Urban Forestry & Urban Greening 26 (2017) 169–177

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

Original article

Shade response of bermudagrass accessions under different management practices☆

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ARTICLE INFO

Article history:
Received 31 May 2016
Received in revised form 9 February 2017
Accepted 17 February 2017
Available online 24 February 2017

Keywords:
Bermudagrass
Shade tolerance
Management

ABSTRACT

The development of cultivars 'TifGrand' and 'Celebration' has shown potential increases in shade tolerance compared to previous industry standards of bermudagrass (*Cynodon* spp.). Based on the literature, further improvements in shade tolerance can be attained through changes in nitrogen fertility rates, mowing heights, and the application of plant growth regulators. In this study, two South African hybrid (*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt Davy) bermudagrass accessions ('WIN10F' and 'STIL03') and three standard cultivars (Celebration, Tifgrand, and 'Tifway') were compared for their ability to persist under 63% shade, two mowing heights, two trinexapac-ethyl (TE) treatments, and two nitrogen fertility rates. The experimental design was a strip-strip-split plot and digital image analysis was used to measure percent turfgrass cover, percent turfgrass spread after cup-cutter removal, and percent turfgrass regrowth after divot formation. Turf quality was measured using the normalized difference vegetation index (NDVI). Differences among genotypes, TE treatments, and mowing heights were observed across all response variables in 2014 and 2015. Differences in fertility treatments were observed in NDVI, percent turfgrass growth, and percent turfgrass recovery within and across years. Significant differences were observed for the interactions between entry by plant growth regulator (PGR) treatments, entry by mowing height, and mowing height by PGR. These results suggest shade management recommendations should be dependent on genotype and site-specific considerations. The development and implementation of specific management plans for certain bermudagrass varieties will contribute to the more widespread use of *Cynodon* spp. in shaded environments.

1. Introduction

Bermudagrass (*Cynodon* spp.) is a long-living perennial turfgrass that is well suited to a wide range of environments because of its aggressive growth, drought and traffic tolerance, resistance to weed encroachment, and recuperative potential (DiPaola and Beard, 1992; Carrow and Petrovic, 1992). However, bermudagrass exhibits poor tolerance to low light environments forcing golf course superintendents, athletic field and park managers, and homeowners alike to consider other options where trees dominate the landscape (Dudeck and Peacock, 1992). A number of management strategies can help improve the conditions of tree-dense home lawns and recreation areas, including, but not limited to: 1) selecting shade tolerant/improved varieties, 2) increasing mowing heights, 3) plant growth regulator applications, and 4) reduced nitrogen fertility levels. These cultural practices have been examined in many applied research settings.

Plant breeders routinely make selections among a range of genotypes for specific traits of interest. For shade response, research has shown significant variation among bermudagrass genotypes. Gaussoin et al. (1988) showed the diversity in shade tolerance among 32 bermudagrasses. Baldwin et al. (2008) classified 42 genotypes from the National Turfgrass Evaluation Program (NTEP) based on responses in turfgrass quality, shoot chlorophyll concentration, root length, and total root biomass under low light conditions. Hanna et al. (2010) evaluated 'TifGrand' (*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt Davy) (PP21017; Hanna and

☆ This article is part of a special feature entitled: 5th ETS 2016 Conference: Turfgrass – towards sustainability and perfection for aesthetic, recreational and sports published at the journal Urban Forestry & Urban Greening 26C.

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http://dx.doi.org/10.1016/j.ufug.2017.02.011
1618-8667/

Table 1
List of factors and treatments used for the evaluation of cultural practices under a perpetual shade treatment (63%).

Entry[†]	Mowing Height	Plant Growth Regulator	Nitrogen Fertility
Celebration	1.9 cm (0.75 in)	No Trinexapac-Ethyl	Low Nitrogen 48.8 kg ha^{-1} Applied every 60 days
TifGrand			
Tifway	5.1 cm (2 in)	Trinexapac-Ethyl 0.45 L ha^{-1} (0.051 g a.i. ha^{-1}) Applied every 2-weeks	High Nitrogen 48.8 kg N ha^{-1} Applied every 30 days
STIL03[‡]			
WIN10F[‡]			

[†] Species designation for all entries is *Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt Davy, with the exception of Celebration, which is *C. dactylon* (L.) Pers.
[‡] South African accessions from Dunne et al. (2015).

Braman, 2008) against other dwarf-type bermudagrass cultivars and selected it based on a two-fold increase in turfgrass cover under 70% continual shade conditions. Tifgrand is the first bermudagrass release to be marketed as a shade tolerant cultivar. Dunne et al. (2015) evaluated a collection of South African accessions for shade tolerance, and determined that some were able to maintain turfgrass quality and cover, and a normalized difference vegetation index (NDVI) value similar to those of 'Celebration' and Tifgrand, the current industry standards for shade tolerance.

Increasing the mowing height of a turfgrass stand has been shown to help lessen the effects elicited by tree shading (Bell and Danneberger, 1999; White, 2004). However, Bunnell et al. (2005) showed that although increased mowing heights improved the overall quality of 'TifEagle' bermudagrass, total non-structural carbohydrates and chlorophyll content improved with lower mowing heights. In some cases, the decline of a turfgrass stand under shade can be due to secondary effects or stressors, such as improper mowing (low mowing heights), excessive nitrogen fertility, and disease pressure (Busey and Davis, 1991).

The application of a plant growth regulator (PGR), such as trinexapac-ethyl, can be part of a management strategy for turfgrass grown under low-light conditions. Trinexapac-ethyl has been shown to reduce clipping yield, improve leaf color, increase canopy photochemical efficiency and photosynthetic capacity, increase root mass and viability, increase non-structural carbohydrates, and improve turfgrass quality in the presence of shade (Qian and Engelke, 1999; Bunnell et al., 2005; McCullough et al., 2006; Ervin and Zhang, 2007; McCullough et al., 2007).

Although bermudagrass generally has a higher nitrogen fertility requirement than other warm-season turfgrass species (McCarty and Miller, 2002), a number of studies have suggested that reducing the nitrogen fertility rate may be an effective strategy to improve bermudagrass quality under shade (Baldwin et al., 2009; Bunnell et al., 2005; Goss et al., 2002; Bell and Danneberger, 1999). Furthermore, Dunne et al. (2015) showed that there was no benefit from higher nitrogen fertility rates when compared to a lower nitrogen fertility rate across shade levels or genotypes. In contrast, excessive nitrogen has been shown to compound secondary problems due to shade stress, including improper mowing (Busey and Davis, 1991).

Given the individual potential of each cultural practice in improving shade response, a promising management program for bermudagrass under shade could be developed. However, understanding the complexities of the interactions between cultivars and cultural practices is crucial in the development of such a plan. The objective of this study was to evaluate the shade response determined through the NDVI, percent turfgrass cover, percent turfgrass growth, and percent turfgrass recovery of three bermudagrass cultivars and two experimental accessions, as affected by two mowing heights, two TE programs, and two nitrogen fertility rates.

2. Materials and methods

2.1. Management

A two-year study was conducted at the Lake Wheeler Turfgrass Experimental Field Lab in Raleigh, NC, USA. Plots were established on 29 May 2013 using eight, 22.9-cm wide strips spaced 25.4 cm apart and totaling 3.7 m. The strips were 1.8 m in length producing plot sizes of 6.7 m^2 (3.7 × 1.8). The plots were established on an Appling fine sandy loam/Cecil sandy loam (NRCS, 2013). An 18–46-0 (N-P_2O_5-K_2O) fertilizer (Southern Seeds, Inc.; Middlesex, NC, USA) was applied at a nitrogen rate of 48.8 kg ha^{-1} when the strips were laid. Additional applications of a complete fertilizer (18-9-18 N-P_2O_5-K_2O, Harrell's, Lakeland, FL, USA) were made monthly at a rate of 48.8 kg N ha^{-1} during the first year to provide a total annual rate of 195.2 kg N ha^{-1}. Irrigation was applied at 0.3 cm day^{-1}, totaling 1.8 cm $week^{-1}$, and the plots were maintained throughout the summer, with mowing once per week at a mowing height of 5.1 cm. Buffer areas between plots and replications were maintained using monthly applications of glyphosate at the labeled rate. Furthermore, two topdressing applications of a sand/soil mix at a 0.6-cm depth were applied on 23 July and 6 August 2013 to level the area between the sod strips. The plots were core cultivated in the spring of both years using 1.3-cm tines on 5.1-cm centers at a 5.1-cm depth, effectively disrupting roughly 10% of the soil surface for the two years in total. The cores were incorporated back into the plots using hand rakes. The plots were irrigated to prevent drought stress and mowed using a rotary mower, with mowing once per week at a mowing height of 5.1 cm.

2.2. Factors and factor levels

Plots were allowed to become completely established before being subjected to shade stress. On 1 July 2014, a 63% neutral density, poly-fiber black shade cloth (Long's Greenhouse Enterprise, Inc. Jacksonville, FL, USA) was installed by connecting it to a 96 × 96 × 9 ft pole and cable shade structure surrounding the established plots. Percent shade was determined by comparing the photosynthetic photon flux under the shade fabric at the turfgrass canopy to full sunlight measurements using a quantum sensor (LI-190SA; LiCor; Lincoln, NE, USA). The shade fabric was removed on 7 November 2014 in order to simulate deciduous tree leaf drop in autumn. On 1 May 2015, the shade fabric was re-installed after the plots had come out of winter dormancy and 100% cover was achieved for the second year of evaluation. The study was established as a strip-strip-split plot design with three replications in order to accommodate the applications of trinexapac-ethyl and mowing heights (strips), and the levels of fertility (split). The whole plot factor was the entries that were selected for the study (Table 1). Two South African accessions were selected based on their performance in a previous shade tolerance evaluation (Dunne et al., 2015). 'Celebration', 'TifGrand', and 'Tifway' (Table 1) were selected as controls, ranging in shade tolerance from the most shade tolerant to most shade susceptible, respectively (Burton, 1966; Riley, 2000; Hanna and Maw, 2007; Hanna et al., 2010; Dunne et al., 2015). Sub-plot treatments were initiated after shade fabric installation each year. Bermudagrass entries were stripped across plot rows and randomly assigned one of two mowing factor levels. To apply the mowing treatments, half of the strips were maintained at the pre-study mowing height of 5.1 cm and the other