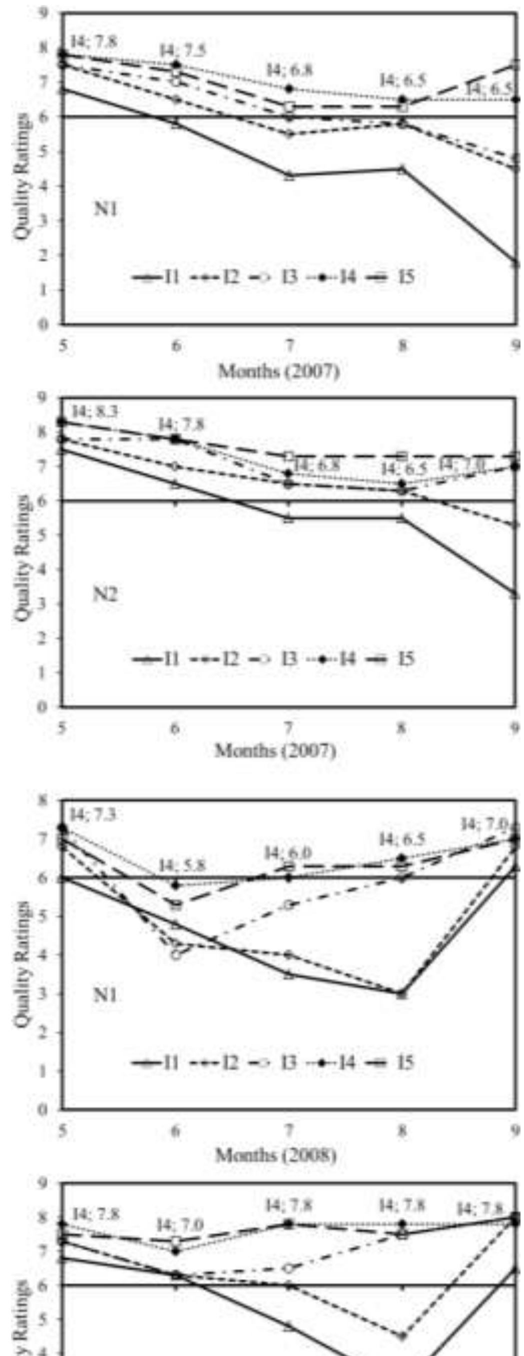

Fig. 3: Quality rating of perennial ryegrass as a function of N application rate and irrigation levels in 2007 and 2008. The horizontal line at a quality rating of 6 denotes the minimum acceptable quality

Table 2: Monthly and total amount of irrigation water (TAIW) and seasonal rainfall (mm) for 2007 and 2008

Year	Irrigation Treatment	Monthly amount of irrigation water May	June	July	August	Sept.	TAIW	Seasonal Rainfall
2007	I_1	28.4	34.8	57.8	51.5	32.3	204.8	77.1
	I_2	56.8	69.5	115.7	103.0	64.5	409.5	
	I_3	85.3	104.3	173.5	154.5	96.8	614.3	
	I_4	113.7	139.0	231.3	206.0	129.0	819.0	
	I_5	142.1	173.8	289.2	257.5	161.3	1023.8	
2008	I_1	21.6	37.1	54.3	47.4	15.5	175.9	180.3
	I_2	43.1	74.2	108.7	94.8	31.0	351.8	
	I_3	64.7	111.3	163.0	142.1	46.5	527.6	
	I_4	86.3	148.4	217.3	189.5	62.0	703.5	
	I_5	107.8	185.5	271.7	236.9	77.5	879.4	

Table 3: Evapotranspiration (ET, mm) of perennial ryegrass determined in irrigation levels and nitrogen rates for 2007 and 2008

Year	Nitrogen Treatment	Irrigation Treatment	Month May	June	July	August	Sept.	Seasonal ET
2007	N_1	I_1	55	82	74	60	39	309
		I_2	71	123	135	106	75	509
		I_3	100	157	180	159	100	695
		I_4	132	190	254	225	133	934
		I_5	161	229	304	267	171	1131
	N_2	I_1	62	86	81	70	48	346
		I_2	74	132	145	118	85	554
		I_3	109	164	193	167	117	750
		I_4	139	199	267	230	145	980
		I_5	178	243	313	275	182	1178
2008	N_1	I_1	40	70	62	58	149	379
		I_2	72	109	118	100	154	552
		I_3	94	146	169	151	172	731
		I_4	106	173	226	194	192	891
		I_5	135	216	277	243	203	1073
	N_2	I_1	44	77	67	64	142	393
		I_2	74	100	122	108	162	566
		I_3	98	151	171	158	181	759
		I_4	112	181	231	203	186	913
		I_5	140	221	284	252	200	1097

Effects of N Application on Turfgrass ET

ET values were found to increase with increases in N fertilizer rates (Table 3). For example, in both years, turfgrass ET was higher under N_2I_4 treatment (100% E_{pan}, 50 kg N ha^{-1}) than N_1I_4treatment (100% E_{pan}, 25 kg N ha^{-1}). Both water consumption and average seasonal turf color rating decreased by 5% when the N fertilizer rate was reduced from 50 kg ha^{-1} to 25 kg ha^{-1}with 100% E_{pan} irrigation in 2007; a similar decrease in N fertilizer rate in 2008 resulted in a 2% decrease in water consumption and a 15% decrease in average seasonal turf color rating (Fig. 2). Additionally, the same reduction in N fertilizer rate led to decreases in average seasonal turf quality ratings of 4% in 2007 and 15% in 2008 (Fig. 3).

Discussion

The amount of irrigation water applied in the 2007 and 2008 study periods differed due to differences in the amount and distribution of rainfall between years (Figs. 1a, 1b, Table 2). In the 2008 study period, ET values for six of the 10 treatments were higher in September than in August (Table 3), which could be explained by the fact that the majority of precipitation in the 2008 study period (132.2 mm out of 180.3 mm) fell in September (Fig. 1b). Seasonal ET increases were observed with increases in both irrigation and N application. Carrow and Duncan (2003) stated that turfgrass water use increases with an increase in nitrogen fertilization rates due to an increase in growth stimulated by the fertilizer.

Bastug and Buyuktas (2003) reported evapotranspiration rates of golf course turfgrass (a mixture of 3 cool-season species) irrigated at 100%, 75% and 50% of Class A pan evaporation to be 895.8, 710.7 and 524.7 mm, respectively, compared to 809.0 mm under the existing irrigation program. Emekli *et al*. (2007) found seasonal ET of Bermuda grass irrigated at 100%, 75%, 50% and 25% of Class A pan evaporation to be 1186, 900, 614 and 353 mm, respectively. Although our study was conducted under a sub-humid climatic condition, seasonal ET values were close to the values obtained in studies under arid climatic

Table 4: Colour and quality ratings (1-9) and clipping yields (g m^{-2}) of perennial ryegrass under different nitrogen rates (NR, kg ha^{-1}) and irrigation levels (IL, %) in the 2007 experimental season

Factors	Month					Seasonal average
	May	June	July	August	September	
			Colour			
NR						
N_1	7.9 b[a]	7.4 b	5.9 b	5.9 b	5.6 b	6.5 b
N_2	8.3 a	7.8 a	6.6 a	6.9 a	6.8 a	7.3 a
F-test	**	*	*	**	**	**
$LSD_{0.05}$	0.2599	0.3809	0.6560	0.4773	0.2919	0.6312
IL						
I_1	7.5 c	6.5 d	4.8 b	5.4 b	3.9 d	5.6 c
I_2	7.9 bc	7.1 c	6.6 a	6.6 a	6.0 c	6.8 b
I_3	8.3 ab	7.6 bc	6.3 a	6.3 a	6.1 c	6.9 b
I_4	8.4 a	8.4 a	6.9 a	7.0 a	7.1 b	7.6 a
I_5	8.3 ab	8.1 ab	6.6 a	6.6 a	7.6 a	7.4 a
F-test	**	**	**	**	**	**
$LSD_{0.05}$	0.4368	0.4493	1.001	0.6144	0.4096	0.2103
			Quality			
NR						
N_1	7.5 b	6.8 b	5.8 b	5.8 b	5.0 b	6.2 b
N_2	7.9 a	7.4 a	6.5 a	6.4 a	6.0 a	6.8 a
F-test	*	**	**	**	**	*
$LSD_{0.05}$	0.3047	0.5519	0.2597	0.5329	0.4773	0.3820
IL						
I_1	7.1 b	6.1 c	4.9 c	5.0 c	2.5 d	5.1 d
I_2	7.6 ab	6.8 b	6.0 b	6.0 b	4.9 c	6.3 c
I_3	7.6 ab	7.4 ab	6.3 ab	6.0 b	5.9 b	6.6 b
I_4	8.0 a	7.6 a	6.8 a	6.5 ab	6.8 a	7.1 a
I_5	8.0 a	7.5 a	6.8 a	6.8 a	7.4 a	7.3 a
F-test	*	**	**	**	**	**
$LSD_{0.05}$	0.5769	0.6032	0.6177	0.6594	0.7477	0.2371
			Clipping yield			
NR						
N_1	25.6 b	4.9 b	17.3 b	7.5 b	2.1 b	11.5 b
N_2	61.0 a	10.3 a	29.0 a	26.7 a	10.0 a	27.4 a
F-test	**	**	**	**	**	**
$LSD_{0.05}$	14.771	2.676	4.727	1.427	1.678	5.341
IL						
I_1	31.2 c	2.0 c	9.7 c	3.6 c	0.0 b	9.3 c
I_2	39.8 bc	4.0 c	14.0 c	5.2 c	0.0 b	12.6 c
I_3	39.1 bc	7.0 b	18.5 c	28.7 a	2.8 b	19.2 b
I_4	49.1 ab	8.8 b	42.0 a	20.2 b	11.7 a	26.4 a
I_5	57.2 a	16.3 a	31.6 b	27.8 a	15.6 a	29.7 a
F-test	**	**	**	**	**	**
$LSD_{0.05}$	12.74	2.457	9.728	5.979	4.197	5.617

[a]Mean values in the same column followed by the same letter do not differ significantly at the 0.05 level according to LSD
[*]significant at $P < 0.05$
[**]significant at $P < 0.01$

conditions conducted by Bastug and Buyuktas (2003) and Emekli *et al*. (2007). This can be explained mainly by the fact that our irrigation period was one month longer than the irrigation period in those studies.

The N fertilization requirement of turfgrass species generally varies from 0 to 100 kg N ha^{-1}, but on average, 50 kg ha^{-1} is recommended for perennial ryegrass per growing month (Beard, 1973). Our previous studies also indicated that acceptable quality of perennial ryegrass under conditions similar to those in the present study can be maintained by the application of 50 kg N ha^{-1} per month during the active growing period (Bilgili and Acikgoz, 2005, 2011a; Bilgili *et al*., 2011b). In close agreement with those studies, 50 kg N ha^{-1} per month fertilization regime (N_2 fertilization treatment) resulted in acceptable turf visual color and quality as well as the highest clipping yields throughout both seasons in the present study (Table 4 and 5).

The I_3 irrigation treatment resulted in acceptable turfgrass visual color and quality throughout the study, with the exception of a slight dip in quality ratings below acceptable levels in June 2008 (Table 4 and 5). Bastug and Buyuktas (2003) also found satisfactory turfgrass color could be attained under Mediterranean conditions with irrigation at 75% of Class A pan evaporation. Several recent studies have shown that irrigation rates significantly below a 100% rate of replacement of moisture lost to evapotranspiration can still result in acceptable turfgrass

Table 5: Colour and quality ratings (1−9) and clipping yields (g m^{-2}) of perennial ryegrass under different nitrogen rates (NR, kg ha^{-1}) and irrigation levels (IL, %) in the 2008 experimental season

Factors	Month					Seasonal average
	May	June	July	August	September	
			Colour			
NR						
N_1	6.4 b[a]	6.4 b	6.0 b	5.6 b	7.5 b	6.4 b
N_2	8.0 a	7.5 a	7.5 a	6.7 a	8.0 a	7.5 a
F-test	**	**	**	**	**	**
$LSD_{0.05}$	0.5809	0.4004	0.5511	1.0869	0.3047	0.8904
IL						
I_1	6.5 c	6.1 c	5.1 d	3.4 c	7.1 b	5.6 c
I_2	6.9 c	6.8 b	6.0 c	4.9 b	7.6 ab	6.4 b
I_3	6.9 c	7.0 ab	6.9 b	7.3 a	8.1 a	7.2 a
I_4	8.1 a	7.5 a	7.8 a	7.5 a	8.0 a	7.8 a
I_5	7.6 b	7.3 ab	7.8 a	7.5 a	7.8 a	7.6 a
F-test	**	**	**	**	**	**
$LSD_{0.05}$	0.4663	0.5453	0.7993	0.9745	0.5453	0.5123
			Quality			
NR						
N_1	6.9 b	4.8 b	5.0 b	4.8 b	6.9 b	5.7 b
N_2	7.3 a	6.6 a	6.6 a	6.1 a	7.7 a	6.9 a
F-test	*	**	**	**	**	**
$LSD_{0.05}$	0.3096	0.3768	0.7056	1.1765	0.7348	1.015
IL						
I_1	6.4 b	5.5 b	4.1 d	2.5 c	6.4 b	5.0 c
I_2	7.0 a	5.3 b	5.0 c	3.8 b	7.4 a	5.7 b
I_3	7.3 a	5.1 b	5.9 b	6.8 a	7.6 a	6.5 a
I_4	7.5 a	6.4 a	6.9 a	7.1 a	7.4 a	7.1 a
I_5	7.3 a	6.3 a	7.0 a	6.9 a	7.5 a	7.0 a
F-test	**	**	**	**	**	**
$LSD_{0.05}$	0.5453	0.7881	0.8104	0.8210	0.6424	0.6178
			Clipping yield			
NR						
N_1	10.2 b	3.5 b	7.3 b	6.5 b	25.2 b	10.5 b
N_2	19.6 ab	20.4 a	19.0 a	26.3 a	43.5 a	25.8 a
F-test	**	**	**	**	**	**
$LSD_{0.05}$	0.817	2.170	5.887	3.836	9.317	4.754
IL						
I_1	12.0 c	7.8 d	3.1 c	3.7 c	19.9 c	9.3 c
I_2	13.5 bc	10.2 cd	7.3 bc	4.8 c	30.7 b	13.3 b
I_3	13.8 bc	11.7 bc	12.3 b	26.2 a	45.7 a	21.9 a
I_4	19.0 a	15.8 a	23.7 a	18.3 b	38.7 ab	23.1 a
I_5	16.1 ab	14.3 ab	19.6 a	29.0 a	36.9 ab	23.2 a
F-test	**	**	**	**	**	**
$LSD_{0.05}$	3.441	3.087	5.003	3.507	9.152	8.651

[a]Mean values in the same column followed by the same letter do not differ significantly at the 0.05 level according to LSD
[*]significant at $P < 0.05$
[**]significant at $P < 0.01$

quality (Fu *et al.*, 2004; DaCosta and Huang, 2006; Fu *et al.*, 2007a, b). Moreover, many turf and forage grasses have found to respond to moderate deficit irrigation regimes with improvements in quality and other positive growth characteristics (Fry and Huang, 2004), such as greater rooting (Qian and Fry, 1996; Jordan *et al.*, 2003) and stress resistance (Qian and Fry, 1996) and smaller clipping yields (Biran *et al.*, 1981). In the present study, I_3 irrigation (75% E_{pan}) treatment resulted in lower seasonal average clipping yields than the I_4 (100% E_{pan}) and I_5 (125% E_{pan}) irrigation treatments for both 2007 and 2008.

Several earlier studies have also rated turf color and quality ratings on a scale of 1-9, with 6 considered to be the acceptable minimum for visual quality (Kopp and Guillard, 2002; Bilgili and Acikgoz, 2005). Using the same criteria, the present study found acceptable turfgrass color and quality could be sustained throughout the study under both N_1I_4 and N_2I_3 treatments. Visual Color, quality and clipping yields were found to decrease with decreases in both N rates and irrigation levels. Feldhake (1981) stated that in comparison to adequately fertilized turf, nitrogen-deficient turf experiences a more rapid decline in quality when subjected to moisture stress.

Some studies have reported reductions in turfgrass ET with reductions in N fertilizer application under a non-limiting water supply; however, not all of these studies have provided quantitative assessments of the effects of N application rate on turfgrass quality (Shearman and Beard, 1973; Feldhake *et al*., 1983). Ebdon *et al.* (1999) reported decreases in ET of Kentucky bluegrass in line with

Table 6: Clipping yields (g m^{-2}) of perennial ryegrass for the nitrogen rates (NR) x irrigation levels (IL) interactions in the 2007 and 2008 experimental seasons

Year	NR (kg ha^{-1})	IL (%)	Month					Seasonal average
			May	June	July	August	Sept.	
2007	N_1	I_1	10.6 e[a]	2.0 e	5.7 c	1.7 d	0.0 c	4.0 f
		I_2	21.0 de	4.0 de	5.7 c	3.7 cd	0.0 c	6.9 f
		I_3	26.5 de	6.0 cd	16.0 bc	12.0 c	0.0 c	12.1 e
		I_4	33.5 d	6.0 cd	37.6 a	11.1 c	4.0 bc	18.4 d
		I_5	36.4 cd	6.5 cd	21.4 b	8.9 cd	6.5 b	15.9 de
	N_2	I_1	51.8 bc	2.0 e	13.7 bc	5.5 cd	0.0 c	14.6 de
		I_2	58.6 b	4.0 de	22.3 b	6.7 cd	0.0 c	18.3 d
		I_3	51.8 bc	8.0 c	21.0 b	45.4 a	5.6 bc	26.4 c
		I_4	64.8 ab	11.5 b	46.4 a	29.2 b	19.4 a	34.3 b
		I_5	78.1 a	26.0 a	41.8 a	46.7 a	25.2 a	43.6 a
		F-test	**	**	**	**	**	**
		$LSD_{0.05}$	18.02	3.475	13.76	8.456	5.935	8.147
2008	N_1	I_1	7.4 e	2.9 e	1.6 e	0.7 f	16.8 d	5.9 e
		I_2	8.5 e	2.0 e	5.4 c-e	3.7 ef	23.2 d	8.6 e
		I_3	11.0 de	3.1 e	8.8 b-d	9.5 d	37.6 c	14.0 d
		I_4	10.8 de	4.0 e	11.7 bc	9.9 d	25.7 cd	12.4 d
		I_5	13.6 cd	5.6 e	9.3 b-d	8.9 d	23.0 d	12.1 d
	N_2	I_1	16.7 bc	12.7 d	4.6 de	6.8 de	23.0 d	12.8 d
		I_2	18.5 b	18.5 c	9.1 b-d	5.9 de	38.1 bc	18.0 c
		I_3	16.7 bc	20.4 bc	15.7 b	42.9 b	53.8 a	29.9 b
		I_4	27.2 a	27.6 a	35.8 a	26.7 c	51.8 a	33.8 a
		I_5	18.7 b	23.1 b	30.0 a	49.2 a	50.9 ab	34.4 a
		F-test	*	**	**	**	**	**
		$LSD_{0.05}$	4.867	4.366	7.075	4.960	12.94	4.091

[a]Mean values in the same column followed by the same letter do not differ significantly at the 0.05 level according to LSD

[*]significant at $P < 0.05$

[**]significant at $P < 0.01$

decreases in N fertilizer rates, the effect was not significant among those application rates required to maintain acceptable turfgrass quality. Barton *et al.* (2009) reported that water consumption of older Kikuyu [*Pennisetum clandestinum* (Holst. Ex Chiov)] turfgrass (established from 20-yr-old turf grass) could be reduced by 20% without compromising turfgrass quality by not fertilizer application, whereas not applying N fertilizer to younger turfgrass (established from 20-wk-old turf grass) could save water by sacrificing turfgrass quality. As the authors noted, any assessment of how adjustments in N fertilizer rates can be used to achieve water conservation must include an evaluation of turfgrass quality. The present study found that under a non-limiting water supply, acceptable turfgrass visual color and quality could be maintained with less water consumption by adjusting N fertilizer rates.

Conclusion

This study showed that perennial ryegrass visual color, quality and clipping yields decreased with decreases in irrigation water and N fertilizer application. A reduction in perennial ryegrass water use was achieved by reducing the rate of N fertilizer application. Measurements of turfgrass visual color and quality demonstrated that reductions in turfgrass water use could be achieved by adjusting N fertilizer rates under a non-limiting water supply. According to the results of this study, acceptable turfgrass visual color and quality can be sustained in sub-humid climatic conditions by the application of 25 kg N ha^{-1} and 761.3 mm irrigation or by the application of 50 kg N ha^{-1} and 571.0 mm irrigation.

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