Clemson University Study

Summary

- Three Bermudagrass cultivars and Meyers Japanese Zoysiagrass were evaluated for shade tolerance
- Bermudagrass cultivars included Tifway, Tifsport and Celebration

Results

- Celebration rated #1 for Shade Tolerance among bermudagrass cultivars

EVALUATION OF THREE BERMUDAGRASS CULTIVARS AND MEYER JAPANESE ZOYSIAGRASS GROWN IN SHADE

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ABSTRACT

Shade can be a major growth limiting factor to bermudagrasses (Beard, 1997; Jones, 1985; McBee and Holt, 1966; Nada, 1980). Bermudagrass cultivars have been documented to differ in shade tolerance (Gaussoin et al., 1988; McBee and Holt, 1966). This study evaluated the turfgrass performance and total non-structural carbohydrates of three bermudagrass cultivars: 'Tifway' [*Cynodon dactylon* (L.) Pers. x *C. transvaalensis* Burtt-Davy], 'TifSport' [*Cynodon dactylon* (L.) Pers. x *C. transvaalensis* Burtt-Davy], and 'Celebration' [*Cynodon dactylon* (L.) Pers.] and 'Meyer' Japanese zoysiagrass (*Zoysia japonica* Steud.) at two mowing heights (16 and 25 mm) under continuous shade exposure. Four shade treatments (0, 41, 58, and 71%) were applied continuously during the summer and autumn months of 2002 and 2003 to turfgrasses grown in pots. The resulting Daily Total of PAR (photosynthetically active radiation) (DTP; mol m^{-2} d^{-1}) was calculated for each shade level. Meyer Japanese zoysiagrass maintained acceptable turfgrass quality under 71% shade cloth during summer months at both mowing heights. Celebration demonstrated best shade tolerance among bermudagrass cultivars, with acceptable turf quality under 58% shade cloth during both summer and autumn months. Tifway and TifSport maintained acceptable TQ under 41% shade. Under 58 and 71% shade, total non-structural carbohydrate (TNC) concentration of roots and rhizomes did not differ among the three bermudagrass cultivars and Meyer Japanese zoysiagrass at equal mowing heights. A curvilinear decrease in TNC content of roots and rhizomes occurred with decreasing DTP among all turfgrasses.

Abbreviations

DTP, daily total of PAR; PAR, photosynthetically active radiation; PPF, photosynthetic photon flux; SE, standard error; TNC, total non-structural carbohydrates. TQ, turfgrass quality; USGA, United States Golf Association; WAS, weeks after shading.

Keywords

daily total of PAR, mowing height, total non-structural carbohydrates, turf quality

INTRODUCTION

Hybrid bermudagrass (*Cynodon dactylon* (L.) Pers. x *C. transvaalensis* Burtt-Davy) and Meyer Japanese zoysiagrass (*Zoysia japonica* Steud.) are popular grasses for use on golf course fairways/tees, athletic fields, and home lawns in the southern United States. A major factor limiting growth of *Cynodon* species is their lack of shade tolerance (Beard, 1997; Gaussoin et al., 1988). Reductions in turfgrass performance, non-structural carbohydrates, and chlorophyll content have been observed in several bermudagrass cultivars grown under shade (Coffey and Baltensperger, 1989; Gaussoin et al., 1988; McBee and Holt, 1966; Winstead and Ward, 1974). A glasshouse study in New Mexico found that Tifway, 'Santa Ana', and 'AZ Common' had the least shade tolerance while 'Boise', 'No Mow', and 'Common' had the highest shade tolerance (Gaussoin et al., 1988).

Several studies have evaluated the performance of various zoysiagrass cultivars in shaded environments. A Texas study found 'Diamond' zoysiagrass (*Zoysia matrella* (L.) Merr.) maintained acceptable turfgrass quality (TQ) for 3 months under 73% continuous shade cloth (Qian and Engelke, 1997). In a similar study, a linear decrease in total non-structural carbohydrates (TNC) of roots occurred with increasing shade levels to 'Diamond' zoysiagrass (Qian and Engelke, 1999). Ervin et al. (2002) reported a significant loss of turfgrass quality with high shade (77 and 89%) on Meyer Japanese zoysiagrass.

Previous research has demonstrated that the turfgrass quality, performance, and total non-structural

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Table 1. Soil physical properties of sand used in cultivar shade evaluations at Clemson University compared with USGA recommendations for golf green root zone media.

Sample	Particle Density ($g\ cm^{-3}$)	Bulk Density ($g\ cm^{-3}$)	Infiltration Rate ($cm\ h^{-1}$)	Total Porosity %	Aeration Porosity %	Capillary Porosity %	Organic Matter %
Clemson Mix	2.64	1.41	17	46.8	23.4	23.3	1.4
USGA Value	—	1.3-1.6	15-60	33-58	15-30	15-25	0.7-3.0

Table 2. Average, maximum, and minimum daily total of PAR (DTP; mol $m^{-2}\ d^{-1}$) of four levels of shade (0, 41, 58, and 71%) in Clemson, SC during 2002 and 2003. DTP means are followed by ± SE of solar sunlight over 12 and 8 wk studies in 2002 and 2003, respectively.

		Daily Total of PAR			
		% Shade Level			
Year	Quantity	0	41	58	71
		mol $m^{-2}\ d^{-1}$			
2002	Mean	28.2 ± 1.49†	16.7 ± 0.88	11.9 ± 0.63	8.2 ± 0.43
	Maximum	52.2‡	31.3	21.9	15.1
	Minimum	3.8	2.3	1.5	1.1
2003	Mean	43.9 ± 0.96†	25.9 ± 0.57	18.4 ± 0.40	12.7 ± 0.28
	Maximum	59.3‡	35.0	24.9	17.2
	Minimum	26.6	15. 7	11.2	7.7

† DTP of 2002 study measured from 29 July to 31 October; 2003 study from 7 July to 31 August.

‡ Maximum and minimum DTP for 2002 occurred on 30 July and 29 October, respectively. In 2003, maximum and minimum DTP occurred on 12 July and 10 July, respectively.

carbohydrate content of bermudagrass and zoysiagrass cultivars can vary under various percentages of shade cloth (Ervin et al., 2002; Gaussoin et al., 1988; Qian and Engelke, 1997; 1999). Therefore, the objective of this study was to evaluate the turfgrass performance and total non-structural carbohydrate concentration of three bermudagrass cultivars and Meyer Japanese zoysiagrass maintained at 4 levels of continuous shade (0, 40, 58, and 71%) and two mowing heights (16 and 25 mm) during summer and autumn months. Two hybrid bermudagrass cultivars are industry standards, Tifway and TifSport bermudagrass. The third cultivar, Celebration bermudagrass is a new cultivar from Australia with potential shade tolerance. In the second year, Meyer Japanese zoysiagrass was added to evaluate its performance under various treatments of continuous shade.

MATERIALS AND METHODS

A two-year evaluation was performed during 2002 and 2003 in Clemson, SC. The 2002 study was performed during the late-summer and early-autumn months from 29 July to 31 October. The 2003 study was performed during the summer from 7 July to 31 August. Turf was grown in 15 cm diameter by 20 cm deep plastic pots with four drainage outlets. Growing medium was a 85:15 (v:v) sand: sphagnum peat mix meeting USGA greens specifications (Table 1) (USGA, 1993). Certified mature soil-washed sod of each cultivar was harvested. Ten cm diameter turfgrass plugs were cut from the sod, planted in the pots, and allowed to establish in full sunlight for 3 wks prior to imposing the shade treatments. Weekly applications of 49 kg N ha^{-1} were made using a Peters 20N-8.8P-16.6K water-soluble complete liquid fertilizer with micronutrients (Spectrum Group, St. Louis, MO) during establishment. Samples were watered daily with a potable water source to prevent wilting. After establishment, the turfgrass was fertilized bi-weekly.

Four levels of shade were applied continuously using a neutral density, poly-fiber black shade cloth. Shade levels were 0, 41, 58, and 71%, therefore allowing 100, 59, 42, and 29% of full sunlight (International Greenhouse, model # SC-BL40, SC-BL60, and SC-BL70, Sidel, IL). Percent shade was determined by comparing photosynthetic photon flux (PPF; ˜µmol $m^{-2}\ s^{-1}$) under shade cloths at the turfgrass canopy to full sunlight measurements with a hand-held LI-190SA quantum sensor (LiCor; Lincoln, NE). PPF and infra-red canopy temperature measurements (Raynger ST2, Raytek; Santa Cruz, CA) were taken twice during each year on clear, cloud-free days between 1200 and 1400 h. Shade cloth reduced canopy temperature approximately 1 to 2 °C, regardless of shade level. Light quality measurements were made with a spectroradiometer (LI-1800; LiCor Inc., Lincoln, NE) under shade tents. No differences in red: far-red were detected among shade treatments. Shade cloth (2 m long and 1.5 m wide) was supported by 2.5 cm diameter PVC structure of the same dimensions. Shade tents were supported 30 cm above the turfgrass. Shade tent dimensions and directional orientation prevented low angle incidence sunlight during early-morning and late-evening hours.

Table 3. Turfgrass quality of Celebration, Tifway, and TifSport bermudagrasses in response to different shade (0, 41, 58, 71%) and mowing heights (16 and 25 mm) in Clemson, SC from 29 July to 31 October, 2002.

Cultivar	% Shade Level	Turfgrass Quality† Mowing Height, mm 16	25
		1-9	
Celebration	0	7.3 bc‡	7.5 b
TifSport	0	7.7 ab	8.0 a
Tifway	0	7.8 a	7.8 a
Celebration	41	7.3 bc	7.8 a
TifSport	41	7.2 c	7.8 a
Tifway	41	7.4 bc	7.8 a
Celebration	58	6.6 d	7.2 c
TifSport	58	5.6 f	6.7 e
Tifway	58	6.2 e	6.7 e
Celebration	71	6.2 e	6.9 d
TifSport	71	5.5 f	6.7 e
Tifway	71	5.8 f	6.7 e

† Turfgrass quality ratings were measured at 4, 6, 8, and 12 weeks after shading on a 1-9 scale, with 1=dead turf. TQ<7 is deemed commercially unacceptable.

‡ Within mowing heights, means followed by the same letter are not significantly different according to Fisher's LSD (α=0.05) test.

Table 4. Turfgrass quality of Celebration, Tifway, and TifSport bermudagrasses and Meyer Japanese zoysiagrass in response to different shade (0, 41, 58, 71%) and mowing heights (16 and 25 mm) in Clemson, SC from 6 July to 29 August, 2003.

Cultivar	% Shade Level	Turfgrass Quality† Mowing Height, mm 16	25
		1-9	
Celebration	0	7.8 ab‡	7.8 ab
TifSport	0	7.7 ab	7.8 ab
Tifway	0	7.8 ab	8.0 a
Meyer	0	8.0 a	8.0 a
Celebration	41	7.7 b	7.9 ab
TifSport	41	7.5 bc	7.8 ab
Tifway	41	7.6 bc	7.8 abc
Meyer	41	8.0 a	8.0 a
Celebration	58	7.0 d	7.4 de
TifSport	58	5.9 e	6.7 f
Tifway	58	5.8 e	6.4 f
Meyer	58	7.3 c	7.6 bcd
Celebration	71	6.7 d	7.2 e
TifSport	71	5.2 f	5.9 g
Tifway	71	5.2 f	5.9 g
Meyer	71	7.3 c	7.5 cd

† Turfgrass quality ratings were measured at 2, 4, 6, and 8 weeks after shading on a 1-9 scale, with 1=dead turf. TQ<7 is deemed commercially unacceptable.

‡ Within mowing heights, means followed by the same letter are not significantly different according to Fisher's LSD (α=0.05) test.

Mowing height was maintained with hand held trimmers (Black and Decker, model GS500, Denver, CO). Mowing guides were constructed with 10 cm diameter PVC pipe cut to a height of 16 and 25 mm. Guides were pressed against grass samples to provide a mowing template. Turfgrasses were mowed 3 times wk^{-1}. Grasses were watered 3 times weekly to prevent wilting. No significant disease pressure was observed during both years.

Measurements

Hourly totals of PAR were recorded with a LI-1000 (LiCor; Lincoln, NE) datalogger fitted with a LI-190SA (LiCor; Lincoln, NE) quantum sensor at a fixed location 1.5 m above the ground. The DTP (mol m^{-2} d^{-1}) for shade treatments (0, 41, 58, and 71%) was calculated by taking percentages of PPF transmitted. DTP were averaged over the growing season for both years. Standard errors were calculated for yearly and two-year DTP averages for each shade treatment.

Visual ratings of turfgrass quality (TQ), assessing color, shoot density, and uniformity were determined weekly. Turfgrass quality was rated on a 1-9 scale with 9 = best turfgrass quality. Unacceptable turfgrass quality was deemed < 7.0.

Total nonstructural carbohydrates (TNC) of below ground tissue (roots and rhizomes) were measured at the end of the study for both years. Below ground tissues were harvested using a 5 cm diameter plugger to a depth of 6.5 cm. Two samples were taken per individual replicate prior to sunrise to minimize diurnal fluctuations in carbohydrates (Westhafer et al., 1982). Roots and rhizomes were washed free of sand and organic matter, placed in aluminum foil and submerged in liquid nitrogen to cease all biological activity. Samples were stored at -75 C until freeze dried at -40 C for 14 d. Freeze dried samples were ground to a powder with an A-10 plant grinder (IKA Works, Inc., Wilmington, NC). Ground samples were stored in desiccant at -20 C. Below ground tissue (50 mg) was weighed into glass test tubes and rehydrated with 100 ˜l of 80% ethanol and mixed with 2 ml of 0.1 M sodium acetate buffer. Following heating in a boiling water bath for two 1 hr periods to kill any exogenous enzymes. Invertase (Sigma I-4753, 433 units/mg) and amyloglucosidase (Sigma A-7255, 23,000 units/g) were added to convert sucrose to glucose and fructose moieties and starch to glucose, respectively. TNC was measured by using Nelson's Assay, which quantifies the reducing sugars, glucose and fructose, in plants (Nelson, 1944; Somogyi, 1945). Absorbance was measured at 520 nm using a spectrophotometer (Beckman DU-64, Beckman Instrument Inc., Fullerton, CA). TNC was calculated using a standard curve development by known glucose concentrations.

Statistical Design and Analysis

The study was randomized complete block design for shade and split by mowing height and grass species. Two studies were conducted during 2002 and 2003. Due to differences in study timing and duration and cultivars evaluated, years are presented separately. Within

Table 5. Total non-structural carbohydrates (TNC) of Celebration, Tifway, and TifSport bermudagrasses in response to different shade (0, 41, 58, 71%) and mowing heights (16 and 25 mm) in Clemson, SC from 29 July to 31 October, 2002.

Cultivar	% Shade Level	TNC	
		Mowing Height, mm	
		16	25
		mg g^{-1}	
Celebration	0	29.8 a†	33.7 ab
TifSport	0	25.0 abcd	42.5 a
Tifway	0	29.5 a	43.1 a
Celebration	41	26.6 abc	25.8 bcde
TifSport	41	27.0 ab	28.1 bcd
Tifway	41	25.1 abcd	30.4 abc
Celebration	58	13.2 bcd	15.3 de
TifSport	58	17.0 abcd	14.8 de
Tifway	58	14.4 bcd	17.1 cde
Celebration	71	12.0 d	14.5 de
TifSport	71	12.3 d	13.1 e
Tifway	71	13.0 cd	13.6 e

† Within mowing heights, means followed by the same letter are not significantly different according to Fisher's LSD (α=0.05) test.

Table 6. Total non-structural carbohydrates (TNC) of Celebration, Tifway, and TifSport bermudagrass and Meyer Japanese zoysiagrass in response to different shade (0, 41, 58, 71%) and mowing heights (16 and 25 mm) in Clemson, SC from 6 July to 29 August, 2003.

Cultivar	% Shade Level	TNC	
		Mowing Height, mm	
		16	25
		mg g^{-1}	
Celebration	0	37.9 ab†	27.6 cd
TifSport	0	47.6 a	48.2 a
Tifway	0	29.1 bcd	51.9 a
Meyer	0	19.9 def	22.1 def
Celebration	41	36.0 bc	33.0 bc
TifSport	41	34.0 bc	42.5 ab
Tifway	41	26.3 cde	23.4 cde
Meyer	41	16.9 ef	17.4 def
Celebration	58	17.1 ef	17.2 def
TifSport	58	16.5 ef	18.3 def
Tifway	58	14.6 f	15.2 ef
Meyer	58	11.7 f	12.7 ef
Celebration	71	13.7 f	14.3 ef
TifSport	71	13.3 f	13.6 ef
Tifway	71	12.5 f	13.3 ef
Meyer	71	11.9 f	11.6 f

† Within mowing heights, means followed by the same letter are not significantly different according to Fisher's LSD (α=0.05) test.

individual shade blocks, three replicates of grass species at both mowing height were maintained. All data were analyzed using analysis of variance (ANOVA) general linear model procedure (GLM) of SAS (SAS Institute, 1987). A cultivar x mowing height interaction was significant for TQ and TNC; therefore data will presented separately within mowing heights for both years. Means separation were performed with all data using Fishers LSD at the a = 0.05 level. SigmaPlot program (SPSS Inc., Chicago, IL) was used for TNC data subjected to regression analysis.

RESULTS AND DISCUSSIONS

Daily Total of PAR

In year 1, the study duration continued into autumn months which were not conducive to best bermudagrass growth because of reduced DTP and temperatures (Table 2). In contrast, the year 2 study was conducted during summer months where DTP intervals were higher compared to year 1 (Table 2). The average DTP increased 15 mol sunlight m^{-2} d^{-1} from year 2 to year 1 in 0% shade treatments.

Turfgrass Quality

Year 1

Commercially acceptable ($\geq$7) TQ was found with 0 and 41% shade treatments on Tifway, TifSport, and Celebration bermudagrasses at both mowing heights (Table 3). At the 16 mm mowing height, Tifway and TifSport bermudagrass with 0% shade application maintained the highest TQ ratings of 7.8 and 7.7, respectively. At the 25 mm mowing height, TQ $\geq$ 7.5 was found with all bermudagrass cultivars under a 0 and 41% shade. Therefore, acceptable TQ was found with all bermudagrass cultivars at both mowing heights when receiving an average DTP of 16.7 mol m^{-2} d^{-1} during August through October (Table 3).

When shade increased to 58%, turfgrass quality differences occurred among bermudagrass cultivars. Celebration bermudagrass maintained at 25 mm mowing height provided acceptable TQ under 58% shade (Table 3). Therefore, Celebration bermudagrass mowed at 25 mm maintained acceptable TQ when receiving a DTP of 11.9 mol m^{-2} d^{-1} from August through October. At the 16 mm mowing height, Celebration bermudagrass possessed 6 and 16% greater TQ rating compared to Tifway and TifSport bermudagrass, respectively. When receiving an average DTP of 11.9 mol m^{-2} d^{-1} from August through October, TQ of Tifway and Tifway was unacceptable.

Of the grasses tested, Celebration bermudagrass had the highest TQ when grown under 71% shade. However, the TQ was not high enough to be commercially acceptable. At the 16 mm mowing height, Celebration bermudagrass maintained 12 and 7% higher TQ compared to TifSport and Tifway (Table 3). Turfgrass quality was 3% higher with Celebration bermudagrass compared to other cultivars when maintained at 25 mm under 71% shade. In this study during year 1, bermudagrass cultivars tolerated a 41% reduction in sunlight (16.7 mol m^{-2} d^{-1}) from August to October, but generally were unable to maintain acceptable TQ under a 58% or greater shade, except Celebration bermudagrass at the 25 mm mowing height.

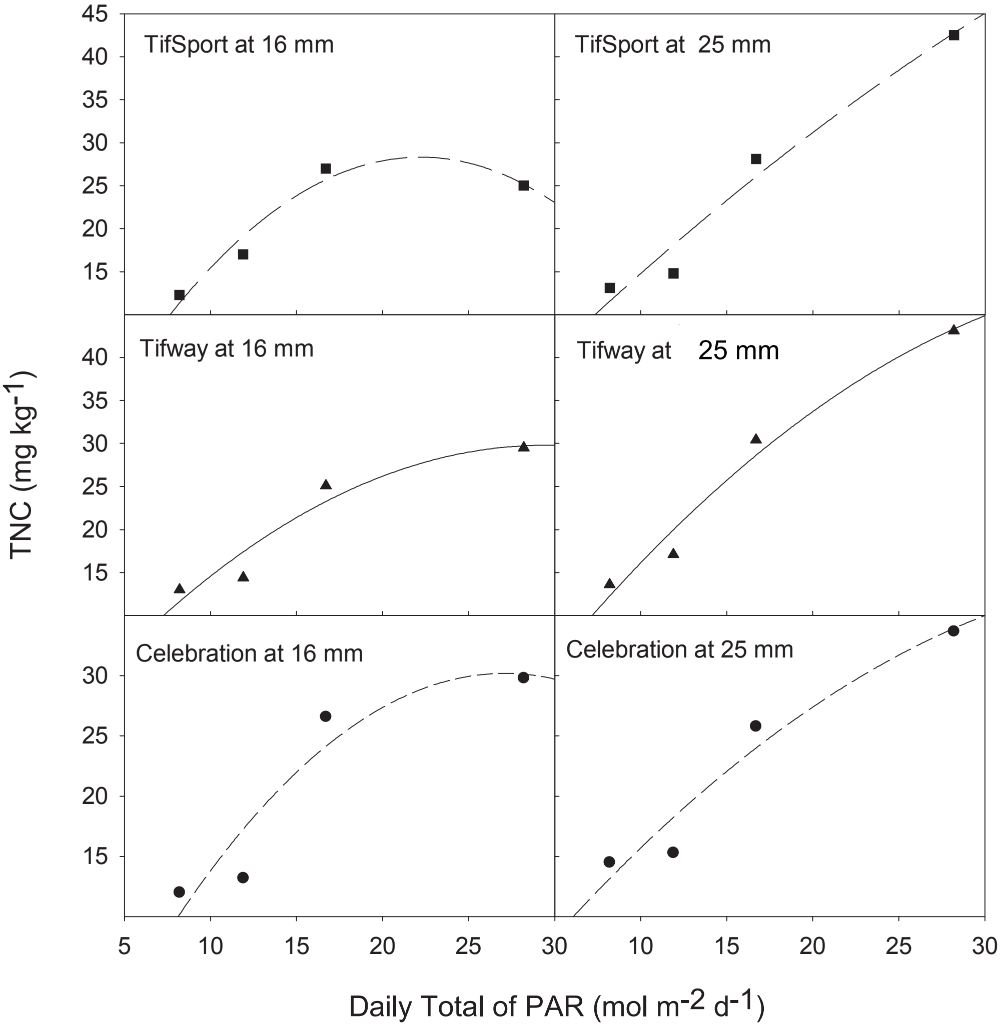

Figure 1. Total non-structural carbohydrates (TNC; mg g^{-1}) of the roots and rhizomes of bermudagrass cultivars to various daily totals of PAR (DTP; mol m^{-2} d^{-1}) during 2002.

Year 2

Similar to year 1, in year 2 all cultivars plus Meyer Japanese zoysiagrass at both mowing heights maintained acceptable TQ ratings in 0 and 41% shade applications (Table 4). Best TQ ratings of 8.0 at both mowing heights occurred with Meyer Japanese zoysiagrass under 0 and 41% shade. Tifway bermudagrass maintained at 25 mm under 0% shade had a TQ rating of 8.0. During July and August, all bermudagrass cultivars maintained acceptable TQ when receiving an average DTP of approximately 25.9 mol m^{-2} d^{-1} (Table 4). A similar study in SC established 'TifEagle' bermudagrass maintained at 3.2 mm required a daily light integral (DTP) of 32.6 mol m^{-2} d^{-1} to maintain acceptable turf quality (TQ) during the months of June through August (Bunnell et al., 2005).

A 58% shade reduced TQ to unacceptable levels in Tifway and TifSport bermudagrasses at both mowing heights (Table 4). Therefore, acceptable TQ did not occur with Tifway or TifSport receiving a DTP of 18.4 mol m^{-2} d^{-1} during July and August. Meyer Japanese zoysiagrass and 'Celebration bermudagrass both maintained acceptable TQ under 58% shade, with 'Meyer' showing greatest TQ ratings of 7.3 and 7.6 at the 16 and 25 mm mowing height, respectively. The 71% shade showed similar results to the 58% shade with TifSport and Tifway demonstrating little shade tolerance with TQ ratings of 5.2 and 5.9 at the 16 and 25 mm mowing heights, respectively. Meyer Japanese zoysiagrass and Celebration at 25 mm were able to maintain acceptable TQ ratings at both mowing heights under 71% shade. Therefore, acceptable TQ with Meyer Japanese zoysiagrass at both mowing heights and Celebration at 25 mm occurred with an average DTP of 12.7 mol m^{-2} d^{-1}.

From these data, cultivars can be ranked according to their shade tolerance with Meyer Japanese zoysiagrass possessing the greatest shade tolerance followed closely by Celebration bermudagrass. The hybrid bermudagrasses, TifSport and Tifway possessed very little shade tolerance and required a DTP of 25.9 mol m^{-2} d^{-1} during July and August. Other research has shown limited

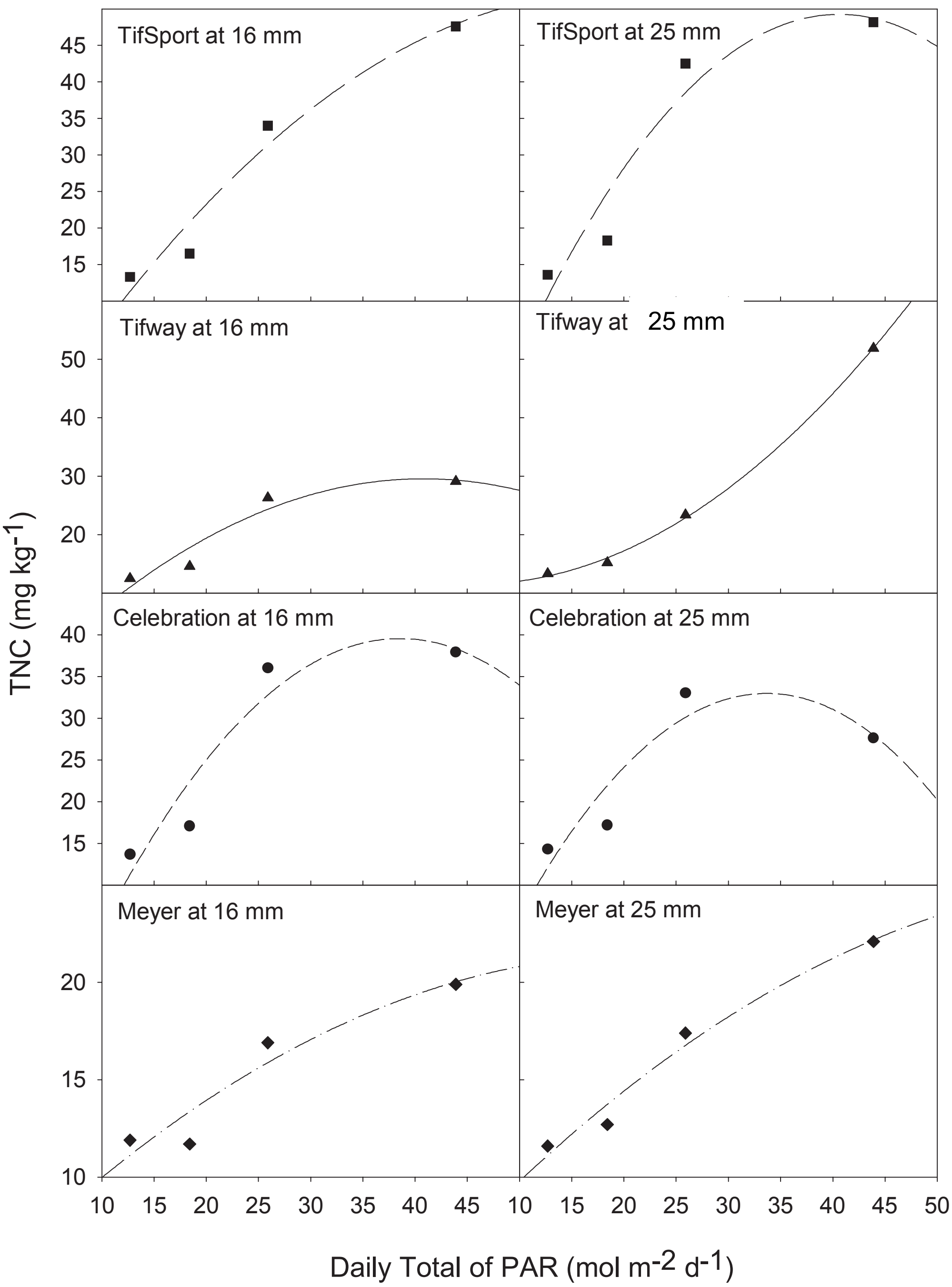

Figure 2. Total non-structural carbohydrates (TNC; mg g^{-1}) of the roots and rhizomes of bermudagrass cultivars and Meyer Japanese zoysiagrass to various daily totals of PAR (DTP; mol m^{-2} d^{-1}) during 2003.

shade tolerance with Tifway compared to other bermudagrasses, such as 'Common' [*Cynodon dactylon* (L.)] (Gaussoin et al., 1988).

Total Non-structural Carbohydrates

Year 1

At the 16 mm mowing height, no differences in TNC of roots and rhizomes were found among bermudagrass cultivars receiving 0 and 41% shade (Table 5). All cultivars receiving $\geq$58% shade, had less TNC in roots and rhizomes than those receiving $\leq$41% shade, except TifSport. At the 25 mm mowing height, bermudagrass cultivars under full sunlight and Tifway bermudagrass under 41% shade and mown at 25 mm had highest TNC in roots and rhizomes (Table 5). Under 58 and 71% shade, TNC concentration in roots and rhizomes did not differ among bermudagrass cultivars maintained at equal mowing heights.

The TNC content of roots and rhizomes of bermudagrass cultivars were plotted against the corresponding DTP to form a second-order polynomial regression for each cultivar at each mowing height (Figure 1). The general response, regardless of cultivar or mowing height, was curvilinear with TNC content of roots and rhizomes decreasing as DTP decreased.

Year 2

At the 16 mm mowing height, TNC concentrations in roots and rhizomes ranged from 47.63 to 11.71 mg g^{-1}. Highest TNC concentrations of 47.63 and 37.93 mg g^{-1} occurred with the roots and rhizomes TifSport and Celebration bermudagrass under 0% shade, respectively (Table 6). Lowest TNC concentrations of roots and rhizomes were measured in all bermudagrass cultivars receiving 58 or 71% shade treatments and Meyer Japanese zoysiagrass at 41, 58, and 71% shade. At the 25 mm mowing height, TNC concentrations of roots and rhizomes ranged from 51.90 mg g^{-1} in Tifway under 0% shade to 11.55 mg g^{-1} in Meyer Japanese zoysiagrass under 71% shade (Table 6). Among all treatments, Tifway and TifSport bermudagrass had highest TNC concentrations of roots and rhizomes of 51.9 and 48.2 mg g^{-1}, respectively, under 0% shade. Lowest TNC concentrations of roots and rhizomes was found with all bermudagrass cultivars under 58 and 71% shade and Meyer Japanese zoysiagrass under all shade levels.

Regression analysis for year two also resulted in a negative second-order polynomial relationship between roots and rhizomes of bermudagrass cultivars and Meyer Japanese zoysiagrass and DTP (Figure 2). The TNC content of roots and rhizomes reduced as DTP decreased.

CONCLUSIONS

During both years, continuous shade of 58 and 71% lowered TQ ratings to unacceptable levels in the hybrid bermudagrasses, TifSport and Tifway. During year 1, acceptable TQ of Tifway and TifSport bermudagrass occurred with a DTP of 16.7 mol m^{-2} s^{-1} (41% shade) between the months of August and October. A more common-type bermudagrass from Australia, Celebration at 25 mm, demonstrated acceptable TQ when receiving an average DTP of 11.9 mol m^{-2} s^{-1} (58% shade) from August through October. TNC content of all bermudagrass cultivars were reduced under 71% shade at the 16 mm mowing height. At the 25 mm mowing height, shade of 58 and 71% reduced TNC of all bermudagrass cultivars.

In year 2, acceptable TQ of hybrid bermudagrasses occurred with a DTP of 25.9 mol m^{-2} s^{-1} (41% shade) during July and August. Unacceptable TQ was associated with these grasses receiving a DTP of 18.4 mol m^{-2} s^{-1} (58% shade). Celebration bermudagrass maintained acceptable TQ at both mowing heights under a 58% shade application receiving an average DTP of 18.4 mol m^{-2} s^{-1}. Best shade tolerance was found with Meyer Japanese zoysiagrass. At both mowing heights, Meyer Japanese zoysiagrass maintained acceptable TQ under 71% shade or a DTP of 12.7 mol m^{-2} s^{-1} during July and August.

Results show acceptable hybrid bermudagrass TQ under 41% shade or when receiving a DTP 16.7 and 25.9 mol m^{-2} s^{-1} during the late-summer/early-autumn months and summer months, respectively. Total non-structural carbohydrates in roots and rhizomes of bermudagrass cultivars were greatly influenced by shade treatments and resulting DTP (Figures 1 and 2). The TNC of all bermudagrass cultivars and Meyer Japanese zoysiagrass at both mowing heights demonstrated a decreasing curvilinear response to DTP. Future research should continue to investigate the performance of these and other cultivars of bermudagrasses and zoysiagrasses under a variety of shade conditions.

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