‘Diamond’ Zoysiagrass Putting Green Establishment Affected by Sprigging Rates, Nitrogen Sources, and Rates in the Southern Transition Zone

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Abstract. ‘Diamond’ zoysiagrass [Zoysia matrella (L.) Merr.] has a potential to become a new alternative warm-season putting green turfgrass. The main objective of the study was to determine factors affecting establishment speed for ‘Diamond’ zoysiagrass as a putting green in the southern transition zone of the United States. Two sprigging rates, three nitrogen (N) sources, two N rates, and two mowing heights (2.5 and 3.2 mm) were compared at Clemson University, Clemson, SC. Sprigs of ‘Diamond’ zoysiagrass were planted at rates of 91 or 182 m³·ha⁻¹ in 2007 and repeated in 2008. Urea, ammonium nitrate, and ammonium sulfate were applied at 1.5 or 3.3 g N/m²/week from weeks after sprigging (WAS) 3 to 10. Rates were halved from WAS 11 to 16. The N fertilizers were applied as solutions weekly for 16 weeks. Weekly percent cover, turf color ratings, root and clipping sample, and ball rolling were collected for both years. A significant difference occurred in turf cover between high and low sprig rates. Turf color and cover results show that high rates of fertility associated with high rates of sprigs produced 100% turf cover at WAS 11 and 13 in both years. At the 2.5-mm mowing height, ball rolling reached 258 cm in August and was significantly faster than the 3.2-mm mowing height. Results show ‘Diamond’ zoysiagrass can be established within the same growing season to meet a playable putting green quality, but the establishment speed may vary depending on summer monthly temperature fluctuations.

Zoysiagrass (Zoysia spp.) is a popular warm-season, perennial turfgrasses used on golf courses, sports fields, home lawns, and commercial landscapes from the northern transition zone to the southern region in the United States (Beard, 2002; Engelke and Anderson, 2003). Most commonly used zysiagrasses in these zones include three species of Zoysia matrella [(L.) Merr.], Zoysia japonica (Steud.), and Zoysia pacifica (Wildl. ex Thiele) (Engelke and Anderson, 2003). Zoysiagrass has a wide range of leaf textures and appearances and provides excellent summer-month growth performance compared with cool-season turfgrasses in the transition zone. It forms a dense, uniform turf by producing both rhizomes and stolons. It also tolerates stress and unfavorable conditions, including lower light intensity (Baldwin et al., 2009; Qian and Engelke, 1999a), moderate to high salinity (Marcum et al., 1998; Qian et al., 2000), moderate drought conditions (Qian and Engelke, 1999b; White et al., 2001), and cold temperatures (Patton and Reicher, 2007; Wurmund et al., 1998). High quality of turf appearance under a wide range of environmental conditions has increased zoysiagrass popularity.

There is limited research published about ‘Diamond’ zoysiagrass [Zoysia matrella (L.) Merr.] use for putting greens. Zoysiagrass establishment using vegetative plugs or sprigs can take months or even longer to reach adequate coverage and turf quality in comparison with other warm-season turfgrasses (McCarty and Miller, 2002). Furthermore, improper establishment of warm-season turfgrasses may increase plant stress (Richardson and Boyd, 2001) to pest problems, winter-hardiness, maintenance cost during establishment, and reduce overall turfgrass quality and function of the desired turf use (Stiglbauer, 2009).

‘Diamond’ zoysiagrass was developed and released by the Texas Agricultural Experiment Station in Apr. 1996 and registered in 2002 (Engelke et al., 2002). It has adapted throughout the southern region to the transition zone of the United States as a fine turf requiring medium to high maintenance for use on golf course tees, fairways, sports fields, and home lawns (Engelke et al., 2002). However, among zoysiagrasses, relatively faster establishment rates from plugs have been observed for cultivar Z. japonica than for Z. matrella (Patton et al., 2007). In comparison with sod establishment, zoysiagrass sprig establishment has been shown to be economically feasible and practical. Planting time, fertilizer input, and sprigging rates affect warm-season turfgrass establishment speed and quality depending on location (Guerat and Hicks, 2009; Patton et al., 2004; Richardson and Boyd, 2001). Increased nitrogen (N) fertilization rate during establishment can hasten vegetative establishment. Richardson and Boyd (2001) reported a 5% to 10% increase in turf cover of ‘Meyer’ zoysiagrass (Zoysia japonica Steud.) 120 d after sprigging at a low rate of 18 m³·ha⁻¹ when monthly N was increased from 0 to 2.5 g m⁻². There is a lack of published research regarding N rates, N sources, and sprigging rates for warm-season putting green establishment. However, a few seeding rates studies about zoysiagrass establishment were reported. Portz et al. (1981) recommended seeding rates of 3.8 to 9.8 g·m⁻² zoysiagrass, whereas Landry and Choi (1995), in greenhouse studies, found 9.8 g·m⁻² produced the highest shoot and root growth. Carroll et al. (1996) reported that sprigs (using sprigging rates of 19 or 31 m³·ha⁻¹) of ‘Meyer’ zoysiagrass treated with urea-N, a biostimulator, and one of three pre-emergence herbicides or one of two postemergence herbicides hastened establishment in two field studies. Monthly rate of N at 4.9 g·m⁻² applied during the growing season had no influence on sprig establishment in the first year, but slightly increased (+5%) turf cover the second year with a higher sprigging rate of 31 m³·ha⁻¹. Overall, sprigging rate recommendations for establishment are lacking or inclusive. Therefore, the objective of this field study was to evaluate ‘Diamond’ zoysiagrass responses to sprigging rate and fertilizer N source and rate during establishment of putting greens in the transition zone of the United States. 

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cover and color were monitored weekly after sprigging, and clipping and root mass were measured after complete cover was achieved. In addition, ball roll was measured after complete cover for two mowing heights.

Materials and Methods

Establishment and treatments. Research was conducted from May to Sept. 2007 and repeated in 2008 at the Turfgrass Research Center, Clemson University, Clemson, SC, on field research plots with the soil profile constructed to U.S. Golf Association (USGA) recommendations (USGA, 1993) with 85% sand and 15% peatmoss (v:v). The experiment design was a factorial combination of two sprigging rates, two N rates, and three N sources with a total of 12 treatments. Plot size was $2.75 \times 1$ m. Treatments were replicated three times each year and the experiment was repeated over 2 years at two adjacent sites. For the higher sprigging rate treatments, each plot (2.75-m side) was further split into subplots with two mowing heights of 2.5 and 3.2 mm, which are common mowing height range for golf putting greens. As a result of the lower turf cover to avoid scalping, the 2.5-mm mowing height was not implemented on the plots with the lower sprigging rates.

‘Diamond’ zoysiagrass sprigs were harvested less than 15 h before planting by New Life Turf, Norway, SC. Sprigs were planted by hand on 17 May 2007 and 16 May 2008 at rates of 91 m$^{-2}$ and 182 m$^{-2}$, which represent a recommended rate and twofold of the recommended rate for putting green establishment. After sprigging, to increase sprig and soil contact, the plots were cultivated in two directions with a 5-cm spacing disk with a depth of 2 cm. Plots were heavily topdressed (greater than 1 mm) with the 85:15 (sand:peatmoss; v:v) putting green sand similar to the green root zone mix. After topdressing, plots were rolled several times in different directions. Water was applied as needed to avoid any water stress during the whole establishment period of 15 weeks. A granular starting fertilizer of 17-7-14 of N (100% quick-release N), phosphorus (P), and potassium (K) was applied at 4.9 g N/m$^2$·week before the establishment and additional applications of liquid forms of P and K at 4.0 g K/m$^2$ and 2.2 g P/m$^2$, respectively, at 2 weeks after sprigging (WAS) 6. Urea, ammonium nitrate, and ammonium sulfate were applied at 1.7 or 3.4 g N/m$^2$/week from WAS 3 to 10. From WAS 11 to 12, half rates of N were applied.

In both years, the plots were first mowed in late June (40 d after sprigging) at a height of 12.7 mm. Thereafter, plots were mowed three times per week for 4 weeks at 6.4 mm and the second time at 3.2 mm. Two weeks later, half of each plot with the higher sprigging rate was mowed to 2.5 mm.

Treatment abbreviations used to present the data are as follows: the number either 182 or 91 in each treatment indicates the two sprigging rates, in which 182 = 182 m$^3$·ha$^{-1}$ as the higher rate and 91 = 91 m$^3$·ha$^{-1}$ as the lower rate; the single upper case letter indicates the three N sources as U = urea, N = ammonium nitrate, and S = ammonium sulfate; the second number with a decimal point either 3.4 or 1.7 in each treatment indicates the two N rates, in which 3.4 = the high rate of 3.4 g N/m$^2$/week from WAS 3 to 10 and 1.7 g N/m$^2$/week from WAS 11 to 16.

1.7 = the low rate of 1.7 g N/m$^2$/week from WAS 3 to 10 and 0.85 g N/m$^2$/week from WAS 11 to 16.

Data collection. Turf color readings were visually quantified on a 1 to 9 scale, in which 1 = lowest quality as brown turf and 9 = highest quality as dark green turf. Turf cover readings were taken as percentage of green turf tissue cover weekly using a laboratory-made grid. The grid was an 18.5 cm × 18.5-cm frame made from 2.5-cm diameter polyvinyl chloride pipe with strings evenly spaced to form 100 equal small squares (1.85 × 1.85 cm). During data collection, the grid was randomly placed on each plot and grid squares with or without green turfgrass shoots or leaves were counted to determine percent cover from each reading. During each reading, Stimpmeter readings were taken on each plot for ball rolls. Ball rolls were measured three times in one direction and three times in the opposite direction and then averaged for each plot. A shortened stimpmeter (Mini-Stimp; Scientific Golfer, Thousand Oaks, CA) was used to keep the ball roll within each plot. Clippings were collected from each plot using a walk-behind green mower (Greensmaster 800; The Toro Company, Bloomington, MN) and then were oven-dried at 80 °C for 48 h before weighing. Root samples were collected using a standard green cup cutter with 10 cm diameter to a depth of 25 cm. Canopy, stolons, rhizomes, and thatch were removed by hand and roots were washed using a strainer to be soil-free. Roots samples were oven-dried (80 °C), weighed, ashed in a muffle furnace (550 °C) for 3 h, and reweighed. Root data are presented as ash-free weight, i.e., oven-dry weight minus ash weight (Snyder and Cisar, 2000).

Results and Discussion

Turf cover and color. Interactions occurred between most parameters measured for both years; therefore, the data are presented separately by years (Tables 1, 2, and 3). Yearly interactions occurred as a result of the

Table 1. Weekly percent cover of ‘Diamond’ zoysiagrass established on 17 May 2007 using sprigs at two sprigging rates, three nitrogen (N) sources, and two N rates with readings started from week after sprigging (WAS) 3.

| Treatment/WAS  | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   | 13   |
|----------------|------|------|------|------|------|------|------|------|------|------|------|
| 182-N-3.4      | 50.0 | 66.0 | 62.7 | 88.0 | 90.3 | 93.3 | 95.0 | 96.3 | 99.3 | 100.0| 100.0|
| 182-N-1.7      | 51.7 | 62.3 | 60.7 | 87.7 | 86.0 | 91.3 | 92.3 | 95.7 | 99.7 | 100.0| 100.0|
| 91-N-3.4       | 26.7 | 52.7 | 48.3 | 56.7 | 70.0 | 75.3 | 81.7 | 85.0 | 93.7 | 98.0 | 100.0|
| 91-N-1.7       | 24.7 | 51.7 | 44.3 | 51.0 | 68.3 | 73.0 | 80.0 | 82.3 | 96.3 | 98.0 | 100.0|
| 182-S-3.4      | 46.7 | 68.0 | 65.3 | 89.7 | 91.3 | 95.0 | 96.3 | 99.7 | 100.0| 100.0| 100.0|
| 182-S-1.7      | 50.7 | 63.3 | 60.3 | 85.3 | 88.3 | 94.0 | 94.7 | 98.3 | 99.7 | 100.0| 100.0|
| 91-S-3.4       | 24.7 | 52.7 | 44.7 | 52.3 | 67.7 | 74.7 | 79.0 | 87.3 | 94.7 | 97.0 | 100.0|
| 91-S-1.7       | 23.7 | 50.0 | 44.0 | 52.0 | 67.3 | 72.7 | 79.0 | 82.0 | 95.3 | 96.7 | 100.0|
| 182-U-3.4      | 49.0 | 67.7 | 67.3 | 90.3 | 93.1 | 93.7 | 95.0 | 98.0 | 100.0| 100.0| 100.0|
| 182-U-1.7      | 47.3 | 63.7 | 59.0 | 85.0 | 89.0 | 91.3 | 93.3 | 96.7 | 99.7 | 100.0| 100.0|
| 91-U-3.4       | 26.0 | 55.0 | 46.3 | 53.0 | 67.7 | 75.0 | 79.3 | 82.7 | 95.0 | 97.0 | 100.0|
| 91-U-1.7       | 28.0 | 55.7 | 50.7 | 60.0 | 68.7 | 75.0 | 79.7 | 83.7 | 96.0 | 97.0 | 100.0|

*Treatment abbreviations: Either 182 or 91 in each treatment indicates the two sprigging rates, in which 182 = 182 m$^3$·ha$^{-1}$ as the higher rate and 91 = 91 m$^3$·ha$^{-1}$ as the lower rate; the single upper case letter indicates the three N sources as U = urea, N = ammonium nitrate, and S = ammonium sulfate; the second number with a decimal point either 3.4 or 1.7 in each treatment indicates the two N rates, in which 3.4 = the high rate of 3.4 g N/m$^2$/week from WAS 3 to 10 and 1.7 g N/m$^2$/week from WAS 11 to 16.

Values in columns followed by the same letter are not significantly different at $P \leq 0.05$ using Fisher’s protected least significant difference.

*The values in the table are presented as ash-free weight, i.e., oven-dry weight minus ash weight (Snyder and Cisar, 2000).

Figure 1. Stem establishment and treatments.
temperature variations in 2007 and 2008 in the Clemson, SC, area. Between WAS 1 and 2, there were 13 d with maximum temperatures below 29.4 °C in 2008, whereas there were only 8 d in 2007. Also, August average maximum temperature in 2007 was 35.5 °C compared with 31.8 °C in 2008 with these two extremes occurring in the past few years at Clemson (Baldwin, 2008; Long, 2006; Sarvis, 2008), although no degree-day differences were found between the 2 years. Relatively cooler days in the early Summer 2008 slowed the establishment speed for ‘Diamond’ zoysiagrass. Higher spraying rates significantly enhanced turf cover starting at WAS 3 in both 2007 and 2008. For putting green establishment, turf cover must reach 100% to assure proper ball rolling on a smooth green surface; ‘Diamond’ zoysiagrass reached 100% turf cover at WAS 11 in 2008. It is worthy to note that higher spraying rates provided twice the turf cover as the lower spraying rate starting WAS 3, although the difference between two spraying rates in turf cover became closer starting at WAS 4 (Tables 1 and 2). All higher spraying rate treatments reached greater than 90% turf cover with high N rates at WAS 7 in 2007 and WAS 11 in 2008.

Table 2. The weekly percent cover of ‘Diamond’ zoysiagrass established on 16 May 2008 using sprigs at two sprigging rates, three nitrogen (N) sources, and two N rates with readings started from week after sprigging (WAS) 5.

| Treatment/WAS | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|
| 182-N-3.4c   | 40.3 | 52.7 | 65.3 | 72.3 | 85.0 | 88.0 | 96.3 | 98.7 |
| 182-N-1.7   | 29.7 | 47.3 | 59.7 | 71.0 | 81.7 | 87.7 | 95.6 | 98.0 |
| 91-N-3.4     | 15.3 | 26.7 | 39.3 | 45.7 | 63.3 | 56.7 | 82.3 | 81.3 |
| 91-N-1.7     | 22.0 | 31.0 | 43.0 | 52.3 | 51.0 | 52.0 | 85.0 | 76.3 |
| 182-S-3.4    | 29.0 | 44.7 | 65.7 | 79.7 | 86.0 | 89.7 | 99.7 | 100.0 |
| 182-S-1.7    | 34.7 | 44.0 | 63.7 | 78.0 | 85.7 | 85.3 | 99.7 | 100.0 |
| 91-S-3.4c    | 16.3 | 28.3 | 45.3 | 54.5 | 63.3 | 56.7 | 82.3 | 77.3 |
| 91-S-1.7     | 21.3 | 35.0 | 45.3 | 55.7 | 67.3 | 51.0 | 87.3 | 77.0 |
| 182-U-3.4    | 36.3 | 50.0 | 66.7 | 82.7 | 85.3 | 90.3 | 98.0 | 99.7 |
| 182-U-1.7    | 40.7 | 54.0 | 63.7 | 68.3 | 78.7 | 85.0 | 96.7 | 98.7 |
| 91-U-3.4     | 12.3 | 22.3 | 36.7 | 43.7 | 64.7 | 60.0 | 83.7 | 85.0 |
| 91-U-1.7     | 13.6 | 22.3 | 41.7 | 50.0 | 53.3 | 50.0 | 82.7 | 77.3 |

*Treatment abbreviations: Either 182 or 91 in each treatment indicates the two sprigging rates, in which 182 = 182 m^2 ha^-1 as the higher rate and 91 = 91 m^2 ha^-1 as the lower rate; the single upper case letter indicates the three N sources as U = urea, N = ammonium nitrate, and S = ammonium sulfate; the second number with a decimal point of 3.4 or 1.7 in each upper case letter indicates the two N rates, in which 3.4 = the high rate of 3.4 g N/m^2/week from WAS 3 to 10 and 1.7 g N/m^2/week from WAS 11 to 16; 1.7 = the low rate of 1.7 g N/m^2/week from WAS 3 to 10 and 0.85 g N/m^2/week from WAS 11 to 16.

| Table 3. The weekly percent cover of ‘Diamond’ zoysiagrass established on 16 May 2008 using sprigs at two sprigging rates, three nitrogen (N) sources, and two N rates with readings started from week after sprigging (WAS) 3 to 12.

| Treatment/WAS | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 182-N-3.4c   | 6.0 a | 5.7 ab | 6.0 a | 5.3 bc | 7.0 ab | 7.3 ab | 8.0 a | 8.0 a | 8.0 a |
| 182-N-1.7    | 4.7 b | 6.0 a | 4.7 cd | 5.7 ab | 6.7 ab | 7.7 ab | 7.0 c | 7.3 ab | 7.3 ab |
| 91-N-3.4c    | 6.0 a | 5.3 abc | 5.3 abc | 6.6 a | 7.1 a | 8.0 a | 8.0 a | 8.0 a | 8.0 a |
| 91-N-1.7     | 5.0 b | 5.3 abc | 5.3 abc | 6.6 a | 7.1 a | 7.7 ab | 7.0 c | 7.3 ab | 7.3 ab |
| 182-S-3.4    | 6.0 a | 6.0 a | 6.0 a | 5.3 bc | 7.3 ab | 8.0 a | 8.0 a | 7.7 ab | 7.7 ab |
| 182-S-1.7    | 5.0 b | 6.0 a | 6.0 a | 5.3 bc | 7.0 ab | 7.0 bcd | 7.0 c | 7.3 ab | 7.3 ab |
| 91-S-3.4c    | 2.7 c | 4.3 c | 4.3 c | 4.7 d | 6.7 ab | 7.0 bcd | 8.0 a | 7.7 ab | 7.7 ab |
| 91-S-1.7     | 2.3 c | 4.3 c | 4.3 c | 5.0 cd | 6.7 ab | 6.7 cd | 7.0 c | 7.0 b | 7.0 b |
| 182-U-3.4    | 2.7 c | 4.7 bc | 4.7 bc | 4.7 d | 6.3 ab | 6.3 cd | 6.7 cd | 8.0 a | 8.0 a |
| 182-U-1.7    | 2.3 c | 4.3 c | 4.3 c | 5.0 cd | 5.7 ab | 6.3 cd | 6.7 cd | 8.0 a | 8.0 a |
| 91-U-3.4     | 2.3 c | 4.7 bc | 4.7 bc | 5.0 cd | 6.0 ab | 6.7 cd | 8.0 a | 8.0 a | 8.0 a |
| 91-U-1.7     | 2.7 c | 4.7 bc | 4.7 bc | 5.0 cd | 6.0 ab | 6.7 cd | 7.3 ab | 7.3 ab | 7.3 ab |

*Values in columns followed by the same letter are not significantly different at P < 0.05 using Fisher’s protected least significant difference.

| Table 4. Turf color readings of ‘Diamond’ zoysiagrass established using sprigs at two sprigging rates, three nitrogen (N) sources, and two N rates in 2007 and 2008.

| Treatment/WAS | 2007 | 2008 |
|---------------|------|------|
| 182-N-3.4c   |       |      |
| 182-N-1.7    |       |      |
| 91-N-3.4c    |       |      |
| 91-N-1.7     |       |      |
| 182-S-3.4    |       |      |
| 182-S-1.7    |       |      |
| 91-S-3.4c    |       |      |
| 91-S-1.7     |       |      |
| 182-U-3.4    |       |      |
| 182-U-1.7    |       |      |
| 91-U-3.4     |       |      |
| 91-U-1.7     |       |      |

*Values in columns followed by the same letter are not significantly different at P < 0.05 using Fisher’s protected least significant difference.
particularly at later WAS in both years (Table 3). In the 2-year study, N sources did not affect turf cover and color, which agreed with findings by Guertal and Hicks (2009) who indicated that nitrogen sources [either as NH$_4$NO$_3$ or Ca(NO$_3$)$_2$] rarely affected percentage turf cover, shoot density, or dry weight of stolons and rhizomes of ‘Tifway’ or ‘TifSport’ bermudagrasses (C. dactylon × C. transvaalensis Pers. L.). However, for cool-season turfgrass putting greens, N sources seem to affect turf growth and performance. Schlossberg and Schmidt (2007) reported that N rates >24.4 g m$^{-2}$/year containing greater than 50% NH$_4$-N significantly enhanced shoot growth and color when compared with equal rates containing ≥50% NO$_3$-N. Frequent fertilization with NH$_4$-N at annual rates greater than 24.4 g m$^{-2}$ maximized canopy color and tissue nutrient levels of a putting green with a mixture of bentgrass (Agrostis stolonifera L.)/annual bluegrass (Poa annua L.). Guertal and Evans (2006) reported increasing N from 0.3 to 4.8 g N/m$^2$/week reduced ‘TifEagle’ bermudagrass turf cover in Year 1 of the 3-year study. In Year 2, turf cover was maximized at N rates from 3.6 to 4.3 g N/m$^2$/week on a loamy sand native soil as a putting green. A slightly negative impact was also observed at WAS 6 in 2007 using both lower and higher N rates of ammonium sulfate (182-S-3.4 and 182-S-1.7) with turf color rating dropping 6.0 to 5.3 with a possibility of fertilizer burn, but it only lasted for 1 week (Table 3). However, the complicated roles of N sources and rates for warm-season turfgrass growth and performance, including ‘Diamond’ zoysiagrass putting green establishment-associated environmental issues and other nutrient elements, need further investigation (Erickson et al., 2008; Guertal, 2006, 2008; Liu et al., 2008; Snyder et al., 2008).

Root weight, clipping yield, and ball rolling. There were no significant differences in ash-free root weight with samples collected at WAS 14 in both years (Table 4). As expected, no differences were found in the following spring green-up and summer month performance (data not shown). Root weight results might imply that establishment with different spriigging rates and N rates would not have residual effects on future seasons. Although there were no significant differences in ash-free root weight, the broad range of root weight data might be affected excluding stolons, rhizomes, or other biomass. However, the yearly interaction was significant for root weight and the first year had much higher root weight, presumably as a result of relatively higher temperatures in early Summer 2007.

Differences were found in clipping yields for both mowing heights in both years. Under 3.2-mm mowing height in both years, 182-S-3.4 had a greater clipping yield than the treatments with a lower spriigging rate except 91-S-3.4 in 2007. However, all lower N rate treatments had a lower clipping yield at 2.5-mm mowing height. To avoid scalping ‘Diamond’ zoysiagrass, the lower spriigging rates were not mowed at the lower mowing height as a result of a lack of information of ‘Diamond’ zoysiagrass response to a mowing height of 2.5 mm. In 2008, clipping yields differed when compared with the other treatments at both 2.5- and 3.2-mm mowing heights corresponding with different N rates (Table 5).

Ball rolling is one of the important characteristics for playability of a putting green (Beard, 2002). In both years, a lack of significance was found for ball rolling at the 2.5-mm mowing height but in 2007, 91-S-1.7 and 91-U-1.7 showed significantly different ball roll than 182-U-3.4 and 182-S-3.4 (Table 6). In 2008, 91-N-1.7 had further ball rolling than all treatments with higher spriigging rates and N rates except 182-U-1.7. The trend of higher spriigging rates slowed ball roll in both years with a possibility of faster thatch accumulation, although thatch data were not collected. ‘Diamond’ zoysiagrass putting green ball rolling needs to be further enhanced and the current furthest ball rolling was still less than an acceptable distance for tournament purposes.

Conclusions

‘Diamond’ zoysiagrass has shown to be a new alternative warm-season putting green turfgrass. Putting green turf quality can be reached within a single season in the transition zones and establishment speed can vary according to summer temperature fluctuations. Proper spriigging rates and N rates play important roles in ‘Diamond’ zoysiagrass putting green establishment in the southern transition zone of the United States. ‘Diamond’ zoysiagrass establishment speed can be hastened by using higher spriigging rates within a timeframe of 10 to 12 weeks. It was tested in both years that ‘Diamond’ zoysiagrass can be mowed as low as 2.5 mm without scalping or winter month survival problems at a spriigging rate of 182 m$^{-2}$ ha$^{-1}$. In both years of the study, higher spriigging rates benefited turf cover, whereas higher N rates benefited turf color. Nitrogen sources did not play significant roles in ‘Diamond’ zoysiagrass establishment. However, rates combined with higher spriigging rates negated ball roll, possibly as a result of a possibly thickened thatch layer, and further ball rolling enhancement of ‘Diamond’ zoysiagrass putting green is needed. Recommendations for

Table 4. Root samples of established ‘Diamond’ zoysiagrass were collected on 15 Aug. 2007 and 19 Aug. 2008 and burned in a muffle furnace (550 °C) for 3 h.

Table 5. Oven-dried clipping yields of established ‘Diamond’ zoysiagrass collected on 7 Sept. 2007 and 10 Sept. 2008 by using a walk-behind mower.
Table 6. Ball rolling distances of established ‘Diamond’ zoysiagrass by using a modified stimpmeter and the data collected on 31 Aug. 2007 and 20 Sept. 2008.

| Treatment/mowing ht. | 2007 | | | 2008 | | | |
|----------------------|------|------|-------|------|------|-------|
|                      | 3.2 mm | 2.5 mm | 3.2 mm | 2.5 mm | 3.2 mm | 2.5 mm |
| 182-N-3.4<sup>a</sup> | 194.6 bc<sup>c</sup> | 240.1 | 188.0 cd<sup>c</sup> | 251.4 | | |
| 182-N-1.7 | 204.0 abc | 242.4 | 205.2 bcd | 249.1 | | |
| 182-S-3.4 | 205.0 abc | 235.2 | 204.6 bcd | 241.5 | | |
| 182-S-1.7 | 209.9 ab | 244.4 | 206.5 bcd | 261.5 | | |
| 182-U-3.4 | 185.6 c | 238.0 | 178.4 d | 249.5 | | |
| 182-U-1.7 | 205.4 abc | 239.7 | 219.4 and St. Augustinegrass lawn? Crop Sci. 48:1586–1594. |
| 91-N-3.4 | 215.9 ab | 237.9 | 215.9 ab | 244.4 | | |
| 91-N-1.7 | 217.2 ab | 237.9 | 215.9 ab | 244.4 | | |
| 91-S-3.4 | 207.9 abc | 213.9 abc | | | | |
| 91-S-1.7 | 219.5 a | 230.3 ab | | | | |
| 91-U-3.4 | 213.1 ab | 213.8 abc | | | | |
| 91-U-1.7 | 223.9 a | 222.1 ab | | | | |

<sup>a</sup>Treatment abbreviations: Either 182 or 91 in each treatment indicates the two spraying rates, in which 182 = 182 m<sup>2</sup>ha<sup>−1</sup> as the higher rate and 91 = 91 m<sup>2</sup>ha<sup>−1</sup> as the lower rate; the single upper case letter indicates the three N sources as U = urea, N = ammonium nitrate, and S = ammonium sulfate; the second number with a decimal point either 3.4 or 1.7 in each treatment indicates the two N rates, in which 3.4 = the high rate of 3.4 g N/m<sup>2</sup>/week from weeks after sprigging (WAS) 3 to 10 and 0.85 g N/m<sup>2</sup>/week from WAS 11 to 16; 1.7 = the low rate of 1.7 g N/m<sup>2</sup>/week from WAS 3 to 10 and 0.85 g N/m<sup>2</sup>/week from WAS 11 to 16. Values in columns followed by the same letter are not significantly different at P = 0.05 using Fisher’s protected least significant difference.

‘Diamond’ zoysiagrass putting green establishment in the transition zone may include a spraying rate greater than 91 m<sup>2</sup>ha<sup>−1</sup>, a total N input between 20 and 35 g m<sup>−2</sup>/year, and a timeframe of 10 to 12 weeks. Finally, within 90 to 120 d, ‘Diamond’ may be successfully established as a putting green turf using relatively low rates of sprigs and quick-release N sources.

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