

Diversity of 42 bermudagrass cultivars in a reduced light environment

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Abstract

Morphological limitations, such as reduced lateral stem growth, reduced stress resistances to unfavorable environments and pests, and overall reduction of carbohydrate synthesis contribute to bermudagrass (*Cynodon* spp.) decline under shade. Due to shade sensitivity and possible genetic variability of bermudagrasses, a two-year replicated greenhouse study in 2005 and 2006 determined the shade tolerance of 42 bermudagrass cultivars selected from the 2002 National Turfgrass Evaluation Program (NTEP). Cultivars were subjected to 64% continuous artificial shade for 60 days. Data collection included visual turfgrass quality (TQ), shoot chlorophyll concentration, root length, and total root biomass. Seeded cultivars included 'Sunstar', 'B-14', 'SWI-1003', 'SWI-1012', 'SWI-1014', 'SWI-1041', 'SWI-1044', 'SWI-1045', 'SWI-1046', 'Arizona Common', 'Numex Sahara', 'Princess 77', 'Mohawk', 'FMC-6', 'SWI-1001', 'Sundevil', 'Southern Star', 'Riviera', 'Transcontinental', 'CIS-CD5', 'CIS-CD6', 'CIS-CD7', 'Panama', 'La Paloma', 'Yukon', 'TiftNo.1', 'TiftNo.2', and 'Sunbird'. Vegetative cultivars included 'TiftNo.3', 'TiftNo.4', 'Tifway', 'Midlawn', 'Tifsport', 'MS-Choice', 'Aussie Green', 'GN-1', 'Premier', 'Ashmore', 'Patriot', 'OKC 70-18', and 'Celebration'. Cultivars with best shade tolerance were Celebration, TiftNo.4, TiftNo.1, and Transcontinental. Cultivars with intermediate shade tolerance included Aussie Green, MS-Choice, Princess 77, SWI-1045, SWI-1041, and SWI-1012. Most shade sensitive cultivars included SWI-1014, Arizona Common, Sundevil, SR 9554, GN-1, and Patriot.

INTRODUCTION

Bermudagrass (*Cynodon* spp.), a C₄ plant, growth and development is interrupted when light interception is reduced. In shade, warm-season turfgrass decline is attributed to morphological limitations, such as reduced lateral stem growth (Beard, 1997). A shaded micro-

environment initiates excessive shoot vertical growth, depleting turfgrass root carbohydrate status (Qian and Engelke, 1999). Previous warm-season and cool-season turfgrass evaluations have noted a linear relationship as shade increases, vertical shoot growth increases (Qian et al., 1998; Tegg and Lane, 2004).

Bermudagrasses continue to be the preferred turfgrass species used as variable turf types in the southern United States (McCarty and Miller, 2002; McCarty, 2005), however, its use is often limited when optimal light interception is interrupted. For example, a 'TifEagle' bermudagrass putting green requires $32.6 \text{ mol m}^{-2} \text{ d}^{-1}$ for acceptable turfgrass quality (≥ 7) (Bunnell et al., 2005a), while 'Floradwarf' and Tifdwarf bermudagrass requires $38.6 \text{ mol m}^{-2} \text{ d}^{-1}$ for sustained growth (Miller et al., 2005). Cultural practices to enhance warm-season turfgrass TQ under shade includes raising mowing heights (Bunnell et al., 2005b; White, 2004), reducing nitrogen rates (Bunnell et al., 2005b; Goss et al., 2002; Bell and Danneberger, 1999; Burton et al., 1959), applying plant growth regulators (Bunnell et al., 2005b; Ervin et al., 2003; Qian et al., 1998; Qian and Engelke, 1999), and watering deeply and infrequently (Dudeck and Peacock, 1992).

Variation among C4 turfgrasses shade sensitivity has been previously investigated. Bunnell et al. (2005c) reported 'Meyer' Japanese zoysiagrass (*Zoysia japonica* Steud.) had greatest shade tolerance maintaining acceptable TQ (>7) at 71%, 'Celebration' bermudagrass at 58%, and 'TifSport' and 'Tifway' bermudagrass at 41% continuous shade. Jiang et al. (2004) noted significant variation between seashore paspalum (*Paspalum vaginatum* Swartz) and bermudagrass entries under 70% and 90% shade. 'Sea Isle 1' and 'Temple 1' paspalum were shade tolerant, while TifSport and TifEagle bermudagrass showed least shade tolerance. In a similar study, Jiang et al. (2005) also noted greater shade tolerance of Sea Isle 1 compared to TifSport bermudagrass. Gaussoin et al. (1988) noted the diversity of 32 bermudagrass cultivars under 90% uninterrupted shade. According to results, 'Boise', 'No Mow', and 'NM 2-13' were relatively shade tolerant, while 'Arizona Common' and 'Santa Ana' were relatively shade sensitive. Due to the genetic variation and diversity among existing bermudagrass cultivars, it is critical to continue shade tolerance evaluation of new bermudagrass cultivars. Therefore, the objectives of this research were to evaluate bermudagrass growth and determine the diversity of 42 bermudagrass cultivars maintained at 64% reduced irradiance.

MATERIALS AND METHODS

This two-year greenhouse study was conducted from 15 June 2005 to 15 August 2005 and repeated in 2006 at Clemson University (Clemson, SC). Greenhouse conditions averaged 30.8°C /26.2°C high/low air temperature and 73% relative humidity for both years. Environmental conditions (temperature and humidity) were maintained by an automated computer recording system (Argus Controls, Whiterock, British Columbia V4B 3Y9).

This study consisted of two treatments including a control (full-sun) and 64% continuous shade applied daily using a neutral density, polyfiber black shade cloth (Glenn Harp and Sons, Inc., Tucker, GA). Shade clothes were placed on a polyvinyl chloride (PVC) structure 15.2 cm in length and 12.7 cm in diameter with 2.5 cm diameter PVC pipes. Shade tents were 30.48 cm above the turf surface to reduce early morning and late afternoon sunlight encroachment. Photon flux density ($\mu\text{mol m}^{-2} \text{s}^{-1}$) and light quality were measured on a clear, cloudless day using a quantum radiometer (Model LI-250, LiCor, Lincoln, NE) and spectroradiometer (Model LI-1800; LiCor, Inc., Lincoln, NE). Surface temperatures for both treatments were recorded twice on a clear/cloudless day using an indoor/outdoor thermometer (model# 1455, Taylor, Oakbrook, IL).

Plugs were collected from the 2002 Bermudagrass National Turfgrass Evaluation Program (NTEP) field research plots located at Clemson University and transplanted into cone-tainers with 85% sand and 15% peat as growth media. Cone-tainer dimensions were 25.4 cm in height and 5.1 cm in diameter. Following potting, plugs were established one month prior to treatment initiation. Fertilizers were provided at 49 kg N ha⁻¹ on 1 d and 30 d using a complete fertilizer (16N-1.7P-6.6K) with a slow release urea and micronutrients (kg ha⁻¹): Calcium, 6; Magnesium, 3; Sulfur, 9; Boron, 0.06; Copper, 0.03; Iron, 0.3; Manganese, 0.15; Molybdenum, 0.0015; and Zinc, 0.15. Cone-tainers were mowed at a height of 12.8 mm four times a week with clipping removal.

Data collection was identical in year I and II. Turfgrass quality ratings were recorded after 4 and 8 weeks of shade exposure based on a subjective combination of color, density, texture, and uniformity of the bermudagrass surface. Quality was visually evaluated from 1 to 9, 1 = brown, dead turf, 6 = minimal acceptable turf, 9 = ideal green, healthy turf.

Root biomass (g) and length (cm) were determined at the end of the study. Roots were extracted from the soil and thoroughly washed until all soil was removed. Following soil

removal, root length was measured from the base of the thatch to the longest fully extended root present. Roots were then clipped from the base of thatch and dried in an oven at 80.0 °C for 48 hours. Once dried, samples were weighed to determine total root biomass.

Chlorophyll (mg g^{-1}) was recorded at week 4 and 8. Clippings were collected from each cone-tainer and immediately placed in a plastic bag inside a covered bucket to prevent sunlight degradation. Clippings were weighed (0.1 g) and placed in a glass test tube (1.0 cm in width and 14.8 cm in length) with 10 ml of dimethyl sulfoxide (DMSO) (Hiscox and Israelstam, 1979). Samples were incubated in 65 °C water on a hot plate (PC-600, Corning, Corning, NY) for 1.5 hours and continuously shaken. Upon completion, samples were passed through filter paper (Whatman 41, Whatman, England) and remaining extract (2 ml) was transferred into cuvettes. The absorbance values were recorded at 663 nm and 645 nm wavelengths using a spectrophotometer (Genesys™ 20, ThermoSpectronic, Rochester, NY). The following formula was used to calculate total chlorophyll = $(8.02 * D_{663} + 20.2 * D_{645}) * 0.1$ (Arnon, 1949).

Data Analysis

Each treatment was replicated three times in a randomized complete block design. Data from both years were combined as year I x year II interactions were not significant. All statistical computations were conducted using analysis of variance (ANOVA) within the Statistical Analysis System (SAS Institute, 2005) with means separated by Fisher's Least Significance Difference (LSD) test. An alpha of 0.05 was used to determine statistical significance.

RESULTS

Micro-environment

Compared to full-sun, shade cloths reduced temperatures 13%, while no difference in light quality were detected. Although light quality has been shown to impact turfgrass growth (Wherley et. al., 2005), the focus of this study was stadium (artificial) shade. The greenhouse glass provided an additional 9% reduction in solar irradiance for all treatments.

Turfgrass Quality

Most cultivars visual TQ scores dropped well below acceptable threshold of 6 following 4 weeks of 64% continuous shade (Table 1). Poorest performing cultivars included NuMex

Sahara (3.8), Arizona Common (4.2), B-14 (4.3), and Panama (4.3), while Aussie Green (7.2), Celebration (6.5), TiftNo.4 (6.2), TiftNo.1 (6.3), Sunbird (6.2), and Transcontinental (6.0) maintained acceptable TQ ratings following 4 weeks of 64% shade. Industry standards, Tifway and TifSport, had TQ scores of 5.0 and 5.5, respectively. After 8 weeks of continuous 64% shade, all cultivars had severe tissue discoloration (Table 2). However, Aussie Green (5.3), TiftNo.4 (4.8), and Celebration (4.5) maintained significantly higher TQ scores compared to Patriot (2.5), Premier (2.7), NuMex Sahara (2.7), Panama (2.7), La Paloma (2.8), and Midlawn (2.8). In the absence of shade, most cultivars maintained or showed near acceptable TQ by week 8.

Within week 4 TQ ratings, shade grown cultivars Transcontinental, CIS-CD6, Aussie Green, Celebration, TiftNo.1, TiftNo.2, TiftNo.4, and Mohawk did not have significant TQ reductions compared to full-sun. However, within week 8, all cultivars grown in shade had a significant decline in TQ compared to full-sun ratings.

Chlorophyll

Significant variations occurred for shoot chlorophyll concentrations at weeks 4 and 8 (Table 2). The shade-grown cultivar with highest chlorophyll was TiftNo.4 at week 4 (2.47) and week 8 (2.77), while TifSport and Arizona Common had lowest chlorophyll concentrations at week 4 (1.54) and week 8 (1.31), respectively. SWI-1003, SWI-1041, Princess 77, and TiftNo.1 had ~33% greater chlorophyll than Tifway, Southern Star, GN-1, and Arizona Common at this time. By week 8, SWI-1003, SWI-1012, SWI-1045, SWI-1046, SWI-1041, and Celebration had ~45% greater chlorophyll when grown in shade than GN-1, SWI-1014, NuMex Sahara, OKC 70-18, B-14, and Ashmore.

SWI-1041, TiftNo.1, and Yukon produced significantly higher chlorophyll concentrations at week 4 when grown in shade compared to full-sun, however, this response was transient (Table 2). Transient increases in chlorophyll content have previously been reported under other environmental stresses (Jiang and Huang, 2001). Within week 8, many cultivars chlorophyll concentration declined. Compared to full-sun, shade-grown cultivars Ashmore, SWI-1014, B-14, and Premier, had a ~66% decline in chlorophyll, while SWI-1046, La Paloma, Aussie Green, and Midlawn showed a ~28% chlorophyll reduction.

Root Length

Overall, root length was least affected by shade compared to other parameters measured. No significant variations were noted for root length when grown in full-sun (Table 3). Cultivars grown under 64% shade had some statistically different root length variation. Most striking differences were TiftNo.2 producing 89% greater root length than Arizona Common, while SWI-1014 had a 57% root length reduction compared to Riviera. Shade-grown Arizona Common, SWI-1014, and Sundevil, had a 63%, 59%, and 41% decrease, respectively, compared their sun-grown counterparts.

Root Biomass

Each cultivar, regardless of shade tolerance or sensitivity, had a significant reduction in root biomass (Table 4). Under shade, cultivars with least root mass reduction (-121%) included B-14, NuMex Sahara, TiftNo.3, and MS-Choice, while cultivars with greatest root mass decline (-325%) included SWI-1001, SR9554, and Yukon, compared to full-sun. In addition, shade-grown SR9554 had a 265% decrease in root biomass compared to SWI-1003. Celebration and TiftNo.2 also produced -124% greater root biomass when grown in shade compared to Arizona Common and GN-1.

DISCUSSION

These results suggest great potential for future breeding of bermudagrass focusing on shade tolerance improvement. Bermudagrass cultivars, especially newer ones, demonstrated great diversity. Based on rank of significant parameters (TQ, chlorophyll, root biomass, and root length), best cultivars were Celebration, TiftNo.4, TiftNo.1, and Transcontinental. Cultivars with intermediate shade tolerance included Aussie Green, MS-Choice, Princess 77, SWI-1045, SWI-1041, and SWI-1012. Most shade sensitive cultivars were SWI-1014, Arizona Common, Sundevil, SR 9554, GN-1, and Patriot (Table 5).

The most consistent performing cultivar across all parameters was Celebration. When grown in shade, Celebration was able to consistently maintain TQ, chlorophyll, root length, and root biomass in the top statistical category. In a previous investigation, Celebration was noted for its relative shade tolerance (Bunnell et al., 2005c). At 71% shade, Celebration and 'Meyer' zoysiagrass maintained similar TQ scores at a 25 mm mowing height, while Tifway and TifSport were deemed commercially unacceptable. In this study, Celebration had TQ scores of 6.5 and

4.5 at weeks 4 and 8, respectively, while Tifway and TifSport TQ scores were consistently lower throughout the duration of the 8-week study (Table 1). Jiang et al. (2004 and 2005) also noted TifSport bermudagrass as shade sensitive when compared to various seashore paspalum cultivars. Gaussoin et al. (1998) noted Tifway as shade sensitive when compared to 31 other bermudagrass cultivars.

Arizona Common was in the lowest statistical category for all parameters measured when grown in shade. In another greenhouse shade study, Gaussoin et al. (1988) regarded Arizona Common as highly shade-intolerant. Similar results in this study were noted as Arizona Common did not rank in the top statistical category for any of the measured parameters, indicating relative shade sensitivity (Table 5).

While relatively shade-tolerant cultivars were identified in this study, all cultivars, including shade tolerant ones, had unacceptable TQ scores. Future research will further analyze the relatively shade-tolerant and shade-intolerant cultivars to provide insight into the physiological mechanisms associated with such variation that exists among bermudagrass shade responses.

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Table 1. Turfgrass quality of 42 bermudagrass cultivars after 4 and 8 weeks of full-sun (control) and 64% continuous shade at the Clemson University greenhouse research complex.

Cultivar	Week 4		Week 8		Rank ^z
	Full-Sun	Shade	Full-Sun	Shade	
Celebration	7.5a-c ^y	6.5ab	7.3a-d A	4.5a-c B	2/2
TiftNo.4	7.3a-d	6.2a-d	7.8a A	4.8ab B	2/2
TiftNo.1	7.2b-e	6.3a-c	7.2a-d A	4.3a-dB	2/2
Transcontinental	7.0c-f	6.0a-e	6.8b-fA	4.3a-d B	2/2
SWI-1003	8.0a A ^x	5.7b-fB	7.3a-dA	3.5c-i B	0/2
Sunbird	7.5a-c A	6.2a-d B	7.3a-d A	4.3a-d B	2/2
Aussie Green	7.5a-c	7.2a	7.8a A	5.3a B	2/2
MS-Choice	6.8c-g A	5.8b-e B	7.3a-dA	3.7c-hB	0/2
Princess 77	7.2b-e A	5.3b-h B	6.8b-fA	3.7c-hB	0/2
SWI-1045	7.2b-e A	5.5b-g B	7.0a-e A	3.7c-hB	0/2
SWI-1041	7.8ab A	5.3b-hB	7.3a-dA	3.5c-i B	0/2
SWI-1012	7.0c-fA	5.3b-hB	7.0a-e A	4.0b-fB	0/2
B-14	6.3f-i A	4.3g-i B	6.0fg A	3.0f-i B	0/2
Riviera	7.2b-e A	5.7b-fB	7.7ab A	3.7c-h B	0/2
SWI-1046	7.2b-e A	5.3b-h B	6.7c-fA	4.0b-fB	0/2
TiftNo.3	6.7d-hA	4.8e-i B	6.5d-fA	4.0b-fB	0/2
Southern Star	7.0c-fA	5.3b-hB	6.8b-fA	3.7c-h B	0/2
TiftNo.2	6.8c-g	5.5b-g	7.0a-e A	4.2b-e B	0/2
Sunstar	6.3f-i A	4.5f-i B	6.2e-g A	3.2e-i B	0/2
SWI-1044	6.8c-g A	5.3b-h B	7.5a-c A	4.0b-fB	0/2
FMC-6	6.5e-i A	5.0d-i B	6.7c-fA	3.5c-i B	0/2
Mohawk	6.7d-hA	5.3b-hB	6.2e-g A	3.2e-i B	0/2
SWI-1001	6.8c-g A	4.8e-i B	7.0a-e	3.8b-gB	0/2
Tifway	7.5a-c A	5.0d-i B	7.5a-c A	3.2e-i B	0/2
Midlawn	6.5e-i A	4.8e-i B	6.5d-fA	2.8g-i B	0/2
Tifsport	7.2b-e A	5.5b-gB	7.7ab A	3.3d-i B	0/2
Premier	6.7d-hA	5.2c-h B	7.3a-d A	2.7hi B	0/2
Ashmore	6.8c-g A	4.8e-i B	6.7c-fA	3.2e-i B	0/2
CIS-CD5	6.2g-j A	5.0d-i B	6.8b-fA	3.3d-i B	0/2
CIS-CD6	6.3f-i	5.2c-h	7.0a-e A	3.3d-i B	0/2
CIS-CD7	6.7d-h A	5.3b-hB	6.8b-fA	3.2e-i B	0/2
Panama	6.2g-j A	4.3g-iB	7.2a-d A	2.7hi B	0/2
La Paloma	6.0h-j A	4.5f-i B	6.7c-fA	2.8g-i B	0/2
Yukon	7.0c-fA	5.5b-gB	7.3a-dA	3.2e-i B	0/2
OKC 70-18	7.0c-fA	4.8e-i B	7.0a-e A	3.2e-i B	0/2
NuMex Sahara	5.8ij A	3.8iB	6.0fg A	2.7hi B	0/2
SWI-1014	7.5a-c A	5.5b-gB	7.2a-dA	3.2e-i B	0/2
GN-1	6.2g-j A	4.5f-i B	6.2e-g A	3.2e-i B	0/2
Patriot	6.3f-i A	4.5f-i B	6.5d-fA	2.5iB	0/2
Sundevil	6.7d-h A	5.0d-i B	6.8b-fA	3.7c-hB	0/2
SR 9554	6.3f-i A	4.8e-i B	6.7c-fA	3.0f-i B	0/2
Arizona Common	5.5jA	4.2hi B	5.5gA	3.0f-i B	0/2
<i>P</i>	0.0001	0.0001	0.0001	0.0001	

^z Rank indicates number of times a cultivar placed in the top statistical category when grown under 64% shade. Greatest shade tolerance = 2/2, greatest shade sensitivity = 0/2.

^y Values within a column followed by the same letter are not significantly different at $P \leq 0.05$ by protected LSD.

^x Values within a row within in each week followed by the same letter are not significantly different at $P \leq 0.05$ by protected LSD.

^w Indicates statistical difference at $P \leq 0.05$.

Turfgrass quality based on a scale of 1 - 9, 1 = brown/dead turf, 6 = minimal acceptable turf, 9 = ideal green, healthy turf.

Table 2. Total shoot chlorophyll (mg g⁻¹) concentration of 42 bermudagrass cultivars after 4 and 8 weeks of full-sun (control) and 64% continuous shade at the Clemson University research greenhouse complex.

Cultivar	Week 4		Week 8		Rank ^z
	Full-Sun	Shade	Full-Sun	Shade	
Celebration	1.78b-h ^y	2.08a-e	2.64	2.24a-e	2/2
TiftNo.4	2.39a	2.47a	3.19	2.77a	2/2
TiftNo.1	1.70b-hB ^x	2.15a-eA	2.71	2.13b-f	1/2
Transcontinental	1.72b-h	1.95a-h	2.53	1.82c-j	1/2
SWI-1003	2.00b	2.30ab	2.97	2.31a-d	2/2
Sunbird	1.57d-h	1.90b-h	2.43	2.15b-f	0/2
Aussie Green	1.74b-h	1.92b-h	2.42 A	1.87c-jB	0/2
MS-Choice	1.89b-d	2.07a-e	2.24	1.75e-j	1/2
Princess 77	1.67b-h	2.22a-d	2.54	2.09b-h	1/2
SWI-1045	1.76b-h	2.10a-e	2.34	2.36a-c	2/2
SWI-1041	1.84b-fB	2.29a-c A	2.97	2.24a-e	2/2
SWI-1012	1.88b-d	1.95b-h	2.78	2.60ab	1/2
B-14	1.46gh	1.83d-h	2.45 A	1.69e-jB	0/2
Riviera	1.71b-h	1.91b-h	2.64	1.98c-i	0/2
SWI-1046	1.96bc	2.06b-e	2.75 A	2.22b-e B	0/2
TiftNo.3	1.48f-h	1.90b-h	2.13	2.13b-f	0/2
Southern Star	1.45gh	1.78e-h	2.18	2.11b-h	0/2
TiftNo.2	1.71b-h	1.93b-h	2.82	2.12b-g	0/2
Sunstar	1.42h	1.79e-h	2.19	1.88c-j	0/2
SWI-1044	1.93b-d	2.04b-f	2.58	2.03c-h	0/2
FMC-6	1.65b-h	1.85d-h	2.22	1.92c-j	0/2
Mohawk	1.50e-h	1.78e-h	2.18	2.06b-h	0/2
SWI-1001	1.89b-d	1.93b-h	2.33	1.90c-j	0/2
Tifway	1.84b-f	1.60gh	2.61	1.84c-j	0/2
Midlawn	1.83b-g	1.93b-h	2.57 A	1.95c-jB	0/2
Tifsport	1.81b-g	1.54h	2.56	1.98c-i	0/2
Premier	2.01b	1.93b-h	2.84 A	1.74e-j B	0/2
Ashmore	1.87b-e	1.85d-h	2.62 A	1.47ij B	0/2
CIS-CD5	1.78b-h	1.89b-h	2.55 A	1.82c-jB	0/2
CIS-CD6	1.56d-h	1.81d-h	2.24	1.71e-j	0/2
CIS-CD7	1.60c-h	1.87d-h	2.32	1.80d-j	0/2
Panama	1.80b-h	1.86d-h	2.52 A	1.77d-j B	0/2
La Paloma	1.67b-h	1.85d-h	2.14 A	1.68f-jB	0/2
Yukon	1.58d-hB	1.88c-hA	2.48 A	1.85c-jB	0/2
OKC 70-18	1.97bc	1.95-f	2.7 A	1.67f-jB	0/2
NuMex Sahara	1.85b-f	1.98b-g	2.52 A	1.56h-jB	0/2
SWI-1014	1.74b-h	1.85d-h	2.78 A	1.58g-j B	0/2
GN-1	1.88b-d	1.74e-h	2.48 A	1.67f-jB	0/2
Patriot	1.82b-g	1.86d-h	2.55 A	1.73e-jB	0/2
Sundevil	1.61c-h	1.88c-h	2.36	2.19b-f	0/2
SR 9554	1.69b-h	1.91b-h	2.38	1.78d-j	0/2
Arizona Common	1.62c-h	1.63f-h	2.09	1.43j	0/2
<i>P</i>	0.0021 ^w	0.0400	0.8000	0.0004	

^z Rank indicates number of times a cultivar placed in the top statistical category when grown under 64% shade. Greatest shade tolerance = 2/2, greatest shade sensitivity = 0/2.

^y Values within a column followed by the same letter are not significantly different at P≤0.05 by protected LSD.

^x Values within a row within each week followed by the same letter are not significantly different at P≤0.05 by protected LSD. ^w Indicates statistical difference at P≤0.05.

Table 3. Root length (cm) of 42 bermudagrass cultivars after 8 weeks of full-sun (control) and 64% continuous shade at the Clemson University research greenhouse complex.

Cultivar	Full-Sun	Shade	Rank ^z
Celebration	8.78	7.00a-d ^y	1/1
TiftNo.4	9.23	8.72a-d	1/1
TiftNo.1	9.20	8.27a-e	1/1
Transcontinental	9.62 A ^x	8.40a-e B	1/1
SWI-1003	8.87	8.97ab	1/1
Sunbird	9.43	8.30a-e	1/1
Aussie Green	9.35	8.9 1ab	1/1
MS-Choice	8.76	8.70a-d	1/1
Princess 77	9.78	8.08a-e	1/1
SWI-1045	9.47	8.18a-e	1/1
SWI-1041	9.93 A	8.52a-e B	1/1
SWI-1012	9.13	8.37a-e	1/1
B-14	9.45	8.90a-c	1/1
Riviera	9.52	9.03ab	1/1
SWI-1046	9.58 A	8.00a-e B	1/1
TiftNo.3	9.32	8.52a-e	1/1
Southern Star	9.53	9.25ab	1/1
TiftNo.2	9.43	9.60a	1/1
Sunstar	8.85	6.67c-g	0/1
SWI-1044	9.45	8.80a-c	1/1
FMC-6	9.10	7.60a-f	1/1
Mohawk	9.42 A	7.74a-fB	1/1
SWI-1001	9.08	8.42a-e	1/1
Tifway	9.45	8.63a-d	1/1
Midlawn	9.22	7.63a-f	1/1
Tifsport	10.23 A	8.87a-c B	1/1
Premier	8.70	8.78a-d	1/1
Ashmore	9.92	7.85a-f	1/1
CIS-CD5	10.13 A	8.28a-e B	1/1
CIS-CD6	9.45	8.33a-e	1/1
CIS-CD7	9.21	7.62a-f	1/1
Panama	8.27	8.27a-e	1/1
La Paloma	8.83	7.45a-f	1/1
Yukon	8.80	7.73a-f	1/1
OKC 70-18	8.30	8.75a-d	1/1
NuMex Sahara	9.32	7.50a-f	1/1
SWI-1014	9.15 A	5.75fgB	0/1
GN-1	8.97	7.05b-g	0/1
Patriot	8.39	6.37e-g	0/1
Sundevil	9.23 A	6.55d-g B	0/1
SR 9554	8.5 A	6.28e-g B	0/1
Arizona Common	8.3 A	5.08g B	0/1
<i>P</i>	0.07	0.05 ^w	

^z Rank indicates number of times a cultivar placed in the top statistical category when grown under 64% shade.

Greatest shade tolerance = 1/1, greatest shade sensitivity = 0/1.

^y Values within a column followed by the same letter are not significantly different at P≤0.05 by protected LSD.

^x Values within a row followed by the same letter are not significantly different at P≤0.05 by protected LSD.

^w Indicates statistical difference at P≤0.05.

Table 4. Total root biomass (g) of 42 bermudagrass cultivars after 8 weeks of full-sun (control) and 64% continuous shade at the Clemson University research greenhouse complex.

Cultivar	Full-Sun	Shade	Rank ^z
Celebration	0.201ab ^y A ^x	0.064a-e B	1/1
TiftNo.4	0.127d-1A	0.049b-m B	0/1
TiftNo.1	0.207a A	0.053a-kB	1/1
Transcontinental	0.179a-dA	0.067a-c B	1/1
SWI-1003	0.175a-eA	0.073a B	1/1
Sunbird	0.178a-dA	0.056a-j B	1/1
Aussie Green	0.095i-m A	0.038f-o B	0/1
MS-Choice	0.161a-hA	0.069ab B	1/1
Princess 77	0.173a-fA	0.059a-hB	1/1
SWI-1045	0.146b-jA	0.044c-m B	0/1
SWI-1041	0.149b-iA	0.048b-m B	0/1
SWI-1012	0.163a-hA	0.056a-j B	1/1
B-14	0.116f-mA	0.05 1a-lB	1/1
Riviera	0.189a-cA	0.061a-fB	1/1
SWI-1046	0.147b-j A	0.052a-l B	1/1
TiftNo.3	0.127d-1A	0.060a-g B	1/1
Southern Star	0.187a-cA	0.058a-i B	1/1
TiftNo.2	0.155a-hA	0.066a-dB	1/1
Sunstar	0.170a-gA	0.052a-l B	1/1
SWI-1044	0.126d-1A	0.045b-n B	0/1
FMC-6	0.113g-mA	0.050b-mB	0/1
Mohawk	0.124d-mA	0.04 1e-o B	0/1
SWI-1001	0.162a-hA	0.037g-o B	0/1
Tifway	0.118e-mA	0.041e-o B	0/1
Midlawn	0.067mA	0.025no B	0/1
Tifsport	0.146b-jA	0.042e-o B	0/1
Premier	0.091j-mA	0.032k-o B	0/1
Ashmores	0.163a-hA	0.041e-o B	0/1
CIS-CD5	0.133c-kA	0.033j-o B	0/1
CIS-CD6	0.095i-m A	0.036h-o B	0/1
CIS-CD7	0.151a-iA	0.050b-m B	0/1
Panama	0.115g-mA	0.031k-oB	0/1
La Paloma	0.097i-m A	0.034i-o B	0/1
Yukon	0.147b-j A	0.034j-o b	0/1
OKC 70-18	0.088k-m A	0.027m-o B	0/1
NuMex Sahara	0.085k-m A	0.040f-o B	0/1
SWI-1014	0.164a-hA	0.038g-o B	0/1
GN-1	0.108h-mA	0.029l-o B	0/1
Patriot	0.076lm A	0.030k-o B	0/1
Sundevil	0.110h-mA	0.043d-o B	0/1
SR 9554	0.081k-mA	0.020o B	0/1
Arizona Common	0.085k-m A	0.029l-o B	0/1
<i>P</i>	0.0001	0.0001	

^z Rank indicates number of times a cultivar placed in the top statistical category when grown under 64% shade. Greatest shade tolerance = 1/1, greatest shade sensitivity = 0/1.

^y Values within a column followed by the same letter are not significantly different at $P \leq 0.05$ by protected LSD.

^x Values within a row followed by the same letter are not significantly different at $P \leq 0.05$ by protected LSD. ^w Indicates statistical difference at $P \leq 0.05$.

Table 5. Overall shade tolerance rank of 42 bermudagrass cultivars after 8 weeks of full-sun (control) and 64% continuous shade at the Clemson University research greenhouse complex.

Cultivar	Rank ^z	Cultivar	Rank
Celebration	6	Mohawk	1
TiftNo.4	5	SWI-1001	1
TiftNo.1	5	Tifway	1
Transcontinental	5	Midlawn	1
SWI-1003	4	Tifsport	1
Sunbird	4	OR 2002	1
Aussie Green	3	Ashmore	1
MS-Choice	3	CIS-CD5	1
Princess 77	3	CIS-CD6	1
SWI-1045	3	CIS-CD7	1
SWI-1041	3	Panama	1
SWI-1012	3	La Paloma	1
B-14	2	Yukon	1
Riviera	2	OKC 70-18	1
SWI-1046	2	NuMex Sahara	1
TiftNo.3	2	SWI-1014	0
Southern Star	2	GN-1	0
TiftNo.2	2	Patriot	0
Sunstar	1	Sundevil	0
SWI-1044	1	SR 9554	0
FMC-6	1	Arizona Common	0

^z Rank indicates number of times a cultivar placed in the top statistical category when grown under 64% continuous shade. Greatest shade tolerance = 6, greatest shade sensitivity = 0.