Turfgrass Cultivars for Water-Limited Environments

Michael D. Richardson and Douglas E. Karcher, University of Arkansas, Fayetteville AR 72701 USA and
Kenneth W. Hignight and Debra Rush, NexGen Seed Research, Albany OR 97322 USA

ABSTRACT

The development of turfgrass cultivars with improved tolerance to limited or low-quality water remains one of the most important research objectives facing the turfgrass industry, especially as turf irrigation practices become more restrictive. Although some turfgrasses can escape drought by going into quiescence (growth cessation and leaf senescence) during prolonged drought periods, most turfgrass managers desire to maintain a green surface during drought periods for aesthetics, playability, and safety. Drought tolerance mechanisms are more readily adapted to maintained turfgrass systems, as these processes allow the turfgrass to maintain turgor and avoid prolonged senescence. 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 can greatly minimize the need for supplemental irrigation while producing an acceptable quality turf. The overall goal of our research is to identify turfgrass species and cultivars that can maintain green cover during extended periods of drought. All studies were conducted in either arid environments or rain-exclusion facilities where acute drought stress was imposed on plots. Digital image analysis was used to monitor the loss of green color as drought became more severe, and non-linear statistics were used to model green cover data against days without water. These techniques have been successful at identifying turfgrass cultivars that can maintain green cover as much as 3 weeks longer without irrigation than drought-sensitive cultivars.

INTRODUCTION

Turfgrasses continue to be an important component of the human environment, adding social, physical, and economic value to our lives (Beard and Green, 1994). Some of the functional and environmental benefits attributed to turfgrasses include protection against soil erosion, filtration and protection of ground and surface water, carbon dioxide sequestering, heat dissipation, and reduction of fire hazards. In addition, turfgrasses can enhance the mental and physical well-being of people by providing an environment that is conducive to a range of recreational and social activities. As modern society becomes increasingly urbanized, the benefits of turfgrass systems are even more pronounced as the demand for green space increases in densely populated communities.

A controversial aspect of using turfgrasses in urban environments is that these plants can require substantial water to sustain a dense, actively growing canopy. These concerns have heightened over the past two decades in the U.S. as increased population growth in water-limited areas such as the desert Southwest, and incidences of long-term drought have significantly strained water reserves in many regions. In response to this, many communities have suggested that other types of landscape systems, such as xeriscaping, could better conserve water resources into the future (Beard, 1993). Unfortunately, these reactions have not always been based on long-term scientific observations, but more on perceived inadequacies of turfgrass systems over other plant types such as trees, shrubs, or ground covers. It has been well documented that many turfgrass species have the ability to survive for extended periods without water, and many are able to sustain active growth with very low water expenditures (Asay et al., 2001; Karcher et al., 2008; Richardson et al., 2008).

The selection and breeding of turfgrass cultivars with improved tolerance to limited water remains one of the most critical research objectives facing the turfgrass industry. 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.

Numerous experimental approaches have been used to evaluate the drought tolerance of turfgrass species and cultivars. Many of these techniques require large inputs of labor and infrastructure and are often limited in scope with regards to the number of entries that can be evaluated in a single trial. The most common means of evaluating drought tolerance of turfgrasses has been to used either lysimeters (Feldhake et al., 1985) or gradient irrigation (Asay et al., 2001) systems to determine the effects of deficit irrigation on turfgrass performance. It has been demonstrated from these studies that certain turfgrass species and cultivars can sustain a base level of performance and quality when irrigated at 40-60% of evapotranspiration (ET) rate, suggesting that turfgrasses can be sustained in the landscape without excessive irrigation. Unfortunately, most of these studies have been limited to a few species or cultivars owing to the burdens of the experimental protocols. In an effort to improve the screening of turfgrasses for drought tolerance, the overall goal of our research has been to develop screening methods that will allow a broad range of plant selections to be evaluated with a minimal cost such that superior cultivars and breeding lines can be identified.

MATERIALS AND METHODS

Drought simulation. All studies have been conducted either at sites in which summer rainfall is minimal (primarily western Oregon, USA) or in rain-controlled structures at the University of Arkansas in Fayetteville. All experimental sites have deep, fertile soils in which root restriction is minimized. Two types of rainout structures have been used in these studies, including a moveable-roof structure that uses a moisture sensor to engage the roof to close when rain begins. A second type of structure is a fixed-roof structure in which a clear greenhouse film (6 mm thickness) covers the plot area at all times and prevents rain from reaching the plots. In the fixed-roof system, the sides and ends of the structure are open to a height of 2 m, which allows optimum airflow in the structure and minimizes heat buildup.

In all trials, experimental entries were replicated three or four times in a randomized complete block experimental design. Irrigation was provided at planting to promote establishment and at a rate of 2.5 cm wk^{-1} thereafter to provide optimal growing conditions. The experimental area was maintained under typical lawn maintenance conditions, including a mowing height of 2.5 cm.

Experimental entries. Two studies are summarized (Table 1). The first study (Richardson et al., 2008) included 22 Kentucky bluegrass (KBG) cultivars representing a range of KBG classification types (Murphy et al., 1997) and one KBG x Texas bluegrass (*Poa arachnifera* Torr.) hybrid. The second study (Richardson et al., 2009) investigated a range of KBG and hybrid bluegrasses (HBG), primarily hybrids between *P. pratensis* and *P. arachnifera*.

Drought stress and recovery evaluations. Prior to initiating a drought period, the experimental area was saturated with 5 cm of irrigation per day for 3 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 percentage green turf cover for each plot as drought became more severe. When all plots had fallen below 25% green turf cover, the experimental area was saturated with 5 cm of irrigation to initiate drought recovery and recovery was evaluated weekly using digital image analysis until plots reached 100% green cover. Data regarding recovery from drought will not be presented in the current paper.

Statistical analysis. Scatter plots of the percentage green turf cover data versus days after irrigation (DAI) withheld during drought stress, indicated a strong nonlinear relationship. Furthermore, the data fit very well to a sigmoid variable slope model, [green turf cover (%) = 100/(1+10^((Days50-DAI)*Slope))] where DAI = days after irrigation was ceased for dry-down and Days50 and Slope are estimated model parameters. Days50 is estimated to be the DAI when green turf cover = 50%. The Slope parameter defines how rapidly turf cover changes over time with larger positive or negative values representing steeper positive or negative slopes of the sigmoid curve.

A sum of squares reduction F-test was used to determine if entries 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 Days50 and Slope values) against the cumulative sum of squares from models where Days50 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 (irrigation ceased or initiated) until each entry reached 75, 50, and 25% green turf color (Motulsky and Christopoulos, 2003). At each turf coverage percentage (75, 50, and 25%), entries were considered significantly different if their confidence intervals did not overlap. Nonlinear regression analysis of the green cover data was performed using GraphPad Prism version 4.0 for Windows, (GraphPad Software, San Diego, CA).

Results and Discussion

Turfgrass entry significantly affected green turf coverage during drought stress in both studies. Sigmoid models were used to predict turf coverage and provided a good fit of the green turf cover data, resulting in average R^2 values of above 0.90 in all studies. A full presentation of the statistical methods and results was provided elsewhere (Karcher et al., 2008; Richardson et al., 2008; Richardson et al., 2009).

In Experiment 1, KBG cultivars began to show initial symptoms of drought stress, as measured by loss of green cover, at approximately 15 d after withholding irrigation. The KBG cultivars Mallard and Diva demonstrated the greatest drought tolerance, with Mallard reaching 50% green cover at 45 DAI withheld and Diva reaching 50% green cover at 41 DAI (Fig. 1). Mallard and Diva were also the last entries to reach 25% green cover in this trial (Fig. 1). These results demonstrate that additional water savings would be realized with these cultivars in those situations where greater levels of growth reduction [or quiescence] can be tolerated. Other cultivars that performed well in this trial included SR 2284, Brilliant, Mercury, Monte Carlo, and Midnight (Fig. 1). Entries that exhibited the least drought tolerance, as manifested by fewest days to reach 50% green cover, included the cultivars Geronimo, Eagleton, and Yvette and the experimental hybrid, PST-99LM-15 (Fig. 1).

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) (Murphy et al., 1997). However, these studies clearly demonstrate that a range of drought tolerance capabilities exist within the species, and that selection of drought-tolerant cultivars can have a significant impact on long-term water use. In some instances, there were 20-d differences between entries with respect to the onset of drought stress symptoms (Fig. 1), which could have a significant impact on supplemental irrigation requirements over an entire growing season. This would be especially important in humid regions, where periodic rain can significantly reduce or even eliminate the need for irrigation. In those environments, the delay of drought stress symptoms would delay the need for supplemental irrigation and provide additional opportunity for rainfall to occur.

The poor drought tolerance of the hybrid cultivar, PST-99LM-15, in this study (Fig. 1) was somewhat contradictive, since *P. pratensis* x *P. arachnifera* hybrids have been promoted in the turfgrass industry as having superior heat and drought tolerance compared to KBG. Until recently, very few studies have examined a range of hydrids compared to a range of Kentucky bluegrasses, 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 Experiment 2, a much larger number of HBG and KBG cultivars were tested, and there was also a wide range of drought tolerance among HBG types in that study (Fig. 2). The average number of days for entries to reach 50% green cover in this study was approximately 27 days (Fig. 2). The commercially available KBG cultivars Mallard, Bluestone and Arrow demonstrated the best drought tolerance in this trial, with Mallard reaching 50% green cover at 32 days after irrigation was withheld (Fig. 2). Mallard was also the top-performing bluegrass in Experiment 1, which was conducted under similar conditions. Several HBG entries also exhibited excellent drought tolerance characteristics in this trial, including the cultivar Longhorn and the experimental entries 103-509 and A00TB-99 (Fig. 2). Interestingly, the most drought-tolerant hybrid in the trial was 103-509, an experimental hybrid between *P. pratensis* x *P. angustifolia*. Although most hybridization attempts with *Poa* spp. have focused on hybrids involving *P. arachnifera*, these results suggest other species may also be promising candidates for introducing desirable traits into Kentucky bluegrass. One experimental *P. pratensis* x *P. densa* hybrid, 1A4-529, also performed well under acute drought stress (Fig. 2).

In general, most of the *P. pratensis* x *P. arachnifera* hybrids did not perform as well under these conditions as might be expected (Fig. 2), based on much of the marketing literature surrounding these hybrids. Several HBG cultivars, such as Solar Green, Fire and Ice, and Thermal Blue, were among the most sensitive to drought stress and lost 50% of their green cover as much as 10 days earlier than the most drought-tolerant lines (Fig. 2). With the exception of the HBG entries mentioned previously (i.e. Longhorn and 103-509), most of the HBG entries tested in this trial were in the bottom half of the trial in relation to drought tolerance. It should be noted that these cultivars did not experience any significant heat stress during the experimental periods, which could affect their response to drought.

Collectively, these studies demonstrate that selecting appropriate cultivars can have a significant impact on turf responses to long-term drought stress. The delay in drought stress response 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. These results also suggest that improvements in drought tolerance in KBG may not necessarily occur by making crosses with other *Poa* spp., unless the parents used for those crosses are also determined to have improved drought tolerance characteristics. 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, has proven 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.

As a follow-up to these studies, in which superior drought tolerance has been documented, research is underway to ascertain the actual water savings that might be realized in the landscape when using cultivars identified with these methods. Preliminary findings across multiple turfgrass species suggest that a water savings of approximately 50% can be realized when comparing the best to the worst cultivars identified with these methods (Hignight, unpublished data). As such, these grasses have the potential to significantly reduce water needs in urban environments if coupled with appropriate irrigation system design and use. Furthermore, numerous public and private entities are also engaging in a process to develop a “branding” mechanism for drought-tolerant grasses that will provide consumers with easy access to these superior turfgrass cultivars.

REFERENCES

Abraham, E. M, B. Huang, S. Bonos, and W.A. Meyer. 2004. Evaluation of drought resistance for Texas bluegrass, Kentucky bluegrass, and their hybrids. Crop Sci. 44:1746-1753.

Asay, K.H., K.B. Jensen, and B.L. Waldron. 2001. Responses of tall fescue cultivars to an irrigation gradient. Crop Sci. 41:350-357.

Beard, J.B., and R.L. Green. 1994. The role of turfgrasses in environmental protection and their benefits to humans. J. Environ. Qual. 23:452-460.

Beard, J.B. 1993. The xeriscaping concept: What about turfgrasses. Int. Turfgrass Soc. Res. J. 7: 87-98.

Feldhake, C.M., R.E. Danielson, and J.D. Butler. 1984. Turfgrass evapotranspiration: II. Responses to deficit irrigation. Agron. J. 76:85-89

Karcher, D.E., M.D. Richardson, K. Hignight, and D. Rush. 2008. Drought tolerance of tall fescue varieties selected for high root:shoot ratios. Crop Sci. 48:771-777.

Motulsky, H.J. and A. Christopoulos. 2003. Fitting models to biological data using linear and nonlinear regression: a practical guide to curvefitting. GraphPad Software, Inc. San Diego, CA. www.graphpad.com.

Murphy, J.A., S. Bonos, and P. Perdomo. 1997. Classification of Poa pratensis genotypes. Int. Turfgrass Soc. Res. J. 8:1176-1183.

Richardson, M.D., D.E. Karcher, and L.C. Purcell. 2001. Quantifying turfgrass cover using digital image analysis. Crop Sci. 41:1884-1881.

Richardson, M.D., D.E. Karcher, K. Hignight, and D. Rush. 2008. Drought tolerance and rooting capacity of Kentucky bluegrass cultivars. Crop Sci. 48:2429–2436.

Richardson, M.D., D.E. Karcher, K. Hignight, and D. Rush. 2009. Drought tolerance of Kentucky bluegrass and hybrid bluegrass cultivars. Online. Applied Turfgrass Science doi:10.1094/ATS-2009-0112-01-RS.

Table 1. Experimental entries tested in two drought studies.

Expt. 1 – Kentucky bluegrass		Expt. 2 – KY and hybrid bluegrass	
Entry	Classification[†]	Entry	Species
Festina	Aggressive	1A3-1015	*P. pratensis*
Larissa	Aggressive	1QG-38	*P. pratensis*
Limousine	Aggressive	AKB287	*P. pratensis*
Touchdown	Aggressive	AKB449	*P. pratensis*
Yvette	Aggressive	AKB958	*P. pratensis*
Diva	Compact	Arrow	*P. pratensis*
Boutique	Compact-America	Bluestone	*P. pratensis*
Brilliant	Compact-America	Broadway	*P. pratensis*
Mallard	Compact-America	Cadet	*P. pratensis*
Royale'	Compact-America	Julius	*P. pratensis*
SR 2284	Compact-America	Mallard	*P. pratensis*
Unique	Compact-America	Midnight	*P. pratensis*
Midnight	Compact-Midnight	Pp H8510	*P. pratensis*
Julia	Julia	Royce	*P. pratensis*
PST-99LM-15	Ky x Tx Hybrid	103-509	*P. pratensis x P. angustifolia*
Eagleton	Mid-Atlantic	103-630	*P. pratensis x P. angustifolia*
RSP	Mid-Atlantic	1A4-312	*P. pratensis x P. angustifolia*
Cocktail	No classification	A00TB-101	*P. pratensis x P. arachnifera*
Cynthia	Other	A00TB-99	*P. pratensis x P. arachnifera*
Geronimo	Other	A03TB-256	*P. pratensis x P. arachnifera*
Mercury	Other	A03TB-390	*P. pratensis x P. arachnifera*
Monte Carlo	Other	A03TB-417	*P. pratensis x P. arachnifera*
		A03-TB-676	*P. pratensis x P. arachnifera*
		A03TB-708	*P. pratensis x P. arachnifera*
		A03TB-795	*P. pratensis x P. arachnifera*
		A04TB-192	*P. pratensis x P. arachnifera*
		Fire & Ice	*P. pratensis x P. arachnifera*
		Longhorn	*P. pratensis x P. arachnifera*
		Solar Green	*P. pratensis x P. arachnifera*
		Thermal Blue	*P. pratensis x P. arachnifera*
		1A4-529	*P. pratensis x P. densa*
		1A4-221	*P. pratensis x P. nemoralis*

[†] Based on descriptions provided by Murphy et al., 1997.

Figure 1. 95% confidence intervals for the number of days after water was withheld until Kentucky bluegrass entries (Expt. 1) reached 75%, 50%, and 25% green cover. Entries with overlapping bars were not significantly different.

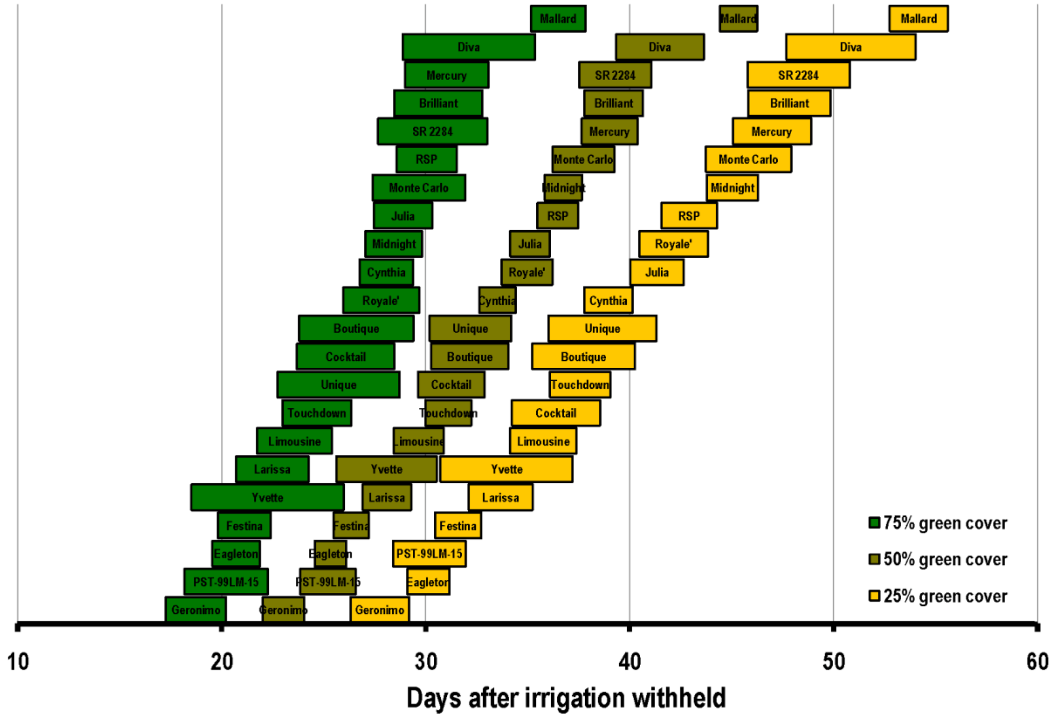

Figure 2. 95% confidence intervals for the number of days after water was withheld until bluegrass entries (Expt. 2) reached 75%, 50%, and 25% green cover. Entries with overlapping bars were not significantly different.