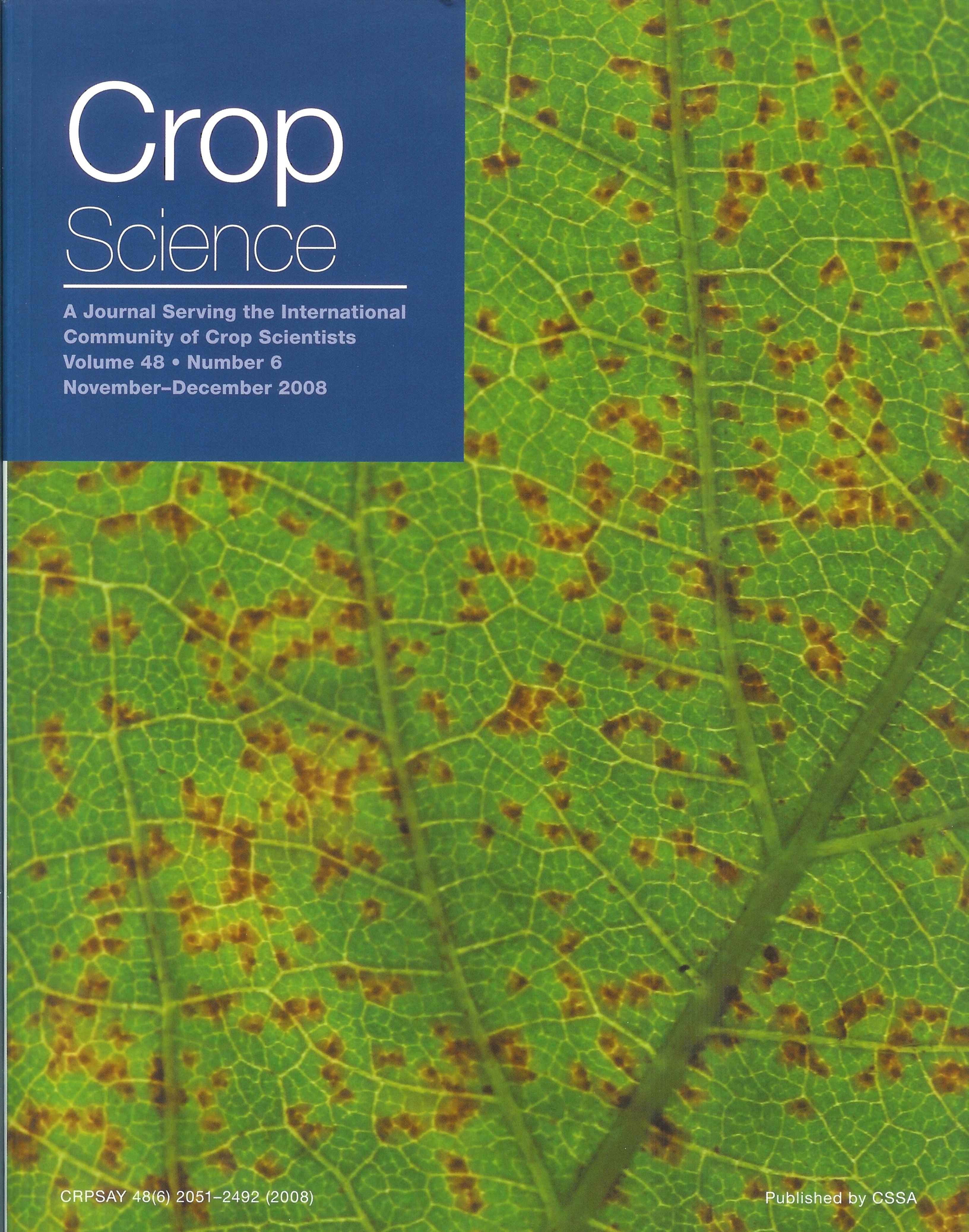
Crop Science

A Journal Serving the International Community of Crop Scientists

Volume 48 • Number 6
November–December 2008



CRPSAY 48(6) 2051–2492 (2008)

Published by CSSA

RESEARCH

Drought Tolerance and Rooting Capacity of Kentucky Bluegrass Cultivars

Michael D. Richardson,* Douglas E. Karcher, Kenneth Hignight, and Debra Rush

ABSTRACT

As freshwater resources for turfgrass irrigation become more limited, the development of drought-tolerant turf cultivars will be of great value to turf managers. The objective of the following research was to evaluate the field drought tolerance of Kentucky bluegrass (*Poa pratensis* L.) cultivars and compare their drought tolerance to rooting capacity. Fifty bluegrass entries were established in the field in Albany, OR and evaluated during drought stress (irrigation withheld) events in 2005 and 2006. Drought tolerance was measured, using digital image analysis, as the number of days until a cultivar reached 50% green tissue. In both years, there was a wide range of cultivar responses to drought, with some cultivars losing 50% green tissue 23 d after irrigation was withheld, while others maintained 50% green tissue up to 45 d after irrigation was withheld. Several cultivars, including Mallard, Moonlight, Prosperity, SR2284, Brilliant, and Diva, demonstrated significantly better drought tolerance than other cultivars. Twenty of the cultivars tested under field conditions were also screened for shoot and root growth in a greenhouse study. There was no correlation between shoot growth, root growth, or root:shoot ratios when compared to drought responses in the field. These results demonstrate that there is wide variability in drought tolerance of bluegrasses but factors other than rooting capacity appear to be responsible for those differences.

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Abbreviations: DAI, days after irrigation; KBG, Kentucky bluegrass; RSR, Root-to-shoot ratios;

The development of turfgrass cultivars with improved tolerance to limited or low-quality water remains a critical research objective in the turfgrass industry, especially as turf irrigation practices become more restrictive across the United States. Plants endure or survive water deficits with a variety of escape, avoidance, and tolerance mechanisms, all of which serve to improve the efficiency of water uptake, water use, or water loss. Drought escape is a rather narrow classification and usually refers to plants which exploit rapid phenological development when water is available, followed by dormancy during severe stress (Kramer, 1980). Although some turfgrasses can utilize drought escape by going into dormancy during prolonged drought periods, most turfgrass managers desire to maintain a green surface during drought periods for aesthetics, playability, and safety. Therefore, drought escape is only considered a viable alternative for turfgrasses in those areas where irrigation is not available and survival of the turfgrass following drought is the primary objective.

Drought tolerance mechanisms are more readily adapted to maintained turfgrass systems, as these processes allow the turfgrass to maintain turgor and avoid dormancy. Plant tolerance to drought stress can be sub-divided into those plants which tolerate drought while maintaining a low tissue water potential and

Published in Crop Sci. 48:2429–2436 (2008).
doi: 10.2135/cropsci2008.01.0034

those plants that tolerate drought by maintaining a high tissue water potential (Jones et al., 1981). Plants that tolerate drought while experiencing low tissue water potential accumulate various solutes in a process termed osmotic adjustment. Osmotic adjustment allows the plant to maintain turgor under severe low-soil water potentials by decreasing cellular osmotic potential. Osmotic adjustment has been demonstrated in numerous grasses (DaCosta and Huang, 2006; Qian and Fry, 1997) and usually involves the accumulation of compatible solutes such as carbohydrates, amino acids, and mineral ions.

A second grouping of drought tolerance mechanisms includes those plants that tolerate drought by maintaining high tissue water potential through reduced water loss or enhanced water uptake. Plant water loss can be reduced under water deficit stress by leaf rolling or rapid stomatal closure and these mechanisms have been demonstrated in many grasses (Frank and Berdahl, 2001; Xu et al., 2006). However, this mechanism has negative consequences, as stomatal closure also reduces carbon dioxide fixation and can lead to temperature increases in the canopy due to a drop in transpirational cooling (Throssell et al., 1987).

Enhanced water uptake through increased root size and depth is one of the most desirable drought tolerance mechanisms for turfgrass systems, as this allows the turf to fully utilize available soil-water resources and prolong the need for supplemental irrigation. This can be especially beneficial in areas where rainfall is sporadic during the summer season, as the ability of the plant to maintain a favorable water balance until the next rainfall event could greatly minimize the need for supplemental irrigation while producing an acceptable quality turf.

Kentucky bluegrass (*Poa pratensis* L.) is one of the most widely planted cool-season turfgrasses and is used in both high- and low-maintenance turf systems. There have been numerous studies that have documented differences in either drought tolerance (Abraham et al., 2004; Bremer et al., 2006; Su et al., 2007), summer stress tolerance (Perdomo et al., 1996; Murphy et al., 1997), or water use efficiency (Ebdon and Kopp, 2004) of Kentucky bluegrass varieties and experimental hybrids. In all of these studies, wide differences in performance under water-limiting conditions have been reported and numerous physiological parameters have been associated with drought or summer stress tolerance, including osmotic adjustment (Perdomo et al., 1996), deep rooting (Ebdon and Kopp, 2004), and reduced electrolyte leakage (Abraham et al., 2004). Unfortunately, most of these studies have been conducted under greenhouse and growth chamber conditions and may not accurately reflect responses to drought stress under field conditions.

Recently, techniques have been described to both screen turfgrass germplasm for enhanced rooting characteristics (Bonos et al., 2004) and assess the drought tolerance of those grasses under prolonged water-deficit stress (Karcher et al., 2008). In tall fescue, gains in root:shoot ratios following two generations of selection (Bonos et al., 2004) translated to improved drought tolerance in the field (Karcher et al., 2008), suggesting that focused breeding efforts on deep rooting can improve field performance of turfgrasses under drought stress. However, this relationship has only been tested in tall fescue, a grass that inherently possesses deep rooting capacity and drought tolerance. The objective of this research was to assess the drought tolerance of numerous Kentucky bluegrass (KBG) cultivars and determine the relationship between drought tolerance and rooting capacity in those cultivars.

MATERIALS AND METHODS

Experimental Area for Drought Study

All studies were conducted at the Nexgen Seed Research, LLC research facilities in Albany, OR (44° 33′ N, 123° 04′ W) during the 2005 and 2006 growing seasons. On 4 Sept. 2004, experimental entries and cultivars of KBG (Table 1) were seeded at 15 g m^{-2} into 1.0 × 2.0 m plots on a native silt-loam soil (Woodburn silt loam, fine-silty, mixed, superactive, mesic Aquultic Argixerolls, pH 5.6–6.5, organic matter 3–5%). This soil is generally classified as a deep (>2.0 m) topsoil with no zones in the upper 2.0 m that would restrict root development. Each entry was replicated three times in a randomized complete block experimental design. Irrigation was provided as needed during establishment to promote germination and establishment and at a rate of 2.5 cm wk^{-1} in the absence of rainfall to provide optimal growing conditions. Following establishment, the experimental area was mowed two to three times per week at a height of 2.5 cm with clippings returned. Fertilizer was applied in March, April, May, and October of each season with a 19–3–16 ($N:P_2O_5:K_2O$) product (Woodburn Royal Green, Woodburn Fertilizer, Inc, Woodburn, OR) at a rate of 190 kg ha^{-1}.

Drought Stress and Recovery Evaluations

Forty-nine KBG cultivars and one KBG × Texas bluegrass (*Poa arachnifera* Torr.) hybrid were included in these field trials (Table 1). The cultivars represented a range of KBG classification types (Bonos et al., 2000; Murphy et al., 1997). On 15 July 2005 and 16 June 2006, the experimental area was saturated with 5 cm of irrigation per day for three consecutive days to eliminate any dry areas and produce uniformly wet conditions across all plots. Immediately thereafter, irrigation was withheld to encourage drought stress symptoms. The response of entries to drought stress was evaluated weekly using digital image analysis techniques (Richardson et al., 2001) to quantify the percent green turf cover for each plot as drought became more severe. In both years, plots were evaluated until all plots had fallen below 25% green turf cover and then the experimental area was saturated with 5.0 cm of irrigation to initiate drought recovery. Thereafter, the experimental area was irrigated weekly with 2.5 cm water until plots reached 100% green cover.

Statistical Analysis of Drought Study

Scatter plots of the percent green turf cover data versus days after irrigation withheld during drought stress indicated a strong

Table 1. Statistical parameters for predicting dry-down characteristics of Kentucky bluegrass cultivars. Smaller (more negative) slope values translate to more rapid changes in green cover over time. $Days_{50}$ is the predicted number of days (from irrigation withheld) until the turf reaches 50% green cover. An average $Days_{50}$ was computed (data not shown) and cultivars are sorted by that average from most drought-tolerant to least drought-tolerant.

		2005					2006				
Cultivar	Type[†]	Slope	SE[‡]	$Days_{50}$	SE[¶]	R^2	Slope	SE[‡]	$Days_{50}$	SE[¶]	R^2
Mallard	Compact-America	–0.054	0.003	45.3	0.45	0.98	–0.080	0.004	41.6	0.24	0.98
1QG-38	Compact-America	–0.046	0.006	44.5	1.17	0.88	–0.081	0.005	41.2	0.32	0.97
Moonlight	Compact	–0.054	0.004	41.5	0.61	0.97	–0.084	0.005	41.0	0.28	0.98
Prosperity	NC	–0.055	0.004	41.1	0.65	0.96	–0.082	0.004	40.9	0.28	0.98
Diva	Compact	–0.051	0.006	41.4	1.06	0.91	–0.069	0.006	40.2	0.53	0.94
SR 2284	Compact-America	–0.053	0.006	39.3	0.87	0.94	–0.077	0.006	40.0	0.39	0.96
Brilliant	Compact-America	–0.055	0.005	39.2	0.71	0.96	–0.088	0.005	39.2	0.29	0.98
Mercury	Other	–0.060	0.005	39.0	0.68	0.96	–0.097	0.010	39.1	0.48	0.94
Full Moon	Other	–0.057	0.007	38.9	1.01	0.92	–0.087	0.006	38.9	0.36	0.97
Monte Carlo	Other	–0.059	0.006	37.7	0.75	0.96	–0.087	0.005	39.4	0.30	0.98
Midnight	Compact-Midnight	–0.058	0.003	36.7	0.45	0.98	–0.077	0.006	39.7	0.41	0.96
Kingfisher	Compact-America	–0.058	0.005	36.9	0.72	0.96	–0.090	0.007	38.9	0.36	0.97
RSP	Mid-Atlantic	–0.074	0.006	36.4	0.49	0.98	–0.091	0.007	39.0	0.36	0.97
Sonic	Common	–0.072	0.005	35.9	0.42	0.98	–0.086	0.005	38.8	0.27	0.98
America	Compact-America	–0.072	0.007	36.5	0.61	0.97	–0.108	0.010	37.6	0.41	0.96
Arcadia	Compact-Midnight	–0.059	0.003	34.5	0.40	0.99	–0.083	0.005	39.3	0.32	0.97
Blue Angel	Common	–0.065	0.007	34.6	0.75	0.96	–0.075	0.008	38.0	0.57	0.93
Princeton P105	Compact	–0.065	0.006	34.7	0.62	0.97	–0.094	0.007	37.9	0.36	0.97
Julia	Julia	–0.077	0.006	35.1	0.48	0.98	–0.101	0.007	37.4	0.34	0.97
Royale'	Compact-America	–0.067	0.006	34.9	0.62	0.97	–0.103	0.007	37.5	0.29	0.98
Ginney	Compact-Midnight	–0.067	0.010	33.1	1.06	0.92	–0.078	0.008	39.0	0.54	0.94
Moon Beam	Compact	–0.080	0.008	34.2	0.59	0.97	–0.091	0.008	37.6	0.45	0.96
Midnight II	Compact-Midnight	–0.061	0.009	33.7	1.07	0.92	–0.083	0.007	38.0	0.48	0.95
Bedazzled	Compact-America	–0.063	0.006	33.7	0.69	0.96	–0.112	0.007	37.6	0.26	0.98
Moonstruck	Common	–0.066	0.006	34.7	0.62	0.97	–0.085	0.008	36.4	0.50	0.95
Parade	NC	–0.061	0.005	32.0	0.59	0.97	–0.074	0.005	38.2	0.37	0.97
Boutique	Compact-America	–0.086	0.014	32.1	0.94	0.93	–0.096	0.008	37.9	0.41	0.96
Cynthia	Other	–0.088	0.007	33.5	0.44	0.98	–0.123	0.009	36.1	0.28	0.98
Brooklawn	Shamrock	–0.064	0.008	32.1	0.93	0.94	–0.088	0.005	36.6	0.31	0.98
BlueRidge	Other	–0.064	0.006	32.1	0.72	0.96	–0.098	0.009	36.4	0.40	0.97
Unique	Compact-America	–0.074	0.011	32.1	0.99	0.93	–0.112	0.016	35.9	0.56	0.94
Touchdown	Aggressive	–0.074	0.006	31.1	0.56	0.98	–0.084	0.007	35.6	0.44	0.96
Rampart	NC	–0.080	0.009	30.6	0.72	0.96	–0.112	0.007	35.9	0.26	0.99
Midnight Star	Compact-Midnight	–0.073	0.007	30.6	0.60	0.97	–0.087	0.005	35.5	0.30	0.98
Cocktail	NC	–0.092	0.014	31.2	0.81	0.94	–0.107	0.012	34.8	0.47	0.96
Preakness	Mid-Atlantic	–0.091	0.008	30.4	0.45	0.98	–0.113	0.008	35.5	0.27	0.98
Limousine	Aggressive	–0.078	0.008	29.6	0.61	0.97	–0.119	0.008	35.9	0.26	0.98
Guinness	Shamrock	–0.121	0.010	29.5	0.34	0.99	–0.117	0.008	35.2	0.27	0.98
Pp H6351	NC	–0.081	0.014	28.6	1.06	0.91	–0.094	0.010	34.9	0.52	0.95
Larissa	Aggressive	–0.086	0.009	28.0	0.59	0.97	–0.104	0.007	35.5	0.30	0.98
Moonshine	Shamrock	–0.080	0.015	28.0	1.16	0.90	–0.106	0.013	35.2	0.53	0.95
Baron	BVGM	–0.069	0.007	28.0	0.68	0.97	–0.107	0.007	35.2	0.28	0.98
Yvette	Aggressive	–0.082	0.017	28.0	1.21	0.88	–0.093	0.010	34.1	0.51	0.96
Champlain	Shamrock	–0.094	0.015	27.5	0.81	0.94	–0.125	0.013	34.3	0.37	0.97
Festina	Aggressive	–0.091	0.007	26.3	0.42	0.98	–0.117	0.010	34.9	0.32	0.98
Blue Star	BVGM	–0.084	0.007	26.5	0.47	0.98	–0.103	0.006	33.7	0.27	0.99
Dragon	BVGM	–0.097	0.011	25.8	0.55	0.97	–0.103	0.007	34.4	0.31	0.98
Eagleton	Mid-Atlantic	–0.103	0.008	25.3	0.38	0.99	–0.118	0.009	34.1	0.29	0.98
PST-99LM-15	Ky x Tx Hybrid	–0.096	0.013	25.2	0.67	0.96	–0.119	0.016	32.1	0.52	0.96
Geronimo	Other	–0.111	0.012	23.0	0.50	0.97	–0.113	0.006	32.4	0.22	0.99
Mean				33.2		0.96			37.1		0.97

[†]Kentucky bluegrass classification type as previously published (Bonos et al., 2000). NC, not classified.

[‡]Standard error of slope.

[¶]Standard error of $Days_{50}$.

nonlinear relationship. Furthermore, the data fit very well to a Sigmoid variable slope model, [green turf cover (%) = 100 / (1 + 10^((Days$_{50}$ – DAI) × Slope))] where DAI = days after irrigation was withheld and Days$_{50}$ and Slope are estimated model parameters. Days$_{50}$ is estimated to be the DAI when green turf cover = 50%. The Slope parameter defines how rapidly turf cover changes over time with more negative values representing steeper slopes of the sigmoid curve.

A sum of squares reduction *F*-test was used to determine if KBG cultivars significantly affected green turf cover during drought stress (Motulsky and Christopoulos, 2003). The *F*-test compared the sum of squares from a global model (all varieties share Days$_{50}$ and Slope values) against the cumulative sum of squares from models where Days$_{50}$ and Slope values were determined separately for each variety. If the sum of squares were reduced significantly ($P < 0.05$) using separate parameter values, variety effects were determined to be significant. Parameter estimates were used to calculate confidence intervals (95%) for the number of DAI withheld until each entry reached 25, 50, and 75% green turf color (Motulsky and Christopoulos, 2003). At each turf coverage percentage (25, 50, and 75), entries were considered significantly different if their confidence intervals did not overlap. Nonlinear regression analysis of the turf cover data was performed using GraphPad Prism version 4.0 for Windows, (GraphPad Software, San Diego, CA).

Root Growth Study

Twenty-two bluegrass entries tested in the drought study were also evaluated for rooting capacity using a rooting tube method described previously (Bonos et al., 2004). The twenty-two cultivars selected for this trial represented a range of bluegrass types (Bonos et al., 2000) and were representative of entries that performed both well and poorly in the field, dry-down portion of the present study. Each bluegrass entry was established as a single seedling in a cell tray containing vermiculite. After approximately 4 wks, a single seedling plant was transferred to each rooting tube. The plants were irrigated by a drip irrigation system and received 5.9 to 8.8 mL of H_2O during each irrigation cycle timed every 2 h daily and every 4 h nightly. The sand medium was maintained at or near field capacity during the study. Greenhouse conditions varied during the seasons of evaluation; however, constant temperatures were maintained between 24 and 29°C. Supplemental lighting with high-pressure sodium lamps (1000 W, Ruud Lighting, Racine, WI) (1.2 m above plant height) was used to obtain 12 h of light during cloudy winter months in Oregon, U.S. Two runs of the experiment were conducted.

Plants were clipped weekly at 5.1 cm and fresh weights of clippings recorded. After approximately 12 wk of growth, or when 25% of the tubes had roots reaching the bottom of the tube, the flexible root tubes were cut at 30 cm and the roots in the lower 30 cm were harvested. Roots were washed free of excess silica sand using a gentle stream of water over a sieve. Excess moisture was removed by patting roots with paper towels. Fresh weight of roots was measured immediately. Shoot weight was determined as the average weekly clipping yields obtained over the 12 wk. Root-to-shoot ratios (RSR) were determined by dividing root weight by shoot weight. All data were analyzed by analysis of variance procedures and cultivar means were separated using Fisher's protected least significant difference ($P = 0.05$). A regression analysis, modeling shoot weight, root weight, and root-to-shoot ratios in the greenhouse against average days to 50% cover during the dry-down period (2005 and 2006 data combined) was conducted to determine if morphological parameters were associated with field drought stress tolerance. For regression analysis, the root, shoot, and root:shoot ratio from the two experimental runs of the root-tube study were combined for each cultivar.

RESULTS AND DISCUSSION

Drought Stress Study

Environmental conditions during the two years of the study were ideal for evaluating cultivar responses to drought stress, as average high temperatures were 29.5 and 28.7°C during the 2005 and 2006 seasons, respectively (Fig. 1). In addition, only traces of rainfall were recorded during the dry-down phase in either year (7.8 mm in 2005 and 4.8 mm in 2006) and did not compromise the study (Fig. 1). KBG cultivars significantly affected green turf coverage during the dry-down in both years of the study (Table 2). As observed in a previous study (Karcher et al., 2008), the sigmoid models used to predict turf coverage (Fig. 2 and Fig. 3) provided a good fit of the green turf cover data, resulting in average R^2 values of 0.96 and 0.97 during drought stress in 2005 and 2006, respectively (Table 1). The dry-down characteristics of all 50 entries are included for comparison in Table 1, but to simplify other data presentation and discussion, corresponding figures and comparisons to rooting characteristics only include the 22 entries also examined in the rooting study.

In 2005, KBG cultivars began to show initial symptoms of drought stress, as measured by loss of green cover, at approximately 15 d after withholding irrigation (Fig. 2). In the 2006 trial, cultivars did not begin to lose green cover until approximately 27 d after irrigation was withheld (Fig. 3). The average number of days for cultivars to reach 50% green cover was 33.2 in 2005 and 36.9 in 2006 (Table 1). Although air temperatures in 2006 were slightly more variable than 2005 (Fig. 1), the delay in drought stress cannot be easily attributed to different environmental conditions. More likely, the differences between the two years of the trial is a reflection of turfgrass maturity, as the 2005 trial would still be considered a juvenile stand of turf compared to the 2006 trial. Nonetheless, when drought stress symptoms began to appear in the trial, the trends between cultivars were similar between the two years of the study.

The KBG cultivars, Mallard and Diva, demonstrated the best drought tolerance in both years of the trial, with Mallard reaching 50% green cover at 45 and 42 DAI withheld in 2005 and 2006, respectively, and Diva reaching 50% green cover at 41 and 40 DAI during the two trials (Table 1, Figs. 4 and 5). Mallard and Diva were also the last entries to reach 25% green cover in both years of the trial (Figs. 4 and

5). Other cultivars that performed well in both years of the trial include SR 2284, Brilliant, Mercury, Monte Carlo, and Midnight (Fig. 4 and 5).

Entries that exhibited the least drought tolerance, as measured by days to reach 50% green cover, included the cultivars, Geronimo, Eagleton, and Yvette and the experimental hybrid, PST-99LM-15 (Table 1, Fig. 4 and 5). The poor drought tolerance of the hybrid cultivar, PST-99LM-15, is somewhat contradictive, since *P. pratensis* × *P. arachnifera* hybrids have been promoted in the turfgrass industry as having superior heat and drought tolerance compared to KBG. Unfortunately, very few studies have examined a range of hydrids compared to a range of KGB, especially under field conditions. Abraham et al. (2004) reported nominal improvements in drought resistance in hybrid bluegrasses, but the most significant gains were observed when the KBG parent also had excellent drought resistance characteristics. In a more recent study, a larger collection of hybrid and KBG cultivars were tested similarly to the present study and there was also a wide range of drought tolerance among hybrid types tested in that study (Hignight, unpublished, 2007). Collectively, these data suggest that hybrid bluegrasses may not inherently have improved drought tolerance unless the parents used to create those crosses also have good drought characteristics.

There were no clear trends in this study relating drought tolerance of cultivars, as measured by days to 50% green cover, to KBG type classification (Table 1) (Bonos et al., 2000). Keeley and Koski (2001) reported that several mid-Atlantic types exhibited better drought tolerance than BVMG or common types. In the present study, two mid-Atlantic types exhibited either poor (Eagleton) or moderate ('Preakness') drought tolerance while two BVGM types ('Blue Star' and 'Dragon') both exhibited very poor drought tolerance (Table 1). In contrast to the reports of Keeley and Koski (2001), common types tested in this study, including 'Blue Angel', 'Moonstruck', and 'Sonic', all exhibited good drought tolerance, with days to 50% cover ranging from 34.6- 35.9 (Table 1).

Although there were outliers in the data, some of the better performing cultivar types in this trial included compact (Moonlight and Diva) and compact-America types (Mallard, SR 2284, and Brilliant), suggesting that these groups should be considered in future breeding efforts for improved drought tolerance. The cultivar, Brilliant, had been reported to be drought-sensitive in previous studies (Wang et al., 2003; Wang and Huang, 2003), but was one of the more drought-tolerant cultivars tested in this trial. These differences may simply reflect a field vs. growth-chamber response, as the bluegrass cultivars were established for minimal periods (60 d) under controlled conditions before initiating drought stress in the previous work (Wang et al., 2003; Wang and Huang, 2003), while the present study utilized a full season of development in the field before initiating stress.

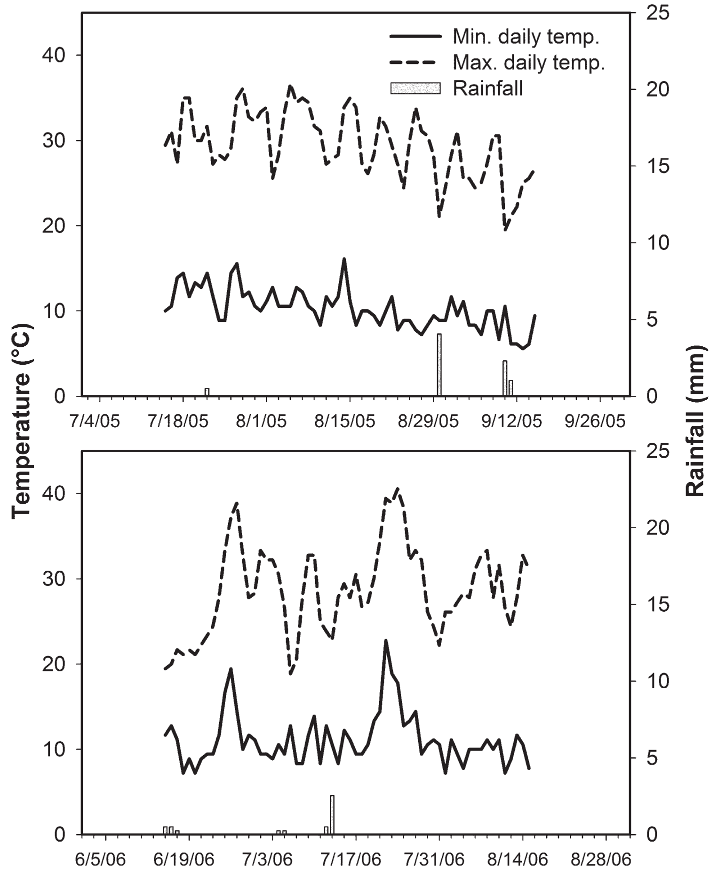

Figure 1. Maximum and minimum daily temperatures and daily rainfall totals in Albany, OR during the experimental periods.

Table 2. Hypothesis test summaries for Kentucky bluegrass cultivar effects on green turf coverage during dry-down in 2005 and 2006.

Sum of squares reduction test	2005	2006
Null hypothesis	Shared regression parameters (Slope and Days_{50})† for all varieties	
Alternative hypothesis	Different regression parameters for each variety	
Numerator df	22	22
Denominator df	588	346
F-value	8.71	11.77
P-value	< 0.001	< 0.001

†Slope and Days_{50} values determine percent green turf cover according to the formula: 100/(1+10^((Days_{50}–X)*Slope)) where X = days after irrigation was ceased.

Root Growth Study

There was a significant cultivar effect on shoot and root weight and RSR in both experiments (analysis of variance not shown). There was a relatively wide range in clipping yields (0.30–0.54 g), root weight (0.001–0.72 g) and RSR (0.01–1.38) across the two runs of the experiment (Table 3). Cultivars that exhibited the greatest root growth and RSR included RSP, Touchdown and Festina (Table 3).

When root and shoot characteristics were regressed against days until 50% cover, there was no significant correlation between drought tolerance and any of the root or shoot characteristics (data not shown). These results are different from observations made on tall fescue, where selection for deep rooting led to increases in drought tolerance over the parent cultivars (Karcher et al., 2008). Bonos and Murphy (1999) reported that KBG cultivars that had been described as "summer stress tolerant" had greater root mass in the upper 30 cm of the root zone after stress had occurred compared to cultivars that lacked stress tolerance. In addition, they reported that stress-tolerant types had greater root mass in the 30 to 45 cm profile when sampled before stress. It should be noted that, in the present study, drought stress was

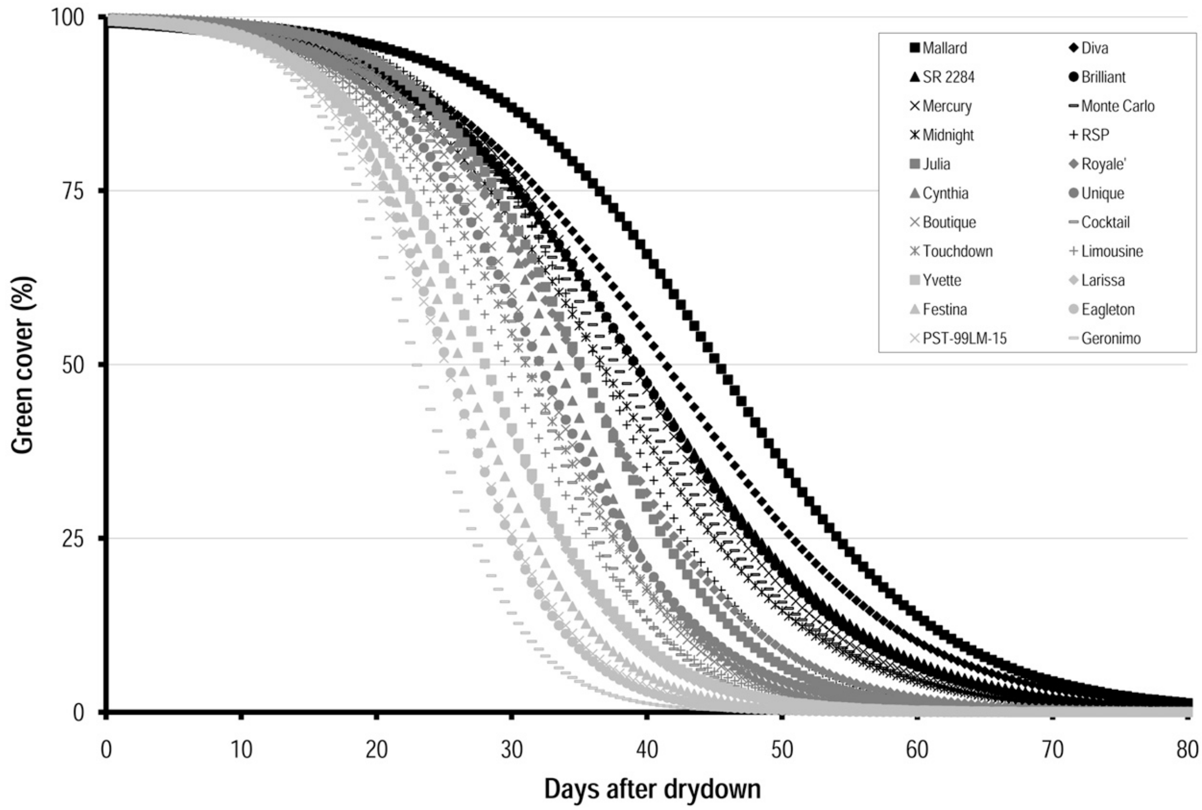

Figure 2. Predicted dry-down curves for bluegrass entries in 2005.

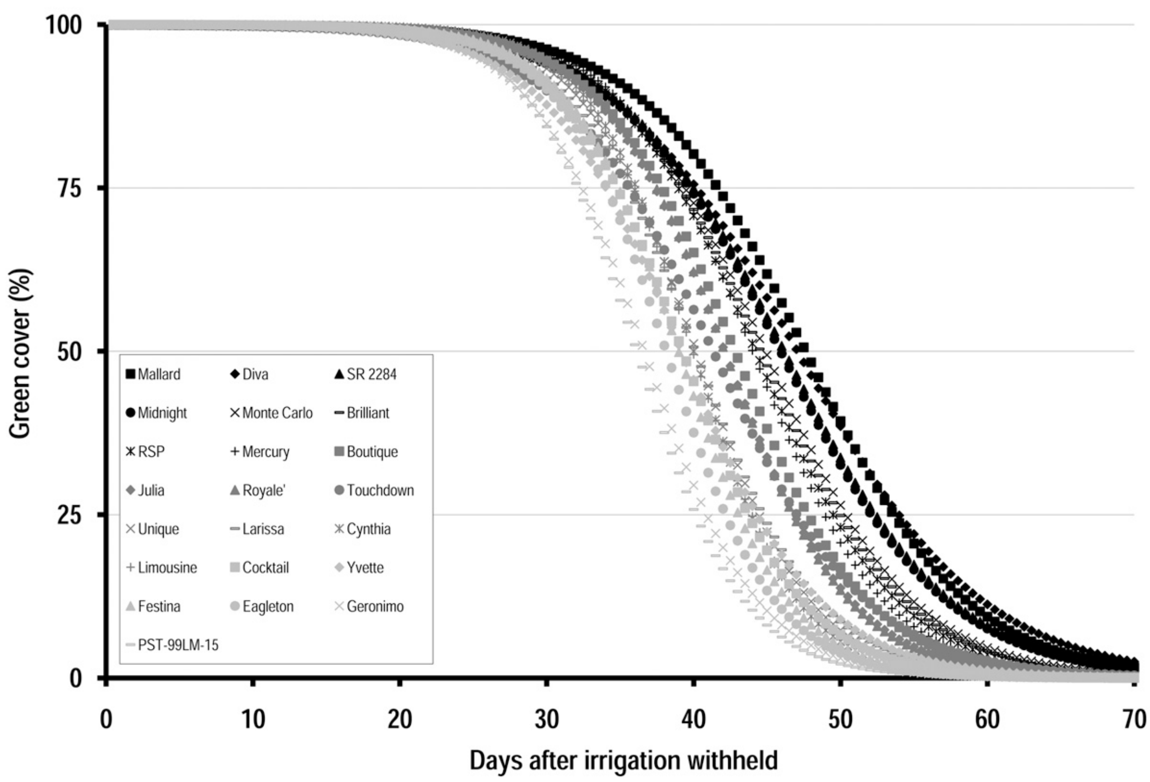

Figure 3. Predicted dry-down curves for bluegrass entries in 2006.

the sole factor affecting these cultivars, while heat stress likely played a compounding role in summer survival in the studies by Bonos and Murphy (1999). In areas where both stresses occur simultaneously, enhanced rooting may play a more significant role in overall stress survival. In addition, Ebdon and Kopp (2004) also found a relationship between deep rooting and reduced leaf firing in KBG under drought stress in a lysimeter study, suggesting that deep rooting can play a role in drought tolerance of KBG.

In the present study, root growth was measured in the 30 to 60 cm zone (Table 3) under ideal growing conditions and there was no correlation between deep rooting and the ability to withstand long periods of water deficit (data not shown), suggesting that other morphological or physiological parameters are involved. Factors other than root growth have been previously associated with drought or stress tolerance in KBG, including higher stomatal resistance and osmotic adjustment (Perdomo et al., 1996) and reduced electrolyte leakage and increased photosynthetic efficiency (Abraham et al., 2004). These results suggest that multiple factors contribute to drought tolerance in KBG and selection for deep, extensive rooting may not be as effective in this species as was previously reported with tall fescue (Bonos et al., 2004; Karcher et al., 2008). However, this study only included a limited number of cultivars and the selection of deep-rooted cultivars could still be a viable means to identify drought-tolerant lines of bluegrass.

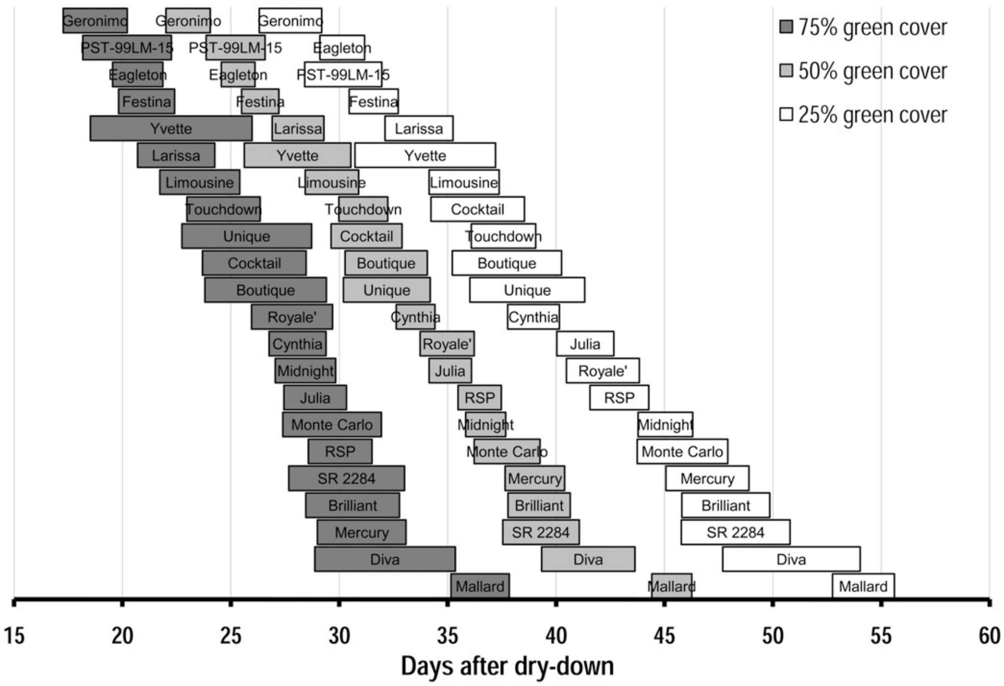

Figure 4. 95% confidence intervals for the number of days after water was withheld until Kentucky bluegrass cultivars reached 75, 50, and 25% green cover in 2005. Within each green cover percentage, cultivars with overlapping bars were not significantly different.

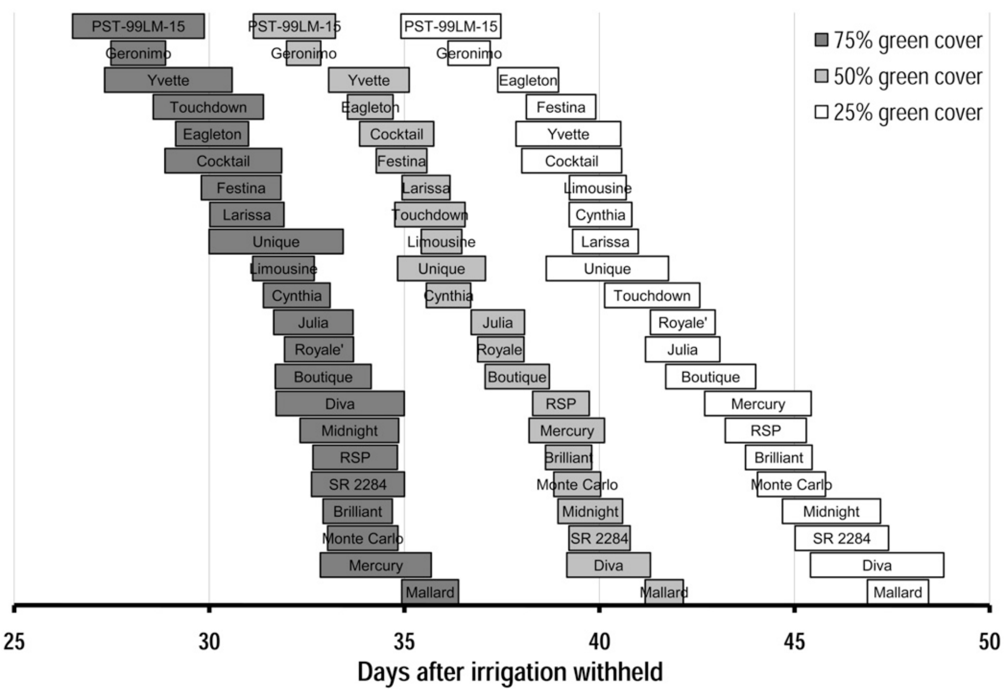

Figure 5. 95% confidence intervals for the number of days after water was withheld until Kentucky bluegrass cultivars reached 75, 50, and 25% green cover in 2006. Within each green cover percentage, cultivars with overlapping bars were not significantly different.

CONCLUSIONS

These results clearly demonstrate that KBG cultivars can have a significant impact on turf responses to long-term drought stress. In some instances, there was as much as 20 d difference between entries in respect to the onset of drought stress symptoms (Table 1, Figs. 4 and 5). This could have a significant impact on supplemental irrigation requirements over an entire growing season, especially in humid regions, where periodic rain can significantly reduce or even eliminate the need for irrigation. In those instances, the delay of drought-stress symptoms would delay the need for supplemental irrigation and provide additional opportunity for rainfall to occur.

Table 3. Average weekly clipping yield (shoot fresh wt.) and root growth (fresh wt.) in greenhouse studies that examined root development under optimum conditions. The root:shoot ratio (RSR) was calculated as root wt./shoot wt. An average RSR was computed from the two experiments (data not shown) and cultivars are ranked from highest to lowest average RSR.

Cultivar	Experiment 1			Experiment 2		
	Shoot wt.	Root wt.	Root:Shoot	Shoot wt.	Root wt.	Root:Shoot
	—— g ——			—— g ——		
Festina	0.39	0.49	1.38	0.34	0.30	0.89
Monte Carlo	0.46	0.45	0.99	na†	na	na
Larissa	0.31	0.28	0.89	0.33	0.27	0.84
Touchdown	0.54	0.57	1.05	0.45	0.29	0.65
RSP	0.59	0.71	1.22	0.54	0.24	0.44
Cocktail	0.37	0.37	0.99	0.31	0.20	0.64
Brilliant	0.44	0.45	1.05	0.52	0.20	0.39
Yvette	0.42	0.30	0.66	0.46	0.27	0.58
Unique	0.40	0.33	0.88	0.51	0.18	0.34
SR 2284	0.47	0.36	0.78	0.48	0.20	0.42
Cynthia	0.33	0.24	0.78	0.33	0.11	0.34
Mallard	0.42	0.30	0.71	0.44	0.13	0.30
Diva	0.36	0.24	0.71	0.42	0.11	0.25
Julia	0.62	0.47	0.77	0.32	0.06	0.19
Midnight	0.47	0.29	0.64	0.35	0.07	0.19
Limousine	0.46	0.16	0.35	0.35	0.17	0.47
Geronimo	0.46	0.29	0.60	0.49	0.10	0.20
Mercury	0.34	0.21	0.64	0.39	0.06	0.15
Boutique	0.38	0.11	0.33	0.39	0.08	0.21
Eagleton	0.45	0.13	0.29	0.48	0.05	0.11
Royale'	0.34	0.08	0.24	0.37	0.03	0.07
PST-99LM-15	0.33	0.02	0.06	0.30	0.00	0.01
LSD (0.05)	0.12	0.18	0.42	0.05	0.06	0.14

†na, not available in the second experiment.

Improvements in drought tolerance in KBG may not necessarily occur by selecting germplasm with deep rooting or high root:shoot ratios, as was the case with tall fescue. For KBG, the use of a rain-controlled facility or field environments with limited rainfall, coupled with the precise measurement of green cover attainable with digital image analysis, proved to be an effective means of evaluating the drought tolerance of a wide range of germplasm and may yield more desirable long-term results in a breeding program compared to other screening techniques.

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