

# Mowing and Drought Effects on a Hybrid Bluegrass compared with a Kentucky Bluegrass

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**Abbreviations:** ET, evapotranspiration; HBG, a hybrid between Texas bluegrass and Kentucky bluegrass; KBG, Kentucky bluegrass;  $P_g$ , canopy gross photosynthesis.

**Keywords:** Texas bluegrass hybrid, *Poa arachnifera* Torr., *Poa pratensis* L., photosynthesis, turfgrass, mowing height, irrigation deficit.

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## ABSTRACT

Hybrid bluegrasses (HBG) resemble Kentucky bluegrass (*Poa pratensis* L.)(KBG) but HBG may have greater heat and drought tolerance. Little is known about the performance of HBG under low mowing heights and during drought. A two-year field study was conducted near Manhattan, Kansas, USA to investigate effects of mowing and drought on visual quality and gross canopy photosynthesis ( $P_g$ ) in a KBG ('Apollo') and HBG ('Thermal Blue'). Treatments included three main factors at two levels each: 1) species (Apollo, Thermal Blue); 2) mowing height (7.6 cm or 3.8 cm); and 3) irrigation (100% [well watered] and 60% [drought])

evapotranspiration [ET] replacement). Visual quality in Thermal Blue was similar to or lower than Apollo during both years. Visual quality and  $P_g$  declined at the lower mowing height in both species in 2004 and in Thermal Blue in 2005, but visual quality in Apollo improved slightly in 2005 including under drought. At the lower mowing height, visual quality in Thermal Blue was nine to 15% lower than Apollo in 2005, perhaps because KBG had greater leaf area and extracted more soil moisture than Thermal Blue. When well watered,  $P_g$  was lower in Thermal Blue than in Apollo but differences converged as drought progressed. Drought reduced visual quality of both grasses during both years. Data suggest that Apollo may be better suited than Thermal Blue as a turfgrass selection for the transition zone. Further research is needed to identify new cultivars of HBG that may perform better than KBG at low mowing and during drought.

A growing challenge facing the turfgrass industry is limited availability of water for irrigation (Snow, 2001). Local water-use restrictions may be imposed during drought that limit growth and cause severe declines in the visual quality of many cool-season turfgrasses (Perdomo et al., 1996; Bonos and Murphy, 1999). On golf courses, lower mowing heights in fairways may result in additional stress to turfgrass during drought because lower mowing typically reduces root growth and development (Parr et al., 1984; Liu and Huang, 2002). Research is needed to identify species or cultivars of cool-season turfgrasses that may perform better under drought stress and at lower mowing heights (2 to 4 cm).

Hybrid bluegrasses (HBG), which are genetic crosses between native Texas bluegrass (*Poa arachnifera* Torr.) and Kentucky bluegrass (KBG), may have greater drought and heat resistance than other cool-season grasses (Read et al., 1999). Hybrid bluegrasses have similar visual qualities as KBG, which is a fine-textured cool-season turfgrass that is commonly used on

athletic fields and golf course fairways and roughs (Turgeon, 2002). Some turfgrass managers, however, find it undesirable that KBG may go dormant and lose its green color during periods of drought or high heat. Drought and heat stresses are common in the transition zone of the USA, which spans between northern regions where cool-season grasses are adapted and southern regions where warm-season grasses are adapted (Dunn and Diesburg, 2004). Consequently, new cultivars of HBG are being investigated as potential drought-resistant alternatives.

Until recently, limited data have been available regarding the drought resistance of HBG. In a growth chamber study, the drought resistance of thirty cultivars of HBG and their genetic parents varied significantly (Abraham et al., 2004). In the same experiment, the most significant improvements in drought resistance in HBG were achieved when first generation hybrids with good drought resistance were backcrossed with elite drought resistant genotypes of KBG. Su et al. (2007) reported minor differences in the drought resistance of a HBG (Thermal Blue) and a KBG (Apollo) in a growth chamber study, although heat resistance was greater in the HBG.

In field tests in Colorado, USA, 'Reveille' HBG used significantly less water, while maintaining higher quality than 'Bensun's A-34' KBG (Suplick-Ploense and Qian, 2005). In field studies in Kansas, USA, however, few differences were found in the general performance or drought resistance among HBG (Thermal Blue, 'Dura Blue', and 'Reveille') and a KBG (Apollo) (Bremer et al., 2006; Su et al., 2008). An experimental HBG ('PST-99LM-15') exhibited poorer drought tolerance than most of 49 cultivars of KBG in a field trial in Oregon, USA (Richardson et al., 2008).

Even fewer data are available concerning the performance of HBG at different mowing heights, although lower mowing heights (< 3 cm) are typical in golf course fairways compared with lawns. Stier et al. (2005) reported that HBG (Thermal Blue and Dura Blue) had similar

visual quality to KBG (Apollo and 'Unique') at mowing heights of 2.5, 5.0, and 7.5 cm and earlier spring greenup than KBG. Consequently, those authors suggested that Thermal Blue and Dura Blue may be acceptable replacements for KBG in the Upper Midwest, USA. Results from a study conducted further south in the transition zone where summers are warmer, however, indicated that mowing height for Thermal Blue should be greater than 3.5 cm to avoid decreasing turf visual quality in late summer and fall (Teuton, 2006).

The combined effects of mowing height and drought on HBG have not been investigated. Therefore, the objectives of this two year study were to evaluate the performance of a HBG compared with a KBG at high and low mowing heights under both well-watered and drought conditions. Performance was evaluated by visual quality and measurement of canopy photosynthesis, and ancillary measurements of soil moisture were also collected.

## **MATERIALS AND METHODS**

### ***Study site and Experimental design***

This study was conducted from 3 August to 8 October, 2004 and from 27 June to 15 September, 2005 under an automated rainout shelter (12 m x 12 m) at the Rocky Ford Turfgrass Research Center near Manhattan, Kansas (39°13'53" N, 96°34'51" W); Manhattan lies in the U.S. transition zone. The rainout shelter rested north of the study area but automatically covered the research plots as precipitation began and retracted one hour after precipitation ceased. The soil at the site was a Chase silt loam (fine, smectitic, mesic Aquertic Argiudoll).

The experiment was arranged in a randomized complete block design with whole plot treatments in a two (mowing height) by two (irrigation) factorial (Fig. 1). Species was a split-plot factor. The mowing height factor (high mowing = 7.6 cm and low mowing = 3.8 cm) was randomized in a whole-plot strip to one of the two rows in each block. The irrigation factor

(100% and 60% ET replacement) was randomized to one of two columns in each block (Cochran and Cox, 1992). Therefore, in a block, each of the four combinations of mowing height by irrigation treatments were applied to two plots, and the two species (HBG and KBG) were randomly seeded in those two plots. In this experimental design, arrangement of irrigation treatments was balanced across the four blocks.

Thirty two plots (1.4 m x 1.8 m) were bordered by metal edging (10 cm depth) to prevent lateral soil water movement between adjacent plots. Plots were seeded on 17 September 2003 with Apollo KBG and Thermal Blue HBG at a rate of 147 kg/ha. Plots were mowed twice a week with a walk-behind rotary mower. Water was applied by hand twice weekly through a fan spray nozzle attached to a hose; a meter (Model 03N31, GPI, Inc., Wichita, KS) was attached to ensure proper application rate. To determine irrigation requirements, evapotranspiration (ET) was calculated by using the Penman-Monteith equation (FAO, 1998) from climatological data obtained at a weather station located at the research site.

### ***Plot Maintenance***

Prior to seeding in 2003, the plot area was treated with 575 kg a.i./ha of dazomet (tetrahydro-3,5-dimethyl-2H-1,3,5-thiadiazine-2-thione) to kill vegetation and weed, insect, and disease pests. In 2004, all plots were fertilized with urea to give an annual total of 163 kg N/ha applied in April, September, and November, and in 2005 an annual total of 144 kg N/ha was applied in April, September, and October. Insecticide applications for controlling billbug grubs (*Sphenophorus parvulus* Gyllenhal) and white grubs (*Cyclocephala lurida* Bland) in 2004 included imidacloprid (1-[(6-chloro-3-pyridinyl)methyl]-N-nitro-2-imidazolidinimine) at 0.44 kg a.i./ha on 19 April, bifenthrin (2-methyl [1,1'-biphenyl]3-yl)-methyl 3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethylcyclopropanecarboxylate) at 0.12 kg a.i./ha on 27 May, and

halofenozide (Benzoic acid, 4-chloro-, 2-benzoyl-2-(1,1-dimethylethyl)hydrazide) at 1.69 kg a.i./ha on 8 July. In 2005, the same insect pests were controlled with imidacloprid at 0.44 kg a.i./ha on 18 June and bifenthrin at 0.06 kg a.i./ha on 22 June. Dithiopyr (S,S'-dimethyl 2-(difluoro-methyl-4-(2-methylpropyl)-(trifluoromethyl)-3,5-pyridinedicarbothioate) was applied at 0.58 kg a.i./ha on 27 May in 2004 and 4 May in 2005 to control annual grassy weeds. Broadleaf weeds were controlled with carfentrazone-ethyl (0.03 kg a.i./ha)+ 2, 4- D, 2-ethyl hexyl ester (1.29 kg a.i./ha) + mecoprop-p acid (0.27 kg a.i./ha) + dicamba acid (0.08 kg a.i./ha) on 27 May and 22 October in 2004 and 4 May and 19 October in 2005. Fungicide applications for controlling summer patch (*Magnaporthe poae*) included azoxystrobin (methyl(E)-2-{2-[6-(2-cyanophenoxy)pyrimidin-4-yloxy]phenyl}-3-methoxyacrylate) at 0.61 kg a.i./ha on 21 April, 24 May, and 22 June and triadimefon (1-(4-Chlorophenoxy)-3,3-dimethyl-1-(1H-1,2,4- trizol-1-yl)-2-butanone) at 1.53 kg a.i./ha on 23 July in 2005.

### ***Measurements***

Turf quality was rated visually on a scale of 1 to 9 (1=poorest quality, 6=minimally acceptable, and 9=highest quality) according to color, texture, density, and uniformity (Emmons, 2000). Quality ratings were recorded weekly by the same individual during the 2-year study.

Photosynthesis was measured biweekly on clear days between 1000 and 1400 CST with a LI-6400 portable gas exchange system (LI-COR Inc., Lincoln, NE) using a custom surface chamber described by Bremer and Ham (2005). Permanent polyvinyl chloride collars (10-cm diam.) were placed randomly at one location in each plot and were driven approximately 5 cm into the soil. A closed-cell foam gasket was used to maintain an effective seal between collars and the chamber during photosynthesis measurements.

In all plots, the volumetric soil water content ( $\theta_v$ ) in the 0 to 50 cm profile was measured weekly in 2004 and 2005 using time domain reflectometry (TDR) (model 6050XI, Soilmoisture Equipment, Santa Barbara, CA); data from 2004 were discarded because of an instrument error. In drought plots, additional  $\theta_v$  measurements were collected at a shallower depth (5 cm) in 2004 and 2005, which presumably is a region of denser root mass compared to deeper in the profile (Ervin and Koski, 1998; Liu and Huang, 2002; Turgeon, 2002; Su et al., 2007, 2008). These  $\theta_v$  measurements near the surface were used to investigate possible differences in root activity (i.e., soil water depletion) between HBG and KBG in plots mowed at low and high heights, including during drought. The  $\theta_v$  at 5 cm depth was measured using the dual-probe heat-pulse (DPHP) technique (Campbell et al., 1991; Tarara and Ham, 1997; Song et al., 1998); DPHP sensors were fabricated in the authors' laboratory as described by Basinger et al. (2003) and Bremer (2003). Measurements of  $\theta_v$  at 5 cm depth were automated and logged twice daily at 0600 and 1800 CST. All data acquisition and control were accomplished with a micrologger and accessories (CR10x, two AM16/32's, and one AM25T, Campbell Scientific, Logan, UT).

### ***Calculations and Data analysis***

Gross photosynthesis in each plot was estimated from measurements of photosynthesis and respiration according to the method of Bremer and Ham (2005). Briefly, this method involves consecutive measurements with a sunlit and shaded chamber, respectively, at each collar; shaded measurements were obtained by covering the chamber with an opaque cloth that blocked solar radiation from the chamber. Using Equations 5 and 6 from Bremer and Ham (2005), sunlit measurements were used to determine  $P_g - (R_c + R_s')$  and shaded chamber measurements to determine  $R_c + R_s'$ , where  $P_g$  is gross photosynthesis,  $R_c$  is canopy respiration, and  $R_s'$  is residual soil respiration in a pressurized chamber; all values are positive and units are

$\mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$ . Gross photosynthesis was calculated using their equation 8:  $P_g = \text{sunlit chamber} + \text{shaded chamber}$ .

All data, except for  $\theta_v$  at 5 cm were pooled into three periods per year to evaluate treatment effects as the study progressed: 1) early (0-7 days of treatment); 2) mid (8-28 days of treatment); and 3) late (29-70 days of treatment). In each period, values of visual quality,  $P_g$ , and  $\theta_v$  (0-50 cm) were averaged across all measurement days during the period and the values were then analyzed with the mixed procedure of SAS ( $P=0.05$ ; SAS Institute Inc., Cary, NC). The model contained three factors: species, mowing height, irrigation, and their interactions. No significant interactions were found among main factors with the exception of species by mowing height in 2005 for the variables visual quality (early and mid periods) and  $\theta_v$  at 0-50 cm depth (mid and late periods).

For  $\theta_v$  at 5 cm depth, weekly averages were analyzed, also with the mixed procedure of SAS, to evaluate differences in  $\theta_v$  among treatments as the study progressed. Because soil moisture sensors were placed at 5 cm depth only in drought plots, the model contained only two factors (species and mowing height); sensors were only placed in drought plots because of practical limitations in sensor availability and datalogging capacity.

## **RESULTS AND DISCUSSION**

There were few interactions among the main effects of species, mowing height, and irrigation (Tables 1, 2 and 3), so this section is organized by main factor. However, because the objective was to compare HBG and KBG performance as affected by mowing height and drought, and because species by mowing height interactions were significant in early and middle 2005, all figures have been constructed to show the interactions, for the sake of clarity and consistency in presentation. Instructive observations about the species responses to the other



main effects, especially to mowing height, are gained by presenting the data in this way, and significant interactions are discussed in the appropriate sections below.

### *Species*

The visual quality of HBG was generally similar to or lower than KBG (Fig. 2). For example, visual quality was statistically similar between species in the early and late periods of 2004 but was lower in HBG than in KBG in the mid period of 2004 and the late period of 2005 (Table 1). Although there was a significant species by mowing height interaction in visual quality during the early and mid periods of 2005, the trends revealed consistently lower visual quality in HBG than in KBG under both mowing regimes (Fig. 2C and 2D; Murray et al., 1999). During the early and mid periods of 2005, visual quality in HBG ranged from 2 to 5% lower than KBG at high mowing and 9 to 14% lower than KBG at low mowing and thus, the greatest differences between species were at low mowing. Lower visual quality in HBG was caused, in part, by its lighter color and coarser texture than KBG.

In the early period of both years,  $P_g$  was lower in HBG than in KBG (Table 2; Fig. 3). In the mid and late periods of both years, however, no statistical differences ( $P=0.05$ ) were observed in  $P_g$  between KBG and HBG (Table 2) although in well-watered plots  $P_g$  was always numerically lower in HBG (Fig. 3A and 3C). Closer inspection of  $P_g$  in drought plots revealed that declines in  $P_g$  with drought were greater in KBG than in HBG and consequently, differences in  $P_g$  between species diminished as drought stresses became more severe (Fig. 3B and 3D). For example, by the late period, or presumably when drought effects were most severe,  $P_g$  in KBG was 23% and 30% lower in 2004 and 2005, respectively, in drought than in well-watered KBG (Fig. 3). Interestingly, in the same periods  $P_g$  in HBG was 6% greater in drought than well-watered plots in 2004 while in 2005,  $P_g$  in HBG was reduced 18% by drought. This indicates a

slightly greater resiliency to drought in the photosynthetic capacity of the canopy in this HBG than in this KBG.

In the early period of 2005,  $\theta_v$  in the 0-50 cm profile averaged 6% higher in HBG than in KBG (Table 3; Fig. 4). Although there was a significant species by mowing height interaction during the mid and late periods of 2005,  $\theta_v$  at 0-50 cm depth was also 17 to 29% higher in HBG than in KBG in low-mown plots;  $\theta_v$  at 0-50 cm depth was similar between species at the high mowing height during these periods. These results indicate that HBG extracted less water from the 0-50 cm profile than KBG at low mowing.

In low-mown drought plots,  $\theta_v$  was also consistently higher in HBG than KBG at shallower depths (i.e., 5 cm) during both years (Fig. 5C and 5D). This indicates that when mown low and soil moisture is limiting, HBG extracts less water than KBG in a region of the soil profile where root density and soil-surface evaporation rates are presumably highest (Ervin and Koski, 1998; Liu and Huang, 2002). In 2004 and to a lesser extent in 2005, the trend in  $\theta_v$  and hence, soil water extraction at 5 cm depth was reversed in high-mown drought plots, because  $\theta_v$  was consistently lower in HBG than in KBG (Figs. 5A and 5B). This suggests that when mown high, HBG extracts more water than KBG at shallower depths when soil moisture is limited. Higher mowing, which may improve rooting capacity (Parr et al., 1984; Liu and Huang, 2002), may have benefited root development in the upper profile more in HBG than in KBG.

### ***Mowing height***

Lower mowing reduced the average visual quality of both species by 7 to 10% in 2004 (Table 1; Fig. 2). Lower visual quality in low-mown plots in 2004 may have been partially caused by some scalping of the turfgrass that occurred after the first low mowing in late June, which was before the study began; the scalping exposed the leaf sheaths and resulted in a lighter

color than in high-mown plots. The mowing height in low mowing was later raised from 2.5 cm to 3.8 cm (12 July, 2004) to allow for recovery from scalping, and mowing height remained 3.8 cm thereafter. Thus, the mowing height in low-mown plots was 3.8 cm during the entire study, but residual effects of scalping may have affected visual quality data well into the 2004 evaluation period.

In 2005, visual quality was similar between mowing heights (Table 1). However, there was a significant interaction in species by mowing height in visual quality during the early and mid periods of 2005. Interestingly, low mowing reduced visual quality in HBG by 3 to 7% during those periods in 2005, but low mowing increased the visual quality of KBG by up to 11% compared with high mowing height (Fig. 2C and 2D). Measurements of green leaf area index (LAI) in the same well-watered plots in the year after this study revealed that LAI was 68% greater in KBG than in HBG at low mowing (Lee, 2008). Therefore, in low-mown plots, greater LAI in KBG than in HBG, combined with greater soil moisture extraction by KBG at low mowing (Figs. 4 and 5), probably contributed to greater visual quality in KBG. These results generally indicated a poorer tolerance to low mowing in this HBG than in KBG, and are similar to results from another transition-zone study (Teuton, 2006) that reported lower visual quality in Thermal Blue when it was mowed at or less than 3.5 cm.

Lower mowing reduced  $P_g$  by 20 to 51% in 2004 and by 2 to 34% during 2005 although the reduction was not statistically significant for the mid period of 2005 (Table 2; Fig. 3). Greater reductions in  $P_g$  with mowing in 2004 may have been caused in part by the scalping that occurred earlier in the summer, before the study began. Presumably, however, lower  $P_g$  in low-mown plots was primarily caused by a reduction in green LAI with mowing, which probably decreased the overall photosynthetic capacity of the canopy (Pearce et al., 1965; Bremer et al.,

1998; Bremer and Ham, 2005). Measurements of LAI in the same well-watered plots in the year following this study revealed reductions in LAI of 34% in KBG and 48% in HBG with low mowing (Lee, 2008).

Lower mowing did not statistically affect  $\theta_v$  in the 0-50 cm profile in 2005 although there was a significant species-by-mowing height interaction in the mid and late periods (Table 3). In all three periods of 2005,  $\theta_v$  at 0-50 cm depth decreased with mowing by 5 to 22% in KBG but  $\theta_v$  increased by 8 to 11% in drought plots in HBG (Fig. 4). During both years in the drought treatment,  $\theta_v$  at 5 cm depth in KBG also averaged about 14% lower in low- than in high-mown plots, while in HBG,  $\theta_v$  at 5 cm depth increased with low mowing by 17% in 2004 and 3% in 2005 (Fig. 5). Consistently greater reductions in  $\theta_v$  with mowing in KBG indicate that KBG extracted more water from the soil than HBG at the low mowing height, including during drought. Greater water extraction ability in KBG, in combination with generally higher visual quality in KBG than in HBG in low-mown plots, suggests that this KBG (Apollo) is better suited for conditions of low mowing and drought than this HBG (Thermal Blue).

### ***Irrigation level***

The  $\theta_v$  in the 0-50 cm profile was similar between irrigation treatments early in 2005, before soil moisture began to decline as a result of the drought treatment (Table 3; Fig. 4);  $\theta_v$  data were not available in the 0-50 cm profile in 2004. In the mid and late treatment periods of 2005, however, drought had significantly reduced  $\theta_v$  in the 0-50 cm profile compared with well-watered plots, which had subsequent effects on visual quality and  $P_g$  in drought plots.

Visual quality was similar between irrigation treatments early in the study in both years, before drought effects were evident (Table 1; Fig. 2). As the study progressed, however, drought significantly reduced the visual quality in the mid and late periods of both years although the

effects of drought on visual quality were less severe in 2004 than in 2005; reductions in visual quality during drought were similar between HBG and KBG. Drought reduced mean visual quality by 7% and 12% in mid and late periods, respectively, of 2004 and by 13% and 31% in mid and late periods, respectively, of 2005. The greater decline in visual quality with drought in 2005 than in 2004 was likely caused by higher temperatures during 2005 (Table 4). This result is similar to other reports where the combined stresses of heat and drought caused a more rapid decline in visual quality of turfgrass than individual treatments of high temperature or drought (Jiang and Huang, 2001; Su et al., 2007).

In both years,  $P_g$  was similar between 60 and 100% irrigation treatments except for late in 2005 (Table 2; Fig. 3). Drought significantly reduced average  $P_g$  by 25% in the late period of 2005 and by 17% in the mid period of 2005, although the reduction in the mid period was not statistically significant. Interestingly, trends indicated that the effects of drought on  $P_g$  were not as severe in HBG as in KBG. For example, in the mid and late periods of 2005, drought reduced  $P_g$  in KBG by 19% and 30%, respectively, and only 14% and 18%, respectively, in HBG. Similarly, in the mid and late periods of 2004, drought reduced  $P_g$  in KBG by 11% and 23%, respectively, and increased slightly in HBG by 10% and 6%, respectively. As indicated earlier, this indicates a slightly greater drought tolerance of  $P_g$  in HBG than in KBG although  $P_g$  was similar between species under drought in the late periods of both years.

## CONCLUSIONS

At the low mowing height (3.8 cm), the performance of Thermal Blue was poorer than Apollo. Gross photosynthesis was less sensitive to drought in Thermal Blue than in Apollo, but visual quality and  $P_g$  under drought were similar between species;  $P_g$  was higher in KBG than in HBG under well-watered conditions, but  $P_g$  in KBG declined to levels similar to HBG as drought

progressed. Therefore, in this study, any practical advantages of greater tolerance of Pg to drought were slight in Thermal Blue compared with Apollo. Data suggest that Apollo may be better suited than Thermal Blue as a turfgrass selection for the transition zone, particularly at lower mowing heights. As new HBG cultivars have been, and will be released in the future, further field research is needed to evaluate their performance in comparison with KBG during drought and at lower mowing heights.

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## List of Figures

Figure 1. Schematic of plots in the rainout shelter area. Turfgrass species are denoted by HBG (hybrid bluegrass) and KBG (Kentucky bluegrass) and irrigation level by percentage evapotranspiration (ET) replacement (60 and 100%).

Figure 2. Effects of mowing height on visual quality in the hybrid (HBG) and Kentucky bluegrass (KBG) in 2004 (A and B) and 2005 (C and D) under well-watered (100% ET replacement) and drought (60% ET replacement) conditions. Data are averaged by days of treatment: early (0-7 d); 2) mid (8-28 d); and 3) late (29-70 d). Vertical bars indicate standard errors.

Figure 3. Effects of mowing height on gross photosynthesis ( $P_g$ ) in the hybrid (HBG) and Kentucky bluegrass (KBG) in 2004 (A and B) and 2005 (C and D) under well-watered (100% ET replacement) and drought (60% ET replacement) conditions. Data are averaged by days of treatment: early (0-7 d); 2) mid (8-28 d); and 3) late (29-70 d). Vertical bars indicate standard errors.

Figure 4. Effects of mowing height on volumetric soil water content ( $\theta_v$ ) at 0-50 cm in the hybrid (HBG) and Kentucky bluegrass (KBG) under well-watered conditions (100% ET replacement) (A) and drought (60% ET replacement) (B) in 2005. Data are averaged by days of treatment: early (0-7 d); 2) mid (8-28 d); and 3) late (29-70 d). Vertical bars indicate standard error values.

Figure 5. Volumetric soil water content ( $\theta_v$ ) at 5cm in the hybrid (HBG) and Kentucky bluegrass (KBG) under 60% evapotranspiration (ET) replacement in high-mown plots in 2004 (A) and 2005 (B) and low-mown plots in 2004 (C) and 2005 (D).

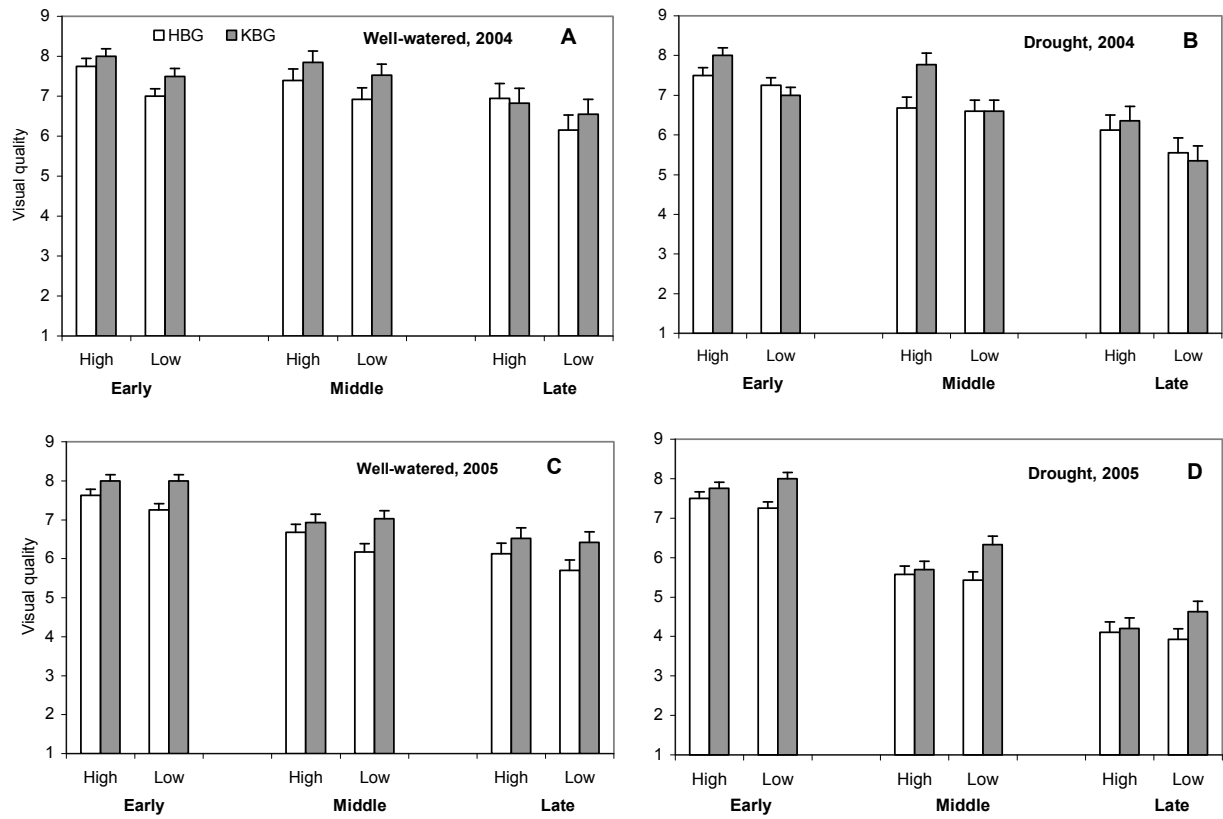
	Column 1		Column 2		
Row 1	KBG	HBG	HBG	KBG	Block I
Row 2	HBG	KBG	KBG	HBG	
Row 3	KBG	HBG	HBG	KBG	Block II
Row 4	HBG	KBG	KBG	HBG	
Row 5	HBG	KBG	HBG	KBG	Block III
Row 6	KBG	HBG	KBG	HBG	
Row 7	KBG	HBG	KBG	HBG	Block IV
Row 8	HBG	KBG	HBG	KBG	

60%ET      100%ET      100%ET      60%ET      60%ET      100%ET      100%ET      60%ET

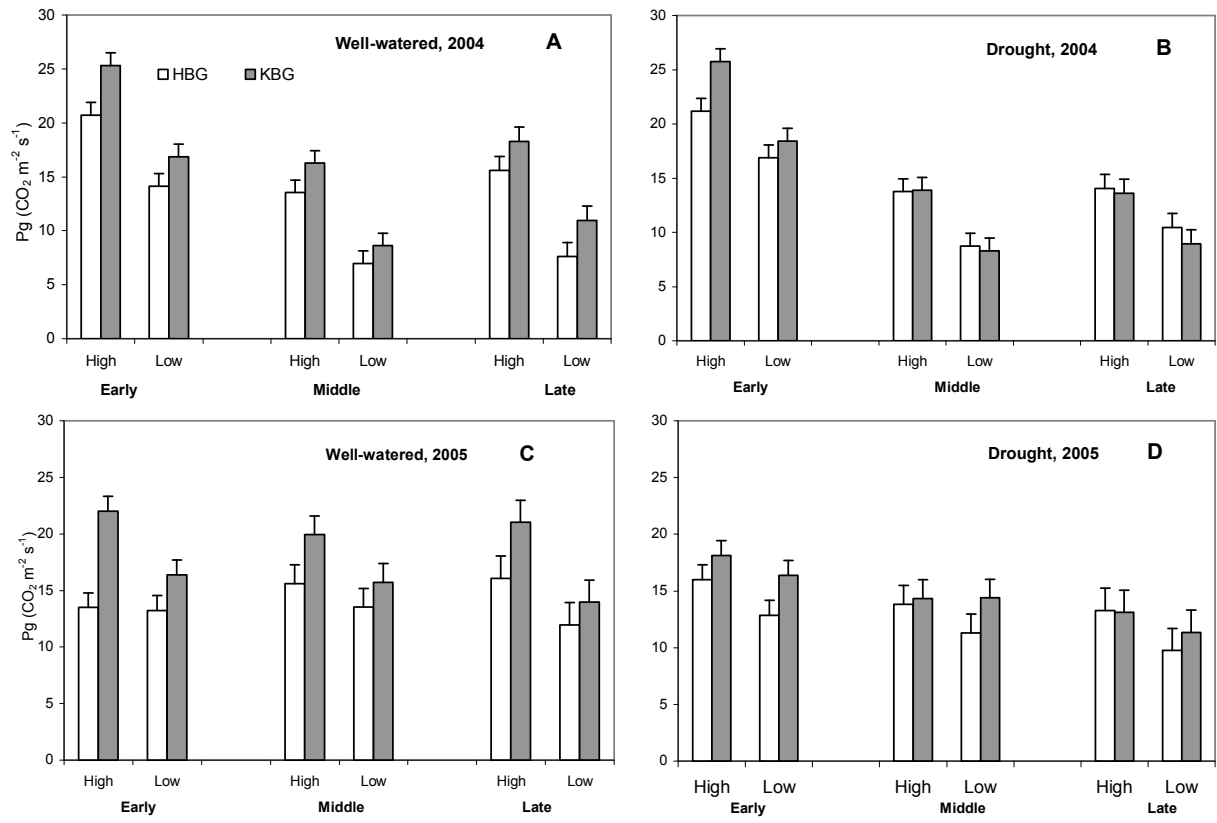
Mowing height: gray =3.81cm  
white =7.62cm

Plot size: 2.4m<sup>2</sup> (1.36 × 1.76 m)

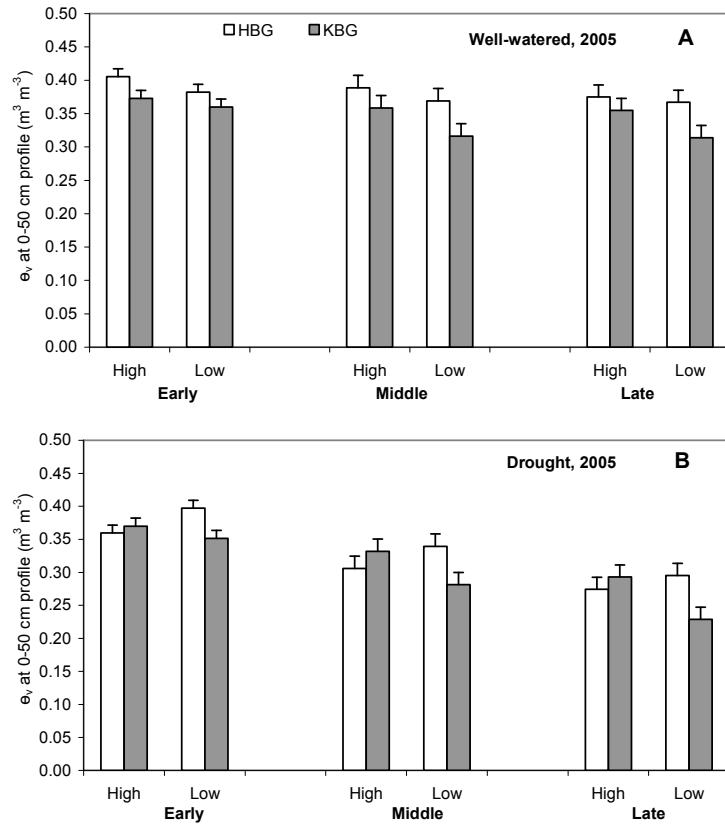
**Figure 1.**



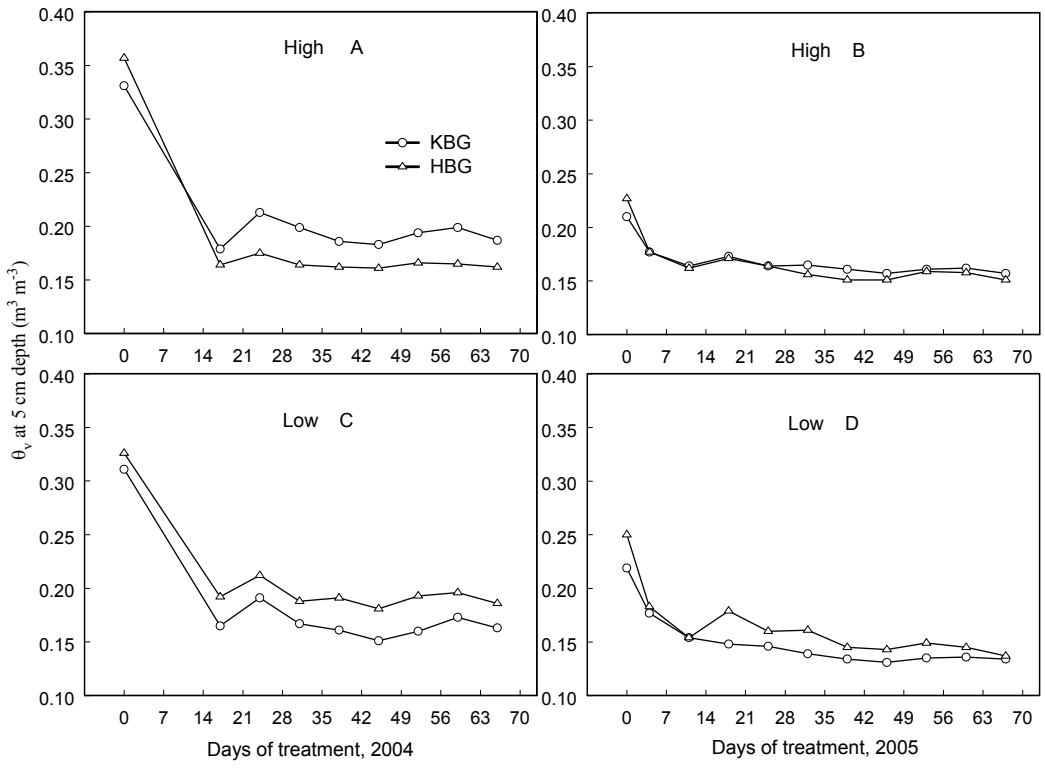
**Figure 2.**



**Figure 3**



**Figure 4.**



**Figure 5.**

Table 1. Analysis of variance for the effect of species, mowing height, and irrigation level treatments on visual quality in 2004 and 2005 ( $P \leq 0.05$ ).

Source	DF	-----2004-----			-----2005-----		
		Early	Middle	Late	Early	Middle	Late
-----Pr > F-----							
Species (S) <sup>†</sup>	1	ns	0.01	ns	0.0001	0.004	0.03
Mowing height (M)	1	0.001	0.02	0.01	ns	ns	ns
S × M	1	ns	ns	ns	0.04	0.04	ns
Irrigation (I)	1	ns	0.02	0.005	ns	0.0001	0.0001

<sup>†</sup>S × I, M × I, and S × M × I interactions were ns.

Table 2. Analysis of variance for the effect of species, mowing height, and irrigation level treatments on gross photosynthesis (Pg) in 2004 and 2005 ( $P \leq 0.05$ ).

Source	DF	-----2004-----			-----2005-----		
		Early	Middle	Late	Early	Middle	Late
-----Pr > F-----							
Species (S) <sup>†</sup>	1	0.003	ns	ns	0.002	ns	ns
Mowing height (M)	1	0.0001	0.0003	0.0007	0.03	ns	0.02
S × M	1	ns	ns	ns	ns	ns	ns
Irrigation (I)	1	ns	ns	ns	ns	ns	0.03

<sup>†</sup>S × I, M × I, and S × M × I interactions were ns.

Table 3. Analysis of variance for the effect of species, mowing height, and irrigation level treatments on volumetric soil water content ( $\theta_v$ ) at 0-50 cm in 2005 ( $P \leq 0.05$ ). Soil moisture data at 0-50 cm were not available in 2004.

Source	DF	-----2005-----		
		Early	Middle	Late
-----Pr > F-----				
Species (S) <sup>†</sup>	1	0.01	0.01	0.02
Mowing height (M)	1	ns	ns	ns
S × M	1	ns	0.02	0.02
Irrigation (I)	1	ns	0.02	0.0003

<sup>†</sup>S × I, M × I, and S × M × I interactions were ns.

Table 4. Average daytime (1000-1800 CST) air temperature of each period during both years of the study and the difference between years.

Periods	2004 (°C)	2005 (°C)	Difference 2005-2004 (°C)
Early	26.9	29.2	2.4
Middle	25.5	30.9	5.4
Late	24.7	28.2	3.6