Stolon Growth and Tillering of Experimental Zoysiagrasses in Shade

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Abstract. Zoysiagrass (*Zoysia* spp.) grown under shade on golf courses and in home lawns is slow to recover from damage and declines in quality over time. We evaluated stolon growth and tillering of ‘Meyer’ and Chinese Common (both *Z. japonica* Steud.); ‘Zorro’, ‘Diamond’, and ‘Cavalier’ [all *Z. matrella* L. (Merr.)]; ‘Emerald’ (*Z. matrella* × *Z. pacifica* Goudsw.); and six experimental progeny from ‘Emerald’ × *Z. japonica* and reciprocal crosses of *Z. japonica* × *Z. matrella* under silver maple (*Acer saccharinum* L.) shade and in full sun in 2008 and 2009 in Manhattan, KS. A single 6-cm diameter plug was planted in the center of 1.2 m × 1.2-m plots, and data were collected weekly on the number of stolons, stolon elongation, and number of stolon branches. Tiller number was collected at the start and end of each study period, and biomass (excluding roots) was determined at the end of each season. Zoysiagrasses under an average of 76% tree shade exhibited reductions of 38% to 95% in stolon number; 9% to 70% in stolon length; 10% to 93% in stolon branching; and 56% to 98% in biomass. Seven of the 10 grasses exhibited a decline in tiller number in each experiment; none of the grasses differed from ‘Meyer’ in percentage change in tiller number under shade. ‘Emerald’, ‘Cavalier’, ‘Zorro’, and several progeny from crosses between ‘Emerald’ × *Z. japonica* or reciprocal crosses of *Z. matrella* × *Z. japonica* produced more, longer, or more highly branched stolons than ‘Meyer’, suggesting they may have improved recovery potential in shade.

Zoysiagrass grown under shade on golf courses and in home lawns is slow to recover from injury and declines in quality over time. Tree shade reduces photosynthetically active radiation (*PAR*) resulting in reduced photosynthesis and altered photomorphogenesis (Bell and Danneberger, 1999; Bell et al., 2000). Furthermore, shade induces leaf elongation and results in a substantial decrease in turf density and rooting (Fry and Huang, 2004). Total nonstructural carbohydrates also decline over time in shaded zoysiagrass (Qian and Engelke, 1999; Qian et al., 1998).

Zoysiagrass cultivars from *Z. japonica* have been reported to have poorer shade tolerance compared with ‘Emerald’ zoysiagrass or cultivars from *Z. matrella* (Fry and Huang, 2004). Under 90% live oak tree [*Quercus virginiana* (Mill.)] shade in Dallas, TX, coverage of ‘Diamond’ (94%), ‘Zorro’ (84%), and ‘Cavalier’

(74%) was superior to ‘Meyer’ (33%) and ‘El Toro’ (*Z. japonica*, 65%) after 3 years of growth from plugs (Yamamoto and Engelke, 1996).

Since 2004, turfgrass researchers at Kansas State University have evaluated over 600 new zoysiagrass progeny for quality and winter survival (Fry et al., 2008). These progeny were the result of controlled pairwise crosses made at Texas AgriLife Research–Dallas, most of which were interspecific hybrids with one parent being a *Z. japonica* and the other ‘Emerald’ or one of several different *Z. matrella* genotypes. The underlying goal of this work is to develop one or more new cultivars that have good density, fine leaf texture, and quality similar to the aforementioned *Z. matrella* genotypes but with freezing tolerance as good or better than ‘Meyer’.

Earlier research on these experimental zoysiagrasses (Okeyo et al., 2011) and zoysiagrass cultivars (Patton et al., 2007) indicated that there is significant variability in stolon production, elongation, and rate of coverage among genotypes in full sun. We hypothesized that ‘Emerald’ × *Z. japonica* or reciprocal crosses of *Z. matrella* × *Z. japonica* would exhibit greater stolon growth and tillering than ‘Meyer’ in shade because one of the parents has superior shade tolerance to ‘Meyer’. The objective of this study was to evaluate stolon growth and tillering of zoysiagrass cultivars and experimental progeny in tree shade.

Six experimental zoysiagrass progeny from ‘Emerald’ × *Z. japonica* and reciprocal crosses between *Z. japonica* × *Z. matrella*; ‘Meyer’ and Chinese Common (both *Z. japonica* Steud.); ‘Zorro’, ‘Diamond’, ‘Cavalier’ [all *Z. matrella* L. (Merr.)]; and ‘Emerald’ (*Z. matrella* × *Z. pacifica* Goudsw.) were evaluated in studies conducted under tree shade and in full sun at the Rocky Ford Turfgrass Research Center, Manhattan, KS (lat. 39°12’8” N; long. 96°35’8” W) in 2008 and 2009. Shaded plots measuring 1.2 m × 1.2 m were arranged in a randomized complete block design with six replicates between 1.5 and 7.5 m to the north side of a line of silver maple trees, most between 8 and 15 m tall. Grasses were arranged in each block parallel to the tree line. The full-sun study area was ≈100 m from the shade study area. Soil in both areas was a Chase silt loam (fine, montmorillonitic, mesic, Aquic, Argiudolls). The soil in the full sun study area had a pH of 7.8 and phosphorus (P) level was 111 mg·kg⁻¹ and potassium (K) level was 451 mg·kg⁻¹; whereas soil test results for soil under tree shade indicated a pH of 5.5, P level of 73 mg·kg⁻¹, and K level of 368 mg·kg⁻¹. Considering there was a short period between the time soil testing was done and grasses were planted, no attempt was made to raise the pH in the soil in shade; zoysiagrass grows sufficiently under a wide range of pH levels (Beard, 1973). A weather station located on site was used to monitor air temperature and precipitation.

Before planting each year, grasses were vegetatively propagated in the greenhouse. A single 6-cm diameter plug was planted in the center of each plot on 30 June 2008 and on 26 June 2009. Turf was not mowed. Nitrogen from urea was applied on 14 July and 12 Aug. 2008 and 21 July and 18 Aug. 2009 to provide 49 kg·ha⁻¹. To minimize differences in soil water content between full-sun and shade study areas, irrigation was used to supplement natural rainfall and maintain the soil moisture level at 25% to 35% v/v at 0 to 15 cm as measured twice weekly using a time domain reflectometer (Model 6050XI, Soilmoisture Equipment Corp., Santa Barbara, CA). Root zone temperatures in each study area were measured using a soil bimetallic digital thermometer (Model 6300; Spectrum Tech., Plainfield, IL). Temperatures were measured at a 0- to 10-cm depth in three randomly selected plots in the shade and full-sun areas once weekly between 1100 and 1200 hr. In 2008, average maximum and minimum soil temperatures over the study period in shade were 18.6 and 17.9 °C, respectively. Average maximum soil temperature in the full sun was 25.0 °C, whereas the average minimum was 21.1 °C. In 2009, average maximum and minimum temperatures in shade were 20.7 and 14.1 °C. In full sun, the average maximum temperature in full sun was 26.1 °C and the average minimum was 23.9 °C.

Photosynthetically active radiation was measured once monthly during each study period using a ceptometer (AccuPAR model LP-80; Decagon, Pullman, WA) at 0730 hr,

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1030 HR, 1330 HR, 1630 HR, and 1930 HR. The ceptometer was held at the grass canopy level (with no grass shading the sensors) in the center of each plot, and readings were taken and then averaged over the study area (Table 1). Measurements of replicates in the shaded area were alternated with those within the full sun area to minimize the effects of solar angle on *PAR* measurements.

Data were collected on the number of stolons, stolon length, number of stolon branches, tillering, and biomass. The number of stolons, stolon length, and number of branches were determined at the end of each study on 29 Sept. 2008 and 24 Sept. 2009. Stolon numbers were determined by counting the number of stolons originating from each plug. Stolon elongation and branching were evalu-

ated on each of the first three stolons that emerged from each plug. Each of the stolons used to evaluate elongation and branching was labeled with a loose knot of thread tied around the stolon to facilitate its identity. Stolon elongation represents the average length of the three stolons from each plug. Branching was determined by counting the number of branches on each stolon and taking the mean. Tillering was determined at the initiation of each study by counting all tillers in the 6-cm diameter plug. At the end of each experiment, a 6-cm diameter template was centered over each plug and tillers were counted. Biomass was determined at the end of study period by excavating all shoots, stolons, and rhizomes; air-drying for 4 weeks at 25 to 30 °C; removing any remaining soil; and weighing.

Data from the full-sun area were used to calculate the percentage growth reduction in stolon growth parameters or biomass that occurred in shaded turf as: (growth parameter in full sun – growth parameter in shade)/growth parameter in full sun × 100. Change in tiller number from the beginning to the end of each experimental period was calculated as: (tiller number at the end of the experiment – tiller number at the beginning of the experiment)/tiller number at the beginning of the experiment × 100. All stolon and biomass data were subjected to square root transformation before analysis and back-transformed before presentation. Data were analyzed using the general linear models procedure (SAS Institute, Inc., 2003) and means were separated using the Ryan-Einot-Gabriel-Welsch multiple

Table 1. Photosynthetically active radiation (*PAR*) in the shade and full sun study areas at Manhattan, KS, in 2008 and 2009.

Time (HR)	<i>PAR</i> (μmol·m ⁻² ·s ⁻¹) ^z											
	July				August				September			
	Shade		Full sun		Shade		Full sun		Shade		Full sun	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
0730	95.3	110.9	612.1	663.2	58.5	51.4	137.1	215.1	56.7	47.4	199.5	169.6
1030	144.5	203.4	1533.9	1521.0	105.7	156.4	1317.8	1317.6	73.8	62.3	1196.6	1017.1
1330	407.9	364.0	2045.9	2012.5	367.1	379.7	1909.4	1020.3	269.0	171.9	1687.6	1624.5
1630	898.3	688.1	1580.2	1481.4	602.6	524.3	1275.7	1353.9	426.7	363.1	1027.8	873.6
1930	107.2	220.5	612.1	254.2	83.3	112.4	156.8	171.4	6.3	13.3	11.7	18.0
Reduction compared with full sun (%) ^y	74.1	73.2			74.6	70.0			79.8	82.2		

^z*PAR* is the average overall study plots and was measured on 7 July, 18 Aug., and 9 Sept. 2008 and 9 July, 12 Aug., and 9 Sept. 2009.

^yReduction in *PAR* was calculated for each month as: (total *PAR* in full sun – total *PAR* in shade)/total *PAR* in full sun × 100.

Table 2. Stolon number, length, branching, and biomass of shade-grown zoysiagrasses and reduction in growth compared with grasses in full sun at Manhattan, KS, in 2008.

Cultivar or progeny ^z	Stolon							
	Number ^y		Length (mm) ^w		Branches (no./stolon) ^v		Biomass (g) ^u	
	Reduction in shade compared with sun (%) ^x		Reduction in shade compared with sun (%)		Reduction in shade compared with sun (%)		Reduction in shade compared with sun (%)	
	Shade		Shade		Shade		Shade	
<i>Z. japonica</i>								
‘Meyer’	3.8 f [†]	95.0 a	162 de	30.6 a	7.8 cd	82.9 ab	26.7 abcd	73.4 a
Chinese Common	6.8 ef	78.0 b	319 abc	20.8 a	15.1 abc	59.5 bcd	29.3 abcd	70.7 a
‘Emerald’ (<i>Z. japonica</i> × <i>Z. pacifica</i>)	12.3 abcd	78.4 b	184 de	18.6 a	16.5 abc	66.1 bcd	33.0 abc	67.0a
<i>Z. matrella</i>								
‘Diamond’	3.2 f	94.5 a	95 e	31.4 a	3.1 d	92.5 a	34.4 ab	65.6 a
‘Cavalier’	10.7 bcde	85.1 ab	243 bcd	18.0 a	11.6 bcd	68.2 abcd	17.8 bcd	82.2 a
‘Zorro’	14.8 ab	86.0 ab	303 abc	29.3 a	19.6 ab	72.2 abcd	6.1 d	93.9 a
‘Cavalier’ × C. Common								
5311-22	17.5 a	79.5 b	309 abc	28.7 a	13.3 abc	61.1 bcd	15.4 bcd	84.6 a
5311-27	12.0 bcde	75.0 b	213 cde	44.3 a	10.9 bcd	73.8 abc	43.9 a	56.2 a
‘Zorro’ × C. Common								
5312-49	9.2 cde	81.9 ab	336 ab	37.7 a	15.2 abc	52.8 cd	17.2 bcd	82.8 a
‘Emerald’ × ‘Meyer’								
5321-3	13.0 abc	86.9 ab	383 a	8.7 a	19.9 ab	57.1 bcd	9.98 cd	90.0 a
5321-18	—	—	—	—	—	—	—	—
‘Meyer’ × ‘Diamond’								
5327-19	9.7 bcde	80.2 b	348 ab	13.6 a	21.3 a	46.6 d	18.8 bcd	81.2 a

^zGrasses were planted in silver maple tree shade and in full sun as 6-cm diameter plugs with six replicates on 30 June 2008.

^yThe average number of stolons per plug over six replicates on 29 Sept. 2008.

^xPercentage reduction in shade compared with full sun was calculated as: (value in full sun – value in shade)/value in sun × 100.

^wThe average total length of three stolons per plug over six replicates on 29 Sept. 2008.

^vThe average number of branches on three stolons per plug over six replicates on 29 Sept. 2008.

^uThe average dry weight of all shoots, including rhizomes, over six replicates, after harvest on 29 Sept. 2008.

[†]Means followed by the same letter in a column are not significantly different according Ryan-Einot-Gabriel-Welsch test at *P* < 0.05.

comparison test (Hochberg and Tamhane, 1987; Mickey et al., 2004) at $P < 0.05$.

Results and Discussion

Photosynthetically active radiation in the shaded plots was reduced by 70% to 82% across months and years evaluated (Table 1). Analysis of variance indicated a significant ($P < 0.05$) difference between years for data collected on zoysiagrass stolon growth and tillering; therefore, years are presented separately. It is common for zoysiagrass managers to note the difficulty of getting zoysiagrass to recover from injury, even under moderate shade. Zoysiagrasses growing under shade exhibited reductions of 38% to 95% in stolon number; 9% to 70% in stolon length; 10% to 93% in branching; and 56% to 98% in biomass compared with turf in full sun (Tables 2 and 3). In addition, tillering declined from beginning to end of the study for seven of the 10 grasses in 2008 and 2009 (Table 4).

Chinese Common, a *Z. japonica*, is not considered to be shade-tolerant (Fry and Huang, 2004), although it exhibited less decline in stolon numbers than 'Meyer' in 2008 in shade in this study (Table 3). Chinese Common exhibited a 21% increase in tillers in 2008 and an 18% increase in 2009 (Table 4).

'Emerald' was superior to 'Meyer' in stolon numbers in shade each year, and the reduction in stolon numbers in 'Emerald' in shade compared with full sun was less than in

'Meyer' in 2008 (Tables 2 and 3). 'Emerald' also increased in tiller number under shade in each year and had more tillers than 'Meyer' at the initiation and end of the study period in 2009 (Table 4). In Dallas, TX, 'Emerald' was among the best-performing cultivars under 90% oak tree shade (Yamamoto and Engelke, 1996). Although 'Emerald' is inferior to 'Meyer' in freezing tolerance (Dunn et al., 1999), progeny from 'Emerald' $\times$ 'Meyer' have exhibited freezing tolerance equivalent to 'Meyer' the field and under controlled freezing experiments (Okeyo, 2010). In this study, 5321-3 ('Emerald' $\times$ 'Meyer') had greater stolon numbers, length, and branching compared with 'Meyer' in the shade in 2008. In addition, 5321-3 ('Emerald' $\times$ 'Meyer') had an increase in tiller number in shade in both years, but neither it nor 5321-18 ('Emerald' $\times$ 'Meyer') was different from 'Meyer' in tiller number at the end of each study period.

Z. matrella cultivars are generally considered to have better shade tolerance than *Z. japonica* cultivars (Fry and Huang, 2004). 'Cavalier' had greater stolon numbers than 'Meyer' in 2008 (Table 2). 'Zorro' had more, longer, and more highly branched stolons in the shade compared with 'Meyer' in 2008 and produced more stolons than 'Meyer' in 2009 (Tables 2 and 3). In addition, the reduction in stolon numbers in 'Diamond' and 'Zorro' in shade compared with full sun was less than that observed for 'Meyer' in 2009. Four years after establishment from plugs under 90% live

oak tree shade in Dallas, TX, 'Meyer' had an average of 25% coverage, whereas *Z. matrella* genotypes had between 50% and 75% coverage (Morton et al., 1991). In Arkansas, subjecting established zoysiagrass plots to 50% artificial shade for 12 weeks resulted in greater than 97% coverage for 'Cavalier', 'Diamond', and 'Zorro' and 90% coverage for 'Meyer' (Trappe et al., 2009).

Progeny from reciprocal crosses between *Z. matrella* $\times$ *Z. japonica* and 'Emerald' $\times$ *Z. japonica*, including those evaluated here, have demonstrated good winter survival in the field and good freezing tolerance under laboratory conditions (Okeyo, 2010). Progeny with higher stolon numbers in the shade compared with 'Meyer' in 1 or both years included 5311-22 and 5311-27 (both 'Cavalier' $\times$ Chinese Common), 5312-49 ('Zorro' $\times$ Chinese Common), and 5327-19 ('Meyer' $\times$ 'Diamond') (Tables 2 and 3). Other experimental lines that also exhibited a smaller reduction in stolon number in shade versus full sun when compared with 'Meyer' in 1 or both years were 5311-22 and 5311-27 (both 'Cavalier' $\times$ Chinese Common) and 5327-19 ('Meyer' $\times$ 'Diamond').

Progeny 5311-22 ('Cavalier' $\times$ Chinese Common) had greater stolon length in the shade in 2008 and 2009 compared with 'Meyer', and 5327-19 ('Meyer' $\times$ 'Diamond') was superior to 'Meyer' in length in 2009 (Tables 2 and 3). Progeny 5327-19 ('Meyer' $\times$ 'Diamond') had more stolon branches than 'Meyer' in the shade in 2008 as did 5311-22

Table 3. Stolon number, length, branching, and biomass of shade-grown zoysiagrass cultivars and experimental progeny and reduction in growth compared with grasses in full sun at Manhattan, KS, in 2009.

Cultivar or progeny ^z	Stolon						Biomass (g) ^u	
	Number ^y		Length (mm) ^w		Branches (no./stolon) ^v			
	Shade	Reduction in shade compared with sun (%) ^x	Shade	Reduction in shade compared with sun (%)	Shade	Reduction in shade compared with sun (%)	Shade	Reduction in shade compared with sun (%)
<i>Z. japonica</i>								
'Meyer'	5.8 d ⁱ	85.3 a	336 c	56.9 ab	14.2 bc	50.0 a	13.2 b	97.2 a
Chinese Common	9.7 cd	89.2 a	545 abc	44.4 bc	16.4 bc	24.3 a	29.3 ab	97.9 a
'Emerald' (<i>Z. japonica</i> × <i>Z. pacifica</i>)	25.8 abc	76.0 ab	407 bc	70.1 a	12.1 c	58.1 a	32.0 ab	89.1 a
<i>Z. matrella</i>								
'Diamond'	14.3 abcd	57.4 bc	379 bc	65.1 ab	15.8 bc	20.4 a	14.0 b	90.5 a
'Cavalier'	21.2 abcd	76.0 ab	454 bc	64.6 ab	15.4 bc	48.7 a	17.7 ab	97.0 a
'Zorro'	28.2 ab	38.0 c	520 abc	68.6 a	20.5 abc	47.5 a	26.2 ab	96.8 a
'Cavalier' × C. Common								
5311-22	30.2 a	65.3 abc	770 a	63.9 ab	31.9 a	10.4 a	41.3 ab	97.9 a
5311-27	20.7 abcd	74.0 ab	482 bc	67.9 a	23.1 abc	51.5 a	34.2 ab	96.2 a
'Zorro' × C. Common								
5312-49	22.5 abc	72.8 ab	638 ab	59.4 ab	25.8 ab	8.5 a	54.7 a	92.8 a
'Emerald' × 'Meyer'								
5321-3	21.8 abcd	80.2 a	601 abc	56.8 ab	24.9 ab	19.1 a	25.3 ab	96.0 a
5321-18	22.5 abcd	59.3 abc	470 bc	63.0 ab	16.8 bc	33.7 a	29.0 ab	91.2 a
'Meyer' × 'Diamond'								
5327-19	19.5 abcd	43.9 bc	515 abc	52.7 abc	16.1 bc	44.1 a	20.7 ab	85.7 a

^zGrasses were planted in tree shade and in full sun as 6-cm diameter plugs with six replicates on 26 June 2009.

^yThe average number of stolons per plug over six replicates on 24 Sept. 2009.

^xPercentage reduction in shade compared with full sun was calculated as: (value in full sun – value in shade)/value in sun $\times$ 100.

^wThe average total length of three stolons per plug over six replicates on 24 Sept. 2009.

^vThe average number of branches on three stolons per plug over six replicates on 24 Sept. 2009.

^uThe average dry weight of all shoots, including rhizomes, over six replicates after harvest on 24 Sept. 2009.

ⁱMeans followed by the same letter in a column are not significantly different according to the Ryan-Einot-Gabriel-Welsch test at $P < 0.05$.

Table 4. Changes in tiller number of zoysiagrass cultivars and experimental progeny in shade from 14 July to 27 Sept. 2008 and 1 July to 23 Sept. 2009 at Manhattan, KS.

Cultivar or experimental progeny ^a	Tillers (no. 20/cm ²) ^b					
	2008			2009		
	14 July	17 Sept.	Change (%) ^c	1 July	23 Sept.	Change (%) ^c
<i>Z. japonica</i>						
‘Meyer’	72.2 bc ^w	56.3 bcde	–18.7 abc	53.3 cde	50.7 de	–0.7 ab
Chinese Common	29.3 c	34.5 e	+21.1 ab	33.2 e	36.2 f	+18.3 a
‘Emerald’ (<i>Z. japonica</i> × <i>Z. pacifica</i>)	68.3 bc	76.2 b	+22.4 a	78.8 bcd	83.8 b	+17.4 a
<i>Z. matrella</i>						
‘Diamond’	189.7 a	114.2 a	–39.2 bc	131.3 a	139.5 a	+19.4 a
‘Cavalier’	89.5 b	65.8 bcd	–8.4 abc	82.8 bcd	70.8 bc	–1.9 ab
‘Zorro’	72.2 bc	69.2 bc	–0.9 abc	91.3 bc	77.0 b	–13.6 ab
‘Cavalier’ × Chinese Common						
5311-22	47.5 bc	36.2 de	–22.8 abc	55.8 cde	43.8 ef	–20.6 ab
5311-27	87.3 b	45.2 cde	–43.3 c	44.0 de	45.3 ef	+4.7 ab
‘Zorro’ × Chinese Common						
5312-49	41.7 c	39.8 cde	–4.4 abc	49.5 de	56.8 cde	+20.8 a
‘Emerald’ × ‘Meyer’						
5321-3	42.0 c	45.0 cde	+9.9 abc	50.7 de	50.3 de	–6.9 ab
5321-18	—	—	—	96.7 b	65.7 bcd	–29.8 b
‘Meyer’ × ‘Diamond’						
5327-19	31.8 c	32.3 e	+6.3 abc	63.7 bcde	48.0 de	–19.6 ab

^aGrasses were planted in tree shade and full sun as 6-cm diameter plugs with six replicates on 30 June 2008 and 26 June 2009.

^bThe average number of tillers is the number of tillers counted within 20-cm² center of the planted plug over six replicates on 14 July and 17 Sept. 2008 and 1 July and 23 Sept. 2009.

^cPercentage change in tiller number from the beginning to the end of each experimental period was calculated as: (tiller number at the end of the experiment – tiller number at the beginning of the experiment)/tiller number at the beginning of the experiment × 100. Values were calculated using changes occurring within each replicate, not means presented in the table.

^wMeans followed by the same letter in a column are not significantly different according to Ryan-Einot-Gabriel-Welsch test at *P* < 0.05.

(‘Cavalier’ × Chinese Common) in 2009. Stolon branches also declined less in shade compared with full sun in 5312-49 (‘Zorro’ × Chinese Common) and 5327-19 (‘Meyer’ × ‘Diamond’) relative to ‘Meyer’ in 2008.

Z. matrella lines are also known for their high tiller density under full sun (Morris, 2000, 2006; Morris and Shearman, 1995). In 2008 and 2009, ‘Diamond’ had higher tiller density than ‘Meyer’ at the initiation and end of study periods in the shade (Table 4). ‘Cavalier’ and ‘Zorro’ also had higher tiller densities than ‘Meyer’ at the end of the study in 2009.

Changes in tiller density across all *Z. matrella* cultivars from the beginning to end of the studies were similar to ‘Meyer’ in both years (Table 4). Likewise, progeny resulting from crosses between *Z. matrella* × *Z. japonica* had a similar number of tillers as ‘Meyer’ in the shade at the end of each study period, and percentage change in the tiller number of each was no different from ‘Meyer’. The superior shade tolerance of these *Z. matrella* cultivars relative to ‘Meyer’ previously reported in the literature could be attributable, in part, to the high tiller densities of these cultivars. All *Z. matrella* cultivars except ‘Diamond’ (2009) declined in tiller density from the beginning to the end of the studies. As such, these cultivars may experience a decline in tiller number in shade, yet maintain better density than other grasses because they have a larger initial number of tillers at the time of planting.

The reductions in stolon production, growth, and tillering in shade demonstrate how zoysiagrass recovery in moderate shade is inhibited and quality often declines. An 85% decrease in

total nonstructural carbohydrates in ‘Diamond’ zoysiagrass occurred under 86% shade in the field (Qian and Engelke, 1999); under 88% shade in a polyhouse, ‘Diamond’ carbohydrate levels declined by 65% 10 weeks after shading began (Qian et al., 1998). Carbohydrate allocation in shade is not well understood. In full sun, zoysiagrasses that allocated more carbohydrates to stolon production than to leaves had longer stolons and quicker establishment rates (Patton et al., 2007). Here, all grasses produced some stolons in shade, yet tillering declined in a number of grasses from the beginning to the end of the study periods. Stolon production, elongation, and branching per se do not necessarily equate to good shade tolerance. For example, a grass that could maintain tiller density, yet produce few or no stolons, may be able to maintain turf quality in shade; this can only be determined in studies evaluating larger plots. Furthermore, some zoysiagrasses inherently produce rhizomes more readily than stolons such as ‘Diamond’ (Engelke et al., 2002).

In summary, several zoysiagrass cultivars produced more, longer, and/or more highly branched stolons than ‘Meyer’ in shade, including ‘Emerald’, ‘Cavalier’, and ‘Zorro’. In addition, several progeny derived from crosses between ‘Emerald’ × *Z. japonica* (‘Meyer’ or Chinese Common) or a *Z. matrella* × *Z. japonica*, which have exhibited good freezing tolerance, also had superior stolon number, length, and/or tillering under shade compared with ‘Meyer’. An important next step will be to evaluate these grasses in longer-term studies using larger, established swards of turf in

the shade so that turf quality and physiological responses can be evaluated.

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