Correlations Between Hybrid Bermudagrass Morphology and Wear Tolerance

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SUMMARY. Hybrid bermudagrasses (*Cynodon dactylon* × *C. transvaalensis*) typically have excellent wear tolerance when compared with other turfgrass species. This trait should be evaluated during variety development to reduce the risk of failure when new grasses are planted in areas with traffic stress. The objective of this research was to evaluate the wear tolerance of four hybrid bermudagrasses with differing morphological characteristics. Traffic was applied to the hybrid bermudagrass varieties ‘Tifway’, ‘TifSport’, and ‘TifTuf’, as well as an experimental hybrids (04-76) using a traffic simulator for 6 weeks. Leaf morphology (leaf width, length, and angle) and quantitative measure of density and color [normalized difference vegetation index ratio (NDVI), dark green color index (DGCI), and percent green turf color] were characterized before traffic, and then percent green turf color after 6 weeks of traffic was measured to estimate wear tolerance. ‘TifTuf’ hybrid bermudagrass provided the greatest wear tolerance, as well as the narrowest and shortest leaf lengths, greatest NDVI values and percent green color, and lowest DGCI before traffic. Conversely, 04-76 produced the poorest wear tolerance, as well as the widest and longest leaves, lowest NDVI values and percent green color, and highest DGCI values before traffic. Regression analysis determined that DGCI, leaf length, and leaf width were inversely, or negatively, correlated to wear tolerance, whereas percent green turf color before traffic was directly correlated to wear tolerance. For these hybrids, DGCI had the strongest correlation to increased wear tolerance.

There has been extensive research to document the effects of various turfgrass physiological and morphological characteristics on wear tolerance of currently used varieties. Physiological characteristics associated with improved wear tolerance across a wide range of cool and warm-season turfgrass species include, but are not limited to, total cell wall content (Brosnan et al., 2005; Shearman and Beard, 2002; Trenholm et al., 2000), lignin content (Shearman and Beard, 1975; Trenholm et al., 2000), leaf moisture content (Brosnan et al., 2005; Trenholm et al., 2000), and shoot nutrient levels (Shearman and Beard, 2002; Trenholm et al.,

2000). However, assessing these physiological characteristics often requires destructive sampling and various laboratory analyses that are time consuming and expensive.

Morphological characteristics, on the other hand, are often assessed relatively quickly and inexpensively in the field and generally require little or no laboratory analysis. Morphological characteristics that have been associated with improved wear tolerance across a variety of cool and warm-season turf species include internode length (Wood and Law, 1974), density (Shearman and Beard, 1975; Trenholm et al., 2000; Wood and Law, 1974), leaf angle (Wood and Law, 1974), leaf width (Shearman and Beard, 1975), and turf quality (Bonos et al., 2001).

New techniques have been recently developed to objectively quantify

various turf canopy morphological characteristics; i.e., turf quality (Bell et al., 2002; Trenholm et al., 1999), color (Karcher and Richardson, 2003), and cover (Goddard et al., 2008; Kowalewski et al., 2013). For example, NDVI and other spectral reflectance parameters have been used to evaluate turf quality (Bell et al., 2002; Trenholm et al., 1999). Richardson et al. (2001) developed digital image analysis techniques to assess percent green turf color and DGCI. In addition to determining turf quality, spectral reflectance and digital image analysis have both been used to successfully quantify turfgrass wear tolerance (Goddard et al., 2008; Haselbauer et al., 2012; Kowalewski et al., 2013; Trappe et al., 2012).

The objectives of this research were to 1) assess the differences in leaf and canopy morphology and wear tolerance of four hybrid bermudagrasses and 2) assess the correlations between these morphological characteristics and wear tolerance. Findings from this research could provide hybrid bermudagrass turf breeders with a list of foliar morphological characteristics that are associated with wear tolerance to select for in new hybrids. Breeders could then use these parameters to identify potentially wear-tolerant experimental crosses before release, rather than wait for additional turf scientists to later conduct field traffic studies. Until recently, it has been more common for wear tolerance to be determined after a variety becomes commercially available, while breeders have selectively concentrated on other characteristics such as decreased mowing height, increased density, improved quality and color, and cold tolerance (Burton, 1966; Hanna et al., 1997).

Project design

Research was conducted from 23 Mar. to 1 June 2012 at two locations in Tifton, GA: the University of Georgia Coastal Plain Experiment Station and the Abraham

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
0.0929	ft ²	m ²	10.7639
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
1.1209	lb/acre	kg·ha ⁻¹	0.8922

Baldwin Agricultural College Woodruff Farm. Hybrid bermudagrasses were established vegetatively from sprigs in May 2009 on a loamy sand (Tifton-Urban land complex; pH = 5.3) at the Coastal Plain Experiment Station and in Apr. 2011 on a loamy sand (Tifton loamy sand; pH = 5.3) at the Woodruff Farm. Experimental design was a 2 × 4 randomized complete block design, with three replications. Factors included location and hybrid bermudagrasses. Hybrids included 'Tifway', 'TifSport', and 'TifTuf' as well as experimental varieties 04-76 established on 3 × 3 m plots.

The turfgrass at both locations was maintained at a mowing height of 0.5 inch (clippings removed) and received monthly applications of 16N-1.8P-8.6K (Super Rainbow Plant Food; Agrium U.S., Denver, CO) ranging from 24 to 48 kg·ha⁻¹ nitrogen (N) from April to October, totaling 366 kg·ha⁻¹ N annually. Plots also received daily irrigation (0.15 inch/d) during the growing season.

Simulated traffic was applied over a 6-week period, from 23 Mar. to 27 Apr. 2012 at the Coastal Plain Experiment Station and from 27 Apr. to 1 June 2012 at the Woodruff Farm, using a traffic simulator [Baldree Traffic Simulator; University of Georgia, Tifton, GA (Kowalewski et al., 2013)]. The weekly traffic rate was two passes per week (one pass forward and one pass backward), for

a total of 12 passes per location applied over 6 weeks.

Reponses variables

Leaf morphology characteristics were collected before the initiation of traffic. Measurements of leaf morphology included the leaf length, leaf width, and leaf angle. Leaf length and leaf width were assessed using an electronic digital caliper with 0.001 mm readability. Leaf angle was measured on a 1 to 4 scale, where 1 = a leaf to sheath angle of 0° to 22.5°, 2 = 22.5° to 45°, 3 = 45° to 67.5°, and 4 = 67.5° to 90° (Bronson et al., 2005).

Quantitative measurements of hybrid bermudagrass density and color included NDVI, DGCI, and percent green turf color were also collected before the initiation of traffic. To determine NDVI and relative vegetation index values, spectral reflectance bands were collected at the 650-nm (red) and 730-nm [near IR (NIR)] range using a multispectral crop canopy sensor (ACS470 Crop-Circle; Holland Scientific, Lincoln, NE). These reflectance bands were then used to calculate NDVI [NDVI = (NIR - red)/(NIR + red)]. To determine DGCI and percent green color, digital images were collected using a digital camera (Powershot G5; Canon, Tokyo, Japan) mounted on a 0.31-m² enclosed photo box with four 40-W spring lamps (TCP; Lighthouse Supply, Bristol, VA). Digital images were then analyzed using

SigmaScan Pro (version 5.0; Systat Software, San Jose, CA) to determine DGCI and percent green color (0% to 100%) according to procedures developed by Richardson et al. (2001). At the conclusion of the two 6-week traffic periods, wear tolerance was assessed using percent green color according to methods described above.

Data were analyzed as a randomized complete block design, with three replications, using SAS (version 5.0; SAS Institute, Cary, NC). Mean separations were obtained using Fisher's least significant difference (LSD) at a 0.05 level of probability (Ott and Longnecker, 2001). A series of regression analysis for various leaf morphology, density, and color parameters across the final percent green turf color observed at the conclusion of the 6-week traffic period were conducted to determine whether these parameters could project turf wear tolerance.

Results and discussion

INITIAL PARAMETER ASSESSMENT. Differences between the leaf length and leaf width of the four hybrid bermudagrasses assessed before traffic were observed (Table 1); however, no differences between the leaf angles of the hybrids were noted. No interactions between location and hybrid were observed for leaf length, leaf width, or leaf angle. The experimental hybrid 04-76 and 'TifSport' produced the greatest leaf lengths, 14.1 and 13.7 mm, respectively. 'Tifway' leaf length was intermediate between these

Table 1. Effects of location and hybrid bermudagrass variety on leaf morphology, leaf length, leaf width, and leaf angle observed before traffic applications at Tifton, GA in 2012.

Source of variation	Numerator df	Denominator df	Leaf length (mm) ^a	Leaf width (mm)	Leaf angle (1–4 scale) ^b
			----- P > F ^c -----		
Location (L)	1	2	NS	NS	NS
Hybrid (H)	3	12	***	***	NS
L × H	3	13	NS	NS	NS
Location^d			Leaf length (mm)	Leaf width (mm)	Leaf angle (1–4 scale)
Coastal Plain Experiment Station			11.7 a ^w	2.0 a	2.3 a
Woodruff Farm			11.1 a	1.9 a	2.3 a
Hybrid			Both locations^v	Both locations	Both locations
04-76			14.1 a	2.4 a	2.5 a
'TifSport'			13.7 a	1.8 b	2.3 a
'Tifway'			10.6 b	1.8 b	2.2 a
'TifTuf'			7.2 c	1.7 b	2.3 a

^a1 mm = 0.0394 inch.

^b1 = sheath angle of 0° to 22.5°, 2 = 22.5° to 45°, 3 = 45° to 67.5°, 4 = 67.5° to 90°.

^cNS = not significant at a 0.05 level of probability; ***significant at a 0.001 level of probability.

^dMeans within columns followed by the same letter are not significantly different according to least significant difference at the 0.05 P level.

^eLocations included the University of Georgia Coastal Plains Experiment Station and Abraham Baldwin Agricultural College Woodruff Farms both in Tifton, GA.

two hybrids and ‘TifTuf’, which had the shortest leaf length, 7.2 mm. 04-76 had the largest leaf width, 2.4 mm. No leaf width differences were observed between ‘TifSport’, ‘Tifway’, and ‘TifTuf’. These leaf width results varied slightly from results collected by Kim and Beard (1988) who recorded an average leaf width of 0.8 mm for ‘Tifway’ hybrid bermudagrass, as well as leaf width of 0.9 and 1.9 mm for ‘Tifgreen’ hybrid bermudagrass and ‘Arizona Common’ common bermudagrass (*C. dactylon*).

With respect to leaf angle, the four hybrids assessed ranged in values from 2.2 to 2.5 (Table 1), which indicates that these hybrid bermudagrasses have a semihorizontal orientation (22.5° to 45°) according to the scale developed by Brosnan et al. (2005). Brosnan et al. (2005) explored the effects of 12 different physiological characteristics, including leaf width and angle, on the wear of 173 varieties of kentucky bluegrass (*Poa pratensis*). They observed significant differences in leaf angle and concluded that this was the single most important parameter within the 12 assessed varieties when separating wear-tolerant and intolerant kentucky bluegrass varieties. Wear-intolerant kentucky bluegrasses possessed leaf angles ranging from 1.2 to 2.0, while wear-tolerant varieties ranged from 1.4 to 2.7. Considering conclusions drawn by Brosnan et al. (2005), the hybrid bermudagrasses in our research would all be considered wear tolerant according to leaf angle orientation.

The analysis of variance for NDVI revealed significant differences among the main effects of location and hybrid before the initiation of traffic, and no location × hybrid interaction was observed (Table 2). Normalized difference vegetation index values at the Coastal Plain Experiment Station were greater than values collected at Woodruff Farm. In reference to hybrids, ‘TifTuf’, ‘Tifway’, and ‘TifSport’ produced the greatest NDVI values (7.2, 7.0, and 6.8, respectively). Hybrid 04-76 produced the lowest NDVI value (6.5). Research conducted by Trenholm et al. (1999) determined that NDVI, as well as a number of reflectance indices, were highly correlated to shoot density; more specifically as NDVI values increased, so did shoot density. Trenholm et al. (1999) also determined that trafficked plots had lower NDVI values than untrafficked plots.

A significant location × hybrid interaction for DGCI before traffic was observed (Table 2), although regardless of hybrid, DGCI values at the Coastal Plain Experiment Station were greater than the DGCI values recorded at the Woodruff Farm location (a magnitude of response), indicating that this interaction was not important. Therefore, DGCI means over both locations are reported, with 04-76 producing the largest DGCI values, followed by ‘TifSport’, then ‘Tifway’, and finally ‘TifTuf’ (Table 2). Research by Karcher and Richardson

(2003) did not observed differences in DGCI values between ‘Tifway’ and ‘Mini-Verde’ hybrid bermudagrass, or ‘Shanghai’ common bermudagrass; however, these varieties did produce DGCI values greater than Cardinal common bermudagrass. Research by Williams et al. (2010) found differences in DGCI of trafficked ‘Tifway’ and ‘TifSport’ on only one data collection date over a 2-year period. On this date, ‘Tifway’ produced a higher DGCI value than ‘TifSport’. This research also determined that ‘Tifway’ and ‘TifSport’ regularly produced lower DGCI values than the six other bermudagrasses (which included hybrid and common bermudagrasses) assessed.

There was a significant location × hybrid interaction for percent green turf color values before traffic (Table 2). Hybrid 04-76 at the Woodruff Farm location produced the lowest percent green cover (76.9%), followed by ‘TifSport’ at the Coastal Plain Experiment Station (88.5%), and then 04-76 at the Coastal Plain location (90.5%). ‘Tifway’ and ‘TifTuf’, regardless of location, had the highest percent green cover before traffic, ranging from 96.2% to 99.3%, respectively.

WEAR TOLERANCE OF FOUR HYBRID BERMUDAGRASSES. Both location and hybrid bermudagrasses were significantly different for percent green turf color assessed after 6 weeks of traffic, and the interaction between these factors was not significant

Table 2. Effects of location and hybrid bermudagrass variety on quantitative measures, normalized difference vegetation index (NDVI), dark green color index (DGCI) and green turf color observed before traffic applications at Tifton, GA in 2012.

Source of variation	Numerator df	Denominator df	NDVI	DGCI	Green turf color (%)
			P > F ^z		
Location (L)	1	2	*	*	NS
Hybrid (H)	3	12	*	***	*
L × H	3	13	NS	*	***
Location^x			NDVI	DGCI	Green turf color (%)
Coastal Plain Experiment Station			7.1 a ^y	0.8148 a	94.2 a
Woodruff Farm			6.6 b	0.7626 a	91.7 a
Hybrid		Both locations^x	Both locations	CPES^y	Woodruff farms
04-76		6.5 b	0.8568 a	90.5 b	76.9 b
‘TifSport’		6.8 ab	0.7979 b	88.5 b	96.2 a
‘Tifway’		7.0 a	0.7733 c	98.5 a	96.2 a
‘TifTuf’		7.2 a	0.7267 d	99.3 a	97.6 a

^zSignificant at a 0.05 level of probability, ***significant at a 0.001 level of probability, ns = not significant at a 0.05 level of probability.

^yMeans within columns followed by the same letter are not significantly different according to least significant difference at the 0.05 P level.

^xLocations included the University of Georgia Coastal Plains Experiment Station (CPES) and Abraham Baldwin Agricultural College Woodruff Farms both in Tifton, GA.

(Table 3). The percent green turf color at the Woodruff Farm location (72.1%) was greater than the cover observed at the Coastal Plain Experiment Stations (63.3%) on average. Before traffic, no differences between these locations were observed. Regarding hybrid bermudagrasses, 'TifTuf' produced the greatest green turf color (86.3%) after the 6-week traffic period. 'Tifway' and 'TifSport' followed 'TifTuf', producing green turf color values of 71.1% and 63.7%, respectively. Hybrid 04-76 produced the lowest percent green turf color after traffic, 49.8%.

Haselbauer et al. (2012) did not observe differences in turf color between 'Tifway' and 'TifSport' in the first year of their traffic study. It was only after 20 further traffic events were applied to the same plots in the 2nd year that 'Tifway' had more cover than 'TifSport'. Trappe et al. (2011) observed no difference in green turf color between 'Tifway' and 'TifSport' hybrid bermudagrass when assessed in the summer and fall. They found 'Tifway' and 'TifSport' to be within the top category in three of the four data assessment dates, the exception being in the Fall 2008 assessment date during which 'Tift No. 2' was the only variety out of 42 to provide greater green turf color than 'Tifway'. Goddard et al. (2008) determined that 'Riviera' common bermudagrass and 'Tifway' provided similar wear tolerance in transition zone climates (Arkansas and Tennessee), and were more wear tolerant than 'Quickstand' common bermudagrass. Williams et al. (2010) determined that 'TifSport' regularly produced higher percent green cover than 'Tifway' when under traffic stress in Florida.

REGRESSION ANALYSIS. Regression analysis determined that percent green turf color after 6 weeks of traffic was significantly correlated to hybrid bermudagrass leaf length and width, DGCI, and percent green turf color before traffic (Table 4). Leaf angle and NDVI values observed before traffic were not significantly correlated to percent green turf color after traffic. Within the significant correlations, DGCI has the strongest relationship with percent green cover after traffic ($R^2 = 0.64$). This inverse, or negative, relationship determined that within the hybrids assessed, greater DGCI values produced lower

Table 3. Effects of location and hybrid bermudagrass variety on green turf color observed after 6 weeks of traffic (12 passes with a traffic simulator) at Tifton, GA in 2012.

Source of variation	Numerator df	Denominator df	Green turf color (%)
			$P > F^z$
Location (L)	1	2	*
Hybrid (H)	3	12	***
L $\times$ H	3	12	NS
Location			Green turf color (%)
Coastal Plain Experiment Station			63.3 b ^y
Woodruff Farm			72.1 a
Hybrid			
04-76			49.8 c
'TifSport'			63.7 b
'Tifway'			71.1 b
'TifTuf'			86.3 a

^z**Significant at a 0.05 level of probability, ***significant at a 0.001 level of probability, NS = not significant at a 0.05 level of probability.

^yMeans within columns followed by the same letter are not significantly different according to least significant difference at the 0.05 P level.

Table 4. Regression analysis results for percent green turf color of four hybrid bermudagrass varieties after 6 weeks of traffic (12 passes with a traffic simulator) across leaf length, leaf width, leaf angle, normalized difference vegetation index (NDVI), dark green color index (DGCI), and green turf color before traffic at the Coastal Plain Experiment Station and Woodruff Farm at Tifton, GA in 2012.

Source of variation	Parameter estimate	$P > F^z$	R^2
Intercept	111.28	***	0.54
Leaf length (mm) ^y	-3.82	***	
Intercept	130.53	***	0.42
Leaf width (mm)	-32.81	***	
Intercept	80.73	**	0.03
Leaf angle (1-4 scale) ^x	-5.58	NS	
Intercept	14.88	NS	0.06
NDVI	7.68	NS	
Intercept	245.81	***	0.64
DGCI	-225.83	***	
Intercept	-18.91	NS	0.19
Green turf color (%)	0.93	*	

^z**Significant at the 0.05 P level, **significant at the 0.01 P level, ***significant at the 0.001 P level, NS = not significant at the 0.05 P level.

^y1 mm = 0.0394 inch.

^x1 = a leaf to sheath angle of 0° to 22.5°, 2 = 22.5° to 45°, 3 = 45° to 67.5°, 4 = 67.5° to 90°.

percent green color after traffic (Fig. 1). Leaf length (Fig. 2) and width (Fig. 3) also produced a negative correlation ($R^2 = 0.54$ and 0.42 , respectively) between cover after traffic.

Contrary to these findings, Lulli et al. (2012) concluded that leaf dimension (width and thickness) of 'Tifway' bermudagrass, 'Zeon' zoysiagrass (*Zoysia matrella*), 'Salem' seashore

paspalum (*Paspalum vaginatum*), and a cool-season mixture of 70% perennial ryegrass [*Lolium perenne* (35% 'Speedster' + 35% 'Greenway')] and 30% kentucky bluegrass (15% 'SR2100' + 15% 'Greenknight') was not related to wear resistance or recovery. However, they determined that 'Zeon' zoysiagrass had the thinnest leaves as well as the greatest wear

Fig. 1. Trends in green turf color of 'Tifway', 'TifSport', 'TifTuf', and 04-76 hybrid bermudagrass observed after 6 weeks of traffic (12 passes with a traffic simulator) across dark green color index (DGCI) at Tifton, GA in 2012; ♦ = actual values (24 data points across three replications, two locations, and four hybrids).

Fig. 2. Trends in green turf color of 'Tifway', 'TifSport', 'TifTuf', and 04-76 hybrid bermudagrass observed after 6 weeks of traffic (12 passes with a traffic simulator) across leaf length at Tifton, GA in 2012; ♦ = actual values (24 data points across three replications, two locations, and four hybrids); 1 mm = 0.0394 inch.

Fig. 3. Trends in green turf color of 'Tifway', 'TifSport', 'TifTuf', and 04-76 hybrid bermudagrass observed after 6 weeks of traffic (12 passes with a traffic simulator) across leaf width at Tifton, GA in 2012; ♦ = actual values (24 data points across three replications, two locations, and four hybrids); 1 mm = 0.0394 inch.

Fig. 4. Trends in green turf color of 'Tifway', 'TifSport', 'TifTuf', and 04-76 hybrid bermudagrass observed after 6 weeks of traffic (12 passes with a traffic simulator) across green turf color before traffic at Tifton, GA in 2012; ♦ = actual values (24 data points across three replications, two locations, and four hybrids).

tolerance within the grasses assessed. In this study, increasing leaf length and width resulted in decreasing green turf color after traffic. Percent green turf color before traffic was the only variable to be positively correlated to cover after traffic [$R^2 = 0.19$ (Fig. 4)].

Conclusions

'TifTuf' provided the greatest wear tolerance, or percent green turf color, followed by 'Tifway' and 'TifSport' after 6 weeks of traffic. The experimental hybrid 04-76 had the poorest wear tolerance. Regression analysis findings suggest that DGCI, followed by leaf length, then leaf width, and finally percent green turf color before traffic are variables to consider when selecting or breeding hybrid bermudagrass for traffic tolerance. It is important to note that hybrids with greater DGCI (darker green) values, as well as longer and wider leaves resulted in reduced wear tolerance. These findings would also suggest that within the hybrid bermudagrasses assessed, leaf angle and NDVI are not correlated to wear tolerance. More research should be done in the future to screen a diverse set of hybrid bermudagrass lines for these characteristics to validate our conclusions.

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