CHAPTER 3

Turfgrass Morphological And Growth Characteristics Of Low-And High-Water Use Kentucky Bluegrass Cultivars

ABSTRACT

As the competition for water increases, there is a need to conserve limited water resources applied to irrigated turfgrass sites. Consistent with this effort is the identification of water conserving Kentucky bluegrass *(Poa pratensis* L.) because low consumptive water use lengthens the time between rainfall and irrigation events, thus reducing irrigation requirements. Low evapotranspiration (ET) rates under non-limiting soil moisture conditions have been associated with turfgrass morphology and growth characteristics that increase canopy resistance to ET and reduce leaf area components. The relative contribution of each component however, can vary significantly between turfgrass species. Much of this previous research emphasized warm-season turfgrass. A greenhouse study was conducted to determine the relationship between morphological and growth characteristics in 61 Kentucky bluegrass (KBG) cultivars and comparative water use. Using cluster analysis, the 61 KBG cultivars were categorized as either low- or high-water use cultivars based on ET rates evaluated in the growth chamber across three temperature environments (25, 3D, and 35°C). Averaged across temperature environments, the low-water use cultivars ranged from a low of 5.36 to a high of 6.02 mm d^{-1} and the high-water use cultivars ranged from a low of 5.82 to a high of 6.82 mm d-1. Morphological and growth characteristics were assessed from unmown space plants and mowed turfgrass grown in 20cm diam., fritted clay filled

lysimeters. Based on space plant morphology, low-water use cultivars had 13% more horizontal leaf orientation, 6% narrower leaf texture, 13% more lateral shoots per plant, 12% slower vertical leaf extension rate, 2% more leaves per shoot, and 7% shorter leaf blades and sheaths than the high-water use cultivars. Based on turfgrass morphology from mowed (45 mm) lysimeters, the low-water use cultivars had 17% more horizontal leaf orientation, 10% narrower leaf texture, 15% more shoots per lysimeter, 4% slower vertical leaf extension rate, and 4% shorter leaf sheaths than the high-water use group. Other differences between comparative water use groups in shoot and root characteristics were also detected. Leaf angle was the only plant character evaluated under mowed conditions whose correlation with turfgrass ET exceeded 0.50 in absolute value. Differences between comparative water use groups based on single plant- and turfgrass-morphology indicate that canopy resistance to ET and leaf area components are also important in cool-season grasses like KBG. Characteristics identified may be useful in selecting for KBG with a low-water use pattern.

INTRODUCTION

Kentucky bluegrass is the most widely used cool-season turfgrass in the United States. In the current 1990 National KBG Test sponsored by the USDA and the National Turfgrass Federation Inc., 125 selections are represented (USDA, 1993). Under non-limiting soil moisture and controlled environment conditions, intraspecific variation in ET rates in KBG have been reported to range from 3.86 to 6.43 mm d^{-1} (Sherman, 1986), a daily ET range as broad as those reported across all turfgrass species (Beard, 1973). In frequently irrigated turfgrass where a primary concern is to conserve finite water resources, the identification of water conserving KBG may be important in order to enhance drought resistance and reduce irrigation requirements.

Low water use in warm-season turfgrass evaluated under non-limiting soil moisture conditions has been associated with i) a high canopy resistance to ET which combine charactersitics such as high shoot and leaf densities and a more horizontal leaf and shoot orientation; and ii) low leaf area components including a narrow leaf width and slow vertical leaf extension rates (Kim and Beard, 1988a). The relative contribution of each character on ET can vary significantly between turfgrass species (Kim and Beard, 1988b). Much of this previous research emphasized warm-season turfgrass, and only a superficial treatment has been given to ET rate in cool-season turfgrass from a mechanistic perspective. Further research is needed to validate the relative importance of each canopy resistance and leaf area component in cool-season turfgrass such asKBG.

In developing cultivars for turf usage, plant breeders typically evaluate plant characteristics obtained from both spaced plant nurseries and dense-mowed swords (Bourgoin and Mansat, 1977). Plant measurements from mowed turfs can be cumbersome and obstructed by diminutive tillers and high stand densities (Brede and Duich, 1982). Physical measurements from unmown space plants are not necessarily the most reliable criteria for predicting the performance of mowed turfgrass (Kramer, 1947; Bourgoin and Mansat, 1977). However, occasionally a relationship between turf performance and single plant morphology can be found (van Wijk, 1989).

The purpose of the research reported here was to evaluate i) the morphological and growth characteristics measured in 61 KBG cultivars maintained as unmown space plants and mowed turfgrass, with emphasis on canopy resistance and leaf area components, and ii) their relationship to ET rate measured under non-limiting soil moisture and controlled environment conditions. The 61 cultivars were categorized as low or high ET cases to be used as a basis for identifying characteristics from unmown space plants and mowed turfgrass that are important in comparative water use.

MATERIALSAND METHODS

A random sample of 61 KBG cultivars were assembled from the National Turfgrass Evaluation Program (NTEP) seed bank, Beltsville, MD. The cultivars included 2 entries from the 1990 low-maintenance and 59 entries from the 1990 medium-high-maintenance variety trials. Commercial cultivars and both standard and experimental selections were included. Only pure or authentic seed obtained from either the USDA or breeder was used in the study. The 61 KBG cultivars chosen for study are shown in Fig. 1.

The 61 KBG cultivars were evaluated for ET rate under controlled conditions across three temperature environments (25,30, and 35°C) using the water balance method. Statistical analysis and ET rates pertaining specifically to each cultivar-temperature combination have been reported (Ebdon et. al., 1995). In this study environment is used as a generic term for temperature environment (25, 30, and 35°C). A significant cultivar by environment interaction was detected, indicating that the cultivar means averaged across the three temperature environments are not an adequate summary of the individual cultivar ET rate measured at 25, 30, and 35°C. As a result, cultivars were grouped using hierarchical agglomerative cluster analysis on the basis of their individual ET rates. Results of this cluster analysis are displayed in a dendogram (Fig. 1). The three grouping variables (ET determined at 25, 30, and 350C) were standardized, similarities between cultivars were measured using a

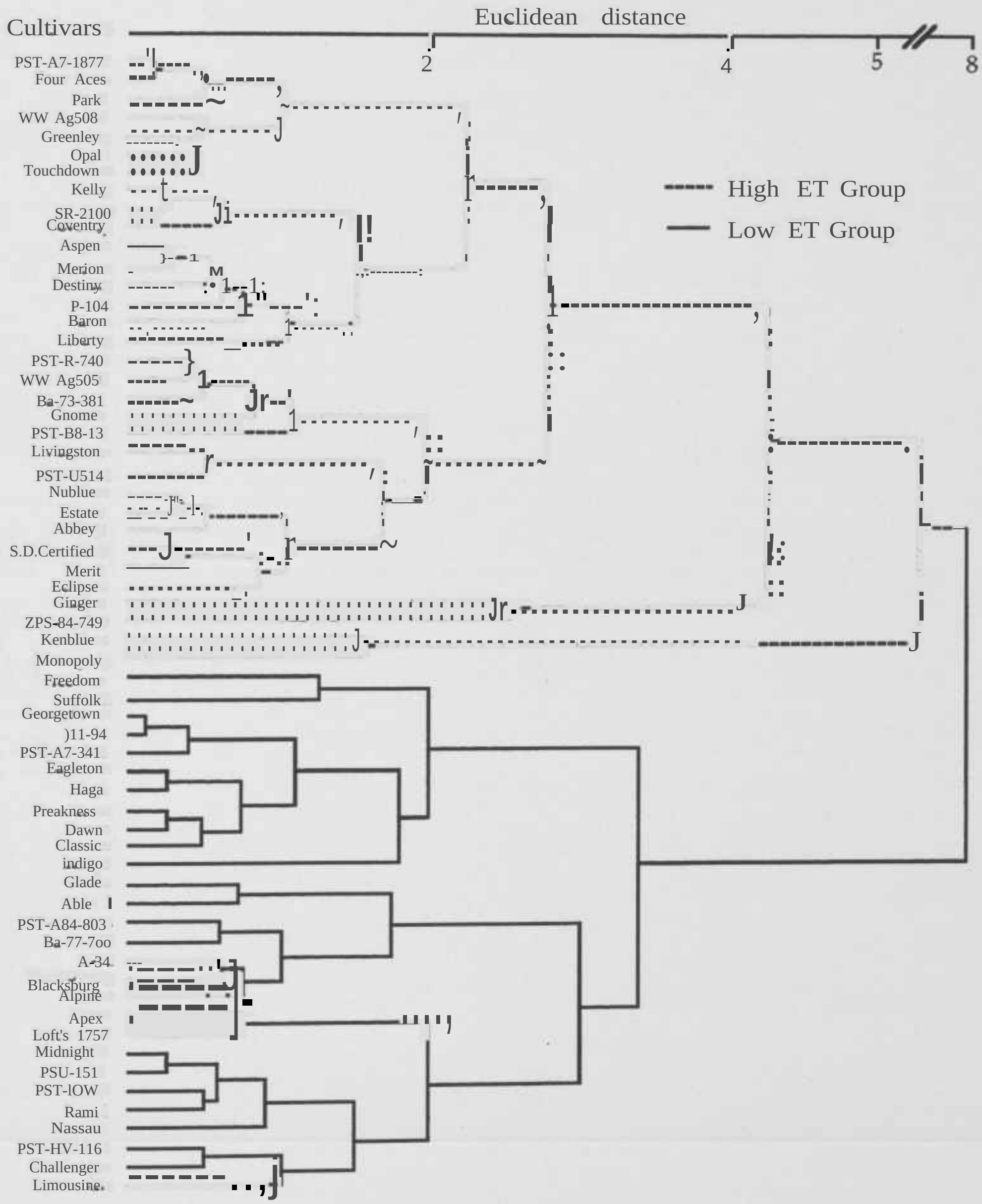

Figure 3.1. Dendogram using complete linkage between groups. Grouping variables are standardized cultivar mean evapo-transpiration rate measured at 25,30, and 35° C in 61 Kentucky bluegrass cultivars.

Euclidean distance metric, and subgroups were combined using the complete linkage (furthest neighbor) method. Two distinct groups (clusters) were revealed in the analysis. The smaller of the two groups contained 28 members and generally clustered below the grand mean of 5.91 mm d^{-1}, hereafter are referred to as the low-ET group (or low-water use cultivars). Averaged across temperature environments, water use for members of this cultivar group ranged from a low of 5.36 to a high of 6.02 mm d^{-1}. The larger of the two groups contained 33 members and generally clustered above the grand mean, and will be referred to as the high-ET group (or high-water use cultivars). The 33 cultivars ranged from a low of 5.82 to a high of 6.82 mm d^{-1}. These groups may not represent any natural grouping. However, the groupings indicate the true closeness of cultivars in 3-dimensional water use space (and hence similarities in water use properties) based on the data. The main use of cluster analysis and the dendogram is as a descriptive tool rather than as a formal test of hypotheses. For more information on the use of clustering techniques in the grouping of variety means, see Jolliffe et al. (1989).

A greenhouse study to evaluate the morphological properties in the 61 KBG cultivars grown as unmown space plants was initiated in February 1993. Root trainer books (A. H. Hummert Co.) with four cells (7.6 x 7.6 x 25.4 cm) per book were used as containers. Containers were filled with a uniform sand containing 96% by weight medium-fine size sand (0.5-0.1 mm diam.). Ten pure live seeds per cell were planted and thined to one plant per cell 3 wks after sowing. Each cultivar was replicated 6 times and the 366 space plants were arranged in the greenhouse under mist heads in a completely randomized design. Space plants were unmown, well watered and fertilized once using 0.4 g of a coated-slow release fertilizer (Osmocote®, 14-6.1-11.6) per cell.

Fifteen plant attributes were evaluated in the unmown space plants, including seven leaf and eight shoot and root characteristics. The first measurement (leaf extension rate) was made 8 wks after sowing and the final measurement (root harvest) was made 16 wks after initial sowing. Measurements were made on 366 space plants by sampling cultivars within a replicate over several days. Time was used as a blocking variable. Leaf character measurements included leaf extension rate, leaf width, leaf fold, leaf length, sheath length, leaf number per shoot, and leaf angle. Leaf extension rate was measured on the youngest leaf (budleaf) over a 24h period using one sample per replicate. All remaining leaf characteristics were measured on two shoot subsamples obtained from each replicate. Leaf width, leaf fold, and leaf length were measured using the second subtending leaf from the budleaf, which has been reported to vary the most between cultivars while minimizing the variation within a cultivar (Sheffer et al., 1978; Brede and Duich, 1982). Leaf width was measured at the midpoint, and leaf fold was a dichotomous variable indicating a folded or flat leaf. Leaf length was the length of the blade or lamina measured from the collar region to the leaf tip. Sheath length was measured from the crown to the upper most portion of the sheath. Leaf number per shoot was the number of green leaves per tiller or shoot. Leaf angle was a rating on a scale of 1 to 4 using the budleaf as the vertical axis, with 1 being a horizontal orientation (=0 to 22.5°), 2 semi-horizontal (=22.5 to 45°), 3 semi-vertical (=45 to 67.5°), and 4 having a vertical orientation (=67.5 to 90°).

The eight shoot and root characteristics measured included crown type category, the number of lateral shoots or tillers, the number of primary rhizomes, shoot fresh-weights and shoot dry-weights, shoot moisture content, root density, and shoot-to-root ratio. Crown type was an overall rating of the outside tillers on a scale of 1 to 4, with 1 indicating a spreading type growth habit, 2 semi-spreading, 3 semi-erect, and 4 indicating an erect growth habit. Crown type ratings were adapted from measurements described by Nittler and Kenny (1976) in which KBG cultivars were reported to differ significantly. At harvest, shoot fresh weights were recorded, and dry weights were determined after oven drying for 24h at 80°C.. Also at harvest the number of primary rhizomes was recorded, roots were carefully washed, and oven dried, and root dry weights were determined and expressed as a root density measurement (mass/soil volume). Shoot moisture content and shoot-to-root ratio were secondary attributes derived directly from shoot fresh-weights and shoot dry-weights, and shoot- and root-dry weights at harvest, respectively. Shoot moisture content was included in the study because research by Burt and Christians (1990) reported low-maintenance (unirrigated turf) KBG cultivars to have lower shoot moisture content than high-maintenance (irrigated turf) cultivars.

Plant measurements were also obtained from mowed lysimeters used for evaluation of ET rate in the 61 KBG cultivars. Each cultivar was replicated four times and arranged in a randomized complete block design, see Ebdon et al. (1995) for a detailed explanation of the treatment arrangement.. Lysimeters were initially established in March and April 1993 and the ET study was completed in August 1994. Thereafter, the 244 lysimeter-containers were kept in a semi-controlled greenhouse environment at a constant day/night temperature of 20±2°C. Containers were mowed weekly at a height of 45 mm, fertilized monthly at a rate of 5 g N M-2 using a coated-slow release fertilizer (Osmocote'P, 14-6.1-11.6), and watered to prevent moisture stress.

All plant measurements were recorded at the time of harvest of the turfed lysimeters beginning 4 December 1994 and ending 23 January 1995, except for leaf extension rates. During ET determinations, vertical elongation rates accumulated weekly above the 45 mm base mowing height were recorded at each temperature environment and converted to mm d^{-1}. Leaf width, sheath length, the number of green leaves per shoot, and leaf angle were measured based on the same methods described for unmown space plants using five shoot subsamples per replicate. The five shoot samples were combined, and fresh weights were recorded and then oven dried at 80°C for 24h for dry weight determination. Shoot moisture content was then derived from the fresh weight and dry weight of five shoots.

Four other shoot and root characteristics were also measured at the time of harvest: the number of tillers were counted; verdure was harvested and expressed on a dry weight basis; and roots were carefully washed, oven dried, and root dry weights were expressed as a root density measurement; verdure and roots dry weights were expressed as a shoot-to-root ratio. Verdure refers to the living shoots of grass-vegetation above ground level not removed by mowing (Madison, 1962). A thin layer of brown mat that had accumulated was separated from the verdure and was not included in the verdure dry weight measurement..

Subsamples taken for various plant characteristics measured on unmown space plants and mowed lysimeters were pooled (averaged) and analysis of variance (ANOVA) was performed on the averages, with the exception of leaf fold data. Leaf fold was analyzed using logistic regression analysis which computed the probability of a folded leaf (versus a flat leaf). Thus, leaf fold data for individual cultivars and for low- and high-water use groups, is reported here as the probability of observing a folded leaf, and formal statistical tests between low- and high-ET cultivars were based on the Wald statistic (Hosmer and Lemeshow, 1989). Cultivar sum of squares for all other plant measurements were partitioned into single degree of freedom (df) contrast using general linear models (GLM) procedures to test for the difference between the combined means for low- and high-water use cultivars. Single df tests were performed even if significant cultivar differences were not detected at *P=0.05* level. Significant treatment effects are not a prerequisite for pre-planned contrasts (Chew,1976). No serious departures from the assumptions of ANOVA were detected in homogeneity of variance and normality of errors. Simple and partial correlation coefficients (Snedecor and Cochran, 1989) were computed between cultivar ET rates measured at 25, 30, and 35°C and morphological characteristics from unmown space plants and mowed lysimeters.

RESULTSAND DISCUSSION

There were 915 treatment means computed for measurements from unmown space plants and 854 treatment means from mowed lysimeters for 61 KBG cultivars. These cultivars were classified as low- or high-ET cases based on each cultivar's individual ET rate across a broad range of evaporative demand. The grouping of cultivars was based on two premises: i) cultivars that are dissimilar in their water use properties will also be dissimilar in their morphological properties, and ii) these differences should separate clearly into low- and high-water use groups for attributes important in comparative water use. Our interest in this present study is in the morphological properties of this dichotomous group derived from a random sample of 61 KBG cultivars.

Unmown Space Plants

The means for the fifteen morphological and growth characteristics in the 61 KBG cultivars grown as unmown space plants and their corresponding ET group membership are shown in Table 3.1. The cultivars differed by as much as 85.0% (% range, maximum-minimum+maximum) in the number of rhizomes produced per plant, and varied the least in their shoot moisture content (12.9%). The coefficient of variation (CV) was smallest for shoot moisture measurements (2.9%) and highest for rhizome number (38.9%). Cultivars differed significantly in all 7 leaf characters (Table 3.2) and in the 8 shoot and root characteristics (Table 3.3). Blocking over time was effective (significant at *P=0.05* level) in 9 of the 15 attributes measured. The cultivar means reported here were within the range reported elsewhere for comparable measurements for spaced plant experiments (Burt and Christians, 1990).

The low- and high-ET cultivars differed significantly (Table 3.2) in the 6 leaf characteristics, including leaf area components (leaf extension rate, leaf width, leaf length and sheath length) and canopy resistance components (leaves per shoot and leaf angle). The low-water use cultivars had 12% slower vertical leaf extension rates, 6% narrower leaf texture, 2% more leaves per shoot and 13% more horizontal leaf orientation than high-ET cultivars. Overall leaf size represented by leaf length and sheath length measurements were highly correlated with vertical leaf extension rates in the unmown space plants, r=0.78*** and 0.67***, respectively. As a result, low-water use cultivars also had 7% shorter leaf blades and sheaths than the high-water use group. Additionally, the low-water use group had a significantly higher probability of folded leaves *(P=0.0057,* probability of 0.28, Table 3.1) than the high-water use

Table 3.1. Fifteen attributes measured on 61 cultivars of Kentucky bluegrass grown as unmown space plants (n=6) under greenhouse conditions and their evapotranspiration (ET) group.

Cultivar	Leaf extension	Leaf fold†	Leaf width	Leaf length	Sheath length	Leaf no. per shoot	Leaf angle‡	Crown type§	Tillers per plant	Rhizomes per plant	Shoot fresh weight	Shoot dry weight	Shoot moisture	Shoot-root ratio¶	Root density#	ET group††
	mm d-1	prob.	mm	mm	mm				no.	no.	mg	mg	%	mg mg-1	mg L-1	
Baron	13.0	0.3	3.5	104.8	43.0	4.4	3.3	3.2	11.2	4.8	3830	1187	69.1	0.82	984	[illegible]
WW Ag 508	16.0	0.0	2.8	118.3	53.1	4.4	2.1	3.2	17.5	6.3	4199	1325	68.5	0.86	1068	[illegible]
Opal	14.2	0.3	2.9	108.3	44.8	3.8	2.4	2.2	18.2	5.0	4656	1419	69.5	1.05	955	[illegible]
Freedom	12.5	0.7	3.3	121.0	37.6	4.1	1.9	2.0	17.2	4.0	5177	1583	69.8	0.99	1089	[illegible]
PST-A7-341	10.7	0.2	3.0	95.8	43.8	4.8	3.4	3.3	11.5	4.7	3330	1000	70.2	1.45	483	[illegible]
Alpine	18.0	0.0	2.9	119.6	48.8	3.7	2.3	2.6	19.5	1.2	4427	1432	67.5	1.01	959	[illegible]
Sulfolk	14.6	0.9	3.3	139.8	43.1	3.5	2.6	2.5	17.7	5.7	5609	1691	70.1	1.31	897	[illegible]
PST-A7-1877	8.5	0.0	3.3	80.3	31.9	4.5	3.0	2.0	15.5	3.8	4078	1089	73.6	1.01	723	[illegible]
Kelly	14.5	0.0	3.6	108.5	53.0	4.8	3.5	2.8	12.2	7.0	5916	1903	67.9	1.44	899	[illegible]
PST-1DW	8.7	0.0	3.3	79.2	44.5	4.9	3.3	3.7	15.0	6.8	4247	1317	69.4	0.91	854	[illegible]
Apex	11.7	0.2	3.3	96.3	50.7	4.8	2.8	3.2	13.0	5.2	4213	1205	71.7	0.96	878	[illegible]
Ginger	22.8	0.0	2.8	136.6	52.8	3.3	4.0	3.2	6.2	2.3	2857	972	66.3	0.79	847	[illegible]
Livingston	12.0	0.2	3.5	92.3	36.4	4.9	3.3	2.5	7.9	4.0	4741	1264	73.9	1.04	846	[illegible]
Aspen	16.6	0.4	3.1	102.1	29.4	3.9	2.2	3.2	13.1	5.0	5858	1566	73.4	1.62	666	[illegible]
Eagleton	11.8	0.3	3.4	107.8	41.4	4.4	2.7	3.7	14.7	3.2	4108	1126	72.6	0.95	795	[illegible]
Kenblue	24.7	0.0	2.7	149.2	64.0	3.3	3.8	3.5	11.7	4.0	4386	1473	66.5	0.94	1096	[illegible]
P-104	13.7	0.8	4.3	125.8	46.9	5.0	2.8	2.3	15.2	5.7	7021	1926	72.7	1.28	1039	[illegible]
PST-A84-803	16.7	0.4	3.7	125.3	45.1	4.1	2.2	2.3	13.7	5.3	5297	1589	69.9	1.35	806	[illegible]
Ram I	11.2	0.0	3.1	114.7	56.3	4.4	2.2	2.2	10.7	5.5	3534	958	72.8	0.96	678	[illegible]
S.D. Certified	14.0	0.2	2.4	139.9	46.6	3.4	3.9	4.0	6.3	2.8	2070	640	69.0	0.86	507	[illegible]
Ba-73-381	15.7	0.0	3.6	105.7	45.5	4.5	3.2	3.2	10.8	2.8	4287	1312	69.9	1.09	802	[illegible]
Glade	17.2	0.0	3.0	114.3	65.8	4.3	3.4	2.7	12.3	7.8	5518	1596	70.6	1.60	700	[illegible]
PST-B8-13	14.3	0.0	3.8	110.0	43.3	4.5	3.2	2.5	12.8	3.7	3675	1195	67.5	1.06	768	[illegible]
PST-R-740	16.9	0.0	3.5	105.8	46.1	4.3	3.2	2.2	12.8	4.8	5047	1397	72.2	1.07	871	[illegible]
Able I	17.0	1.0	3.1	107.5	43.5	3.8	2.2	3.3	13.0	2.8	4652	1640	64.8	1.52	737	[illegible]
Merit	14.7	0.0	4.1	103.8	42.6	4.8	3.1	3.0	14.2	4.5	5133	1475	71.3	1.05	957	[illegible]
Four Aces	15.3	0.3	3.3	120.8	52.1	4.2	2.5	2.0	17.0	5.3	6526	2025	69.1	1.24	1101	[illegible]
Preakness	11.2	0.0	3.6	115.7	44.5	4.8	3.4	3.5	9.5	2.8	3374	956	71.7	0.77	820	[illegible]
Dawn	17.5	0.3	3.3	122.3	53.7	3.8	2.3	2.3	18.8	4.9	5113	1976	67.8	1.44	872	[illegible]
SR-2100	13.3	0.2	4.0	117.6	43.1	4.7	3.4	3.5	5.9	4.2	5341	1478	72.4	1.34	792	[illegible]
PST-HV-116	12.3	0.8	3.3	93.8	39.6	4.4	2.4	1.8	18.4	8.0	5495	1474	73.7	1.08	904	1
Midnight	9.0	0.2	2.8	85.7	27.3	5.8	2.8	1.7	9.2	6.7	4853	1249	74.4	2.03	457	1
Challenger	14.3	0.0	3.2	95.4	41.2	4.3	1.6	1.8	17.7	6.3	6381	1711	73.4	1.58	734	1
Coventry	9.7	0.0	3.4	82.6	32.8	4.4	2.7	1.8	14.3	4.3	3998	1080	73.5	0.99	734	[illegible]
Classic	12.8	0.5	3.3	114.6	37.3	3.8	2.3	2.3	14.3	5.5	4549	1302	71.2	1.03	832	[illegible]
Loft's 1757	12.8	0.3	3.1	95.3	44.3	4.9	2.2	3.2	14.3	5.3	4774	1246	73.9	1.21	715	[illegible]
Abbey	15.2	0.0	3.8	99.3	50.8	4.7	2.9	2.3	15.8	6.5	5165	1513	71.0	0.98	1032	[illegible]
Liberty	12.0	0.3	3.0	102.3	43.8	4.1	2.3	1.7	14.7	5.7	4077	1086	73.6	1.19	659	[illegible]
Georgetown	18.3	0.2	3.4	120.2	43.3	4.1	2.5	2.3	16.0	4.7	5619	1765	69.1	1.11	1050	[illegible]
ZPS-84-749	7.5	0.9	2.3	71.6	32.4	3.9	2.2	1.4	9.8	4.8	2014	577	71.2	0.81	490	[illegible]
Ba-77-700	15.8	0.0	3.5	106.3	45.2	4.3	3.1	3.0	11.3	4.2	4093	1195	71.2	1.01	809	[illegible]
J11-94	13.3	0.5	3.1	108.6	39.6	4.3	2.5	2.8	15.5	6.3	4511	1353	70.2	1.07	850	[illegible]
Park	18.3	0.0	2.3	132.1	49.4	3.1	3.8	3.7	8.8	2.7	2586	853	67.6	0.76	765	[illegible]
Destiny	20.2	0.3	3.7	127.8	50.5	4.1	2.7	3.0	11.8	6.0	6101	1671	72.6	1.07	1069	[illegible]
Haga	12.9	0.4	2.9	94.5	37.0	3.8	2.1	2.8	14.5	4.7	4079	1289	67.6	1.35	641	[illegible]
PST-U514	20.5	0.8	3.4	133.9	51.1	3.6	2.2	3.3	14.3	3.7	5876	1954	67.2	1.27	1023	[illegible]
A-34	9.5	0.4	3.1	95.3	31.3	4.1	3.3	3.0	16.0	4.0	4996	1414	72.1	1.49	634	[illegible]
Eclipse	12.2	0.4	3.4	82.2	37.1	4.6	2.2	1.8	15.3	5.0	4525	1340	70.7	1.06	833	[illegible]
Gnome	15.0	0.0	3.9	112.5	54.8	4.7	3.4	3.0	15.2	4.5	5899	1876	68.5	0.96	1327	[illegible]
Limousine	5.8	0.2	2.4	53.3	21.5	4.3	3.0	1.3	30.3	3.0	3892	1085	72.3	1.45	531	[illegible]
Nublue	15.8	0.8	3.4	109.9	46.5	4.7	2.7	3.0	15.8	6.2	5235	1641	68.8	1.42	786	[illegible]
WW Ag 505	10.7	0.0	3.4	88.8	32.3	5.0	2.3	1.3	19.2	4.0	5349	1525	71.4	1.25	817	[illegible]
Estate	16.7	0.0	3.9	107.3	45.7	4.4	2.8	2.7	16.5	4.5	5616	1795	68.2	0.91	1360	[illegible]
Touchdown	19.5	0.0	3.8	149.8	52.8	3.7	3.4	3.0	11.8	2.8	5614	1801	68.1	0.88	1385	[illegible]
Indigo	16.2	0.0	3.3	107.8	49.3	4.0	2.9	3.0	18.8	5.5	5738	1717	70.1	1.29	907	[illegible]
Greenley	24.0	0.0	2.8	136.6	55.1	3.7	3.3	2.7	11.0	2.5	3865	1207	68.9	0.79	887	[illegible]
PSU-151	15.0	0.4	3.2	94.9	30.4	4.7	2.5	2.3	12.8	4.8	4993	1248	73.4	1.93	446	1
Blacksburg	14.0	0.0	3.3	111.7	52.2	4.4	3.3	3.0	11.0	5.7	5422	1605	70.6	1.31	836	1
Nassau	22.2	0.0	3.5	116.8	45.1	4.5	2.4	2.6	13.5	4.0	4679	1539	66.5	0.95	1102	1
Merion	21.0	0.0	3.0	128.1	61.1	3.9	2.8	2.8	20.3	5.3	6739	2138	68.3	1.31	1088	[illegible]
Monopoly	13.8	0.0	3.5	110.0	42.9	4.4	3.4	2.0	12.3	3.0	4321	1263	67.4	1.09	833	[illegible]
% Range‡‡	76.5	-	46.5	64.3	67.3	46.6	60.0	67.5	80.5	85.0	71.3	73.0	12.9	62.6	67.8	
LSD (.05) for cultivar	4.7	-	0.4	25.0	8.4	0.5	0.5	0.6	4.2	2.1	1507	509	2.3	0.24	265	
CV (%)	28.4	-	11.8	20.3	16.7	9.7	15.9	19.1	26.4	38.9	28.1	31.8	2.9	18.6	27.4	
ET group mean-low	13.7	0.28	3.2	106	43	4.3	2.6	2.6	15.0	4.9	4727	1399	70.7	1.26	783	
ET group mean-high	15.5	0.19	3.4	114	46	4.2	3.0	2.7	13.3	4.5	4776	1431	69.9	1.07	915	

†Probabilty of folded versus flat leaves. ‡Rating; 1=horizontal, 2=semi-horizontal, 3=semi-vertical, 4=vertical. §Overall rating of outside tillers; 1=spreading, 2=semi-spreading, 3=semi-erect , 4=erect. ¶Expressed as [illegible] root dry weights at harvest. #Expressed as root dry weight per L of soil. ††Case cluster membership based on cluster analysis of ET rates, cultivars having the same group membership have similar water use properties, 1=low, 2=high water use groups. ‡‡(Max-min)÷max x 100.

Table 3.2. Mean squares from ANOVA of leaf characteristics in 61 Kentucky bluegrass cultivars grown as unmown space plants under greenhouse conditions.

[illegible]	df	Leaf extension rate	Leaf width	Leaf length	Sheath length	Leaves per shoot	Leaf angle†
		mm d^{-1}	----------------	----mm----	----------------	no.	
Corrected total	[illegible]						
Block	[illegible]	170.8***	0.16	1218.3*	[illegible]***	[illegible]**	0.16
Cultivar	[illegible]	94.7***	1.02***	2451.3***	[illegible]***	[illegible]	1.83***
Contrast‡	[illegible]	303.1***	2.28***	4842.6***	[illegible]***	[illegible]*	10.70***
Error	[illegible]	17.4	0.15	489.4	[illegible]	[illegible]	0.20

*,**,*** Significant at the .05, .01 and .001 levels, respectively.

† Rating of the 2nd subtending leaf from the budleaf; 1=horizontal, 2=semi-horizontal, 3=semi-vertical, 4=vertical.

‡ Single df test for the difference between the combined means of low- vs. high-water use cultivars.

Table 3.3. Mean squares from ANOVA of shoot and root characteristics in 61 Kentucky bluegrass cultivars grown as unmown space plants under greenhouse conditions.

Source	[illegible]	Crown type†	Tillers per plant	Rhizomes per plant	Shoot weight fresh‡	Shoot weight dry‡	[illegible]	[illegible]	Root density‡
			-----no.-----	-----	-----mg-----	-----	[illegible]	[illegible]	mg L^{-1}
Corrected total	365								
Block	5	0.23	37.6*	114.91***	435.01*	32.75	[illegible]**	[illegible]***	7.03
Cultivar	60	2.58***	94.0***	11.65***	657.39***	65.97***	[illegible]**	[illegible]***	25.02***
Contrast§	1	0.03	301.6***	17.42*	2.52	4.84	[illegible]**	[illegible]***	137.76***
Error	300	0.26	13.7	3.33	177.23	20.19	[illegible]	[illegible]	5.48

*,**,*** Significant at the .05, .01 and .001 levels, respectively.

† Overall rating of outside tillers; 1=spreading, 2=semi-spreading, 3=semi-erect, [illegible].

‡ Values should be increased by 10^4 to convert to mg.

§ Single df test for the difference between the combined means of low- vs. high-water use cultivars.

group (probability of 0.19) based on logistic regression analysis results (no attempt was made to separate and test among the 61 cultivars). Leaf folding reduces leaf area in grasses affecting the amount of net radiation incident on the leaf surface (Levit, 1980).

Low- and high-water use KBG cultivars differed significantly in five of the eight shoot and root characteristics including tillers per plant, rhizomes per plant, shoot moisture content, shoot-to-root ratio, and root density (Table 3.3). Compared to the high-water use cultivars, low-water use cultivars had 13% more lateral shoots per plant, 9% more rhizomes per plant, 1% more moisture in shoots, 18% more shoot dry weight relative to roots, and 14% less root mass per unit volume of soil. The combination of greater root mass and a higher water use pattern reported here is not unusual. For example, tall fescue *(Festuca arundinacea* Schreb.) possesses deep and prolific root systems and the highest ET rates among cool-season turfgrass (Beard, 1973; Younger et al., 1981). In summary, these results based on space plant morphology indicate that cultivars having a low water use pattern combine higher canopy resistance to ET and lower leaf area components, results consistent with those reported for warm-season turfgrass (Kim and Beard, 1988a).

Mowed Turfgrass (Lysimeters)

The variability (% range) between cultivars for comparable measurements was similar for space plants and mowed turfgrass, with the exception of sheath length (Tables 3.1 and 3.4). Some of the variability observed for sheath length in space plants was not apparent in the mowed lysimeters. As a result, no difference among the 61 KBG cultivars at $P=0.05$ level was detected for sheath length measurements in mowed turfgrass (Table

Table 3.4. Fourteen attributes measured on 61 cultivars of Kentucky bluegrass maintained as mowed turf in 20 cm diam. lysimeters (n=4) and their evapotranspiration (ET) group.

Cultivar	Leaf extension rate			Leaf width	Sheath length	Leaf no. per shoot	Leaf angle†	Tillers per pot	Verdure dry weight	Shoot fresh weight‡	Shoot dry weight‡	Shoot moisture	Shoot-root ratio§	Root density¶	ET group#
	25°C	30°C	35°C												
	mm d-1			mm				no.	g	mg		%	mg mg-1	mg L-1	
Baron	6.8	8.6	7.9	2.2	32.7	5.0	2.5	923	33.3	233	57	75.5	14.9	533	2
WW Ag 508	4.7	6.2	5.9	1.7	31.8	4.8	1.8	1297	28.0	139	34	75.8	6.0	1121	2
Opal	6.8	7.7	7.8	1.5	31.1	3.8	2.1	774	18.7	107	29	72.9	3.9	1140	2
Freedom	9.0	9.5	8.0	1.9	33.1	5.7	2.2	988	24.8	182	50	72.9	5.3	1103	1
PST-A7-341	7.8	8.9	8.1	2.2	29.1	5.8	2.3	811	21.4	199	49	76.4	9.9	515	1
Alpine	7.6	8.8	7.9	1.6	31.7	4.7	1.8	1375	22.3	129	35	72.9	5.5	971	1
Sulfolk	8.6	9.7	8.7	2.1	32.4	5.1	2.5	832	21.3	199	45	77.4	4.9	1043	1
PST-A7-1877	7.0	7.7	8.2	2.4	31.3	5.9	2.4	805	30.7	228	59	74.1	11.6	667	2
Kelly	7.1	9.2	8.8	2.5	35.6	6.0	2.4	872	25.7	286	69	75.2	6.7	937	2
PST-1DW	5.8	6.4	6.6	1.8	30.2	5.6	1.6	1218	22.0	165	43	73.7	4.5	1183	1
Apex	5.9	6.6	6.8	1.8	29.0	5.8	1.5	1248	27.0	168	43	75.0	5.9	1121	1
Ginger	9.2	9.6	8.9	2.0	34.8	4.4	3.8	445	11.8	212	47	78.1	3.0	1077	2
Livingston	6.3	7.8	6.5	2.7	30.4	6.6	2.4	746	30.6	247	81	76.2	7.3	1101	2
Aspen	9.0	10.3	9.4	2.1	33.0	5.9	2.2	848	20.5	229	57	75.0	4.1	1215	2
Eagleton	8.2	9.9	9.7	2.0	28.1	4.5	2.2	864	17.4	158	32	78.5	5.8	724	1
Kenblue	10.4	12.2	10.3	2.2	31.4	4.8	2.7	566	13.5	225	46	79.7	3.2	1086	2
P-104	7.1	7.8	7.3	2.5	30.6	7.0	2.6	1050	25.3	278	67	76.4	7.6	797	2
PST-A84-803	8.5	9.7	9.6	2.0	32.4	5.2	2.5	797	22.6	226	61	73.1	5.6	983	1
Ram I	6.1	8.0	8.5	1.9	31.9	4.5	1.6	895	21.9	159	40	74.8	3.8	1370	1
S.D. Certified	8.5	10.2	10.6	1.8	31.0	4.5	3.0	787	15.4	155	39	74.9	2.1	1707	2
Ba-73-381	7.8	9.3	9.0	2.2	30.9	5.1	2.3	904	22.3	213	48	77.7	9.3	660	2
Glade	8.0	7.2	7.1	1.9	30.3	5.0	1.4	850	24.2	160	41	74.9	6.4	985	1
PST-B8-13	8.3	8.8	7.7	2.4	32.7	5.2	2.4	833	20.4	235	56	76.7	7.6	670	2
PST-R-740	7.6	8.6	8.2	2.1	30.0	6.1	2.5	953	25.9	195	58	69.7	10.4	602	2
Able I	9.1	10.9	9.3	1.9	29.3	5.0	2.5	957	16.3	172	38	78.4	5.6	698	1
Merit	7.2	8.6	8.5	2.3	31.5	6.0	2.5	907	22.5	247	56	77.2	6.0	899	2
Four Aces	8.6	8.5	8.1	2.3	31.8	5.5	2.2	964	20.2	268	54	79.6	6.3	764	2
Preakness	7.0	9.8	8.3	2.2	32.5	7.1	1.5	958	22.1	260	67	72.9	3.4	1555	1
Dawn	7.6	9.6	8.7	1.9	31.0	6.8	2.1	840	20.3	219	55	75.3	7.6	734	1
SR-2100	7.2	8.9	8.6	2.6	35.2	7.1	2.6	838	23.1	392	96	75.4	4.5	1208	2
PST-HV-116	6.2	7.4	7.3	1.6	28.0	5.3	1.6	1302	23.1	135	34	74.5	3.5	1683	1
Midnight	6.8	6.8	5.7	1.9	31.7	6.2	1.7	1117	24.8	196	49	74.4	6.2	986	1
Challenger	6.6	8.5	7.6	2.0	30.4	5.9	2.2	1160	24.6	215	49	77.0	6.8	952	1
Coventry	6.6	7.5	7.3	2.2	31.8	4.7	2.0	950	27.9	203	49	74.8	6.6	1042	2
Classic	9.4	10.2	8.7	1.8	30.1	5.5	2.2	1026	22.9	177	50	72.6	4.0	1374	1
Loft's 1757	8.3	8.9	9.3	2.3	36.2	6.7	2.2	984	26.0	327	83	74.2	6.0	1041	1
Abbey	7.9	9.0	8.7	2.0	34.0	4.7	2.7	1032	18.6	206	45	78.4	6.0	768	2
Liberty	7.5	9.5	8.7	1.9	32.0	6.3	2.6	933	23.9	221	54	75.5	3.8	1515	2
Georgetown	9.0	10.8	8.2	2.0	32.2	5.1	2.4	1000	19.4	207	49	76.6	4.8	962	1
ZPS-84-749	8.2	9.2	8.1	1.9	32.7	6.5	2.6	934	23.0	245	62	74.1	7.2	789	2
Ba-77-700	7.5	8.7	8.1	2.1	31.5	4.6	2.5	974	24.3	215	56	74.2	8.6	779	1
J11-94	8.5	9.4	9.1	2.1	33.2	5.9	2.2	982	21.6	239	64	73.5	3.7	1592	1
Park	7.9	10.1	9.6	1.7	30.4	4.5	2.8	923	18.8	173	43	75.7	3.3	1339	2
Destiny	8.6	10.6	9.3	2.3	29.3	5.6	2.8	695	20.2	282	63	78.4	4.3	1124	2
Haga	8.9	9.7	8.0	2.3	31.8	6.5	2.4	1039	21.3	251	68	73.2	3.6	1469	1
PST-U514	9.7	10.4	9.6	1.9	34.5	5.0	2.4	1099	18.3	206	47	77.2	4.7	1071	2
A-34	7.6	8.3	8.0	2.0	29.7	5.7	2.0	1769	26.3	175	46	73.8	6.9	928	1
Eclipse	7.2	8.9	8.2	2.0	30.1	5.3	1.8	999	20.4	193	46	75.6	6.2	780	2
Gnome	7.5	8.6	8.5	2.3	29.2	6.3	2.7	828	19.6	270	62	77.1	8.0	638	2
Limousine	6.0	6.2	6.6	1.5	28.0	6.3	2.1	1660	26.0	117	30	74.6	5.1	1442	1
Nublue	7.8	8.7	8.1	2.0	35.2	5.7	2.4	871	19.5	257	71	72.8	3.7	1289	2
WW Ag 505	5.7	7.8	7.1	2.0	28.0	5.8	2.1	1486	28.1	144	42	70.4	8.8	771	2
Estate	6.1	7.6	7.2	2.3	34.7	5.9	2.6	880	30.2	253	58	77.0	7.9	931	2
Touchdown	5.9	6.8	7.6	2.0	35.3	6.2	2.1	1208	29.0	237	59	74.2	5.2	1371	2
Indigo	7.6	9.1	7.9	1.7	32.5	4.8	2.6	960	21.2	180	43	76.1	5.3	1012	1
Greenley	8.2	10.3	10.3	1.8	33.5	5.5	2.5	1018	20.7	192	56	71.5	2.4	2032	2
PSU-151	8.2	8.6	8.8	1.9	31.0	4.9	2.2	1058	16.5	171	35	79.7	9.1	434	1
Blacksburg	7.0	7.3	6.4	2.0	31.0	4.8	1.8	1140	22.2	167	43	74.4	3.0	1846	1
Nassau	8.4	9.4	8.7	2.1	32.9	6.3	2.0	866	21.1	291	76	74.7	9.4	540	1
Merion	6.6	7.6	7.2	1.9	37.0	5.4	2.6	1149	22.9	214	56	74.7	5.8	935	2
Monopoly	9.7	10.3	9.2	2.1	36.1	6.2	2.2	848	19.8	273	73	73.3	4.0	1196	2
% Range††	54.8	49.2	46.2	44.4	24.3	46.5	60.5	74.8	64.6	66.7	69.8	12.6	83.7	78.9	-
LSD (.05) for cultivar	1.4	1.4	1.4	0.3	NS	1.4	0.5	185	6.9	80	22	NS	1.9	408	-
CV (%)	13.0	11.3	12.1	11.7	11.9	18.7	17.7	13.6	22.1	27.8	30.7	5.0	23.4	28.2	-
ET group mean-low	7.7	8.7	8.1	1.9	31.1	5.5	2.0	1060	22.3	195	49	75.0	5.0	1073	-
ET group mean-high	7.6	8.9	8.4	2.1	32.4	5.5	2.4	920	22.7	229	56	75.5	5.3	1024	-

†Rating; 1=horizontal, 2=semi-horizontal, 3=semi-vertical, 4=vertical. ‡Weight of 5 shoots per pot. §Expressed as shoot and root dry weights at harvest. ¶Expressed as root dry weight per L of soil. #Case cluster membership based on cluster analysis of ET rates, cultivars having the same group membership have similar water use properties, 1=low, 2=high water use groups. ††(Max-min)÷max x 100. NS=non significant at P=0.05 level.

Table 3.5. Mean squares from ANOVA of leaf characteristics in 61 Kentucky bluegrass cultivars maintained as mowed turf in 20 cm diam. lysimeters.

Source	df	Leaf extension rate†				Sheath length	Leaves per shoot	Leaf angle‡
		[illegible]	[illegible]	35°C	[illegible]			
		[illegible]					no.	
Corrected total	243							
Block	3	[illegible]	60.91***	32.68***	0.13	113.8***	16.6***	[illegible]**
Cultivar	60	[illegible]	6.41***	4.43***	0.26***	18.6	2.3***	[illegible]**
Contrast§	1	[illegible]	1.27	6.09**	1.70***	100.4**	0.0	[illegible]**
Error	180	[illegible]	0.99	1.00	0.06	14.4	1.1	[illegible]

*,**,*** Significant at the .05, .01 and .001 levels, respectively.

† Vertical elongation rates accumulated weekly above the 45 mm base mowing height factored to mm d^{-1} while maintained in the growth chamber at 25, 30 and 35°C.

‡ Rating of the 2nd subtending leaf from the budleaf; 1=horizontal, 2=semi-horizontal, 3=semi-vertical, 4=vertical.

§ Single df test for the difference between the combined means of low- vs. high-water use cultivars.

Table 3.6. Mean squares from ANOVA of shoot and root characteristics in 61 Kentucky bluegrass cultivars maintained as mowed turf in 20 cm diam. lysimeters.

Source	df	Tillers per pot†	Verdure dry weight	Shoot weight fresh‡	Shoot weight dry‡	Shoot moisture	[illegible]	Root density§
		no.	g	mg		%	[illegible]	mg L^{-1}
Corrected total	243							
Block	3	[illegible]***	1156.5***	69475***	3234***	[illegible]	3.76*	186.54***
Cultivar	60	[illegible]***	69.1***	12011***	739***	[illegible]	12.02***	47.12***
Contrast¶	1	[illegible]***	8.2	70170***	2787***	[illegible]	11.11***	14.41
Error	180	[illegible]	24.8	3346	261	[illegible]	1.90	8.67

*,**,*** Significant at the .05, .01 and .001 levels, respectively.

† Values should be increased by 10^4 to factor to original values of tiller no. per pot.

‡ Weight of 5 shoots per pot.

§ Values should be increased by 10^4 to convert to mg.

¶ Single df test for the difference between the combined means of low- vs. high-water use cultivars.

3.5). Similarly, no difference in shoot moisture content between cultivars was observed for mowed turfgrass (Table 3.6). The CV for shoot moisture content from mowed turfgrass (5.0%) indicated a 42% greater variability between observations than that observed for space plants (2.9%).

The low- and high-water use cultivars differed significantly in leaf characteristics important in comparative water use including leaf extension rate (at 35°C), leaf width, sheath length, and leaf angle (Table 6). Differences between water use groups in leaf characters were similar for space plants and mowed turfs. The low-water use cultivars had 4% slower leaf extension rates, 10% narrower leaf width, 4% shorter leaf sheaths and a 17% more horizontal leaf orientation than high-ET cultivars. Group differences in leaf width, however, may reflect the inverse relationship between plant density (shoot density) and plant size in turfgrass maintained under non-limiting soil moisture and nutrient conditions (Madison, 1962). In mowed turf, leaf width was negatively correlated with shoot density in this study, -0.43***. No difference in the number of leaves per shoot was detected in the mowed lysimeters. Sheffer et al.(1978) noted that KBG cultivars with erect growing leaves compensated for leaf removal and defoliation by producing more leaves per tiller. This response may have negated any group difference on a per tiller basis between low-water use cultivars (the more procumbent group) and high-water use cultivars (the more erect group) in this study. Leaf number on an area basis is probably a more reliable measurement of canopy resistance in mown swords than leaf number on an individual shoot basis.

Low- and high-water use KBG cultivars differed significantly in four of the seven shoot and root characteristics measured, including the number of tillers or shoots per lysimeter, shoot-fresh weights and shoot-dry weights, and shoot-to-root ratio (Table 3.6). The low-water use group had 15% more shoots than the high-water use group. This group difference is consistent with lateral shoot numbers on a per plant basis observed in the unmown space plants. Individual plants sampled from mowed lysimeters were 13 and 15% smaller on a dry-weight and fresh-weight basis, respectively, for the low-water use group (Table 3.4). This difference, however, probably reflects the inverse relationship that exists between shoot density and plant size discussed earlier. Both shoot-fresh weights and shoot-dry weights were negatively correlated with shoot density, with r= —0.43*** and —0.33*, respectively.

In mowed lysimeters we detected no difference in root density between comparative water use groups (Table 3.6). Mowed turfgrass with a more procumbent morphology (represented by low-water use group) can have a physiological advantage over upright types in their utilization of less reserve carbohydrates for regrowth, maintaining larger reserves for root growth, (Sheffer et al., 1978). It is this difference that may have contributed to the lower shoot-to-root ratio that was observed for low water use cultivars (Tables 3.4 and 3.6). No significant difference between water use groups in verdure (shoot biomass) was detected (Tables 3.4 and 3.6), which agrees with the shoot biomass results on an individual plant basis reported in the unmown space plant study.

There were generally stronger linear relationships between ET rate and turfgrass morphology assessed from mowed turf (lysimeters) than were found between ET rate and single plant morphology. For example, leaf angle was the only plant attribute evaluated whose correlation with ET (measured at 25 and 30°C) exceeded 0.50 in absolute value (r= 0.54***). Similarly, shoot density (tiller number) from lysimeters were also highly correlated (at P=.001 level) with ET rate measured at 25 and 30°C (r= —0.42). No significant correlation (at p= .001 level) was detected between ET rate and plant measurements based on single plant morphology.

Relationships developed in KBG between ET rate and morphological characters considered individually can be quite different when considered in combination. Leaf angle and tiller number from lysimeters were highly correlated (at *P=.OOl* level) with ET at 25°C. These two canopy resistance components which are highly correlated with conumptive water use are interdependent because leaf angle and tiller number were highly correlated in space plants (r= -0.47***) and mowed turfgrass (r= -0.51***). The partial correlation coefficient computed between leaf angle and ET at 25°C when tiller number is held constant was 0.42***. The partial correlation coefficient computed between tiller number and ET at 25°C when leaf angle is held constant was -0.20. Shoot density appears to be a unimportant predictor of ET when considered in combination with leaf angle than the simple correlation coefficients indicate. Comparative water use in turfgrass measured under non-limiting soil moisture conditions is the sum total of several morphological and growth characteristics which are operating simultaneously in combination. These characteristics, however, are not necessarily operating independently but are likely to be dependent with important implications for improving the efficiency in predicting ET by considering simultaneously those morphological characteristics correlated with ET.

Space Plant/Mowed Turf Comparisons

Compared to unmown space plants, mowed turfs put five times more effort into shoots relative to roots (on a dry weight basis). Rooting density was consistently higher in lysimeters than in the space plant study. The containers used as lysimeters were 5 cm less in depth and therefore may be more restrictive to rooting compared to the root trainer books used in the space plant study.

No formal statistical tests were performed, however, there were large differences between unclipped space plants and mowed turfs for comparable measurements. Mowed turfs had 48% slower vertical leaf extension rates than space plants, 39% narrower leaf texture, 29% shorter sheath length, 28% more leaves per shoot and a 21% more horizontal leaf orientation. Despite the large differences, there was significant agreement between space plant morphology and turfgrass morphology in the relative ranking of cultivars for canopy resistance to ET and leaf area components indicated by Spearman's rank correlation (r_S). Specifically, leaf width (r_S=O.64***), leaf extension rate (r_s=OAO**), leaves per shoot (r_s=OAO**), tiller number (r_s=OAO**) and leaf angle (r_S=O.26*) are examples. There was little agreement between space plants and mowed lysimeters in sheath length, and in measurements derived from shoot- and root-dry weights, such as shoot moisture content, root density, and shoot-to-root ratio.

CONCLUSIONS

A variable population of 61 KBG cultivars categorized as either low- or high-ET cases based on their water use rates differed significantly in several morphological properties important in comparative water use. Differences between water use groups were comparable for morphological attributes from unmown space plants and mowed turfgrass (lysimeters). These differences in KBG validate canopy resistance to ET and leaf area components that were observed in warm-season turfgrasses and therefore may have universal application in identifying water conserving types in cool-season turfgrass.

REFERENCES

Beard, J. B. 1973. Turfgrass science and culture. Prentice Hall, Englewood Cliffs, NJ.

Bourgoin, B., and P. Mansat. 1977. Comparisons of micro-trials and space planted nurseries with dense swords as means for evaluating turfgrass genotypes. P: 3-9. *In* J. B. Beard (ed.) Proc. 3rd Int. Turfgrass Res. Conf., Munich Germany. 11-13 July. Int. Turfgrass Soc., ASA, CSSA, SSSA, Madison WI.

Brede, A. D., and J. M. Duich. 1982. Cultivar and seeding rate effects on several physical charcacteristics of Kentucky bluegrass turf. Agron. J. 74:865-870.

Burt, M. C., and N. E. Christians. 1990. Morphological and growth characteristics of low- and high-maintenance Kentucky bluegrass cultivars. Crop Sci. 30:1239-1243.

Chew, V. 1976. Comparing treatment means: A compendium. Hortscience. 11(4):348-357.

Ebdon, J. 5., A. M. Petrovic, and R. W. Zobel. 1995. Stability of evapotranspiration rates in Kentucky bluegrass cultivars across low- and high-evaporative environments. (submitted for publication).

Hosmer, D. W., and S. Lemeshow. 1989. Applied logistic regression. John Wiley and Sons, New York, NY.

Jolliffe, I. T., O. B. Allen, and B. R. Christie. 1989. Comparing variety means using cluster analysis and dendograms. Expl. Agric. 25:259-269.

Kim, K. 5., and J. B. Beard. 1988a. Comparative evapotranspiration rates and associated plant morphological characteristics. Crop Sci. 28:328-331.

Kim, K. 5., and J. B. Beard. 1988b. Turfgrass morphological characteristics associated with evapotranspiration rate. Texas Turfgrass Research. Texas Agric. Exp. 5ta. PR-4662.p. 18-19.

Kramer, H. H. 1947. Morphological and agronomic variations in Kentucky bluegrass in relation to chromosome number. Am. Soc. Agron. 39:181-191.

Levit, J. 1980. Response of plants to environmental stresses. Vol. 2: Water, radiation, salt, and other stresses. Academic Press, New York.

Madison, J. H. 1962. Turfgrass Ecology. Effects of mowing, irrigation, and nitrogen treatments of *Agrostis palustris* Huds., '5easide'and *Agrostis ienuis* Sibth., 'Highland' on population, yield, rooting and cover. Agron. J. 54:407-412.

Nittler, L. W. , and T. J. Kenny. 1976. Crown, tiller and rhizome characteristics of Kentucky bluegrass cultivars. Agron. J. 68:395-397.

Sheffer, K. M, T. L. Watschke, and J. M. Duich. 1978. Effect of mowing height on leaf angle, leaf number, and density of 62 Kentucky bluegrasses. Agron. J. 70:686-688.

Sherman, R. C. 1986. Kentucky bluegrass cultivar evapotranspiration rates . Hortscience. 21(3):455-457.

Sherman, R. C. 1989. Perennial ryegrass cultivar evapotranspiration rates . Hortscience.24(5):767-769.

Snedecor, G. W., and W. G. Cochran. 1989. Statistical Methods. Eighth edition. Iowa State university press. Ames, Iowa.

U. S. Department of Agriculture. 1993. 1990 National Kentucky bluegrass test. NTEP No. 94-6. USDA-ARS and National Turfgrass Federation, Inc. Beltsville, MD.

van Wijk, A. J. P. 1989. The relationship between turf performance and single plant morphology data in red fescue. p. 113-115. *In* H. Takatoh (ed.) Proc. 6th Int. Turfgrass Res. Conf. , Tokyo. 31 July- 5 August. Int. Turfgrass Soc., ASA, CSSA, SSSA, Madison WI.

Youngner, V. B., A. W. Marsh, R. A. Strohman, V. A. Gibeault, and S. Spaulding. 1981. Water use and quality of warm-season and cool-season turfgrass. p. 251-257. *In* R. W. Sheard (ed.) Proc. 4th Int. Turfgrass Res. Conf., Ontario Agric. College, Univ of Guelph, Onto Canada. 19-23July. Int. Turfgrass Soc., Ontario Agric. College, Univ of Guelph, Guelph ON.