Journal of Applied Biosciences (2008), Vol. 9(1): 343 – 353.
ISSN 1997 – 5902: www.biosciences.elewa.org

Evaluation of Turf Color and Root Length Density of Hybrid Bluegrass and Tall Fescue under Irrigation Scheduling

Githinji LJM*[1], Dane JH[2], Walker RH[2] and van Santen E[2]
[1]Department of Agriculture and Environmental Sciences, Tuskegee University, AL 36088 USA.
[2]Department of Agronomy and Soils, Auburn University, AL 36849 USA.

*Corresponding author e-mail address: Leonard.Githinji@Tuskegee.edu; Tel.: +1 334 724 4184

ABSTRACT
Objective: To determine turf color (TC) and root length density (RLD) of hybrid bluegrasses (HBGs) [Texas bluegrass (*P. arachnifera* Torr.) × Kentucky bluegrass (*Poa pratensis* L.)], HB 129 ('Thermal Blue'), HB 130, HB 328 and HB 329 ('Dura Blue') and the tall fescue (*Festuca arundinacea* Schreb.) cultivars, 'Green Keeper' and 'Kentucky 31'.
Methodology and results: The grasses were seeded in autumn 2004 for a 2-year field study conducted at the turfgrass research facility, Auburn, Alabama, USA .The experimental design was a 6 by 6 Latin square with six replicates of each treatment combination within each of 3 irrigation blocks. Subsequently, a total of 108 plots, measuring 1.5 m by 2.0 m each, were established. Plots were irrigated at rates of 100, 80 and 60% of potential evapotranspiration. The turf color values were determined using digital images collected once a week, while the root length density was determined from root samples collected in July and September of 2005 and 2006. HBGs had higher RLD and TC values compared to tall fescue. Rankings based on the RLD and TC were: HB 329 (highest) > HB 130 > HB 328 > HB 129 (Thermal Blue) > Kentucky 31 > Green Keeper.
Conclusion and application of findings: The results of this study showed that HBG performed better in terms of RLD, which would enable them to withstand drought better than tall fescue cultivars. The superior TC of HBG makes them a better choice for lawns and sports fields than tall fescue cultivars.

Key words: Hybrid Bluegrass, Tall fescue, Irrigation scheduling.

Citation: Githinji LJM, Dane JH, Walker RH and van Santen E, 2008. Evaluation of Turf Color and Root Length Density of Hybrid Bluegrass and Tall Fescue under Irrigation Scheduling. *Journal of Applied Biosciences* 9(1): 343 - 353.

INTRODUCTION
Quality, which includes aesthetic and functional aspects, is of fundamental importance in evaluation of turfgrass. Turf color, which is a good indicator of water and nutrient status (Beard, 1973), is one of the major components of aesthetic quality that is often evaluated in field studies. Methods for determining turf color include visual ratings, usually on a scale of 1 (yellow to brown turf) to 9 (optimal dark green turf) and digital image analysis (Karcher & Richardson, 2003; 2005).

The importance of root systems in acquiring water has long been recognized as being crucial to cope with drought conditions (Carrow, 1996a; Kashiwagi *et al*., 2006). A decrease in total number of roots and average root length (e.g. at high soil temperatures) reduces plant access to soil water and nutrients (Jordan *et al*., 2003). High root mortality is undesirable as dead roots provide a food source for soil microbes, which may result in increased respiration and reduced soil oxygen concentrations (Kuzyakov *et al*., 2001; Jordan *et al*., 2003). If turfgrasses could be selected with low-shoot-to-high-root ratios with deeper root penetration, significant gain in drought avoidance should be possible (Bonos *et al*., 2004). High soil temperature causes root length density to decline during the summer (Beard & Daniel, 1965) as a result of lower food reserves in the plant root system.

Tall fescue (*Festuca arundinacea* Schreb.), a popular turfgrass grown in the northern, transitional, and upper to mid-southern climates of the USA, has been reported to have superior drought avoidance ability and is able to maintain growth and green color for longer periods between rainfall and irrigation events than many cool-season species. Tall fescue is particularly popular in the transition zone, defined as the area between those adapted for cool-season and warm-season grasses (Sleper & West, 1996). Much of the popularity of tall fescue can be attributed to its adaptation to a wide range of soil, climatic, and management conditions (Asay *et al*., 2001).

Some tall fescue cultivars have better heat tolerance than many commonly grown cool-season turfgrasses (Carrow 1996a; Carrow & Duncan, 2003). Some studies reported greater drought resistance and avoidance characteristics including lower leaf firing, i.e. the total percentage of chlorotic leaf area (Qian *et al*., 2004), greater rooting depth and higher root length density for 'Rebel II' and 'Arid' tall fescue cultivars than for bluegrasses (Carrow, 1996 a, b). Under low maintenance, Qian and Engelke (1999) reported that minimum irrigation quantity needed to prevent drought stress and maintain acceptable quality for tall fescue was 50 to 70% of evaporation from class-A pan. Meyer and Gibeault (1987) observed that a similar amount of irrigation replenishment (60% of wind-modified pan evaporation) would be sufficient to maintain turf quality. Under intensive management conditions, irrigation at 80% of pan-evaporation was required to maintain turf quality (Carrow, 1995). The effects of heat stress in combination with drought stress have been found to more adversely impact photosynthesis, water relations, and root growth for tall fescue than either of these stresses alone (Jiang & Huang, 2001a, b).

Kentucky bluegrass (*Poa pratensis* L, KBG) is a cool-season grass species that is used extensively for athletic fields, lawns, and golf courses in the U. S. (Turgeon, 2002). It has good turf quality and forms attractive turf when supplied with adequate water (Meyer & Funk, 1989). However, it has moderate to low drought resistance (Beard, 1989), going dormant and losing color during periods of high temperature and drought. Due to poor drought resistance the grass requires frequent irrigation to withstand hot and arid summers, and this restricts its use under water deficit conditions (Abraham *et al*., 2004). Meyer and Gibeault (1987) found that the quality of KBG decreased significantly when irrigated at 60% of wind-modified pan evaporation compared to100% irrigation rate.

The HBGs are genetic crosses between KBG and Texas bluegrass (*Poa arachnifera* Torr., TBG). The HBGs have the desirable appearance of KBG, i.e., fine texture, and like TBG, may withstand higher temperatures and extended drought without going dormant (Abraham *et al*., 2004; Su *et al*., 2004; Bremer *et al*., 2006). Some HBGs exhibit lower water-use compared to other cool-season species while maintaining their green color (Supplick-Ploense & Qian, 2005). One such hybrid is 'Reveille' developed by the Texas Agricultural Experiment Station (Read *et al*., 1994), which is well adapted to golf courses, home lawns, and commercial and industrial parks. Its foliar characteristics are similar to Kentucky bluegrasses but other traits resemble those of Texas bluegrasses, as it thrives under heat stress and hot sun, tolerates cold weather and uses less water (Read *et al*., 1994). Abraham *et al*. (2004) found that Reveille possesses a significantly more extensive root system and can survive with lower evapotranspiration compared to Kentucky bluegrass.

Two other hybrid bluegrasses HB 129 and HB 329 were recently released by The Scotts Company, Inc. (Carson, 2004). A preliminary evaluation at Auburn University has indicated that these hybrids are able to withstand high summer heat while maintaining good color. Field evaluation by Dane *et al*. (2006) showed that these hybrid bluegrasses were able to survive stress periods better than tall fescue cultivars. The study subjected HB 129, HB 329, 'Southeast' and 'Rebel III' tall fescue to irrigation at soil water matric head minima of -300 and -600 cm of water pressure, and no irrigation, which represented no, intermediate, and high water stress, respectively. It was concluded that the two hybrid bluegrasses were superior to the tall fescue cultivars in their ability to distribute water uptake and to maintain their desirable characteristics (minimal browning). Other hybrids, including HB 130 and HB 328, are experimental lines that are undergoing research evaluation. Although there is good potential for using hybrid bluegrasses in lawn and golf courses, sufficient scientific data are lacking on their performance compared to that of tall fescue when subjected to deficit irrigation.

Although HBGs have potential use in lawns and golf courses, little scientific information is available about their performance relative to KBG and tall fescue under different climatic stresses or cultural practices (Bremer *et al*., 2006). Furthermore, some researchers have sometimes reported contradicting results of HBGs' performance compared to other cool-season grasses. A study by Su *et al*. (2004) revealed that HB 129 maintained a higher quality than 'Dynasty' tall fescue and 'Apollo' KBG cultivar, under high temperatures in a growth chamber. Bremer *et al*. (2006) reported a better adaptation of tall fescue as compared to HBGs in some transition zones with deep soils. Other trials by Stier *et al*. (2005) in the upper Midwest showed the mean turf color of two HBGs, HB 129 and HB 329, to be similar to those of KBG ('Apollo' and 'Unique') and two tall fescue cultivars ('Masterpiece' and 'Rembrandt') when mowed at 2.5, 5, and 7.5 cm heights and fertilized with N at either 48 or 144 kg ha^{-1} y^{-1}. Other HBGs, including HB 130 and HB 328 are still experimental lines.

The objectives of this study were to i) determine the turf color and root length density and ii) compare the performance of the hybrid bluegrasses (HB 129, HB 130, HB 328 and HB 329) with tall fescue cultivars (Green Keeper and Kentucky 31).

MATERIALS AND METHODS

Experimental design: The experiments were carried out at the Auburn University Turfgrass Research Facility, Auburn, Alabama on a Marvyn loamy sand (Fine-loamy, siliceous, thermic Typic Kanhapludults). Six cool-season turf cultivars, including four hybrid bluegrasses (HB 129, HB 130, HB 328 and HB 329) and two tall fescue cultivars (Kentucky 31 and Green Keeper) were seeded during the fall of 2004. The experimental design was a 6 by 6 Latin square (to block against double slope) with six replicates. Each of the Latin squares measured 14 m × 16 m and in total there were 108 plots (36 per Latin square) each measuring 1.5 × 2.0 m with buffer strips planted to separate the blocks and the plots. Three ET-based irrigation replacements were applied to meet 100, 80 and 60% of potential evapotranspiration. Both irrigation and rainfall were treated as external variables. The daily ET values were calculated with the Penman-Monteith formula (Allen *et al*., 1998) from daily mean air temperature, net solar radiation, relative humidity, and wind speed. The weather data were obtained from a weather station located within two kilometers of the experimental site and maintained by the Agricultural Weather Information Service (AWIS Weather Services, Inc., http://www.awis.com).

Determination of turf color: To determine the turf color, turf images were taken with the aid of a Canon Power Shot G2 digital camera (Canon Inc., Tokyo, Japan), with settings comprising a shutter speed of 1/640s, an aperture of F4.5, and a focal length of 21 mm. The images were collected by the researchers standing immediately next to the plot while holding the camera at 1.5 m above the turf canopy. This was done once a week for a period of 14 weeks (June 14 through September 20, 2005 and June 13 through September 21, 2006). The images were collected between 9 and 10 a.m. under well illuminated conditions with care to avoid casting shadows on the canopy. The image format was JPEG, with a color depth of 16.7 million colors, and an image size of 2272 × 1704 pixels (about 2.6 megabytes per image). The average RGB levels of the digital images were calculated using SigmaScan Pro version 5.0 software (SPSS, 1999). The digital values of RGB were exported to a MS Excel spreadsheet (Microsoft Corporation, 1999) and using programmed formula, the RGB, which are measured on a scale of 0-255, were converted to percentages by dividing each cell by 255. Based on an algorithm described in Adobe (Adobe Systems, 2002), the percent RGB values were converted to HSB values.

Root analyses: Root samples were collected with a 2.5 cm diameter core sampler from each plot in July during the early part of the experiment and again in September before terminating the experiment for that year. The sampling depth was 0-10 cm below the surface, and root excavation was done below thatch. Prior to each sampling date, about 25 mm depth of irrigation water was added uniformly to the plots in order to loosen the soils and roots. Upon collecting the samples, they were immediately packed in polyethylene bags and preserved in a freezer. To prepare the roots for analysis, the samples were first allowed to thaw overnight. The roots were separated from the soil mass by running tap water on the root-soil mass placed on a 2 mm wire-mesh screen. Sand, silt and clay material passed through the sieve openings leaving the roots and gravel on the screen. The gravel was then handpicked and discarded, leaving clean roots. Before scanning, the roots were rinsed, dried using blotting paper and placed in sample bottles. The very fine roots were stained with Congo red dye. During the measurements, the roots were carefully spread on a Comair root scanner (Commonwealth Aircraft Corporation Limited, Melbourne, Australia), calibrated to known lengths and widths of thread. The scanner has a built-in algorithm to calculate root length. Root length density (RLD) was eventually calculated by dividing total root length in centimeters by the volume of the sampler in cubic centimeters.

Mixed models methodology as implemented in PROC MIXED of PC SAS Version 9.13 (SAS Institute, 2006) was used to analyze the response data. Irrigation, cultivar, year (2005, 2006), sampling month (July, September), and their interactions were treated as fixed effects. Because only two columns per irrigation treatment were sampled for turf color, mixed models analysis was based on a RCB design (r=2). In all other respects, analysis was similar to RLD. Multiple comparison procedures involved the “simulation” option with LS means of PROC MIXED (Littell *et al*., 2006).

RESULTS AND DISCUSSION

The mean monthly air temperature, solar radiation, relative humidity, wind speed, total precipitation and potential evapotranspiration for the summer months (June-September) in 2005 and 2006 are summarized in Table 1. Total precipitation was 539.8 mm for 2005 and 294.1 mm for 2006. Compared to the 30-yr (1971-2000) average for the same period (459.0 mm), these results suggest an extreme dry summer for 2006 and a somewhat drier summer than normal for 2005. Mean solar radiation was higher for each month in 2006 than in the corresponding months of 2005. A similar trend was observed for the average air temperature, except for the month of September. The mean monthly relative humidity was lower for each month in 2006 compared to 2005. The higher mean monthly solar radiation could have been the direct cause of higher mean monthly air temperature and lower mean relative humidity in 2006 compared to 2005. The mean monthly wind speeds for the 2 years were comparable. The calculated potential evapotranspiration was higher in 2006 than in 2005.

In the initial statistical analysis we included all possible interactions between irrigation replenishment (I), cultivar (C), year (Y) and month (M). The 4-way and 3-way interactions were non-significant ($P > 0.5$) and were eliminated from the model resulting in a model with main effects and 2-way interactions only.

The root length density over the entire 2-year period was significantly ($P = 0.001$) affected by year, month, and cultivar (Table 2). As indicated earlier, 3- and 4-way interactions were not significant ($P > 0.50$) and were consequently dropped from the model (data not shown). The irrigation x cultivar interaction had a $P = 0.17$. The only important ($P \leq 0.15$) 2-way interactions involving cultivars were the cultivar x month and the cultivar x year interaction. The Slice option (Littell *et al*., 2006) was invoked for these interaction means to test month and year effects separately for each cultivar (data not shown). The effect of sampling month (July vs. September) was significant ($P \leq 0.0001$) for every cultivar. In every case the root length density was significantly larger in July than in September (Fig. 1, top panel), confirming what is known about root development in cool season grasses during summer. The average root length density across the cultivar was higher in 2005 (7.0 cm cm^{-3}) than 2006 (6.3 cm cm^{-3}).

Although year 2006 was dryer than 2005, a higher irrigation rate and more evenness of water application in 2006 may have decreased water stress for each of the turf cultivars leading to a lower mean root length density. Frequent irrigation encourages shallow rooting (Madison and Hagan, 1962; Shearman and Beard, 1973), while infrequent irrigation enhances root development on cool-season grasses including bluegrasses (Bennett & Doss, 1960; Madison & Hagan, 1962). The year effect in C × Y interaction was significant for all cultivars except HB 329 ($P = 0.714$) and HB 328 ($P = 0.084$); root length density was higher (Fig. 1, bottom panel) during the close-to-normal year (2005) compared to the extreme dry and hot year 2006, again confirming what is known about root development in response to temperature. In both cases, the significant interaction is primarily a magnitude effect. The cultivar rankings in July and September were identical and almost identical for 2005 and 2006; the only change in rank was for cultivars HB 328, which ranked 3rd in 2005 and 4th in 2006 and HB 329, which switched ranks with HB 328 in 2006. This justifies a main effects only model.

Table 1: Monthly and total seasonal average weather conditions during the experimental period from June to September 2005 and 2006 at Auburn, Alabama. Evapotranspiration, precipitation and applied irrigation are given as monthly (seasonal) totals.

Month	Air temp.	Solar rad.	Rel. humidity	Wind speed	ET	Prec.	Irrigation (% ET) 100	80	60
	ºC	MJ $m^{-2}d^{-1}$	%	ms^{-1}	----	----	mm	----	----
					2005				
June	24.8	17.7	98.7	6.7	181.1	147.6	82.6	66.0	49.5
July	26.0	17.9	100.0	7.6	184.7	191.3	15.2	12.2	9.1
Aug	25.4	18.2	98.2	7.2	193.4	158.0	18.5	14.8	11.1
Sept	25.4	18.0	98.2	7.2	190.1	42.9	101.6	81.3	61.0
Season	25.4	18.0	98.8	7.2	749.3	539.8	217.9	174.3	130.8
					2006				
June	26.1	27.3	58.3	8.2	228.6	123.4	121.2	96.9	72.7
July	28.1	24.3	64.0	7.1	209.8	85.3	118.6	94.9	71.2
Aug	27.9	22.3	70.3	7.0	177.0	34.8	25.4	20.3	15.2
Sept	23.3	19.3	66.4	6.7	172.7	50.5	50.8	40.6	30.5
Season	26.3	23.3	64.7	7.2	788.1	294.1	316.0	252.8	189.6

Pair-wise comparison showed that in the 2-year period the root length density for HB 130 (average RLD = 8.9 cm cm^{-3}) was significantly ($P \leq 0.001$) higher than that of any other cultivar except HB 129 (Table 3). HB 129, the entry with the second highest RLD of 7.7 cm cm^{-3} had a significantly higher root length density ($P \leq 0.001$) than the tall fescues Green Keeper and Kentucky 31 but did not differ significantly from the remaining HBG. HB 129 had root length density greater ($P = 0.05$) than that of Kentucky 31. The root length density ranking using the combined means for the 2-year period was HB 130 (8.5 cm cm^{-3}) > HB 129 (7.4 cm cm^{-3}) > HB 329 (7.0 cm cm^{-3}) > HB 328 (6.6 cm cm^{-3}) > Green Keeper (5.3 cm cm^{-3}) > Kentucky 31 (5.1 cm cm^{-3}). Even though not statistically significant, these HBG entries (HB 329 and HB 328) had higher root length densities than the tall fescues, suggesting a general pattern of higher root length densities in HBG compared to tall fescues. Drought resistance has been correlated with root length, extensive root system or root length density in field crops (Asch *et al*., 2005; Kashiwagi *et al*., 2006) and turfgrass (Levitt, 1980;

White *et al.*, 1993; Carrow 1996b; Huang & Gao, 2000*et al*).

Table 2: Results from mixed models analysis of variance for root length density (RLD). Four- and three-way interactions were dropped from the model because of *P*-values ≥ 0.50.

Source of variation	Degrees of freedom		
	Numerator	Denominator	P > F
Irrigation (I)	2	16	0.059
Cultivar (C)	5	160	<0.001
I × C	10	160	0.170
Year (Y)	1	160	<0.001
I × Y	2	160	0.001
C × Y	5	160	0.060
Month (M)	1	207	<0.001
I × M	2	207	0.437
C × M	5	207	0.027
M × Y	1	207	0.056

Table 3: Pair-wise differences for root length density (RLD) among four HBG cultivars (HB 129, HB 130, HB 328, HB 329) and two tall fescue cultivars (Green Keeper, Kentucky 31). Differences are given below the diagonal and P-values above the diagonal. Adjusted P-values were calculated using the simulation option within LSMEANS of SAS® PROC MIXED).

Cultivar	HB 129	HB 130	HB 328	HB 329	G. Keeper	KY 31	Avg. RLD ($cmcm^{-3}$)
HB 129	-	0.083	0.307	0.618	0.001	< 0.001	7.7
HB 130	1.19	-	< 0.001	0.001	< 0.001	< 0.001	8.9
HB 328	-0.91	2.10	-	0.996	0.215	0.093	6.8
HB 329	-0.69	-1.88	0.22	-	0.071	0.024	7.1
G. Keeper	-1.91	-3.10	-1.00	1.22	-	0.999	5.8
KY 31	-2.08	3.27	1.17	1.39	0.17	-	5.7

For the entire two year period turf color was significantly (*P* = 0.05) different for cultivar (C), year (Y), and week (W). The 3-way interactions I × C × Y and C × W × Y were significant, but I × W × Y and I × C × W were not (Table 4). For the significant ones, an option was taken to leave out I × C × Y since as discussed earlier, the ANOVA showed non-significance of irrigation on any response variable. This left C × W × Y as the only important 3-way interaction, which has the same main factors as the 2-way interactions C × Y and C × W that are discussed below. Among the 2-way interactions involving irrigation, only I × C interaction is of interest in the context of evaluating the color response by cultivar. There was no indication (*P* > 0.46) of a differential response to irrigation among cultivars.

Table 4: Results from mixed models analysis of variance for turf color response variable hue, saturation, and brightness. Four-way interactions were dropped from the model because *P*-values ≥ 0.25.

Source of variation	Degrees of freedom		*P* > F		
	Num	Den	Hue	Saturation	Brightness
Irrigation (I)	2	3	0.686	0.129	0.495
Cultivar (C)	5	15	<0.001	<0.001	<0.001
I × C	10	16	0.551	0.872	0.461
Year (Y)	1	3	0.009	0.001	0.122
I × Y	2	3	0.126	0.090	0.848
C × Y	5	585	<0.001	<0.001	<0.001
I × C × Y	10	585	<0.001	<0.001	0.019
Week (W)	13	585	<0.001	<0.001	<0.001
I × W	26	585	0.008	0.005	0.090
C × W	65	585	<0.001	<0.001	0.001
I × C × W	130	585	1.000	1.000	0.829
W × Y	12	585	<0.001	<0.001	<0.001
I × W × Y	24	585	<0.001	0.007	0.221
C × W × Y	60	585	<0.001	<0.001	<0.001

The C × Y and C × W interactions were both significant (P ≤ 0.001) indicating that the turf color trait differences among cultivars were dependent on the year and time of year. Pair-wise comparisons of the turf color traits hue, saturation and brightness (Table 5) were evaluated using the simulation option in LSMEAN of PROC MIXED. The average hue for all the cultivars in 2005 was 77° with a range from 69° to 83°. These were slightly higher for 2006, with an average of 80° and a range from 75° to 83 °. All the HBG cultivars had significantly (*P* ≤ 0.032) higher hue values than 'Kentucky 31' and 'Green Keeper' tall fescue cultivars in 2005. The ranking of cultivars based on hue angle in 2005 was: HB 328 (83.1°) > HB 329 (82.5°) > HB 129 (78.5°) > HB 130 (77.3°) > Kentucky 31 (71.7°) > Green Keeper (68.9°). While the hue values for all the HBG cultivars remained nearly the same during the 2-yr experimental period, tall fescue (Green Keeper and Kentucky 31) cultivars had considerable hue increase in 2006, changing the ranking based on hue values: HB 329 (83.5°) > Green Keeper (82.8°) > Kentucky 31 (82.7°) > HB 328 (79.4°) > HB 130 (76.4°) > HB 129 (75.4°).

The average saturation for the turf cultivars was lower in year 2005 (37.5 %) than 2006 (38.8 %). There was no particular trend in saturation over the 2-yr experimental period. Three HBG, HB 328, HB 130 and HB 129 had significantly (*P* ≤ 0.001) higher saturation than Green Keeper in 2005. However, there were no significant differences observed in saturation between any two cultivars during year 2006. The effect of water distribution may have eliminated any differences in saturation between cultivars. The ranking based on mean saturation was HB 329 (41.2 %) > Kentucky 31 (40.9 %)> HB 328 (39.8 %) > HB 130 (39.5 %) >HB 129 (35.7 %) > Green Keeper (31.7 %).

For all cultivars, except Green Keeper tall fescue, the brightness values were slightly higher in year 2006 (average 54.4 %) compared to 2005 (average 54.0 %) (Table 5). HB 129 had higher (*P* = 0.005) brightness than Kentucky 31, while that of HB 130 was higher compared to Green Keeper. Ranking of means based on brightness value was: HB 130 (54.8%) >HB 129 (54.7%) > HB 328 (54.3%) HB 329 (54.0%) > Kentucky 31 = Green Keeper (53.6%). Upon performance of a mean turf color rating (by simply ranking cultivars based on hue, saturation, and brightness) and assigning numbers (1= highest, 6 =lowest) and hence calculating the average, we found the rating to be higher for HBG compared to tall fescue cultivars (data not shown). The ranking for turf color quality was: HB 329 (highest) > HB 328 > HB 130 > HB 129> Kentucky 31 > Green Keeper. The ranking based on root length density and turf color was: HB 329 (highest) > HB 130 > HB 328 > HB 129 > Kentucky 31 > Green Keeper.

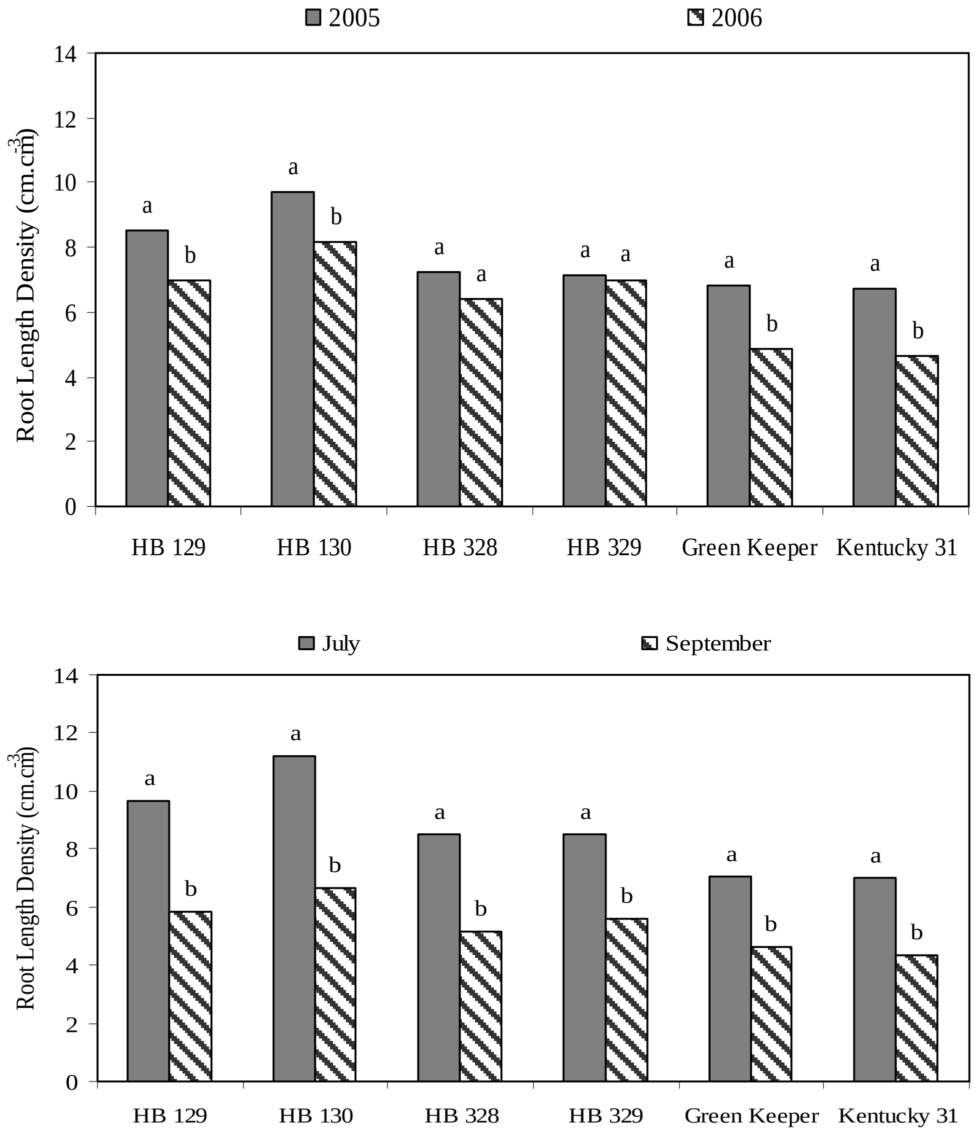

Figure 1: Cultivar x month (top panel) and cultivar x year (bottom panel) interaction means for root length density.

The results of this study showed that HBG performed better in terms of root length density and turf color, and would withstand drought better than tall fescue cultivars. Furthermore, we suggest that HBG cultivars are able to withstand summer heat better than tall fescue. This is supported by visual observations and digital pictures which showed considerable browning for the tall fescue plots, but not for HBG. These results are in agreement with those of Abraham *et al*. (2004), Dane *et al*. (2006) and Read *et al*. (1994) who reported good performance of HBG compared to other cool season cultivars.

Overall, irrigation treatments did not significantly affect turf quality and root length density. The turf color and root length density varied significantly among the cultivars. The study showed that HBG performed better than tall fescue cultivars. The ranking based on root length density (measured between 0-10 cm) and turf color was: HB 329 (highest) > HB 130 > HB 328 > HB 129 > Kentucky 31 > Green Keeper.

Table 5: Probability of pair-wise differences for hue, saturation, and brightness among HBG and tall fescue cultivars. (For each trait, adjusted P-values for 2005 are given above the diagonal and for 2006 below the diagonal. These values were calculated using the simulation option within LSMEANS of SAS® PROC MIXED).

Cultivar	HB 329	G. Keeper	HB 130	HB 328	KY 31	HB 129	Average 2005	Average 2006
				Hue				
							--- degree ---	
HB 329	-	<0.001	0.053	1.000	<0.001	0.213	83	83
G. Keeper	1.000	-	0.001	<0.0001	0.703	<0.001	69	83
HB 130	0.003	0.008	-	0.025	0.032	0.999	77	76
HB 328	0.187	0.389	0.516	-	<0.001	0.110	83	79
KY 31	1.000	1.000	0.009	0.419	-	0.007	72	83
HB 129	0.001	0.002	1.000	0.197	0.002	-	78	75
				Saturation				
							--- % ---	
HB 329	-	0.005	0.026	0.970	1.000	0.006	42	40
G. Keeper	0.011	-	<0.001	<0.001	0.015	<0.001	29	34
HB 130	0.989	0.083	-	0.251	0.009	0.998	37	42
HB 328	0.858	0.214	1.000	-	0.741	0.055	39	40
KY 31	1.000	0.013	0.995	0.897	-	0.001	41	41
HB 129	0.987	0.085	1.000	1.000	0.995	-	36	35
				Brightness				
							--- % ---	
HB 329	-	0.960	0.041	0.954	0.991	0.023	54	54
G. Keeper	0.037	-	0.349	1.000	0.449	0.218	54	53
HB 130	0.484	<0.001	-	0.367	0.005	1.000	55	55
HB 328	0.997	0.005	0.948	-	0.433	0.229	54	55
KY 31	0.873	0.475	0.038	0.355	-	0.003	53	54
HB 129	0.963	0.003	0.993	1.000	0.211	-	55	55

References

Abraham EM, Huang B, Bonos SA, Meyer WA, 2004. Evaluation of drought resistance for Texas bluegrass, Kentucky bluegrass, and their hybrids. Crop Sci. 44:1746–1753.

Adobe Systems, 2002. Adobe Photoshop v. 7.0. Adobe Systems, San Jose, CA.

Allen RG, Pereira LS, Raes D, Smith M, 1998. Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrig. and Drain. FAO, Rome.

Asay KH, Jensen KB, Waldron BL, 2001. Responses of tall fescue cultivars to an irrigation gradient. Crop Sci. 41:350–357.

Asch F, Dingkuhn M, Sow A, Audebert A, 2005. Drought-induced changes in rooting patterns and assimilate partitioning between root and shoot in upland rice. Field Crop Res. 93: 223-236.

Beard JB, 1973. Turfgrass: science and culture. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Beard JB, 1989. Turfgrass water stress: Drought resistance components, physiological mechanisms, and species-genotype diversity. p. 23–28. *In* Takatoh H. (ed.) Proc. Japanese Soc. Turfgrass Sci., Tokyo, Japan.

Beard JB. and Daniel WH, 1965. Effect of temperature and cutting height on the growth of creeping bentgrass (*Agrostis palustris* Huds.) roots. Agron. J. 5:249-250.

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

Bonos SA, Rush D, Hignight K, Meyer WA, 2004. Selection for deep root production in tall fescue and perennial ryegrass. Crop Sci. 44:1770–1776.

Bremer DJ, Su K, Keeley SJ, Fry JD, 2006. Performance in the transition zone of two hybrid bluegrasses compared with Kentucky bluegrass and tall fescue. Applied Turfgrass Science.10:1094.

Carrow RN, 1995. Drought resistance aspects of turfgrasses in the southeast: ET and crop coefficients. Crop Sci. 35:1685–1690.

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

Carrow RN, 1996b. Drought resistance aspects of turfgrasses in the Southeast: Root-shoot responses. Crop Sci. 36:687–694.

Carrow RN. and Duncan RR, 2003. Improving drought resistance and persistence in turf-type tall fescue. Crop Sci. 43:978-984.

Carson T, 2004. Beating the heat but not the blues. Golf Course Management, September issue.

Dane JH, Walker RH, Bahaminyakamwe L, Belcher JL, 2006.Tall fescue and hybrid bluegrass response to soil water matric head limits. Agricultural Water Management. 86:177-186.

Huang B. and Gao H, 2000. Root physiological characteristics associated with drought resistance in tall fescue cultivars. Crop Sci. 40:196-203.

Jordan JE, White RH, Vietor DM, Hale TC, Thomas JC, Engelke CM, 2003. Effect of irrigation frequency on turf quality, shoot density, and root length density of five bentgrass cultivars. Crop Sci. 43: 282–287.

Jiang Y. and Huang B, 2001a. Drought and heat stress injury to two cool-season turfgrasses in relation to antioxidant metabolism and lipid peroxidation. Crop Sci. 41:436-442.

Jiang Y. and Huang B, 2001b. Physiological responses to heat stress alone or in combination with drought: A comparison between tall fescue and perennial ryegrass. HortScience. 36:682–686.

Karcher DE. and Richardson MD, 2003. Quantifying turfgrass color using digital image analysis. Crop Sci. 43:943–951.

Karcher DE. and Richardson MD, 2005. Batch analysis of digital images to evaluate turfgrass characteristics. Crop Sci. 45:1536–1539.

Kashiwagi J, Krishnamurthy L, Crouch JH, Serraj R, 2006. Variability of root characteristics and their contributions to seed yield in chickpea (*Cicer arietinum* L) under terminal drought stress. Field Crops Res. 95:171-181.

Kuzyakov Y, Ehrensberger H, Stahr K, 2001. Carbon partitioning and below ground translocation by *Lolium perenne*. Soil Biol. Biochem. 33:61–74.

Levitt J, 1980. Responses of plants to environmental stresses. Vol. II. Academic Press, New York.

Littell RC, Milliken GA, Stroup WW, Wolfinger RD, Schabenberger O, 2006. SAS for Mixed Models. 2nd ed. SAS Inst., Cary, NC.

Madison JH. and Hagan RM, 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.

Meyer WA. and Funk CR, 1989. Progress and benefits to humanity from breeding cool-season grasses for turf. *In* Contributions from Breeding Forage and Turf Grasses. Crop Sci. Soc. Am. Spec. Publ. No.15. Madison, WI.

Meyer JL. and Gibeault VA, 1987. Turfgrass performance when under irrigated. Appl. Agric. Res. 2:117–119.

Qian Y. and Engelke MC, 1999. Performance of five turfgrasses under linear gradient irrigation. HortScience 34:893–896.

Qian YL, Follett RF, Wilhelm S, Koski AJ, Shahba MA, 2004. Carbon isotope discrimination of three Kentucky bluegrass cultivars with contrasting salinity tolerance. Agron J. 96:571-575.

Read JC, Walker D, Hipp BW, 1994. Potential of Texas bluegrass × Kentucky hybrids for turfgrass. Agronomy Abstracts. ASA, Madison, WI.

Richardson MD, Karcher DE, Purcell LC, 2001. Quantifying turfgrass cover using digital image analysis. Crop Sci. 41:1884–1888.

SAS Institute, 2006. SAS user's guide: Statistics. v. 9.1.3. SAS Inst., Cary, NC.

Shearman RC. and Beard JB, 1973. Environmental and cultural preconditioning effects on the water use rate of *Agrostis palustris* Huds. Crop Sci. 13:424–427.

Sleper DA. and West CP, 1996. Tall fescue. p. 471–502. *In* Moser L.E. (ed.) Cool-season forage grasses. Agron. Mon. 34. ASA, CSSA and SSSA, Madison, WI.

Stier JE, Koeritz E, Frelich J, 2005. Fertility and mowing response of heat tolerant bluegrass and tall fescue in the upper Midwest. *In* Annual meetings abstracts. ASA, CSSA, and SSSJ, Madison, WI.

Su K, Bremer DJ, Keeley SJ, Fry JD, 2004. High temperature and drought effects of aTexas bluegrass hybrid compared with Kentucky bluegrassand tall fescue. *In* Annual meetings abstracts. ASA, CSSA, and SSSA, Madison, WI.

Supplick-Ploense MR. and Qian Y, 2005. Evapotranspiration, rooting characteristics, and dehydration avoidance: Comparisons between hybrid bluegrass and Kentucky bluegrass. Int. Turfgrass Soc. Res. J. 10:891-898.

SPSS, 1999. Sigma Scan Pro v. 5.0. SPSS Science Marketing Dep., Chicago, IL.

Turgeon AJ, 2002. Turfgrass management. 6th ed. p. 1-20. Prentice Hall, Englewood Cliffs, NJ.

White RH, Bruneau AH, Cowett TJ, 1993. Drought resistance of diverse tall fescue cultivars. Int. Turfgrass Soc. Res. 7:607–613.