ABSTRACT

BRISCOE, KYLE ROBERT. Influence of Cultural Practices and Winter Colorant Application on the Establishment and Management of 'Miniverde' Bermudagrass and 'Diamond' Zoysiagrass Putting Greens. (Under the direction of Grady L. Miller.)

The demand for higher quality playing surfaces has resulted in the development of bermudagrass and zoysiagrass cultivars that have finer textures and can be cut lower. However, the hot, humid summers and cold winters of the transition zone are not optimal conditions for maintaining perfect warm-or cool-season turf all year long. Converting creeping bentgrass (*Agrostis stolonifera* Huds.) putting greens to warm-season turfgrasses such as the ultradwarf bermudagrass 'Miniverde' [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* (Burtt-Davy)] or the fine textured zoysiagrass 'Diamond' [*Zoysia matrella* (L.) Merr.] has become more common in the transition zone within the past decade. However, there is limited information available on the best practices for these grasses in terms of establishment, growing season management, and winter management. Therefore, field studies were conducted in North Carolina during 2008 and 2009 to 1) determine the influence of granular fertilizer programs consisting of various nitrogen (N), phosphorus (P), and potassium (K) sources and rates on the turfgrass color and establishment rate of Miniverde bermudagrass and Diamond zoysiagrass; 2) evaluate the influence of N rate, verticutting, and topdressing on the turfgrass quality, thatch accumulation, and ball roll distance of Miniverde bermudagrass and Diamond zoysiagrass putting greens; and 3) evaluate the influence of green turfgrass colorants on the color of dormant Miniverde bermudagrass and semi-dormant Diamond zoysiagrass putting greens during the winter. Establishment studies that were conducted in Raleigh, NC and in Jackson Springs, NC involved the application of seven granular fertilizer programs to Miniverde bermudagrass and Diamond zoysiagrass June through August 2008 and 2009. Fertilizer programs that consisted of a combination of quick and slow-release N sources had higher establishment rates than programs that consisted of quick or slow-release N sources only. The management study conducted May through October 2009 in Raleigh, NC included four N rates, two verticutting programs, and two topdressing programs applied to the bermudagrass and zoysiagrass. Verticutting at a depth of 6.4 mm twice monthly June through August was too aggressive to maintain acceptable bermudagrass quality. Furthermore, turf quality decreased and ball roll distances increased as the annual N rate decreased. Twelve green turfgrass colorants were applied to the bermudagrass and zoysiagrass in the winter of 2008, and one colorant was applied at three different rates during the winter of 2009. Green turfgrass colorants were found to differentially increase the color of bermudagrass and zoysiagrass compared to the untreated. However, some colorants turned bluish as they faded which would not be acceptable on a golf course. Applying colorants at a rate above 75 mL m^{-2} increased the longevity of acceptable turf color. These studies indicate that Miniverde bermudagrass and Diamond zoysiagrass can be successfully established and managed on putting greens in North Carolina.

Influence of Cultural Practices and Winter Colorant Application on the Establishment and Management of 'Miniverde' Bermudagrass and 'Diamond' Zoysiagrass Putting Greens

by
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BIOGRAPHY

Kyle Robert Briscoe was born 13 May 1985 in Kirksville, Missouri to Laddie and Susie Briscoe. He spent his childhood between the family farm in Williamstown, MO and city of Liberty, MO before graduating from Liberty High School in 2003. After graduation he enrolled at the University of Missouri – Columbia, where he began a Bachelor of Science degree in Plant Science with an emphasis in turfgrass management. As an undergraduate, Kyle spent summers working at Witch's Cove and The Club at Porto Cima in Lake Ozark, MO and semesters working at the University of Missouri Turf Research Center. He graduated from the University of Missouri – Columbia in May 2007, at which point he decided to continue his education by pursing a Master of Science degree.

Kyle attended graduate school at the University of Missouri – Columbia for one semester before moving from Missouri to North Carolina in February 2008. He began his graduate studies in Crop Science with an emphasis in turfgrass management at North Carolina State University under the direction of Dr. Grady Miller in May 2008. He has since been residing in Raleigh, NC while working towards his M.S. and plans to pursue a Ph.D. in turfgrass management in the near future.

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LITERATURE REVIEW

Bermudagrass

Bermudagrass (*Cynodon* sp.) is a long-lived perennial grass originating around the Indian Ocean from East Africa to the East Indies (McCarty and Miller, 2002). In the late 18th century and early 19th century bermudagrass spread throughout the southeastern United States as a forage, lawn, and sports turf grass (Dunn and Diesburg, 2004). Common bermudagrass [*Cynodon dactylon* (L). Pers.] was used on golf courses from tee to green prior to the release of the cultivar 'U3' in 1947 (McCarty and Miller, 2002). U3 and other improved cultivars remained the most widely used on golf courses until the 1950s and 1960s (Dunn and Diesburg, 2004). The increasing demand for finer textured bermudagrasses that could be cut lower resulted in the development of many cultivars that are still used today.

The release of the dwarf bermudagrasses [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis*] 'Tifgreen' and 'Tifdwarf' in the 1950s and 1960s set the standard for all of the bermudagrasses that have been released since (McCarty and Miller, 2002). These improved bermudagrasses form a vigorous turf with a high shoot density compared to common bermudagrass (Beard, 1973). Golf courses in the southeastern United States quickly converted their putting greens to Tifgreen and Tifdwarf (Beard and Sifers, 1996). Tifdwarf has become the most dominant in the past two decades due to its ability to withstand lower mowing heights than Tifgreen (White, 1999). However, the demand for faster green speeds and the development of new cultivars have caused many golf courses to replace Tifgreen and Tifdwarf with newer ultradwarf cultivars (White, 1999).

Recently, the ultradwarf bermudagrasses [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* (Burtt-Davy)] 'Champion', 'Floradwarf', 'Miniverde', 'MS Supreme', and 'Tifeagle' have become more widely used on golf course putting greens in the southeastern United States. Ultradwarf bermudagrasses have very fine leaf textures and high shoot densities (McCarty and Miller, 2002). Their ultra-low growth habit allows golf course superintendents to produce faster green speeds than they could with dwarf bermudagrasses. However, ultradwarfs are limited by management problems. Rapid lateral growth produces extensive thatch and mat compared to dwarf bermudagrass cultivars (Gregg and McCarty, 2004), which can result in scalping and slower green speeds. To combat these problems, more frequent vertical mowing and topdressing are required (McCarty and Canegallo, 2005). However, these practices often injure the turf for up to three weeks; thus, further research is needed on the best management practices for each of the ultradwarf cultivars.

'Miniverde' Bermudagrass

Miniverde is an ultradwarf bermudagrass cultivar that was developed in the late 1990s (Guertal and White, 1998), originating as an off-type mutation from one of the dwarf bermudagrass cultivars (McCarty and Canegallo, 2005). It provides a uniform, upright turf with narrow leaves and a shoot density similar to other ultradwarf bermudagrasses (Gregg and McCarty, 2004). Since its release, Miniverde has quickly emerged as one of the most popular ultradwarfs for use on putting greens in the southeastern United States.

Research has indicated that Miniverde performs well under high fertility. White (1999) showed that Miniverde was the only ultradwarf bermudagrass that responded to annual N rates above 480 kg ha^{-1}, and turf quality ratings were the highest of any of the ultradwarfs when annual N rates ranged from 290 to 880 kg ha^{-1}. McCarty and Canegallo (2005) compared the growth of ultradwarf bermudagrasses under high fertility. They found that Miniverde produced longer roots than Tifeagle and Champion and had a greater shoot density than Floradwarf. However, the combination of high fertility and high shoot densities can cause thatch problems over time.

White (1999) reported that Miniverde accumulated five times more thatch than Tifdwarf. Currently, only a limited amount of research exists on the combined effects of nitrogen (N) sources, vertical mowing, and topdressing on Miniverde establishment and cultural management. Therefore, more data are needed on how to best manage Miniverde bermudagrass putting greens in the transition zone.

Zoysiagrass

Zoysiagrass (*Zoysia* sp.), commonly known as Japanese lawn grass, originated in the western Pacific area. It was introduced to the United States around 1900 and has been used on golf courses since the 1950's (Dunn and Diesburg, 2004). Zoysiagrass is primarily found in warm-arid and warm-humid climatic zones, but good winter hardiness also allows it to be used in the upper transition zone (Patton and Reicher, 2007). Despite its popularity as a golf course grass only three cultivars of zoysiagrass were released from 1951 to 1985 (Diesburg, 2001). 'Meyer' (*Zoysia japonica* Steud.), released in 1951, was the most widely used during that time because it provided a high quality turf that required little maintenance. The continued use of Meyer by superintendents and researchers has made it the industry standard for zoysiagrass cultivars (Patton and Reicher, 2007).

Zoysia japonica Steud. and *Z. matrella* (L.) Merr. are currently the most widely used zoysiagrass species in the United States (Patton and Reicher, 2005). ‘El Toro’, ‘Empire’, ‘Palisades’, and ‘Zenith’ (*Z. japonica*) are coarser textured and more cold hardy zoysiagrass cultivars. They can be maintained with lower inputs of water, fertilizer, and pesticides, making them desirable for use on low budget golf courses located in the transition zone (Diesburg, 2001). The finer texture of ‘Cavalier’, ‘Diamond’, ‘Zeon’, and ‘Zorro’ (*Z. matrella*) allow them to be cut lower for use on golf course tees. However, these cultivars require increased management inputs compared to *Z. japonica* due to pest and thatch problems. Both *Z. japonica* and *Z. matrella* have good heat, drought, and wear tolerance but lack the rapid establishment rates of bermudagrass (Patton and Reicher, 2005). Furthermore, significant differences exist between the establishment rates of zoysiagrass species and cultivars (Patton and Reicher, 2007).

Patton and Reicher (2007) data suggest cultivars that established quickly devoted more energy to stems than to leaves. They also found that *Z. japonica* cultivars establish more quickly than *Z. matrella* cultivars. Significant differences in establishment rate also occurred between cultivars within each species (Patton and Reicher, 2007). El Toro (*Z. japonica*) established four times faster than Meyer (*Z. japonica*), and Zorro (*Z. matrella*) established five times faster than Diamond (*Z. matrella*). Although not one of the zoysiagrasses commercially available today establishes as quickly as bermudagrass, they are still highly valued and used extensively. As of 2006 there were 16,293 acres of zoysiagrass planted on golf courses in the United States (Lyman et al., 2007).

'Diamond' Zoysiagrass

Diamond zoysiagrass was released by the Texas Agriculture Experiment Station in April 1996 (Engelke et al., 2002). It is a fine textured zoysiagrass that has high rhizome and tiller density, superior salt and shade tolerance, and excellent recuperative growth (Engelke et al., 2002). Unlike many zoysiagrass cultivars, Diamond tolerates frequent close mowing, making it useful for putting greens in the southeastern United States.

Diamond's superior shade tolerance makes it ideal for putting green situations where bermudagrass will not grow. Field studies have indicated that Diamond maintained acceptable turf quality after 69 days of 83 percent shade (Engelke et al., 2002). Furthermore, Qian and Engelke (1999) found that application of trinexapac-ethyl (Primo Maxx) significantly improved the quality of Diamond under shade conditions. One drawback to Diamond is that it has a poor tolerance to freezing compared to other *Z. japonica* and *Z. matrella* cultivars. Patton and Reicher (2007) found that Diamond had the lowest freeze tolerance (LT_{50}) of 13 zoysiagrasses genotypes. Another limitation is Diamond's slow establishment rate. Of 35 zoysiagrasses evaluated for establishment rate, Diamond had the slowest stolon growth rate (Patton and Reicher, 2007). Furthermore, limited information exists on Diamond zoysiagrass putting greens concerning sprigging rate, N fertility, vertical mowing, and topdressing. Making this data available will help golf course superintendents make informed decisions on how to establish and manage their greens effectively.

Establishment of Bermudagrass and Zoysiagrass Putting Greens

Hybrid bermudagrass and fine textured zoysiagrass are vegetatively planted on putting greens due to the lack of viable seed and the lower cost versus sodding. Furthermore, N rates and fertilizer application frequencies are often increased to establish the putting greens quickly (Rodriguez et al., 2000).

Johnson (1973) reported N fertilization of 49 kg ha^{-1}, applied twice monthly or monthly, significantly increased the establishment rate of Tifway bermudagrass compared to plots receiving no N. By contrast, others found that an N rate of 36 to 43 kg ha^{-1} wk^{-1} was need to maximize the dry weight of Tifeagle stolons, rhizomes, and roots during establishment (Guertal and Evans, 2006; Guertal and Hicks, 2009). A possible cause for the increased need for N is that the coarser textured hybrid bermudagrasses, such as Tifway, may require lower N applications (Guertal and Hicks, 2009). This agrees with the results from Trenholm et al. (1997) who found that Tifdwarf reached maximum cover with lower N inputs than Floradwarf.

Results from Stiglbauer et al. (2009) suggest that total N required to establish Diamond zoysiagrass was not as high as for a hybrid bermudagrass putting green. Furthermore, no difference in establishment rate was found between N rates of 236 and 423 kg ha^{-1} applied over a 16 week grow-in period. Sprigging Diamond at 182 m^3 ha^{-1}, double the recommended rate for putting green establishment, resulted in 100 percent establishment one to three weeks earlier than the recommended sprigging rate (Stiglbauer et al., 2009).

Although N is applied more than any other plant nutrient during establishment, it is also essential to apply adequate amounts of phosphorus (P) and potassium (K) because putting green soil mixes are typically deficient in N, P, and K (Rodriguez et al., 2001). Rodriguez et al. (2001) studied the influence of five N-P-K fertilizer blends (1N-0P-0.8K, 1N-0P-1.7K, 1N-0.4P-0.8K, 1N-0.9P-0.8K, and 1N-1.3P-0.8K) on the establishment rate of four bermudagrass cultivars, three of which (Floradwarf, Tifdwarf, and Tifeagle) were grown on USGA putting greens and one (Tifway) grown on a native, sandy loam soil. They found that the highest cover rates of all four cultivars were achieved with the 1N-0.4P-0.8K fertilizer. The lowest cover rates of the three cultivars grown on USGA greens were seen with the fertilizers lacking P. The native soil that Tifway was grown on likely had higher levels of P and K in the soil; therefore, cover rates were unaffected (Rodriguez et al., 2001). Similar data on the influence of P and K on the establishment rate of zoysiagrass putting greens are lacking.

Cultural Management of Bermudagrass and Zoysiagrass Putting Greens

Changing fertility programs and implementing cultural practices such as topdressing and verticutting are often used to reduce thatch in warm-season putting greens. Thatch is a tightly intermingled layer of living and dead stems, leaves, and roots of grass that accumulates between green vegetation and the soil surface (Beard, 1973). Excessive thatch is detrimental to plant health because it causes a reduction in drought tolerance, cold tolerance, and water infiltration rate. It also can make the turf susceptible to insect and disease damage, as well as scalping during regular mowing (White and Dickens, 1984; Gregg and McCarty, 2004; Hanna, 2005).

Results from Liu et al. (2007b) suggest that weekly, light topdressing with sand (18 mm annually) slows thatch accumulation more efficiently in Miniverde bermudagrass putting greens than weekly moderate (36 mm annually) or heavy (54 mm annually) topdressing. However, White et al. (2004) show no difference in Miniverde thatch depth between twice monthly light topdressing (0.5 mm) applied May through September and heavy topdressing (3.8 mm) applied once in June. Hollingsworth et al. (2005) data show that average thatch depth was greater in "high maintenance plots" than the "standard maintenance plots" of Champion, MS Supreme, Tifeagle, Floradwarf, and Tifdwarf bermudagrass. They attribute these findings to deeper verticutting (2.4 cm twice a year) and less total topdressing material applied (4.4 x 10^{-4} m^3 sand m^{-2} twice a year) in the standard maintenance plots. The high maintenance plots were verticut at 1.3 cm deep and topdressed with 2.2 x 10^{-4} m^3 sand m^{-2} twice monthly June through September. The increase in amount of sand applied to the high maintenance plots likely dispersed the organic matter. This has been shown to be as effective as accelerated biodegradation in controlling excessive thatch (Turgeon, 2000; Hollingsworth et al., 2005). These are similar results to those of White and Dickens (1984) who found that thatch + mat depth was greater when topdressing Tifgreen, Tifdwarf, and Dothan bermudagrass four times, rather than one time a year.

Topdressing often coincides with verticutting to reduce thatch in bermudagrass putting greens. Deep verticutting has been shown to reduce thatch depth turf quality.

Hollingsworth et al. (2005) found that turf quality of plots in the standard and high maintenance programs decreased after verticutting. However, they noted that the standard maintenance plots had higher average turf quality ratings because they had more time to heal after verticutting. Hanna (2005) noted that applications of N at a rate of 24 kg ha^{-1} twice monthly was needed to maintain acceptable Tifeagle quality after verticutting. However, increased nitrogen fertilization may lead to excess thatch accumulation.

Hanna (2005) results suggest N rate plays a role in bermudagrass thatch accumulation. The thatch accumulated in Tifeagle plots receiving twice monthly applications of N at a rate of 24 kg ha^{-1} for two years caused turf quality to decrease 39 percent compared to the 12 kg ha^{-1} rate (Hanna, 2005). These results agree with those of White et al. (2004), which found Tifeagle thatch accumulation increased with increasing N. White and Dickens (1984) found that Tifgreen, Tifdwarf, and Dothan bermudagrass putting greens produced more thatch when activated sewage sludge was applied at an N rate of 1020 kg ha^{-1} yr^{-1} compared to NH_4NO_3 applied at an N rate of 580 kg ha^{-1} yr^{-1}. By contrast, Hollingsworth et al. (2005) found no differences in thatch depth between two N sources, soluble N as urea (46-0-0) and slow release N as Liquiform 32 (32-0-0), applied at an N rate of 40 kg ha^{-1} mo^{-1} to Champion, MS Supreme, Tifeagle, Floradwarf, and Tifdwarf bermudagrass.

The accumulation of thatch can also be detrimental to zoysiagrass health and playability. Currently, there is no documented information on the cultural management of zoysiagrass putting greens. However, the results from studies that have been conducted on the management of fairway and tee height zoysiagrass may prove to be helpful in the development of management plans for zoysiagrass putting greens.

Increased thatch accumulation has been correlated with increased N fertilization in zoysiagrass. Data from Soper et al. (1988) indicated increasing N fertilization of Meyer zoysiagrass from 0 to 98 kg ha^{-1} yr^{-1} significantly increased thatch depth. However, Dunn et al. (1981) found that increasing the N rate from 98 to 293 kg ha^{-1} yr^{-1} did not increase thatch depth of Meyer. A 2007 study concluded that an N rate of at least 179 kg ha^{-1} yr^{-1} was required to maintain Diamond and Empire zoysiagrass at acceptable turf quality and density. However, applying N at 269 kg ha^{-1} yr^{-1} resulted in scalping of Diamond when mowed at 1.27 cm (Schwartz et al., 2008). Routine verticutting is often used to reduce the deep thatch layer that leads to scalping (Dunn et al., 1981).

Dunn et al. (1981) reported that verticutting once a year reduced the thatch layer of Meyer zoysiagrass 12 to 18 percent. These are similar results to Cockerham et al. (1997) who found that verticutting can be used to reduce the thatch layers of ‘Victoria’ and ‘DeAnza’ zoysiagrass by 10 and 11 percent, respectively (Cockerham et al., 1997). Furthermore, they noted one vertical mowing per year was insufficient to reduce thatch, while verticutting four times per year was successful.

Application of Green Turf Colorants to Warm-Season Turfgrass Putting Greens

Applying green colorants to dormant turf during the winter has been in practice since the 1950’s (Anonymous, 1987). However, the application of such colorants to putting greens is a relatively new trend. The difficulty and expense of overseeding ultradwarf bermudagrass has increased the popularity of applying colorants to putting greens during the winter in the transition zone. Furthermore, research indicates that colorants can provide an attractive, playable, and affordable alternative to overseeding (Long, 2006; Liu et al., 2007a).

Affordability is the main benefit associated with colorants compared to overseeding. In 2007, the average cost of applying colorant to golf greens per season was $1600 to $1800 per acre for two applications, depending on the colorant brand (Liu et al., 2007). When compared to overseeding costs of $2,500 to $5,000 per acre, colorant becomes a much less expensive alternative (Liu et al., 2007). However, golf course superintendents also need to provide a playing surface that is attractive, which can become a problem as colorants fade over time.

Long (2006) evaluated turf color provided by two green colorants, Mtp Turfgreen and Titan Green Turf, when applied to Champion bermudagrass. During that study both products faded to a bluish color, which would be unacceptable in a golf course situation. It was observed that Mtp Turfgreen faded shortly after each application and was bluish throughout the study, whereas, Titan Green Turf became bluish approximately six weeks following each application. These results agree with those of Liu et al. (2007) who noted that certain colorant brands, including Titan Green Turf, became bluish over time when applied to Tifeagle bermudagrass.

There is limited research addressing the application of colorants to zoysiagrass putting greens. However, a study was conducted in Knoxville, TN to evaluate the effect of covering and colorant application on the spring green-up of Diamond zoysiagrass, Champion bermudagrass, Tifeagle bermudagrass, and ‘Seadwarf’ seashore paspalum

(*Paspalum vaginatum* Swartz) (Kauffman et al., 2009). Although differences in spring green-up were found between covered, uncovered, and colorant treatments in the bermudagrasses and seashore paspalum there were no differences in zoysiagrass spring green-up. Long (2006) found that colorant treatments increased spring green-up of Champion bermudagrass 12 percent compared to the untreated when applied over the winter season. However, further research needs to be conducted on the application methods, timings, and rates of green turf colorants applied to ultradwarf bermudagrass and zoysiagrass putting greens.

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CHAPTER 1

The Influence of Granular Fertilizer Programs on the Establishment of 'Miniverde' Bermudagrass and 'Diamond' Zoysiagrass Putting Greens

'Miniverde' bermudagrass [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* (Burtt-Davy)] and 'Diamond' zoysiagrass [*Zoysia matrella* (L.) Merr.] are becoming more popular for use on putting greens in the transition zone. However, limited information exists on nitrogen (N), phosphorus (P), and potassium (K) fertilizer sources and rates necessary to rapidly establish Miniverde and Diamond on sand-based putting greens. Field studies were conducted from June through August 2008 and 2009 in Raleigh, NC and in Jackson Springs, NC, respectively. The influence of granular fertilizer programs consisting of various N, P, and K rates and sources on turf color and establishment of Miniverde and Diamond from sprigs was evaluated. In 2008 the experimental area consisted of a putting green built to United States Golf Association (USGA) specifications [85 sand : 15 peat (v:v)]. A native sandy-soil putting green was used in 2009. Seven granular fertilizer programs were initiated one week after planting (WAP). Three quick-release N programs consisted of N as UFLEXX (46N-0P-0K) applied weekly at N rates of 12 to 24 kg ha^{-1}. One slow-release N program consisted of N as Polyon urea (46N-0P-0K) applied at an N rate of 96 kg ha^{-1} once a month. One quick-release N + organic fertilizer program consisted of UFLEXX applied weekly at an N rate of 12 kg ha^{-1} coupled with Milorganite (6N-2P-0K) applied at an N rate of 48 kg ha^{-1}

once every three weeks. Two “Standard” programs consisted of various N-P-K fertilizer blends, Milorganite, UFLEXX, and ammonium sulfate (21N-0P-0K) applied weekly at N rates from 12 to 48 kg ha^{-1}. Bermudagrass established more rapidly than zoysiagrass during both years. In 2008, 100 percent bermudagrass and zoysiagrass coverage was achieved in 70 and 77 days, respectively. However, the bermudagrass reached 100 percent coverage in 56 days during 2009, whereas, the zoysiagrass only reached 95 percent coverage in the 91 day establishment period. Nitrogen source and rate differentially influenced turf color and establishment rate of bermudagrass and zoysiagrass. Programs consisting of both slow and quick-release N sources increased turf color earlier and had the highest establishment rates over both grasses and years. This research indicates that Miniverde bermudagrass and Diamond zoysiagrass can be 100 percent established from sprigs in the transition zone during the summer season using granular fertilizer.

Introduction

Providing adequate fertility during turf establishment from sprigs on sand-based putting greens is necessary because the soil is typically nutrient deficient (Rodriguez et al., 2001). Furthermore, differences in fertility requirements between grass species may influence the rate and source of nutrients that should be applied during the establishment period.

Recently, ultradwarf bermudagrasses have become more widely used on golf course putting greens in the southeastern United States because they have very fine leaf textures and high shoot densities compared to dwarf bermudagrasses (McCarty and Miller, 2002). Miniverde [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* (Burtt-Davy)], an ultradwarf cultivar, provided the highest turf quality of any ultradwarf when annual nitrogen (N) rates were above 290 kg ha^{-1} (White, 1999). However, applying N rates above 480 kg ha^{-1} yr^{-1} has been shown to cause extensive thatch accumulation (White, 1999). Furthermore, poor shade tolerance of the ultradwarf cultivars limits their use on golf courses that have shaded putting greens (Bunnell et al., 2005).

The use of Diamond [*Zoysia matrella* (L.) Merr.], a fine textured zoysiagrass, has been evaluated for shaded putting greens. Diamond has superior shade tolerance compared to bermudagrass and can withstand low mowing heights for extended periods (Engelke et al., 2002). However, zoysiagrass has been shown to establish more slowly than bermudagrass (Busey and Myers, 1979; Patton et al., 2004). Busey and Myers (1979) found that the coverage rate of ‘Tifgreen’ bermudagrass [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis*] was greater than that of Japanese zoysiagrass (*Zoysia japonica*

Steud.). Furthermore, when 'Mirage' bermudagrass [*Cynodon dactylon* var. *dactylon* (L.) Pers.] and 'Zenith' zoysiagrass (*Zoysia japonica* Steud.) were planted by seed the bermudagrass reached 100 percent coverage 24 days earlier than the zoysiagrass (Patton et al., 2004).

Similar to bermudagrass, increasing N rates and application frequencies is a standard practice when trying to achieve 100 percent zoysiagrass coverage. However, results from Stiglbauer et al. (2009) indicate that N rate (240 kg ha^{-1} and 420 kg ha^{-1}) applied over a 16-week establishment period did not influence the establishment rate of Diamond zoysiagrass when sprigged on a sand-based putting green. Nitrogen source (urea, ammonium nitrate, and ammonium sulfate) also did not influence establishment rate. Differences in establishment rate were observed between sprigging rates (91 m^3 ha^{-1} and 182 m^3 ha^{-1}).

It is essential to apply adequate amounts of P and K during establishment because putting green soil mixes are typically deficient in the primary plant nutrients (N, P, and K) (Rodriguez et al., 2001). Phosphorus is involved in almost all energy storage and transfer processes within in the plant (Rodriguez et al., 2000; Carrow et al., 2001). The highest phosphorus requirement is in new leaves and meristematic tissue (Carrow et al., 2001); therefore, applications are necessary during establishment when there is rapid plant growth. Potassium is required for the activation of enzymes and plays a vital role in tolerance to drought, cold, high temperature, wear, and salinity stresses (Carrow et al., 2001). Although K is not known to produce a dramatic response in turfgrass color and growth rate as N, it has been reported to improve turfgrass density and root growth (Sartain, 1999).

Rodriguez et al. (2001) studied the influence of five N-P-K fertilizer blends (1N-0P-0.8K, 1N-0P-1.7K, 1N-0.4P-0.8K, 1N-0.9P-0.8K, and 1N-1.3P-0.8K) on the establishment rate of three ultradwarf bermudagrass cultivars. They found that the fastest coverage was achieved with the 1N-0.4P-0.8K fertilizer; the lowest coverage was with the fertilizers lacking P. The results indicate that P plays a significant role in the establishment of ultradwarf bermudagrasses.

There is limited research regarding granular fertilizer programs used for the establishment of ultradwarf bermudagrass and fine textured zoysiagrass putting greens. Making information available on the optimum granular fertilizer program (N, P, and K sources and rates) will help turfgrass managers make fertilization decisions during the establishment of these turfgrasses. Therefore, the objectives of the study were to 1) determine if sprigged Miniverde bermudagrass and Diamond zoysiagrass could be 100 percent established over a 12 to 13 week establishment period in the transition zone using granular fertilizer programs consisting of various N, P, and K sources and rates; and 2) evaluate the influence of N, P, and K sources and rates on turfgrass color and establishment rate of Miniverde bermudagrass and Diamond zoysiagrass.

Materials and Methods

2008 Establishment

This study was conducted in 2008 at the Lake Wheeler Field Laboratory located in Raleigh, North Carolina. The experimental area consisted of a golf course putting green constructed with an 85 sand : 15 peat (v:v) rootzone to meet United States Golf Association (USGA) specifications (USGA, 1993). The soil had a pH of 5.5, and a P and K content of 14.4 kg ha^{-1} and 35.2 kg ha^{-1}, respectively. Diamond zoysiagrass [*Zoysia matrella* (L.) Merr.] sprigs provided by New Life Turf (Norway, SC) were planted on 29 May 2008 at a rate of 133 m^3 ha^{-1} (35 bushels/1000 ft^2). Miniverde bermudagrass sprigs provided by Modern Turf (Rembert, SC) were planted by hand on 30 May 2008 at a rate of 76 m^3 ha^{-1} (20 bushels/1000 ft^2), a typical sprigging rate for bermudagrass putting greens. Diamond was sprigged at a higher rate than Miniverde because zoysiagrass has been shown to have a slower establishment rate than bermudagrass (Busey and Myers, 1979; Patton et al., 2004). To increase sprig to soil contact, a tractor-mounted cultipacker was used to pinch the sprigs into the soil and roll the surface smooth.

Seven granular fertilizer programs were initiated 5 June 2008 (Table 1). Weekly N accumulation of the seven programs is detailed in Table 2, and the total amount of N, P, and K applied per fertilizer program during the establishment period is specified in Table 3.

Factors involved in choosing the seven fertilizer programs were N source, weekly N rate, and total N, P, and K applied. The programs UFX – 12, UFX – 24, and UFX Progressive were included based on weekly N rate and total N applied. The Polyon program was included to determine the influence of N source being 100 percent slow-release compared to 100 percent quick-release as in UFX – 12, UFX – 24, and UFX Progressive. Due to the slow release of N by the polymer coated prills of the Polyon fertilizer, higher N rates were applied less frequently than in UFX – 12, UFX – 24, and

UFX Progressive. The program UFX – 12+M was included to evaluate the influence of the addition of an organic fertilizer to the quick-release N program UFX – 12. The organic fertilizer increased the total N applied compared to UFX – 12 and provided additional P, as well as calcium (Ca) and iron (Fe). The Standard 1 and Standard 2 programs were modeled after a Harrell's (Harrell's LLC., Lakeland, FL) fertilizer program suggested for the establishment of seashore paspalum (*Paspalum vaginatum* Swartz) putting greens in Florida.

The study was arranged in a randomized complete block with four replications on each grass. Each plot was 2.4 m x 3.7 m. Weekly fertilizer applications were made for 12 consecutive weeks using shaker bottles. In addition to the scheduled N fertilizer, P was applied as triple superphosphate (0N-46P-0K) at a rate of 11 kg ha^{-1} and K as potassium chloride (0N-0P-62K) at a rate of 40 kg ha^{-1} 1, 5, and 9 weeks after planting (WAP) using a rotary spreader.

Irrigation was applied as needed to avoid stress throughout the establishment period. Mowing was initiated on 21 July 2008 at a height of 12.7 mm using a walk behind reel mower. Starting 28 July 2008, plots were mowed at 6.4 mm three times per week for the remainder of the study. Typical putting green mowing heights (~3.2 mm) were never implemented due to low zoysiagrass coverage and to avoid scalping the bermudagrass.

2009 Establishment

The second establishment study was conducted in 2009 at the Sandhills Research Station located in Jackson Springs, North Carolina. Similar to the 2008 establishment study, the experimental area consisted of a putting green area planted with Miniverde bermudagrass and Diamond zoysiagrass. However, in 2009 the putting green consisted of a native sandy soil, classified as a Candor sand (Sandy, kaolinitic, thermic Grossarenic Kandiudults) (USDA-NRCS Soil Survey Division, 2008) with a pH of 5.8, 559.2 kg ha^{-1} P, and 254.2 kg ha^{-1} K. Miniverde bermudagrass sprigs provided by Modern Turf (Rembert, SC) were planted 28 May 2009 at a rate of 76 m^3 ha^{-1} (20 bushels/1000 ft^2). Diamond zoysiagrass sprigs provided by New Life Turf (Norway, SC) were planted 2 June 2009 at a rate of 133 m^3 ha^{-1} (35 bushels/1000 ft^2). To increase sprig to soil contact, hand shovels were used to pinch the sprigs into the soil. The putting greens were rolled in several different directions using a water-filled roller to smooth the surface. The same seven granular fertilizer programs used in the 2008 study were initiated 9 June 2009.

The study was arranged as a randomized complete block with four replications on each grass. Each plot was 1.2 m x 1.2 m. Weekly fertilizer applications were made for 12 consecutive weeks using shaker bottles. In addition to the scheduled N fertilizer, P was applied as triple superphosphate (0N-46P-0K) at a rate of 11 kg ha^{-1} and K as potassium chloride (0N-0P-62K) at a rate of 40 kg ha^{-1} 1, 5, and 9 weeks after planting (WAP) using a rotary spreader.

Mowing was initiated on the bermudagrass 22 July 2009 and on the zoysiagrass 5 August at a height of 12.7 mm using a reel mower. The mowing height was lowered to 6.4 mm on 12 August 2009 and mowed three times a week for the remainder of the study.

Data Collected

Data collected during the 2008 and 2009 studies were visual turf color ratings, visual turf coverage ratings, and digital photographs taken of each plot. Bermudagrass data were collected weekly from 4 to 13 WAP. Zoysiagrass data were collected weekly from 5 to 13 WAP. Bermudagrass data collection began one week earlier than zoysiagrass during both years due to more rapid establishment.

Visual turfgrass color and coverage was evaluated following the National Turfgrass Evaluation (NTEP) guidelines (Morris and Shearman, 2008). Turfgrass color was measured on a 1 to 9 scale, in which 1 = brown turf, 5 = acceptable green color, 9 = dark green color. Visual turfgrass coverage was measured on a 0 to 100% scale (0% = no cover and 100% = full coverage). Digital photos were taken directly overhead each plot with a Nikon Coolpix 8700 digital camera attached to a 46 cm horizontal arm, mounted 90° to the vertical axis of a 91 cm tripod. The images were batch analyzed using a turf analysis macro (Karcher and Richardson, 2005) for SigmaScan Pro software (ver. 5.0, SPSS Science Marketing Dep., Chicago, IL) to determine percent green pixels in each photo. A weighted-mean coverage rate was calculated by dividing percent coverage by the number of weeks for each rating, resulting in a mean coverage rate.

All statistical analyses were performed using Statistical Analysis System (v. 9.1, SAS Inst., Cary, NC). The main and interaction effects were examined with analysis of variance. Fisher's Least Significant Difference ($LSD_{0.05}$) test was used to separate treatment means. The data from each grass were separated by year due to an interaction between fertilizer program and year (Table 4). Furthermore, the data were separated by WAP due to an interaction between week and fertilizer program.

Results and Discussion

Turfgrass Color

Turfgrass color increased throughout the 13 week study for both species (Table 5 and Table 6). Furthermore, total N applied over the establishment period correlated with bermudagrass ($p \leq 0.0001$) and zoysiagrass ($p \leq 0.0001$) turf color in 2008 and bermudagrass ($p = 0.0138$) turf color in 2009. Zoysiagrass turf color did not correlate ($p = 0.1058$) with total N applied in 2009.

UFX Progressive enhanced bermudagrass and zoysiagrass turf color 39 and 42 percent, respectively in 2008. For 2009, the bermudagrass and zoysiagrass turf color increases were 67 and 58, respectively. UFX – 24 total accumulated N was 72 kg ha^{-1} greater than UFX Progressive (Table 2). However, there were no differences in turf color between UFX – 24 and UFX Progressive.

Bermudagrass and zoysiagrass under the Polyon fertilizer program had the most total N (384 kg ha^{-1}) applied during the establishment period. However, differences in bermudagrass and zoysiagrass turf color did not occur between Polyon and the other six programs. Stiglbauer et al. (2009) found that an N rate of 423 kg ha^{-1} yr^{-1} increased

Diamond zoysiagrass color compared to a rate of 236 kg ha^{-1} yr^{-1}. The differences between our results and Stiglbauer et al. (2009) are likely due to slow-release N being applied once every four weeks in the Polyon program; whereas, Stiglbauer et al. (2009) applied quick-release N every week.

Programs that consisted of both slow and quick-release N sources (UFX – 12+M, Standard 1, and Standard 2) provided acceptable color earlier than the programs that consisted of quick or slow-release N only. UFX – 12+M, Standard 1, and Standard 2 provided acceptable bermudagrass and zoysiagrass color during every rating date in 2008. Turf color of bermudagrass under the Standard 1 and UFX – 1.2+M programs was acceptable 5 WAP in 2009 (bermudagrass under Standard 2 was acceptable 6 WAP). All three of the programs provided acceptable zoysiagrass color 7 WAP in 2009.

Turfgrass Coverage

Visual evaluation and digital image analysis were used to determine percent coverage during the establishment period. The correlation coefficients between visual coverage ratings and percent coverage calculated by SigmaScan Pro were 0.92 ($p \leq 0.0001$) in 2008 and 0.95 ($p \leq 0.0001$) in 2009 for bermudagrass. Zoysiagrass correlation coefficients were 0.89 ($p \leq 0.0001$) and 0.92 ($p \leq 0.0001$) in 2008 and 2009, respectively. Only the visual data are presented because percent coverage calculated by the image analyses was affected by algae growth that occurred during the first six weeks after planting in both years.

Air temperature variations occurred between 2008 and 2009 (Figure 1). There were 15 days in June 2008 (1 to 4 WAP) where the maximum air temperature was above 31°C, whereas there were six days in 2009. Minimum air temperatures were also higher in June 2008. There were 13 days above 20°C in 2008 and four days above 20°C in 2009. The air temperature differences likely resulted in reduced coverage early in 2009. However, the bermudagrass and zoysiagrass reached 75 percent coverage in 42 and 63 days, respectively (Table 7 and Table 8). Furthermore, total P applied had an affect on the time to 75 percent coverage.

Bermudagrass and zoysiagrass plots that received over 33 kg ha^{-1} total P were 75 percent established in a fewer days than the bermudagrass and zoysiagrass plots that received under 33 kg ha^{-1} total P. The addition of Milorganite to the quick-release fertilizer program UFX – 12 increased the establishment progress of zoysiagrass and bermudagrass. The UFX – 12+M program reduced the time to reach 75 percent coverage by two weeks compared to UFX – 12 in both grasses during both years. However, the Milorganite increased total N and P applied compared to UFX – 12, a likely cause for the reduced time to 75 percent coverage.

Coverage rate was calculated for bermudagrass and zoysiagrass (Table 9). The results indicate that bermudagrass and zoysiagrass under the fertilizer programs UFX – 12+M, Standard 1, and Standard 2 had highest coverage rate during both years. In 2008, zoysiagrass coverage rate provided by the UFX – 12+M program was significantly higher than the rate provided by the Standard 1 and Standard 2 programs. Furthermore, the bermudagrass under Standard 1 had a significantly higher coverage rate than UFX –

12+M and Standard 2 in 2008. No differences coverage rate occurred between the three programs in 2009.

Total P applied during UFX – 12+M, Standard 1, and Standard 2 was up to 77 kg ha^{-1} more than P applied during UFX – 12, UFX – 24, UFX Progressive, and Polyon. However, the total N applied during UFX – 24 was greater than that of Standard 1, and total N applied during Polyon was greater than UFX – 12+M, Standard 1, and Standard 2. Therefore, it is likely that coverage rate differences were partially due to the amount of P applied during establishment. These results are similar to those of Rodriguez et al. (2001). They found that using a complete fertilizer, 1:1:1, 1:2:1, or 1:3:1 ($N:P_2O_5:K_2O$), rather than a fertilizer without P (1:0:1 and 1:0:2) for bermudagrass establishment produced the highest coverage rate of Floradwarf and Tifeagle on a sand-based soil.

Total K applied to the bermudagrass and zoysiagrass receiving the Standard 2 program was 146 kg ha^{-1} more than applied during the Standard 1 program. However, differences in zoysiagrass coverage rate between Standard 1 and Standard 2 did not occur in either year. Therefore, it is possible that once a certain level of K is applied to bermudagrass and zoysiagrass during establishment, K is no longer limiting. Studies conducted by Sartain (1999) confirmed that increasing K rate past a certain point does not increase K tissue concentration in Tifway bermudagrass. Sartain increased K rate from 72 to 360 kg ha^{-1} 90 $days^{-1}$ and found that tissue concentration was not different. His data also suggest that maximum Tifway growth rate was achieved when K was applied at 96 kg ha^{-1} and N was applied at 144 kg ha^{-1} every 90 days. This supports Snyder and Cisar's

(2000) findings that increasing K:N fertilization ratio beyond 0.5 to 1 had no effect on Tifgreen bermudagrass turf color or growth rate.

Conclusions

The research indicates that Miniverde bermudagrass and Diamond zoysiagrass can be established in the transition zone during the summer season (June – August) using granular fertilizer. The bermudagrass established more rapidly than the zoysiagrass during both years. However, we found Diamond zoysiagrass can be 100 percent established on a sand-based putting green in 77 days (2008).

Programs that incorporated a combination of quick and slow-release N sources increased bermudagrass and zoysiagrass turf color above the acceptable level earlier in the establishment period compared to programs that consisted of quick or slow-release N only. The bermudagrass and zoysiagrass under the Polyon program had the most total N applied over the establishment period, but the Polyon program did not enhance turf color significantly more compared to the other programs. This was likely due to the slow release of N by the polymer coated prills of the Polyon fertilizer.

The Standard 1 and Standard 2 fertilizer programs consisted of the fifth and third most total N applied compared to all other programs. These programs were shown to be adequate for the rapid establishment of the bermudagrass but not the zoysiagrass. The addition of Milorganite to the UFX – 12 program increased the bermudagrass and zoysiagrass coverage rate during both years. Furthermore, it is possible that once a certain level of K is applied to bermudagrass and zoysiagrass during establishment, K is no longer limiting.

It is essential to develop an adequate fertilizer program when establishing Miniverde bermudagrass and Diamond zoysiagrass putting greens. Different fertilizer programs need to be chosen for each situation so that nutrition will not compromise plant health during establishment. Fertilizer programs that include a combination of quick and slow-release N sources appear to benefit turf color and coverage of Miniverde and Diamond more than programs composed of quick or slow-release N sources only.

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Table 1. Fertilizer program name, fertilizer(s) used for each program, N rate, and application week of each fertilizer used for the establishment of Diamond zoysiagrass and Miniverde bermudagrass during June through August 2008 in Raleigh, NC and June through August 2009 in Jackson Springs, NC.

Program Name	Fertilizer†	N Rate (kg ha^{-1})	App. Week (WAP)
UFX – 12	UFLEXX (46N-0P-0K)	12	1-12
UFX – 24	UFLEXX	24	1-12
UFX Progressive	UFLEXX	12	1-4
	UFLEXX	18	5-8
	UFLEXX	24	9-12
Polyon	Polyon Urea (43N-0P-0K)	96	1,5,9,12
UFX – 1.2+M	UFLEXX	12	1-12
	Milorganite (6N-2P-0K)	48	1,4,7,10
Standard 1	Ammonium Sulfate (21N-0P-0K)	24	1,3,7,10
	7N-23P-19K	24	2,11
	Milorganite	12	4,8,12
	Polyon Urea	48	5
	18N-3P-16K	24	6,9
Standard 2	UFLEXX	24	1,3,5,7,9
	15N-15P-15K	24	2,6,10
	5N-10P-31K	12	4,11
	18N-3P-16K	48	8,12

†In addition to the scheduled fertilizer that was applied each week, P was applied as triple superphosphate (0N-46P-0K) at a rate of 11 kg ha^{-1} and K as potassium chloride (0N-0P-62K) at a rate of 40 kg ha^{-1} 1, 5, and 9 weeks after planting (WAP).

Table 2. Weekly N accumulation of seven granular fertilizer programs applied to Miniverde bermudagrass and Diamond zoysiagrass during June through August 2008 in Raleigh, NC and June through August 2009 in Jackson Springs, NC.

Program Name	Weeks after planting											
	1	2	3	4	5	6	7	8	9	10	11	12
	N accumulation (kg ha^{-1})											
UFX – 12	12	24	36	48	60	72	84	96	108	120	132	144
UFX – 24	24	48	72	96	120	144	168	192	216	240	264	288
UFX Progressive	12	24	36	48	66	84	102	120	144	168	192	216
Polyon	96	96	96	96	192	192	192	192	288	288	288	384
UFX – 12+M	60	72	84	144	156	168	180	240	252	264	324	336
Standard 1	24	48	72	84	132	156	180	192	216	240	264	276
Standard 2	24	48	72	84	108	132	156	204	228	252	264	312

Table 3. Total amount of N, P, and K per fertilizer program applied to Miniverde bermudagrass and Diamond zoysiagrass putting greens during the 2008 and 2009 establishment periods (June – August).

Program Name	Total nutrients applied ($kg\ ha^{-1}$)			
	N	P	K	N:P:K ratio
UFX – 12	144	33	120	4.4:1:3.6
UFX – 24	288	33	120	8.8:1:3.6
UFX Progressive	216	33	120	6.6:1:3.6
Polyon	384	33	120	11.6:1:3.8
UFX – 12+M	336	60	120	5.6:1:2
Standard 1	276	110	246	2.5:1:2.2
Standard 2	312	92	392	3.4:1:4.3

Table 4. Mean squares from combined analyses of variance for turf color and turf coverage of Miniverde bermudagrass and Diamond zoysiagrass from the 2008 and 2009 growing seasons. Abbreviation: WAP: Weeks after planting.

bermudagrass			
		mean square	
Source of Variation[†]	df	Color	Cover
Program, P	6	46.3**	4722.1**
Year, Y	1	12.0**	1.1
WAP, W	9	109.1**	36044.2**
Rep, R	3	0.6	256.1**
P x Y	6	3.9**	295.4**
P x W	54	0.6**	245.4**
WAP(Y)	9	14.4**	2521.8**
Error	471	0.3	40.2
CV%		7.7	8.3
Mean		6.9	76.3
zoysiagrass			
Program, P	6	24.6**	6286.8**
Year, Y	1	172.7**	52849.0**
WAP, W	8	118.8**	28310.1**
Rep, R	3	0.2	50.8
P x Y	6	5.8**	483.9**
P x W	48	0.3**	76.5**
W(Y)	8	31.3**	2228.9**
Error	423	0.1	35.5
CV%		5.5	10.5
Mean		6.8	56.7

*,** Indicates significance at 0.05 and 0.01 level, respectively.

[†] P = fertilization programs, Y = year 2008, 2009, and WAP = weeks after planting

Table 5. Visual turf color ratings of Miniverde bermudagrass established with seven granular fertilizer programs in 2008 and 2009. Fertilizer programs were initiated one week after planting (5 June 2008 and 9 June 2009).

Program Name	Turf Color Rating – weeks after planting †									
	4 [z]	5	6	7	8	9	10	11	12	13
	2008									
UFX – 12	4.3 de	4.8 d	6.2 c	6.8 b	6.2 c	6.0 d	7.0 d	7.0 d	7.0 e	7.0 c
UFX – 24	4.8 cd	5.8 bc	7.2 ab	7.2 ab	7.2 b	7.2 b	7.8 bc	7.8 abc	7.8 cd	7.5 bc
UFX Progressive	4.0 e	4.5 d	6.2 c	6.8 b	6.5 c	6.5 cd	7.5 bcd	7.5 bcd	7.5 cde	7.5 bc
Polyon	5.0 bc	5.0 cd	6.5 bc	7.2 ab	7.2 b	7.0 bc	7.2 cd	7.2 cd	7.2 de	7.2 c
UFX – 12+M	5.5 b	6.8 a	8.0 a	8.0 a	8.0 a	8.0 a	8.0 b	8.0 ab	8.5 ab	8.0 ab
Standard 1	7.0 a	6.5 ab	6.5 bc	7.5 ab	8.0 a	8.0 a	8.0 b	8.0 ab	8.8 a	8.0 ab
Standard 2	5.2 bc	6.5 ab	7.5 a	7.2 ab	7.2 b	8.0 a	8.8 a	8.2 a	8.0 bc	8.2 a
$LSD_{0.05}$	0.53	0.77	0.77	0.75	0.69	0.64	0.62	0.62	0.69	0.58
CV%	7.0	9.2	7.5	7.0	6.4	6.0	5.4	5.4	5.9	5.2

Table 5. Continued

	2009									
UFX – 12	1.2 d	3.0 d	4.0 e	5.8 c	6.8 bc	6.8 de	7.0 c	7.0 c	7.0 d	7.0 c
UFX – 24	2.8 b	4.5 bc	6.0 bcd	7.0 ab	7.2 b	7.8 bc	8.0 b	8.0 b	8.0 c	7.8 b
UFX Progressive	2.0 c	4.0 cd	5.2 cde	6.2 bc	7.2 b	7.2 cd	8.0 b	8.0 b	8.0 c	7.0 c
Polyon	1.8 cd	3.0 d	4.8 de	5.8 c	6.2 c	6.2 e	7.0 c	7.0 c	7.8 c	7.0 c
UFX – 12+M	4.8 a	5.5 ab	7.8 a	8.0 a	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	8.0 b
Standard 1	3.2 b	6.2 a	6.8 ab	7.2 ab	9.0 a	8.5 ab	9.0 a	9.0 a	9.0 a	9.0 a
Standard 2	2.8 b	4.5 bc	6.5 abc	7.5 a	9.0 a	8.8 a	9.0 a	9.0 a	8.5 b	8.0 b
$LSD_{0.05}$	0.63	1.35	1.46	1.13	0.53	0.75	0.0	0.0	0.41	0.28
CV%	16.0	20.6	16.8	11.2	4.6	6.6	0.0	0.0	3.3	2.5

† Values with the same letter within each date column are not statistically different according to Fisher's $LSD_{0.05}$ test.

Table 6. Visual turf color ratings of Diamond zoysiagrass established with seven granular fertilizer programs in 2008 and 2009. Fertilizer programs were initiated one week after planting (5 June 2008 and 9 June 2009).

Program Name	Turf Color Rating – weeks after planting †								
	5	6	7	8	9	10	11	12	13
	2008								
UFX – 12	4.8 d	6.2 d	6.5 c	6.5 c	6.5 d	7.0 b	7.0 b	7.0 c	7.0 c
UFX – 24	5.5 bc	6.8 bcd	7.0 b	7.2 b	7.5 b	8.0 a	8.0 a	8.0 b	8.0 ab
UFX Progressive	4.8 d	6.5 cd	7.0 b	7.2 bc	7.0 c	8.0 a	7.8 a	7.8 b	7.8 b
Polyon	5.2 cd	6.5 d	7.0 b	8.0 a	8.0 a	8.0 a	8.0 a	8.0 b	8.0 ab
UFX – 12+M	7.0 a	8.0 a	8.0 a	8.0 a	8.0 a	8.2 a	8.0 a	8.0 b	8.0 ab
Standard 1	6.0 b	7.2 b	8.0 a	8.0 a	8.0 a	8.2 a	8.0 a	8.5 a	8.0 ab
Standard 2	5.5 bc	7.0 bc	7.0 b	7.2 b	8.0 a	8.2 a	8.0 a	8.0 b	8.2 a
$LSD_{0.05}$	0.66	0.66	0.32	0.52	0.46	0.48	0.28	0.41	0.39
CV%	8.1	6.5	3.0	4.7	4.1	4.0	2.4	3.5	3.3

Table 6. Continued

	2009								
UFX – 12	1.8 b	3.0 c	4.0 b	6.2 c	7.0 c	7.0 c	8.0 cd	7.0 c	7.0 b
UFX – 24	1.8 b	3.0 c	4.0 b	6.0 c	7.0 c	7.0 c	7.5 de	7.5 c	7.0 b
UFX Progressive	1.8 b	3.0 c	4.0 b	6.0 c	7.0 c	7.0 c	7.0 e	7.0 c	6.8 b
Polyon	1.2 b	3.0 c	4.0 b	6.0 c	7.0 c	7.0 c	7.0 e	7.0 c	6.8 b
UFX – 12+M	2.5 a	5.0 a	5.8 a	8.0 a	9.0 a	9.0 a	9.0 a	9.0 a	8.0 a
Standard 1	2.8 a	3.8 b	5.8 a	7.8 a	8.2 b	8.2 b	8.2 bc	8.3 b	8.0 a
Standard 2	2.8 a	4.0 b	5.8 a	7.0 b	9.0 a	9.0 a	8.8 ab	8.8 ab	8.0 a
$LSD_{0.05}$	0.67	0.57	0.63	0.39	0.28	0.28	0.54	0.54	0.41
CV%	21.7	10.8	9.0	3.87	2.4	2.4	4.6	4.7	3.7

† Values with the same letter within each date column are not statistically different according to Fisher's $LSD_{0.05}$ test.

Table 7. Visual turf coverage ratings of Miniverde bermudagrass established with seven granular fertilizer programs in 2008 and 2009. Fertilizer programs were initiated one week after planting (5 June 2008 and 9 June 2009).

Program Name	Turf Cover Rating – weeks after planting †									
	4	5	6	7	8	9	10	11	12	13
	2008									
UFX – 12	37.5 bc	37.5 c	55.0 bc	57.5 bc	67.50b	75.0 bc	82.5 c	91.2 bc	93.8 c	98.8 a
UFX – 24	40.0 bc	42.5 c	57.5 b	65.0 b	70.0 b	80.0 b	91.2 b	96.2 ab	98.8 ab	100.0 a
UFX Progressive	35.0 c	40.0 c	47.5 c	55.0 c	62.5 b	67.5 c	80.0 c	87.5 c	93.8 c	97.5 a
Polyon	40.0 bc	42.5 c	50.0 bc	60.0 bc	67.5 b	75.0 bc	83.8 c	87.5 c	95.0 bc	98.8 a
UFX – 12+M	45.0 b	55.0 b	72.5 a	75.0 a	85.0 a	92.5 a	98.8 a	100.0 a	100.0 a	100.0 a
Standard 1	65.0 a	67.5 a	75.0 a	82.5 a	90.0 a	98.8 a	100.0 a	100.0 a	100.0 a	100.0 a
Standard 2	45.0 b	55.0 b	75.0 a	77.5 a	82.5 a	96.2 a	100.0 a	100.0 a	100.0 a	100.0 a
$LSD_{0.05}$	9.22	8.68	8.16	9.73	7.60	7.73	7.19	7.53	3.8	2.61
CV%	14.1	12.0	8.9	9.7	6.8	6.2	5.3	5.4	2.6	1.8

Table 7. Continued

	2009									
UFX – 12	6.2 e	15.0 c	30.0 d	52.5 d	82.5 cd	91.2 c	96.2 b	97.5 b	100.0 a	100.0 a
UFX – 24	15.0 cd	32.5 b	47.5 bc	75.0 bc	91.2 b	95.0 b	100.0 a	100.0 a	100.0 a	100.0 a
UFX Progressive	8.8 de	25.0 bc	42.5 cd	70.0 bc	88.8 bc	95.0 b	100.0 a	100.0 a	100.0 a	100.0 a
Polyon	8.8 de	15.0 c	32.5 d	60.0 cd	77.5 d	90.0 c	96.2 b	98.8 ab	100.0 a	100.0 a
UFX – 12+M	37.5 a	52.5 a	77.5 a	93.8 a	100.0 a	100.0 a	100.0 a	100.0 a	100.0 a	100.0 a
Standard 1	22.5 b	62.5 a	77.5 a	91.2 a	98.8 a	100.0 a	100.0 a	100.0 a	100.0 a	100.0 a
Standard 2	17.5 bc	35.0 b	57.5 b	85.0 ab	98.8 a	100.0 a	100.0 a	100.0 a	100.0 a	100.0 a
$LSD_{0.05}$	6.68	15.83	14.04	15.38	7.25	1.4	2.04	2.24	0.0	0.0
CV%	27.1	31.4	18.1	13.7	5.4	1.0	1.4	1.5	0.0	0.0

† Values with the same letter within each date column are not statistically different according to Fisher's $LSD_{0.05}$ test.

Table 8. Visual turf coverage ratings of Diamond zoysiagrass established with seven granular fertilizer programs in 2008 and 2009. Fertilizer programs were initiated one week after planting (5 June 2008 and 9 June 2009).

Program Name	Turf Cover Rating – weeks after planting †								
	5	6	7	8	9	10	11	12	13
	2008								
UFX – 12	35.0 c	42.5 c	42.5 b	42.5 c	45.0 e	52.5 d	75.0 c	75.0 d	77.5 c
UFX – 24	40.0 bc	47.5 bc	50.0 b	55.0 b	57.5 c	67.5 c	87.5 b	87.5 c	87.5 b
UFX Progressive	40.0 bc	47.5 bc	47.5 b	50.0 bc	52.5 cd	62.5 c	87.5 b	90.0 bc	90.0 b
Polyon	35.0 c	42.5 c	42.5 b	47.5 bc	50.0 de	60.0 cd	80.0 c	80.0 d	80.0 c
UFX – 12+M	52.5 a	62.5 a	67.5 a	70.0 a	80.0 a	90.0 a	100.0 a	100.0 a	100.0 a
Standard 1	47.5 ab	57.5 a	62.5 a	70.0 a	70.0 b	82.5 ab	95.0 a	95.0 ab	98.8 a
Standard 2	45.0 ab	55.0 ab	62.5 a	65.0 a	70.0 b	77.5 ab	95.0 a	95.0 ab	100.0 a
$LSD_{0.05}$	8.0	9.31	9.02	9.02	5.99	8.93	6.14	5.84	6.23
CV%	12.8	12.4	11.3	10.63	6.6	8.5	4.7	4.4	4.6

Table 8. Continued

	2009								
UFX – 12	3.5 bc	7.5 b	22.5 b	40.0 b	47.5 c	50.0 c	57.5 b	70.0 b	75.0 b
UFX – 24	2.8 c	6.2 b	20.0 b	37.5 b	45.0 c	47.5 cd	55.0 b	65.0 b	72.5 b
UFX Progressive	2.0 c	6.2 b	20.0 b	42.5 b	45.0 c	45.0 cd	52.5 b	65.0 b	70.0 b
Polyon	2.8 c	7.5 b	20.0 b	35.0 b	40.0 c	40.0 d	50.0 b	62.5 b	70.0 b
UFX – 12+M	6.2 a	15.0 a	35.0 a	55.0 a	62.5 b	62.5 b	75.0 a	85.0 a	92.5 a
Standard 1	5.0 ab	16.2 a	35.0 a	55.0 a	67.5 b	67.5 b	77.5 a	91.2 a	95.2 a
Standard 2	5.0 ab	15.0 a	35.0 a	55.0 a	77.5 a	77.5 a	80.0 a	87.5 a	95.0 a
$LSD_{0.05}$	2.1	6.52	9.12	11.42	8.78	9.36	10.67	8.89	8.84
CV%	36.3	41.6	22.9	16.8	10.7	11.31	11.2	8.0	7.3

† Values with the same letter within each date column are not statistically different according to Fisher's $LSD_{0.05}$ test.

Table 9. Mean coverage rate of Miniverde bermudagrass and Diamond zoysiagrass in 2008 and 2009. The seven granular fertilizer programs were initiated one week after planting (5 June 2008 and 9 June 2009).

Program Name	Coverage† (percent wk^{-1})			
	2008		2009	
	bermudagrass	zoysiagrass	bermudagrass	zoysiagrass
UFX – 12	8.3 cd	6.1 d	7.2 d	4.1 b
UFX – 24	8.9 c	7.2 c	8.6 c	3.9 b
UFX Progressive	7.9 d	7.0 c	8.1 cd	3.9 b
Polyon	8.4 cd	6.4 d	7.3 d	3.6 b
UFX – 12+M	10.1 b	9.1 a	10.5 a	5.5 a
Standard 1	11.1 a	8.5 b	10.3 ab	5.8 a
Standard 2	10.2 b	8.3 b	9.2 bc	6.0 a
LSD $_{(0.05)}$	0.65	0.43	1.16	0.98
CV%	16.0	12.4	30.2	45.2

† Values with the same letter within each column are not statistically different according to Fisher's $LSD_{0.05}$ test.

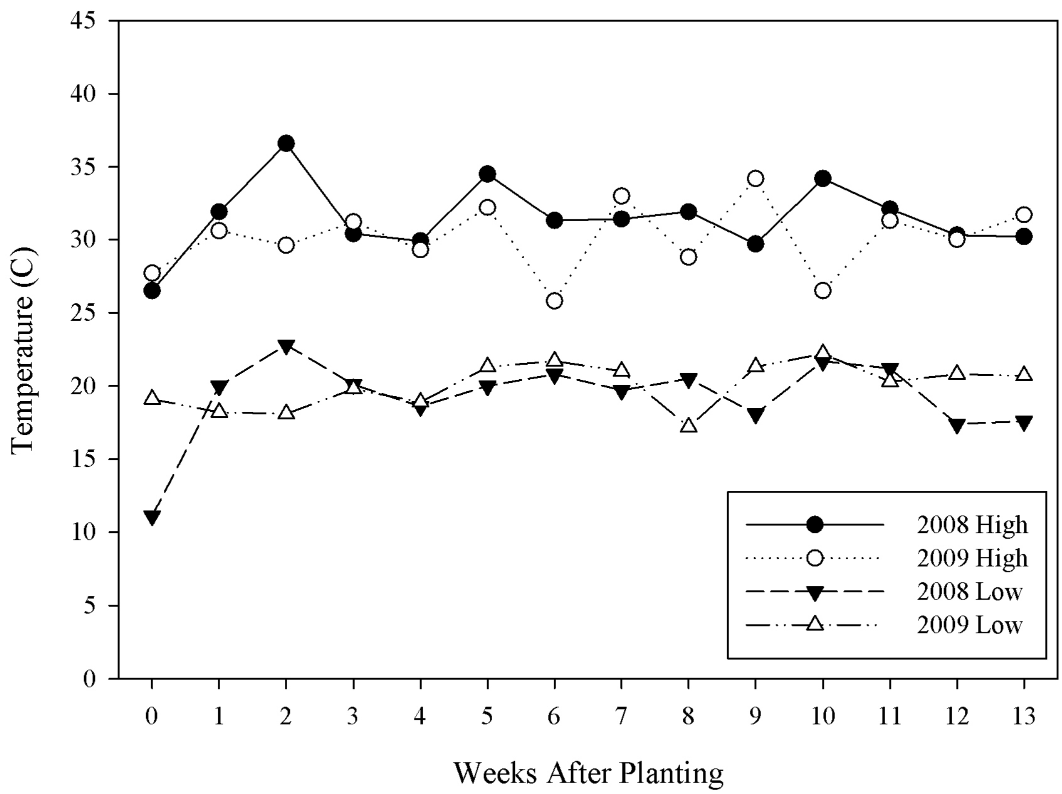

Figure 1. Daily maximum and minimum air temperatures (°C) recorded 25 May to 30 August 2008 at Lake Wheeler Field Laboratory in Raleigh, NC and 25 May to 30 August 2009 at Sandhills Research Station in Jackson Springs, NC.

CHAPTER 2

The Influence of N Rate, Topdressing, and Verticutting on 'Diamond' Zoysiagrass and 'Miniverde' Bermudagrass Putting Greens

Ultradwarf bermudagrasses [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* (Burtt-Davy)] and fine textured zoysiagrasses [*Zoysia matrella* (L.) Merr.] are becoming more popular for use on putting greens in the transition zone. However, there is limited information available regarding the cultural management of these grasses. A field study was conducted from June through October 2009 in Raleigh, NC on two putting greens constructed with an 85 sand : 15 peat (v:v) rootzone to meet United States Golf Association (USGA) standards. One putting green contained a one year old stand of 'Diamond' zoysiagrass and the other a one year old stand of 'Miniverde' bermudagrass. Treatments consisted of four N rates (96, 144, 192, and 240 kg ha^{-1} yr^{-1}), two verticutting programs (noninvasive and invasive), and two topdressing programs (light and heavy). Granular fertilizer (UFLEXX 46N-0P-0K and Contec DG 18N-9P-18K) and foliar fertilizer (Green Flo 30N-0P-0K) formulations were applied weekly May through September, noninvasive verticutting (6.4 mm deep) and light topdressing (0.25 mm sand) were applied twice monthly June through August, and invasive verticutting (12.7 mm deep) and heavy topdressing (0.75 mm sand) were applied once in June and August using a program approach. The influence of these inputs on turf quality, thatch accumulation, and ball roll were examined. Results indicate that Diamond zoysiagrass requires a lower

annual N rate (192 kg ha^{-1} yr^{-1}) than Miniverde bermudagrass (240 kg ha^{-1} yr^{-1}) to maintain acceptable turf quality. The frequency of noninvasive verticutting program was too aggressive to allow the bermudagrass to fully recover between verticuttings. Nitrogen rate influenced ball roll distances of both grasses. The longest ball roll distances were measured on bermudagrass and zoysiagrass that had N applied at a rate of 96 kg ha^{-1} yr^{-1}. Bermudagrass thatch depth was unaffected by verticutting, but differences in thatch depth occurred between the two verticutting programs applied to the zoysiagrass.

Introduction

The demand for higher quality playing surfaces has resulted in the development of bermudagrass and zoysiagrass cultivars that have finer textures and can be cut lower. However, the hot, humid summers and cold winters of the transition zone are not optimal conditions for maintaining perfect warm or cool season turf all year long. Environmental stresses require turf managers within this zone to develop management strategies that keep each grass species in the best possible playing condition. Depending on the grass being managed, different cultural practices must be used to avoid compromising plant health.

Creeping bentgrass (*Agrostis stolonifera* Huds.), a cool-season grass, is widely used on putting greens in the transition zone. It provides a high quality, uniform playing surface that can withstand mowing heights of 3.2 mm or less. However, the high heat and humidity of summer temperatures in the transition zone often causes management difficulties (Fagerness and Yelverton, 2001). This has lead some golf courses in the transition zone to convert their putting greens to warm-season grasses, such as zoysiagrass (*Zoysia* sp.) and bermudagrass (*Cynodon* sp.).

Ultradwarf bermudagrasses [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* (Burtt-Davy)] have become popular for putting green conversion in the transition zone. They provide a denser, more uniform playing surface than the dwarf bermudagrasses [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis*] and cost $75,000 to $130,000 less to maintain than creeping bentgrass putting greens (McCarty, 2005; McCarty and Canegallo, 2005; McCullough et al., 2006). Among the ultradwarf cultivars, Miniverde has proven to be among the most popular since its release in the late 1990's (Guertal and White, 1998). However, bermudagrasses have a high sunlight requirement, with shade causing low turf density and increased disease problems (Baldwin et al., 2010).

The release of fine textured zoysiagrasses [*Zoysiagrass matrella* (L.) Merr.] that are more shade tolerant than bermudagrass has prompted the use of zoysiagrass on putting greens in the transition zone. Specifically, Diamond zoysiagrass is being evaluated for use on putting greens (Engelke et al., 2002). It has been documented that Diamond can be successfully establishment from sprigs in the southeastern United States (Stiglbauer et al., 2009). However, little information is available on the influence of cultural practices on Diamond quality and thatch accumulation.

Thatch can be a problem with both zoysiagrass and bermudagrass. Excessive thatch is detrimental to plant health because it causes a reduction in drought tolerance, cold tolerance, and water infiltration rate. It also can make the turf susceptible to insect and disease damage (White and Dickens, 1984; Gregg and McCarty, 2004; Hanna, 2005). Furthermore, increasing nitrogen fertilization during the growing season may lead to excess thatch accumulation. White (1999) reported that fertilizing Miniverde, Champion, Floradwarf, and Tifeagle with an N rate of 864 kg ha^{-1} yr^{-1} resulted in up to 14 times more thatch accumulation than Tifdwarf. These results are in agreement with Hanna (2005), who found that Tifeagle thatch accumulation from N applied at 24 kg ha^{-1} twice monthly for two years caused turf quality to decrease 39 percent compared to N applied at 12 kg ha^{-1}.

Cultural practices such as topdressing are used to slow thatch accumulation in putting greens. Liu et al. (2007) found that weekly light topdressing (18 mm sand annually) slowed Miniverde thatch accumulation more than weekly moderate (36 mm sand annually) or heavy (54 mm sand annually) topdressing. However, White et al. (2004) show no difference in Miniverde thatch depth between twice monthly light topdressing (0.5 mm sand) applied May through September and heavy topdressing (3.8 mm sand) applied once in June.

Verticutting often coincides with topdressing to reduce thatch in putting greens. The frequency and depth of the verticutting have an impact on bermudagrass turf quality and recovery. Hanna (2005) found that Tifeagle took six weeks to fully recover from verticutting at 25 mm deep. Furthermore, verticutting at a depth of 25 mm reduced turf quality of Champion, Tifeagle, Floradwarf, MS Supreme, Mobile 9, and Tifdwarf bermudagrass significantly more than verticutting at a depth 13 mm (Hollingsworth et al., 2005).

There is a need for further research on the cultural management of both ultradwarf bermudagrass and fine textured zoysiagrass putting greens in the transition zone. Information on the influence of N rate, topdressing, and verticutting on the management of Miniverde bermudagrass putting greens is lacking. No information exists on the influence of those inputs on the management of Diamond zoysiagrass putting greens. Therefore, the objective of this study was to evaluate the influence of four N rates, two topdressing programs, and two verticutting programs on the turfgrass quality, turfgrass recovery from verticutting, thatch accumulation, and ball roll distances of Miniverde bermudagrass and Diamond zoysiagrass putting greens.

Materials and Methods

A field study was conducted from 28 May to 21 October 2009 at the Lake Wheeler Field Laboratory in Raleigh, North Carolina. The study consisted of different N rates, verticutting programs, and topdressing programs applied to two putting greens constructed with an 85 sand : 15 peat (v:v) rootzone to meet United States Golf Association (USGA) standards (USGA, 1993). Diamond zoysiagrass was sprigged 28 May 2008 on one of the greens, and Miniverde bermudagrass was sprigged 30 May 2008 on the other.

The treatments were arranged as a 4x2x2 factorial in a split-plot design with eight whole plot treatments and four replications. Nitrogen rate (96, 144, 192, and 240 kg ha^{-1} yr^{-1}) + topdressing program (light and heavy) were whole plots (2.4 m x 3.7 m), and verticutting program (invasive and noninvasive) were the sub-plots (1.22 m x 3.66 m).

A combination of foliar and granular fertilizers was applied during the study. The first N application was made 28 April using UFLEXX (Agrotain International L.L.C, St. Louis, MO), stabilized urea (46N-0P-0K) at an N rate of 24 kg ha^{-1}. Subsequent N applications began 28 May. Nitrogen sources used for those applications were Green Flo (John Deere Landscapes, Troy, MI), 30N-0P-0K, (15.0% N from urea and 15.0% slow-release N from Urea-Triazone solution) applied as a foliar, and Contec DG (Andersons Golf Products, Maumee, OH), 18N-9P-18K, applied as a granular. Foliar fertilizer was applied using a CO_2-powered backpack sprayer calibrated to deliver 37 mL solution m^{-2}.

Granular fertilizer was applied using shaker bottles. Weekly fertilizer formulations and N rates applied are detailed in Table 1.

Two topdressing programs were applied to whole plots in addition to the four N rates. The light topdressing program consisted of 0.25 mm sand applied twice monthly from 11 June - 27 August. The heavy topdressing program consisted of 0.75 mm sand applied on 18 June and 20 August. Topdressing material was bagged dry sand (Divots, Inc., Sanford, NC) and was applied using a rotary spreader. After topdressing the sand was brushed into the turfgrass canopy using brooms.

Verticutting was applied to the sub-plots using a Graden verticutter (Graden Turf Machinery, Campbellfield, Victoria, Australia) with 3.2 mm thick blades set 26 mm apart. The noninvasive verticutting program was initiated 11 June and consisted of verticutting at a depth of 6.4 mm from the canopy surface twice monthly to 27 August. The invasive verticutting program consisted of verticutting at a depth of 12.7 mm from the canopy surface, applied on 18 June and 20 August.

To represent normal management practices used by turfgrass professionals to manage warm-season putting greens, trinexapac-ethyl (Primo Maxx) was applied to both greens during the study period. Applications of 48 and 24 g a.i. ha^{-1} were made on 22 June and 28 July, respectively. The rate was reduced for the July application because phytotoxicity occurred on the Miniverde bermudagrass green, which lasted for two weeks.

Throughout the duration of the study both putting greens were mowed five days a week at a height of 3.2 mm. Irrigation was applied as needed to maintain healthy turfgrass (typically 3 – 4 times per week to achieve ~2.54 cm total precipitation). Fungicides were applied to both putting greens on a curative basis as needed for dollar spot (*Sclerotinia homoeocarpa*). The first fungicide application (7 May) consisted of chlorothalonil (tetrachloroisophthalonitrile) and iprodione [3-(3,5-dichlorophenyl)-N-(1-methylethyl)2,4-dioxo-1-imidazoline-carboxamide] applied at a rate of 7.3 and 3.0 kg a.i. ha^{-1}, respectively. Subsequent fungicide applications on 26 May and 29 June consisted of chlorothalonil and boscalid [3-pyridinecarboxamide, 2-chloro-N-(4'chloro[1,1'biphenyl]-2-yl)] applied at a rate of 7.3 and 0.4 kg a.i. ha^{-1}, respectively.

Data Collected

Data collection included turfgrass quality, thatch depth, and ball roll distance. Visual turfgrass quality (based on turf color, density, uniformity, and environmental stress) was evaluated following the National Turfgrass Evaluation (NTEP) guidelines (Morris and Shearman, 2008). Turfgrass quality evaluations were made weekly June through October before any cultivation treatment was applied on a 1 to 9 scale (1 = dead turf, 5 = acceptable quality, 9 = best quality).

Thatch depth and ball roll measurements were collected monthly from June to September. To measure thatch depth, three core samples (2.2 cm diameter and 7.6 cm in depth) were randomly removed from each sub-plot and uncompressed thatch depth was measured (in millimeters) using a ruler. Measurements were taken from the closest point below the green foliar tissue to the boarder of the thatch layer and soil surface, similar to the method of Gregg and McCarty (2004). Ball roll was determined using a standard 91 cm Stimpmeter (USGA). The roll distance was measured three times in one direction and three times in the opposite direction and then averaged for each sub-plot.

All statistical analyses were performed using Statistical Analysis System (v. 9.1, SAS Inst., Cary, NC). The main and interaction effects were examined with analysis of variance. Fisher's Least Significant Difference ($LSD_{0.05}$) test was used to separate treatment means. Data were separated by date due to an interaction between N rate and date, as well as verticutting program and date.

Results and Discussion

Turfgrass Quality

No significant two-way or three-way interactions occurred for Miniverde bermudagrass or Diamond zoysiagrass turf quality (Table 2). However, differences in turf quality did occur between N rates and verticutting programs for both grasses. The 240 kg ha^{-1} yr^{-1} N rate resulted in bermudagrass and zoysiagrass turf quality that remained above the acceptable level ($\geq$5) throughout the study (Figure 1). However, the zoysiagrass that had N applied at a rate of 192 kg ha^{-1} yr^{-1} also remained above the acceptable level. Although the lowest annual N rate applied to the grasses, 96 kg ha^{-1} yr^{-1}, provided acceptable bermudagrass quality (5.1) in June, quality decreased over the growing season, reaching a value of 2.7 in October.

The data indicate zoysiagrass turf quality can be maintained above the acceptable level from June through August by applying N at a rate of 96 kg ha^{-1} yr^{-1}. Furthermore, turf quality of zoysiagrass that had N applied at a rate of 144 kg ha^{-1} yr^{-1} remained acceptable June through September; whereas, the quality of bermudagrass receiving the same N rate was 5.7, 4.9, 5.2, and 4.9 in June, July, August, and September, respectively. The decrease in turf quality in July was attributed to the phytotoxicity that the bermudagrass suffered from the trinexapac-ethyl application in late June. Decreases in turf quality of both grasses were also seen after verticutting.

Decreases in turf quality of bermudagrass and zoysiagrass were more evident one week after the invasive verticuttings (12.7 mm deep) than the noninvasive verticuttings (6.4 mm deep) (Figure 2). These are similar results to those of Hollingsworth et al. (2005), which showed verticutting at a depth of 25 mm decreased quality of Champion, Tifeagle, Floradwarf, MS Supreme, Mobile 9, and Tifdwarf bermudagrass more than verticutting at a depth of 13 mm. Zoysiagrass turf quality was not affected by the noninvasive verticutting. However, decreases in zoysiagrass turf quality were 6 and 10 percent one week following the June and August invasive verticuttings, respectively. Therefore, the data suggest that depending on N rate, zoysiagrass putting greens can be maintained at acceptable quality when verticut at a depth of 6.4 mm twice monthly from June through August.

Bermudagrass quality differences occurred between verticutting programs from 23 July through 20 August. The results of Hollingsworth et al. (2005) indicate the same trend. Bermudagrass turf quality in their two-year study was higher in the plots that were verticut at a depth of 25 mm twice a year compared to those verticut at a depth of 13 mm monthly during the summer. Their explanation was that plots verticut at 25 mm had more time to heal after each treatment. The data presented in our study confirms that the differences in turf quality occurred because the 6.4 mm deep verticuttings occurred 16

July, 30 July, and 13 August; whereas, there were no 12.7 mm deep verticuttings during that time period. Furthermore, the frequency of the noninvasive verticutting program did not allow the bermudagrass to fully recover between verticutting treatments. This lead to increased bermudagrass damage and unacceptable quality later in the summer season. Other studies have found that bermudagrass and creeping bentgrass took up to 60 days to fully recover after verticutting with a Graden verticutter (Hanna, 2005; Landreth et al., 2007). Using a less invasive verticutting unit during our noninvasive program would have likely reduced the time to full recovery after each treatment. Therefore, turf quality would be higher than what we observed after using the Graden.

Ball Roll

Bermudagrass ball roll distances increased from June to August (Figure 3). The ball rolls averaging the longest distance (325 cm) were measured in August on the bermudagrass that had N applied at a rate of 96 kg ha^{-1} yr^{-1}. However, a decrease in both bermudagrass and zoysiagrass ball roll was found from August to September. A possible cause for this result is that both putting greens were completely saturated from a rain event the night before the September measurements were taken.

Differences in ball roll distances among N rates applied to bermudagrass were greater than the zoysiagrass. The largest difference in bermudagrass ball roll distance between those two N rates occurred in August (38 cm); whereas, the largest difference in zoysiagrass ball roll distance in August was 11 cm. Furthermore, there were no differences in ball roll distance between zoysiagrass that had N applied at rates of 96 and 144 kg ha^{-1} yr^{-1}.

The USGA has developed guidelines for “green speed” (slow, medium, and fast) of golf courses in “regular membership conditions” and “tournament conditions” based on ball roll distances (Radko, 1977). They determined that ball roll distances of 137, 198, and 259 cm on a golf course under regular membership conditions are considered slow, medium, and fast, respectively. Ball roll distances of 198, 259, and 320 cm on a course under tournament conditions are considered slow, medium, and fast, respectively (Radko, 1977). Our results indicate the zoysiagrass in July and August had ball roll distances that would be considered fast on a course under membership conditions and medium under tournament conditions. Furthermore, the zoysiagrass that had ball roll distances ≥259 cm in July and August also had acceptable zoysiagrass quality (Figure 1). This suggests that our management program could maintain “fast” green speeds and turf quality at an acceptable level under normal membership conditions during July and August.

Bermudagrass ball roll distances were ≥259 cm at every measurement date. In August, the 96 kg ha^{-1} yr^{-1} N rate produced a ball roll distance of 325 cm, which would be considered fast on a course under tournament conditions. However, bermudagrass turf quality provided by that N rate was below the acceptable level (≥5) July through September. Under our management program, an N rate of at least 192 kg ha^{-1} yr^{-1} needs to be applied to the bermudagrass to maintain acceptable turf quality and ball roll distances ≥259 cm June through September.

Thatch Depth

Uncompressed thatch depth of the bermudagrass and zoysiagrass was measured monthly June through September. The only difference in thatch depth that occurred was between verticutting programs applied to zoysiagrass ($p = 0.0363$). Increases in zoysiagrass thatch depth from June through September were 11 mm for both programs. The largest difference between the two programs occurred in July, with thatch depth being 2 mm greater in plots under the noninvasive verticutting program.

A thatch layer of 6.4 to 12.7 mm is desirable on putting greens to provide proper ball bounce and to moderate the soil environment (Beard, 1973). Excessive thatch can cause increased disease problems, susceptibility to scalping, and decreased tolerance to environmental stresses, such as cold temperatures (Beard, 1973). The thatch depth of both grasses increased to around 18 mm by September despite verticutting program. This leads us to believe that thatch could become excessive in Miniverde and Diamond under our management program. Furthermore, thatch accumulates when the rate of organic matter exceeds the amount of decomposition by the soil microbes (Beard, 1973). In warm-season turfgrasses located in the transition zone this typically occurs May through September. Altering the depth and frequency of verticutting and adding core aerification to our management program may lead to slower thatch accumulation. However, based on the results of our study, deeper, more frequent verticutting using our methods would decrease bermudagrass and zoysiagrass turf quality over the summer season (when N rates are 96 to 240 kg ha^{-1} yr^{-1}). Therefore, verticutting at a depth that is less than 6.4 mm and increasing the frequency would likely be necessary to maintain similar zoysiagrass and bermudagrass turf quality.

Conclusions

The use of warm season grasses on putting greens in the transition zone is becoming more prevalent. Ultradwarf bermudagrasses such as Miniverde are already being widely used. The need for more shade tolerant warm season putting greens has prompted to the use of Diamond zoysiagrass as an alternative to bermudagrass. This research suggests that both Miniverde bermudagrass and Diamond zoysiagrass can be effectively managed with acceptable quality on a sand-based putting green in the transition zone. However, the lack of traffic applied to both putting greens during this study may have allowed increased turf quality. Therefore, there is a need for further research on the influence of traffic on Diamond and Miniverde turf quality.

An N rate of 240 kg ha^{-1} yr^{-1} was needed to maintain Miniverde bermudagrass at acceptable quality June through October. However, the frequency of the noninvasive verticutting program was too aggressive to maintain a quality bermudagrass playing surface late in the summer. A two-month recovery period between invasive verticuttings was adequate time to allow the bermudagrass to fully recover. The longest ball roll distances were measured on bermudagrass that had an N rate of 96 kg ha^{-1} yr^{-1} applied. Topdressing did not have an affect on the turf quality, thatch accumulation, or ball roll distance of the bermudagrass or zoysiagrass.

Diamond zoysiagrass results differ from those of bermudagrass. Acceptable zoysiagrass quality was maintained throughout the study with less annual N applied, verticutting damage was less severe, and ball roll distances were shorter. An N rate of 192 kg ha^{-1} yr^{-1} was necessary to maintain zoysiagrass at acceptable quality June through October. Zoysiagrass quality differences did not occur between the two verticutting programs July through mid-August. The results suggest these programs would be adequate for the management of a Diamond zoysiagrass putting green. More data are needed to support the differences in thatch depth between verticutting programs applied to the zoysiagrass.

It has been shown that Miniverde bermudagrass and Diamond zoysiagrass putting greens can be effectively managed using different N rates, verticutting programs, and topdressing programs during the summer season. However, the long-term effects of these cultural practices have yet to be studied. Research that explores the influence of aerification frequency and timing on turf quality and thatch accumulation of Miniverde bermudagrass and Diamond zoysiagrass putting greens should be conducted.

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Table 1. Fertilizer application dates, weekly fertilizer rates, and total N (kg ha^{-1} yr^{-1}) applied to a Miniverde bermudagrass putting green and a Diamond zoysiagrass putting green in 2009 at Lake Wheeler Field Laboratory located in Raleigh, NC.

Application date	Total N applied (kg ha^{-1} yr^{-1})			
	96	144	192	240
	Weekly N Rate (kg ha^{-1} yr^{-1})			
27 April	24 – g[†]	24 – g	24 – g	24 – g
28 May	12 – g	24 – g	48 – g	48 – g
12 June	5 – f	5 – f	10 – f	10 – f
19 June	14 – g	14 – g	28 – g	28 – g
26 June	n/a	5 – f	n/a	10 – f
17 July	5 – f	5 – f	10 – f	10 – f
23 July	n/a	14 – g	14 – g	28 – g
31 July	5 – f	5 – f	10 – f	10 – f
10 Aug.	5 – f	5 – f	10 – f	10 – f
21 Aug.	14 – g	14 – g	14 – g	28 – g
28 Aug.	n/a	5 – f	n/a	10 – f
10 Sept.	12 – g	24 – g	24 – g	24 – g

[†]N rate and fertilizer formulation applied. Abbreviations: g = granular fertilizer, f = foliar fertilizer, n/a = no fertilizer application for that date.

Table 2. Mean squares from combined analyses of variance for turf quality, ball roll distances, and thatch depth of Miniverde bermudagrass and Diamond zoysiagrass from the 2009 growing season.

		bermudagrass		
		Mean square		
Source of variation	df	Quality	Ball roll	Thatch depth
N Rate, N	3	503.3**	8136.1**	44.1
Topdressing, T	1	2.6	773.6	5.4
N x T	3	3.1	167.9	15.8
Rep, R	3	14.4**	1850.0**	15.3
R(N x T)	21	3.3**	199.1	7.3
Verticutting, V	1	12.6**	4.9	0.5
N x V	3	0.5	101.1	1.6
T x V	1	0.4	307.2	4.9
N x V x T	3	0.2	66.0	0.8
N x T x R(V)	24	0.4	94.4	4.1
CV %		17.5	6.3	18.3
Mean		5.5	288.0	15.8
		zoysiagrass		
N Rate, N	3	330.6**	1676.9*	10.7
Topdressing, T	1	10.4	36.0	1.2
N x T	3	5.5	140.8	51.6
Rep, R	3	3.8**	631.1	23.3
R(N x T)	21	2.0**	111.9	24.6
Verticutting, V	1	0.2	51.0	26.1*
N x V	3	0.1	87.8	12.3
T x V	1	0.02	7.3	1.2
N x V x T	3	0.003	23.1	6.1
N x T x R(V)	24	0.2	111.0	5.3
CV %		13.9	6.2	41.5
Mean		6.5	250.3	13.4

*,** Indicates significance at 0.05 and 0.01 level, respectively.

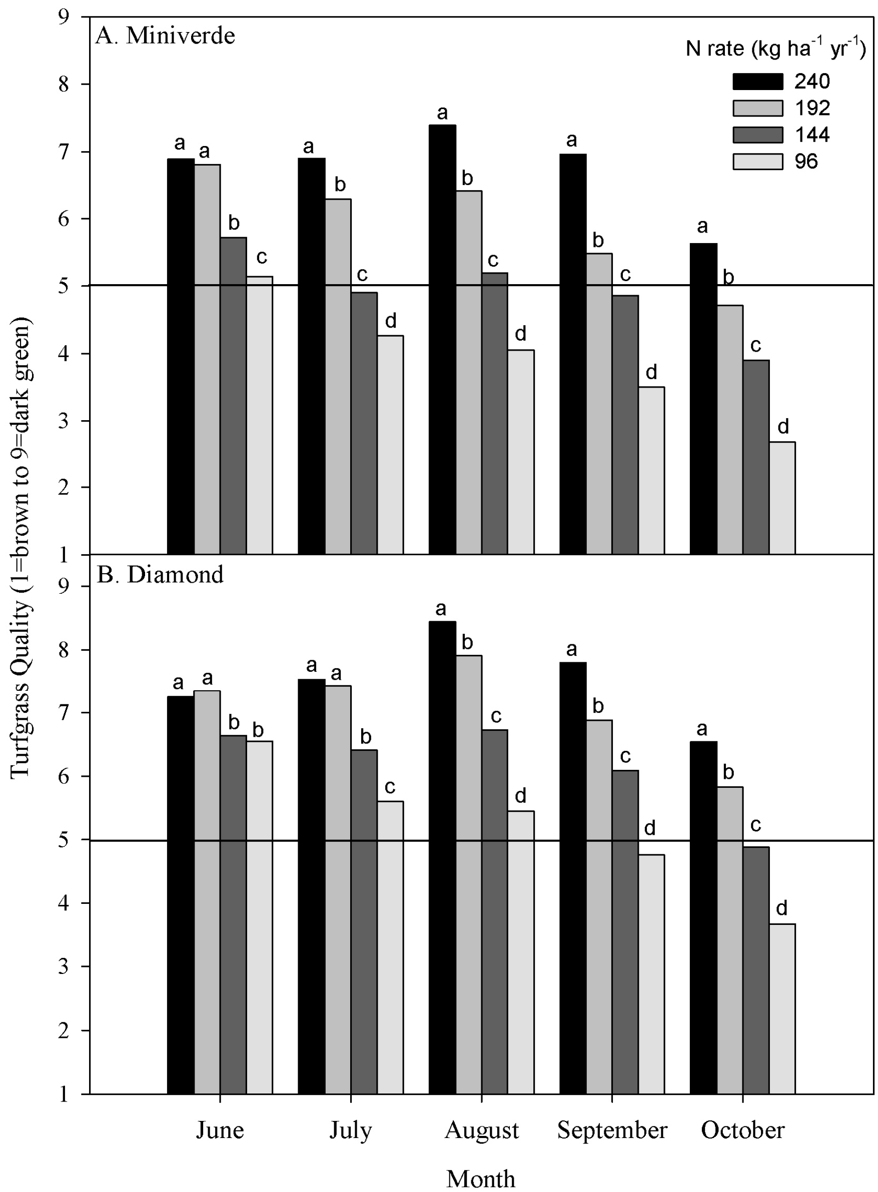
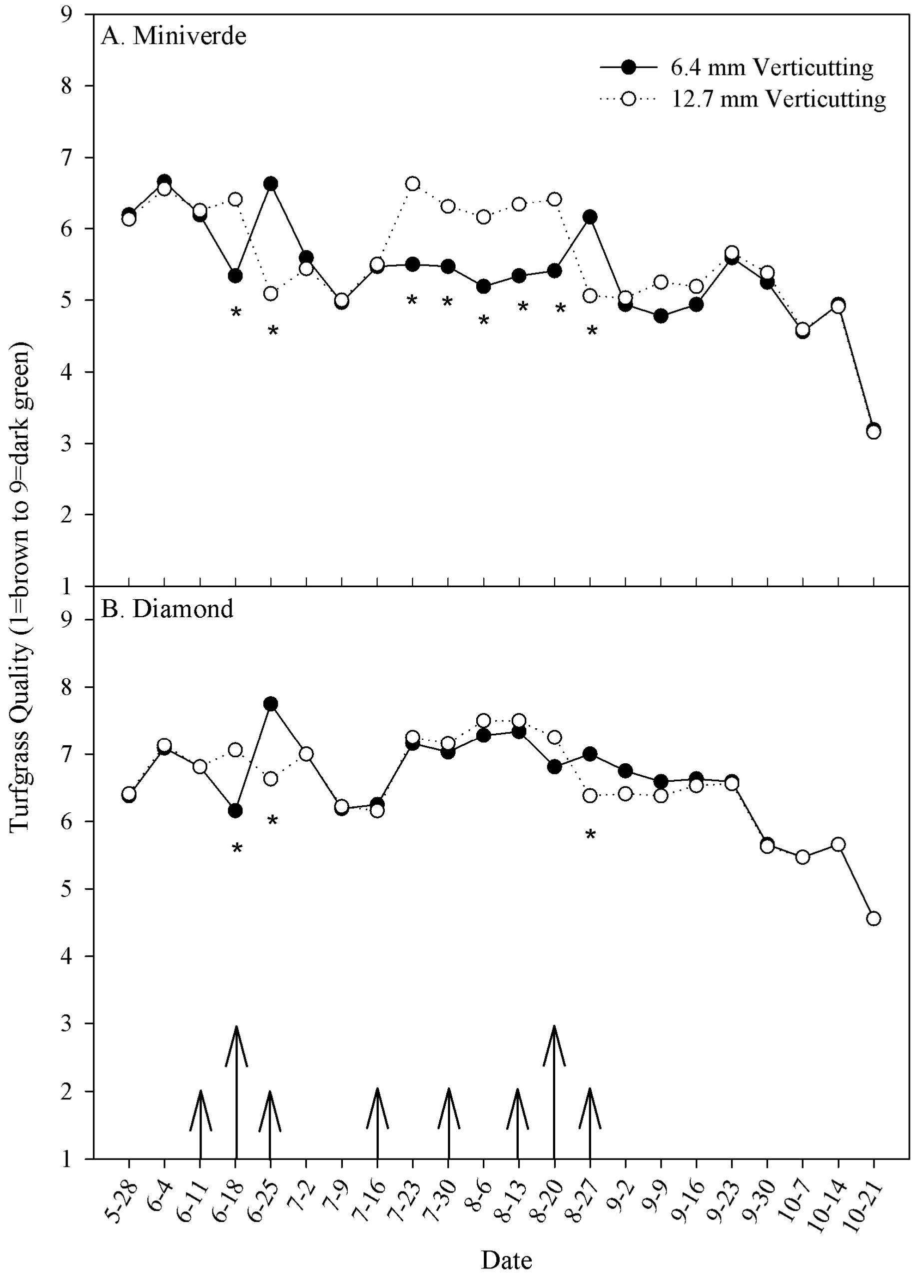


Figure 1. Effect of four N rates on turfgrass quality of A. Miniverde bermudagrass and B. Diamond zoysiagrass June – October 2009. Data represents the mean of four rating weeks during each month averaged over verticutting and topdressing treatments. Horizontal line is an indicator of acceptable quality. Values with the same letter within month are not statistically different according to Fisher's $LSD_{0.05}$ test.

Figure 2. Effect of two verticutting programs (invasive and noninvasive) on the turfgrass quality of A. Miniverde bermudagrass and B. Diamond zoysiagrass. Invasive (12.7 mm) verticuttings, indicated by large arrows, were applied 18 June and 20 August. Noninvasive (6.4 mm) verticuttings, indicated by small arrows, were applied 11 June, 25 June, 16 July, 30 July, 13 August, and 27 August. Asterisks (*) indicate statistical differences between verticutting programs at that date, according to Fisher's $LSD_{0.05}$ test.


A. Miniverde
6.4 mm Verticutting
12.7 mm Verticutting
B. Diamond
Turfgrass Quality (1=brown to 9=dark green)
5-28
6-4
6-11
6-18
6-25
7-2
7-9
7-16
7-23
7-30
8-6
8-13
8-20
8-27
9-2
9-9
9-16
9-23
9-30
10-7
10-14
10-21
Date

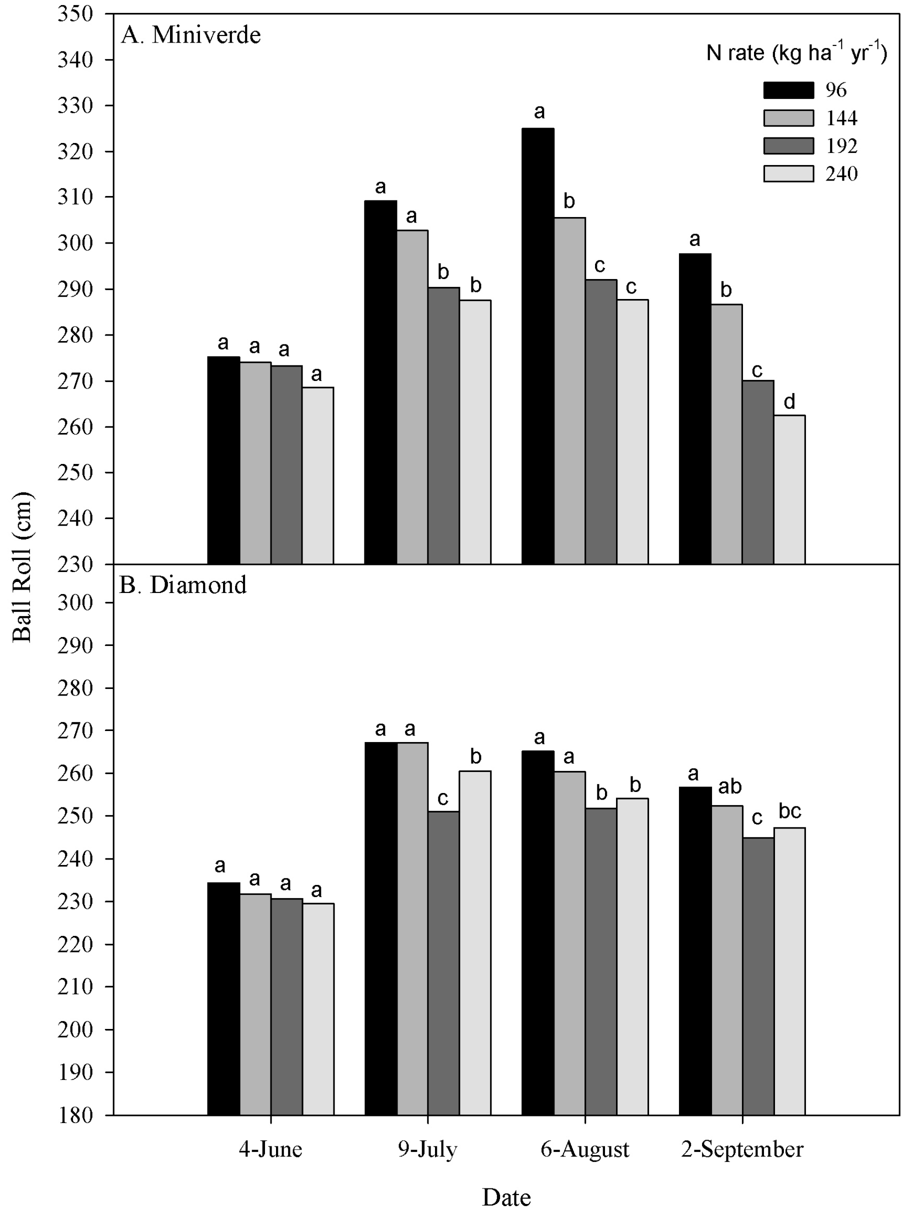


Figure 3. Effect of four N rates on ball roll distance of A. Miniverde bermudagrass and B. Diamond zoysiagrass as collected with a standard 91.4 cm Stimpmeter. Values with the same letter within each date are not statistically different according to Fisher's $LSD_{0.05}$ test.

CHAPTER 3

Evaluation of Green Turf Colorants as an Alternative to Overseeding on Putting Greens

Applying colorant to dormant bermudagrass putting greens in the southeastern United States has become a popular alternative to overseeding during the winter. However, there is limited information available about colorant brands and appropriate application rates. A field study was conducted in Raleigh, North Carolina from fall 2008 to spring 2009 on a dormant 'Miniverde' bermudagrass putting green and semi-dormant 'Diamond' zoysiagrass putting green to evaluate 12 turfgrass colorants. A second study was conducted in the same location from fall 2009 to spring 2010 to evaluate one colorant applied at three application rates. Two applications were made during the 2008 to 2009 study, the first 11 November 2008 (run 1) and the second 9 January 2009 (run 2). One application on 16 November 2009 was made during the 2009 to 2010 study. Results from the 2008 to 2009 study indicate that applying turf colorant at both a 75 mL m^{-2} (80 gpa) and 150 mL m^{-2} (160 gpa) rate differentially enhances the appearance of both grasses. All the colorant brands provided acceptable color when applied to the semi-dormant zoysiagrass. However, the colorants Ryegrass, Ultradwarf Plus, Bermudagrass, and Bermuda Green failed to provide acceptable colorant color when applied to dormant bermudagrass. Residual color from run 1 enhanced the color of 9 (bermudagrass) and 11 (zoysiagrass) colorants during run 2. Turfgrass hue values indicated that Wintergreen

Plus retained color for the longest period of time. Turf in a Bottle and Regreen retained color for an equally long period during run 1 and run 2 when applied to bermudagrass and zoysiagrass, respectively; however, Regreen became bluish as it faded with time. Results from both studies indicate that applying colorants at a rate above 75 mL m^{-2} increased the longevity of acceptable bermudagrass and zoysiagrass turf color. Furthermore, the 2009 to 2010 data suggest that applying the colorant Ultradwarf Super at rates of 94, 140, and 187 mL m^{-2} increased turfgrass surface temperature 1.9 to 2.3 °C (bermudagrass) and 2.0 to 2.7 °C (zoysiagrass) relative to the untreated. The increase in surface temperature likely increased the height of new bermudagrass and zoysiagrass growth during spring green-up. This research shows the aesthetic value that some turf colorant products can offer as an alternative to overseeding and that they may promote early spring growth.

Introduction

Turf managers in the southeastern United States have traditionally overseeded dormant bermudagrass putting greens to maintain golfer acceptance during the winter months (Long, 2006). Typically, greens are overseeded with a cool-season grass as the bermudagrass is starting to go dormant in the fall, and the overseeded grass dies out in the spring. However, the spring transition from overseeded grass to bermudagrass is often problematic due to drought resistant cool-season grass varieties and extended cool and wet conditions in late spring (Horgan and Yelverton, 2001), leading to thin bermudagrass stands (Long, 2006). Therefore, applying a colorant to dormant bermudagrass putting greens has become a popular alternative to overseeding due to its attractiveness, playability, and affordability (Liu et al., 2007).

The earliest use of turf colorants to make turf look natural without causing permanent damage was on Hollywood movie sets in the late 1950's. Larry Krieger developed different dyes in a water-soluble acrylic latex base that were applied to the dormant bermudagrass sets (Anonymous, 1987). Due to golf's growing popularity and limited information about overseeding dormant turf, golf courses in southern California started to implement the painting techniques used on the movie sets. Golf course superintendents found that the colorant did not affect playability and golfers accepted the practice (Anonymous, 1987).

There is increased interest in using zoysiagrass as a putting green surface in the transition zone (John Brown, personal communication). Zoysiagrass has a tendency to stay greener than bermudagrass in the fall and its growth habit makes successful overseeding more difficult. In the last several years, using colorants on greens during the winter has gained popularity with superintendents in the southeast and become the leading alternative to overseeding. The main benefit associated with colorants rather than overseeding is affordability. In 2009, the average cost of colorant on golf greens per season was $700 to $2000 per acre for two applications, depending on the colorant brand. When compared to overseeding costs of $2,500 to $5,000 per acre, colorant becomes a much less expensive alternative (Liu et al., 2007).

Although painting turfgrass has been in practice for several decades there is still a limited amount of information available on green turf colorants and the best methods to apply these colorants to dormant and semi-dormant putting greens. The objectives of this research were to: 1) determine if 12 colorant brands could provide acceptable green color when applied to dormant bermudagrass and semi-dormant zoysiagrass putting greens; 2) determine the longevity of these colorants; and 3) determine if colorant color and longevity are affected by application rate.

Materials and Methods

2008 – 2009 Colorant Brand Study

A field study was conducted fall 2008 to spring 2009 at the North Carolina State University Lake Wheeler Field Laboratory located in Raleigh, North Carolina to evaluate the effects of 12 turfgrass colorants applied to dormant bermudagrass and semi-dormant zoysiagrass. The study was conducted on two separate putting greens, one consisting of Miniverde bermudagrass [*Cynodon dactylon* (L.) Pers. X *C. transvaalensis* Burtt-Davy] and the other of Diamond zoysiagrass [*Zoysia matrella* (L.) Merr.]. Both greens were constructed to USGA specifications and sprigged June 2008. The products were applied to 1.8 m x 2.4 m plots in a randomized complete block design with 18 treatments and five replications.

Colorant brands that were used included: Green Lawnger (Becker Underwood, Ames, IA), LESCO Green (John Deere Landscapes, Alpharetta, GA), Mtp Turfgreen (Missouri Turf Colorant, Kansas City, MO), Titan Green Turf (Burnett Athletics, Inc., Campobello, SC), Turf in a Bottle (US Specialty Coatings, Inc., Norcross, GA), Regreen (Precision Laboratories, Inc., Waukegan, IL), Wintergreen Plus (Precision Laboratories, Inc., Waukegan, IL), Ryegrass (Pioneer Athletics, Cleveland, OH), Ultradwarf Super (Pioneer Athletics, Cleveland, OH), Ultradwarf Plus (Pioneer Athletics, Cleveland, OH), Bermudagrass (Pioneer Athletics, Cleveland, OH), and Bermuda Green (J.C. Whitlam Manufacturing, Wadsworth, OH).

Colorant treatments were initially applied to completely dormant bermudagrass and semi-dormant zoysiagrass on 11 November 2008. To have season-long color, a subsequent application was made 9 January 2009. Colorants were applied using a CO_2-pressurized boom sprayer with four TeeJet 8004 (Spraying Systems Co., Wheaton, IL) flat fan nozzles spaced 51 cm apart and calibrated at 37 mL m^{-2} (40 gpa). Each plot was sprayed in two directions to provide uniform coverage. Applying the colorants in two directions resulted in a 75 mL m^{-2} (80 gpa) application rate which was consistent with all of the colorant labels except for two. Wintergreen Plus was also applied at 112 mL m^{-2} (120 gpa) and Regreen at 37 mL m^{-2} (40 gpa) to achieve a rate near their label range. Three of the colorants, Green Lawnger, Turf in a Bottle, and Ultradwarf Super were also applied at 150 mL m^{-2} (160 gpa) to examine if colorant longevity was increased by doubling the application rate. These colorants were selected because they were judged to have the most natural color when applied at 75 mL m^{-2}. The lowest dilution (most colorant:water) was used from dilution range on the label.

During this study several general observations were made related to individual products. The most noticeable difference during mixing and application was the consistency. Green Lawnger, LESCO Green, Mtp Turfgreen, Titan Green Turf, Turf in a Bottle, Regreen, and Wintergreen Plus had a lower viscosity than Ryegrass, Ultradwarf Plus, Ultradwarf Super, Bermudagrass, and Bermuda Green. While no attempt was made to directly measure viscosity, the first group has a viscosity more similar to water; whereas, the latter was more similar to honey. The high viscosity of the latter group made mixing more challenging and application less consistent.

Nozzle clogging occurred particularly with Bermuda Green, and streaking was noticeable with all of the higher viscosity colorants. A negative trait was also noted with Regreen when applied at 75 mL m^{-2}. Observations were made that colorant easily transferred from the applicator's shoe to non-targeted application areas. One would assume all colorants would "track" during application, but this tendency was not noted with other treatments. A summary of the 2008 and 2009 treatments by colorant, application rate, and dilution rate is outlined in Table 1.

2009 – 2010 Colorant Application Rate Study

A colorant study was conducted fall 2009 to spring 2010 at the North Carolina State University Lake Wheeler Field Laboratory located in Raleigh, North Carolina. During the study, the effect of one turfgrass colorant applied at three different application rates was evaluated. The study was conducted on the same Miniverde bermudagrass and Diamond zoysiagrass putting greens used for the 2008 to 2009 colorant study.

The colorant Ultradwarf Super (Pioneer Athletics, Cleveland, OH) was chosen because it was judged as having one of the most natural colors during the 2008 to 2009 study. The plots in the study were 1.8 m x 2.4 m in a randomized complete block design with four treatments (untreated, 94, 140, and 187 mL m^{-2} application rates) and four replications. Colorant treatments were initially applied to completely dormant bermudagrass and semi-dormant zoysiagrass on 16 November 2009. Unlike the 2008 to 2009 colorant study, a second application was not needed to provide season-long color.

The colorant was applied using a CO_2-pressurized wand sprayer with a single TeeJet 8004 (Spraying Systems Co., Wheaton, IL) flat fan nozzle and calibrated at 37 mL m^{-2}. The colorant was mixed at a 1:7 ratio (colorant:water), the lowest dilution (most colorant:water) from range on the label. To achieve the application rates of 94, 140, and 187 mL m^{-2} (100, 150, and 200 gpa), a known amount of colorant, 52, 78, or 104 mL, was mixed with a known amount of water, 365, 548, or 731 mL, respectively. The solutions were then evenly applied to the plots by moving the wand in a side to side motion at a height of approximately 61 cm. Therefore, a solution of 52 mL colorant and 365 mL water was applied to achieve the 94 mL m^{-2} application rate, a solution of 78 mL colorant and 548 mL water was applied to achieve the 140 mL m^{-2} application rate, and a solution of 104 mL colorant and 731 mL water was applied to achieve the187 mL m^{-2} application rate.

Data Collected

Data collected during both studies included visual rating of turf color, digital photographs of plots, and matching plot color to Pantone® PMS numbers. Surface temperature of the turfgrass and spring green-up measurements were also taken in the 2009 to 2010 study.

Visual turf color ratings were taken twice a month from initial colorant application through initial spring green-up and measured on a 1 to 9 scale (1 = brown turf, 5 = acceptable green color, 9 = dark green color) as is often used to rate actively growing turfgrasses.

A digital photograph was taken once a month from initial application through initial spring green-up. The photos were taken directly overhead each plot with a Nikon Coolpix 8700 digital camera attached to a 46 cm horizontal arm, mounted 90° to the vertical axis of a 91 cm tripod. The images were batch analyzed using a turf analysis macro (Karcher and Richardson, 2005) for SigmaScan Pro software (ver. 5.0, SPSS Science Marketing Dep., Chicago, IL) to determine hue values in each photo. Pantone Colors were assigned using Pantone® Formulate Guide (solid, uncoated) to determine colorant color on the turfgrass. Each treatment was matched to a Pantone color 0 days following and again eight weeks after application.

A Fluke 63 (Fluke Corporation, Everett, WA) infrared thermometer was used to take the turfgrass surface temperature of each plot from initial colorant application through initial spring green-up. Three measurements were taken twice monthly in each plot by holding the thermometer at approximately 91 cm from the surface. Spring green-up was measured 24 March, 31 March, and 7 April using a Prism-Gage right-angle prism (AccuProducts International, Saline, MI). New growth within each plot was measured in three locations by placing the prism on the turf canopy and looking directly overhead from approximately 15 cm. The prism scale, marked in 1.3 mm gradations, was reflected and the height of the new growth (above the turf canopy) was recorded. Data is presented as the mean height of the visible shoots.

All statistical analyses were performed using Statistical Analysis System (v. 9.1, SAS Inst., Cary, NC). The main and interaction effects were examined with analysis of variance. Fisher's Least Significant Difference ($LSD_{0.05}$) test was used to separate treatment means. The turf color and hue data were separated by days after treatment due to an interaction between date and treatment.

Results and Discussion

Influence of Colorant Brand on Turfgrass Color

Visual evaluation of turf color was used in the study to judge the appearance of each colorant brand in the 2008 to 2009 study. Results indicate that applying turf colorant at both a 75 and 150 mL m^{-2} rate enhances the appearance of both grasses. As expected, differences ($p \leq 0.0001$) in turf color were found between the untreated control and each of the 12 colorant brands regardless of the base grass. Applied to bermudagrass, colorant increased turf color from 38 to 67 percent relative to the control 0 days after treatment (DAT) in run 1 (November 2008 t0 January 2009). Ryegrass, Ultradwarf Plus, Bermudagrass, and Bermuda Green failed to provide acceptable color (≥5) when applied to dormant bermudagrass in run 1 (Table 2). Furthermore, bermudagrass turf color when treated with Ryegrass, Ultradwarf Super, and Ultradwarf Plus were not different from the control 56 DAT in run 1. Only Turf in a Bottle had acceptable color 56 DAT on bermudagrass during run 1. The colorants performed better when applied to zoysiagrass due to the greater background color at the time of initial application. Colorants increased zoysiagrass turf color from 27 to 56 percent relative to the control 0 DAT in run 1 (Table 3). All the colorants except Ryegrass, Bermudagrass, and Bermuda Green had acceptable color 56 DAT in run 1.

However, what the data fails to adequately illustrate is the turf's bluish tint as some colorants age. Pantone Colors were used to determine color on the turfgrass 0 and 56 DAT (Table 4). The initial Pantone color for each of the colorants and the resulting Pantone color measured 56 DAT illustrates how the individual products change over time. Regreen had the greatest propensity to turn a bluish tint, which would be unacceptable in a golf course situation. Titan Green Turf turned bluish on the bermudagrass but not on the zoysiagrass. Furthermore, Bermuda Green turned a bluish gray to blue on both grasses.

Data suggest residual color from run1 increased 0 DAT bermudagrass turf color in run 2 (January 2009 through March 2009) in 9 of the 12 colorant brands (Table 5). Although Wintergreen Plus, Regreen, and Turf in a Bottle maintained acceptable color for the greatest length of time after the initial treatment, turf color means were lower when comparing 0 DAT of run 1 to run 2. Wintergreen Plus and Regreen turf color remained acceptable 42 DAT in run 2, but it was noted that the actual color of both colorants had a blue tint 28 DAT. The increase in color from the other six colorant brands suggests that number of applications may play a role providing acceptable color.

Similar to the bermudagrass, residual color from the first colorant application to the zoysiagrass increased 0 DAT turf color in run 2 (Table 6). Turf color of 11 of the 12 colorants 0 DAT in run 2 were greater than or equal to turf color 0 DAT in run 1. Turf color increases ranged from 49 to 76 percent relative to the control 0 DAT in run 2. Bermudagrass and Bermuda Green turf color fell below the acceptable level 28 and 42 DAT, respectively. However, these were the only colorants that did not maintain acceptable turf color 56 DAT in run 2. Zoysiagrass turf color increases ranged from 38 to 62 percent relative to the control 56 DAT in run 2.

Influence of Colorant Application Rate on Turfgrass Color

Application rate affected turf color in the 2008 to 2009 study (Figure 1). Further analysis indicated that applying colorants at 150 mL m^{-2} increased bermudagrass color up to 44 percent in run 1 and up to 22 percent in run 2 relative to colorants applied at 75 mL m^{-2}. Applying colorants at 150 mL m^{-2} increased zoysiagrass color up to 15 percent during run 1 and run 2 relative to the colorants applied at 75 mL m^{-2} (Figure 2). Although the increase in zoysiagrass color was not as large as seen with bermudagrass (run 1) at the higher application rate, applying colorants at rates above 75 mL m^{-2} may be necessary to maintain color longevity over the winter season. The colorant Wintergreen Plus had acceptable color at both rates on both grasses during both runs. However, applying Regreen at 37 mL m^{-2} to bermudagrass and zoysiagrass did not provide acceptable color over the 56 days in run 1 or run 2. Therefore, when using the suggested dilution rate it may be necessary to apply Regreen over the label rate to achieve acceptable color.

The results from the application rate study conducted 2009 to 2010 indicate that applying colorants over 75 mL m^{-2} increased the longevity of acceptable turf color. Differences in bermudagrass and zoysiagrass turf color occurred between colorant treatments and the untreated at every rating date (Table 7). Differences in bermudagrass and zoysiagrass turf color also occurred between the 187 mL m^{-2} application rate and the other two rates eight (bermudagrass) and nine (zoysiagrass) out of nine rating dates.

The application rates 140 and 187 mL m^{-2} provided acceptable bermudagrass and zoysiagrass turf color 112 DAT with one colorant application. These results suggest that two applications over the winter season may be unnecessary at higher application rates. However, the plots did not receive traffic during the study, and it is possible that putting greens receiving traffic might require additional applications.

Influence of Colorant on Turfgrass Hue

Hue is defined as the color reflected from or transmitted through an object, expressed as a degree between 0° and 360°, with green = 120° (Adobe Systems, 2002). In the 2008 - 2009 study hue was used to obtain an objective measurement of colorant degradation over time (Adobe Systems, 2002). Hue values of all 12 colorants were significantly different than the control at 0 and 56 DAT on both grasses (Table 8). At 0 DAT the bermudagrass control hue was 49.6° and the colorant hue values ranged from 71.7° (Wintergreen Plus) to 56.87° (Bermuda Green); whereas, the zoysiagrass control hue was 61.6° and the colorant hue values ranged from 79.0° (Regreen) to 67.6° (Bermuda Green). The zoysiagrass angles are larger than those recorded from the colorants applied to bermudagrass, indicating that background color from the grass species likely influences the "green" appearance of the colorants. Across both grass species, Wintergreen Plus retained color for the longest period of time. Turf in a Bottle performed similarly on bermudagrass and Regreen performed similarly on zoysiagrass. When hue and visual ratings were correlated we found coefficients ranging from 0.76 to 0.84 ($p \leq 0.0001$). However, coefficients of variation (CV%) for hue were 3% to 17% lower than CV% of visual ratings, similar results to those previously found by Karcher and Richardson (2003) when evaluating the influence of N rate on turfgrass color.

Influence of Colorant on Turfgrass Surface Temperature and Spring Green-up

Application of the colorant Ultradwarf Super had an affect on bermudagrass and zoysiagrass surface temperature and the height of new growth during spring green-up (Table 9). The greatest differences in surface temperature on both grasses were between the 187 mL m^{-2} colorant treatments and the untreated, 2.3 and 2.7 °C for bermudagrass and zoysiagrass, respectively. There were also differences in the height of new growth between colorant treatments and the untreated on both grasses. The new growth in plots that received 187 mL m^{-2} ranged from 1.5 mm (bermudagrass) to 2.3 mm (zoysiagrass) higher than the untreated. The data suggest that turfgrass surface temperature is related to spring green-up, but a correlation between the two could not be run because of insufficient data. Increasing spring green-up by applying colorants to dormant and semi-dormant putting greens would benefit both the golfer and golf course superintendent by creating a living surface that is more playable and manageable than dormant turf. It would also allow the superintendent to make an early identification of any areas that may have been subjected to winter kill or disease.

Conclusions

During the 2008 to 2009 study, color and longevity were variable for each brand of colorant when applied at 75 mL m^{-2}. The brands also performed differently on the two grass species, with at least part of that difference due to the level of dormancy. No one turf colorant was clearly superior on both grasses in terms of natural green color at the time of application and 56 days after either application. Furthermore, several of the colorants gave the turf a bluish color when they started to fade over time. Turf in a Bottle and Wintergreen Plus had the best combination of natural green color and longevity on bermudagrass; while, Wintergreen Plus and Ultradwarf Super had the best combination on zoysiagrass.

Different application rates had a significant effect on turf color and color longevity during both the 2008 to 2009 and 2009 to 2010 studies. Doubling the application rate to 150 mL m^{-2} increased both color and longevity of Green Lawnger, Turf in a Bottle, and Ultradwarf Super over the winter season. Applying Regreen at 37 mL m^{-2} did not provide acceptable color over the winter season, and tracking became a problem when Regreen was applied at 75 mL m^{-2}. Applying Ultradwarf Super at rates of 140 and 187 mL m^{-2} provided acceptable bermudagrass and zoysiagrass color for the winter season with one application. However, the putting greens received no traffic during the study. Traffic that putting greens receive during normal winter play would likely cause the need for two colorant applications.

Hue values obtained through digital image analysis followed the same trends as visual ratings. The strong correlation between hue values and visual ratings suggests that visual ratings are an effective method of evaluating colorant performance. However, neither the hue data nor visual turf color ratings adequately illustrates the turf's bluish tint as some colorants age.

Colorant application increased turfgrass surface temperature during the winter season and height of new growth during spring green-up. This suggests that colorant application may promote early spring growth of bermudagrass and zoysiagrass. However, further research is needed to confirm these results. This research shows the aesthetic value that some turf colorant products can offer as an alternative to overseeding and that they may promote early spring growth.

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Table 1. Treatment number, turfgrass colorant manufacturers, brand names, application rates, and dilution rates used applied to dormant Miniverde bermudagrass and semi-dormant Diamond zoysiagrass putting greens during November 2008 at Lake Wheeler Field Laboratory in Raleigh, NC.

	Colorant manufacturer	Colorant name	Application rate (mL m^{-2})	Dilution (colorant:water)
1	N/A	Untreated Control	N/A	N/A
2	Becker Underwood	Green Lawnger	75	1:7
3	John Deere Landscapes	LESCO Green	75	1:10
4	Missouri Turf Paint	Mtp Turfgreen	75	1:7
5	Burnett Athletics, Inc.	Titan Green Turf	75	1:10
6	US Specialty Coatings, Inc.	Turf in a Bottle	75	1:10
7	Precision Laboratories, Inc.	Regreen	75	1:7
8	Precision Laboratories, Inc.	Wintergreen Plus	75	1:10
9	Pioneer Athletics	Ryegrass	75	1:7
10	Pioneer Athletics	Ultradwarf Super	75	1:7
11	Pioneer Athletics	Ultradwarf Plus	75	1:7
12	Pioneer Athletics	Bermudagrass	75	1:7
13	J.C. Whitlam Mnf.	Bermuda Green	75	1:15
14	Becker Underwood	Green Lawnger	150	1:7
15	US Specialty Coatings	Turf in a Bottle	150	1:10
16	Pioneer Athletics	Ultradwarf Super	150	1:7
17	Precision Laboratories, Inc.	Regreen	37	1:7
18	Precision Laboratories, Inc.	Wintergreen Plus	112	1:10

Table 2. Visual turf color rating of Miniverde bermudagrass following application of a colorant as a function of time after the initial application on 11 November 2008 (run 1). All treatments were applied in solution at 75 mL m^{-2}.

Treatment	Turf Color Rating – days after treatment †				
	0	14	28	42	56
Untreated Control	1.0 g	1.0 h	1.0 g	1.0 f	1.0 f
Green Lawnger	5.4 bc	5.0 de	4.4 cd	3.8 bc	2.6 c
LESCO Green	5.4 bc	5.4 cd	4.6 bcd	3.2 cde	2.6 c
Mtp Turfgreen	5.4 bc	5.4 cd	4.6 bcd	3.4 cde	2.0 de
Titan Green Turf	5.6 bc	5.6 cd	4.8 bc	3.6 cd	1.8 e
Turf in a Bottle	6.6 a	6.4 ab	6.2 a	5.8 a	5.0 a
Regreen	5.8 b	5.8 bc	5.0 b	3.0 de	1.8 e
Wintergreen Plus	7.0 a	7.0 a	6.6 a	4.4 b	4.0 b
Ryegrass	4.2 f	3.2 g	3.0 f	1.2 f	1.2 f
Ultradwarf Super	5.2 cd	4.2 f	4.2 de	1.6 f	1.2 f
Ultradwarf Plus	4.6 ef	4.0 f	3.8 e	1.4 f	1.2 f
Bermudagrass	4.4 ef	4.0 f	3.2 f	2.8 e	2.4 cd
Bermuda Green	4.8 de	4.6 ef	4.2 de	2.8 e	1.8 e
LSD ($_{0.05}$)	0.59	0.61	0.6	0.7	0.57
CV%	9.3	10.1	11.0	18.8	20.4

† Values with the same letter within each date column are not statistically different according to Fisher's $LSD_{0.05}$ test.

Table 3. Visual turf color rating of Diamond zoysiagrass following application of a colorant as a function of time after the initial application on 11 November 2008 (run 1). All treatments were applied in solution at 75 mL m^{-2}.

Treatment	Turf Color Rating – days after treatment †				
	0	14	28	42	56
Untreated Control	3.00 g	2.0 g	1.2 f	1.0 h	1.0 e
Green Lawnger	7.0 bcd	7.0 bc	7.0 a	6.0 ab	6.0 a
LESCO Green	6.8 bcd	6.8 c	6.6 ab	5.4 cde	5.4 bc
Mtp Turfgreen	7.2 abc	7.0 bc	7.0 a	5.8 bc	5.6 ab
Titan Green Turf	7.0 bcd	6.8 c	6.2 bc	5.8 bc	5.6 ab
Turf in a Bottle	6.2 def	6.0 de	5.6 cd	5.0 e	5.0 c
Regreen	8.0 a	7.8 a	7.0 a	5.6 bcd	5.0 c
Wintergreen Plus	7.6 ab	7.6 ab	7.0 a	6.4 a	6.0 a
Ryegrass	5.6 f	5.6 e	5.0 de	4.0 f	3.6 d
Ultradwarf Super	7.4 abc	7.2 abc	6.8 ab	6.0 ab	5.8 ab
Ultradwarf Plus	6.6 cde	6.6 cd	6.4 ab	5.2 de	5.0 c
Bermudagrass	5.4 f	4.8 f	4.4 e	3.4 g	3.4 d
Bermuda Green	5.8 ef	5.6 e	5.2 d	3.6 fg	3.4 d
LSD ($_{0.05}$)	0.83	0.66	0.76	0.51	0.51
CV%	10.2	8.4	10.3	8.2	8.6

† Values with the same letter within each date column are not statistically different according to Fisher's $LSD_{0.05}$ test.

Table 4. The progression of colorant color using Pantone® Color chips following colorant treatment.

Treatment/rate (mL m^{-2})		bermudagrass		zoysiagrass	
		Day 0	Day 56	Day 0	Day 56
Green Lawnger 75		PMS 354	PMS 358	PMS 355	PMS 354
LESCO Green 75		PMS 347	PMS 351	PMS 355	PMS 354
Mtp Turfgreen 75		PMS 7481	PMS 7464	PMS 355	PMS 325
Titan Green Turf 75		PMS 7482	PMS 636	PMS 347	PMS 346
Turf in a Bottle 75		PMS 346	PMS 344	PMS 353	PMS 344
Regreen 75		PMS 347	PMS 311	PMS 7482	PMS 325
Wintergreen Plus 75		PMS 340	PMS 344	PMS 3405	PMS 3395
Ryegrass 75		PMS 374	PMS 372	PMS 367	PMS 374
Ultradwarf Super 75		PMS 363	PMS 577	PMS 356	PMS 355
Ultradwarf Plus 75		PMS 362	PMS 577	PMS 348	PMS 362
Bermudagrass 75		PMS 7481	PMS 344	PMS 7482	PMS 345
Bermuda Green 75		PMS 340	PMS 290	PMS 3415	PMS 3262

Table 4. Continued

Green Lawnger 150		PMS 355	PMS 360	PMS 356	PMS 355
Turf in a Bottle 150		PMS 354	PMS 358	PMS 354	PMS 339
Ultradwarf Super 150		PMS 364	PMS 362	PMS 349	PMS 7483
Regreen 37		PMS 3405	PMS 291	PMS 7481	PMS 3252
Wintergreen Plus 112		PMS 340	PMS 3395	PMS 3405	PMS 3395

Table 5. Visual turf color of Miniverde bermudagrass following application of a colorant as a function of time after the second application on 9 January 2009 (run 2). All treatments were applied in solution at 75 mL m^{-2}.

Treatment	Turf Color Rating – days after treatment †				
	0	14	28	42	56
Untreated Control	1.0 g	1.0 f	1.0 e	1.0 f	1.0 f
Green Lawnger	5.6 de	4.8 cd	4.2 cd	4.2 cde	3.8 cde
LESCO Green	5.6 de	4.6 de	4.4 cd	4.4 cde	3.6 de
Mtp Turfgreen	5.8 cde	4.6 de	4.2 cd	4.0 de	3.4 e
Titan Green Turf	6.0 bcd	5.4 abc	4.8 bc	4.4 cde	3.4 e
Turf in a Bottle	6.4 ab	5.8 a	4.8 bc	4.8 abc	4.4 abc
Regreen	6.2 bc	5.8 a	5.6 a	5.2 ab	4.4 abc
Wintergreen Plus	6.8 a	5.8 a	5.4 ab	5.4 a	4.8 ab
Ryegrass	5.4 e	5.4 abc	5.2 ab	4.6 bcd	4.0 cde
Ultradwarf Super	6.2 bc	5.6 ab	5.2 ab	5.2 ab	5.0 a
Ultradwarf Plus	5.4 e	5.0 bcd	4.8 bc	4.6 bcd	4.2 bcd
Bermudagrass	4.8 f	4.0 e	3.8 d	3.8 e	3.6 de
Bermuda Green	5.6 de	4.4 de	4.2 cd	3.8 e	3.6 de
LSD ($_{0.05}$)	0.60	0.62	0.63	0.67	0.63
CV%	8.7	10.2	11.2	12.4	13.0

† Values with the same letter within each date column are not statistically different according to Fisher's $LSD_{0.05}$ test.

Table 6. Visual turf color of Diamond zoysiagrass following application of a colorant as a function of time after the second application on 9 January 2009 (run 2). All treatments were applied in solution at 75 mL m^{-2}.

Treatment	Turf Color Rating – days after treatment †				
	0	14	28	42	56
Untreated Control	1.0 e	1.0 e	1.0 f	1.0 g	1.0 f
Green Lawnger	7.6 a	7.2 a	7.0 a	7.0 a	5.8 bc
LESCO Green	7.4 ab	7.0 a	7.0 a	7.0 a	6.0 b
Mtp Turfgreen	7.6 a	7.2 a	6.8 ab	6.0 cd	5.4 cd
Titan Green Turf	7.4 ab	7.2 a	7.0 a	6.0 cd	5.2 d
Turf in a Bottle	7.0 b	6.2 b	6.0 cd	5.6 de	5.4 cd
Regreen	7.8 a	7.0 a	6.8 ab	5.8 d	5.8 bc
Wintergreen Plus	7.6 a	7.0 a	7.0 a	6.8 ab	6.6 a
Ryegrass	6.2 c	5.8 bc	5.8 d	5.2 e	5.2 d
Ultradwarf Super	7.8 a	7.4 a	7.0 a	6.6 ab	6.2 ab
Ultradwarf Plus	7.0 b	7.0 a	6.4 bc	6.4 bc	6.0 b
Bermudagrass	5.4 d	5.2 d	4.8 e	4.6 f	4.4 e
Bermuda Green	6.2 c	5.6 cd	5.2 e	4.6 f	4.4 e
LSD ($_{0.05}$)	0.47	0.47	0.54	0.53	0.57
CV%	5.6	5.9	7.0	7.5	8.6

† Values with the same letter within each date column are not statistically different according to Fisher's $LSD_{0.05}$ test.

Table 7. Visual turf color of Miniverde bermudagrass and Diamond zoysiagrass following application of a colorant as a function of time after the 16 November 2009 application date. All application rates were applied in solution with a hand wand sprayer.

Application Rate (mL m^{-2})	Turf Color Rating – days after treatment †								
	0	14	28	42	56	70	84	98	112
	bermudagrass								
187	8.0 a	8.0 a	7.0 a	7.0 a	7.0 a	6.0 a	6.0 a	6.0 a	6.0 a
140	7.0 b	7.0 b	7.0 a	6.0 b	6.0 b	5.0 b	5.0 b	5.0 b	5.0 b
94	6.0 c	6.0 c	6.0 b	5.0 c	5.0 c	4.8 b	4.8 b	4.8 b	4.8 b
Untreated	2.0 d	1.0 d	1.0 c	1.0 d	1.0 d	1.0 c	1.0 c	1.0 c	1.0 c
LSD ($_{0.05}$)	0.0	0.0	0.0	0.0	0.0	0.39	0.39	0.39	0.39
CV%	0.0	0.0	0.0	0.0	0.0	6.0	6.0	6.0	6.0
	zoysiagrass								
187	8.0 a	8.0 a	8.0 a	8.0 a	8.0 a	8.0 a	8.0 a	7.0 a	7.0 a
140	7.3 b	7.3 b	7.3 b	7.3 b	7.0 b	6.8 b	6.8 b	6.0 b	6.0 b
94	6.8 b	6.8 b	6.8 b	6.8 b	6.8 b	6.8 b	6.8 b	5.8 b	5.5 c
Untreated	4.0 c	2.0 c	2.0 c	2.0 c	2.0 c	1.0 c	1.0 c	1.0 c	2.0 d
LSD ($_{0.05}$)	0.54	0.54	0.54	0.54	0.39	0.54	0.54	0.39	0.44
CV%	5.4	5.9	5.9	5.9	4.2	6.3	6.3	5.1	5.6

† Values with the same letter within each date column are not statistically different according to Fisher's $LSD_{0.05}$ test.

Table 8. Hue of 12 turfgrass colorant brands as a function of days after treatment. Initial application made 11 November 2008 (0 DAT). All treatments were applied in solution at 75 mL m^{-2}.

Treatment	Hue Angle – days after treatment†					
	bermudagrass			zoysiagrass		
	0	28	56	0	28	56
Untreated Control	49.6 f	36.1 g	34.5 g	61.6 e	59.8 f	53.4 f
Green Lawnger	61.6 c	47.1 c	44.2 bcde	73.1 b	73.1 bc	66.3 b
LESCO Green	60.8 c	46.5 c	44.7 b	72.4 b	71.9 bcd	64.9 bc
Mtp Turfgreen	61.3 c	46.0 cd	43.1 bcde	72.4 b	73.8 b	65.5 bc
Titan Green Turf	61.5 c	46.0 cd	44.0 bcde	72.1 bc	72.3 bc	65.0 bc
Turf in a Bottle	68.2 b	56.4 a	51.7 a	72.3 b	71.9 bcd	65.0 bc
Regreen	67.9 b	50.5 b	44.5 bc	79.0 a	79.8 a	73.4 a
Wintergreen Plus	71.7 a	58.1 a	52.6 a	77.8 a	78.4 a	71.5 a
Ryegrass	58.3 d	42.8 ef	42.0 e	70.8 bcd	69.9 cde	64.4 bcd
Ultradwarf Super	58.4 d	44.5 cde	42.4 cde	71.0 bcd	72.4 bc	65.5 bc
Ultradwarf Plus	55.6 e	43.4 def	42.3 de	68.8 cd	68.5 de	60.9 de
Bermudagrass	61.2 c	47.1 c	44.4 bcd	70.2 bcd	70.1 cde	62.0 cde
Bermuda Green	56.9 de	40.9 de	38.6 f	67.6 d	67.40 e	59.5 e
CV%	2.9	5.3	3.9	3.8	3.9	4.4

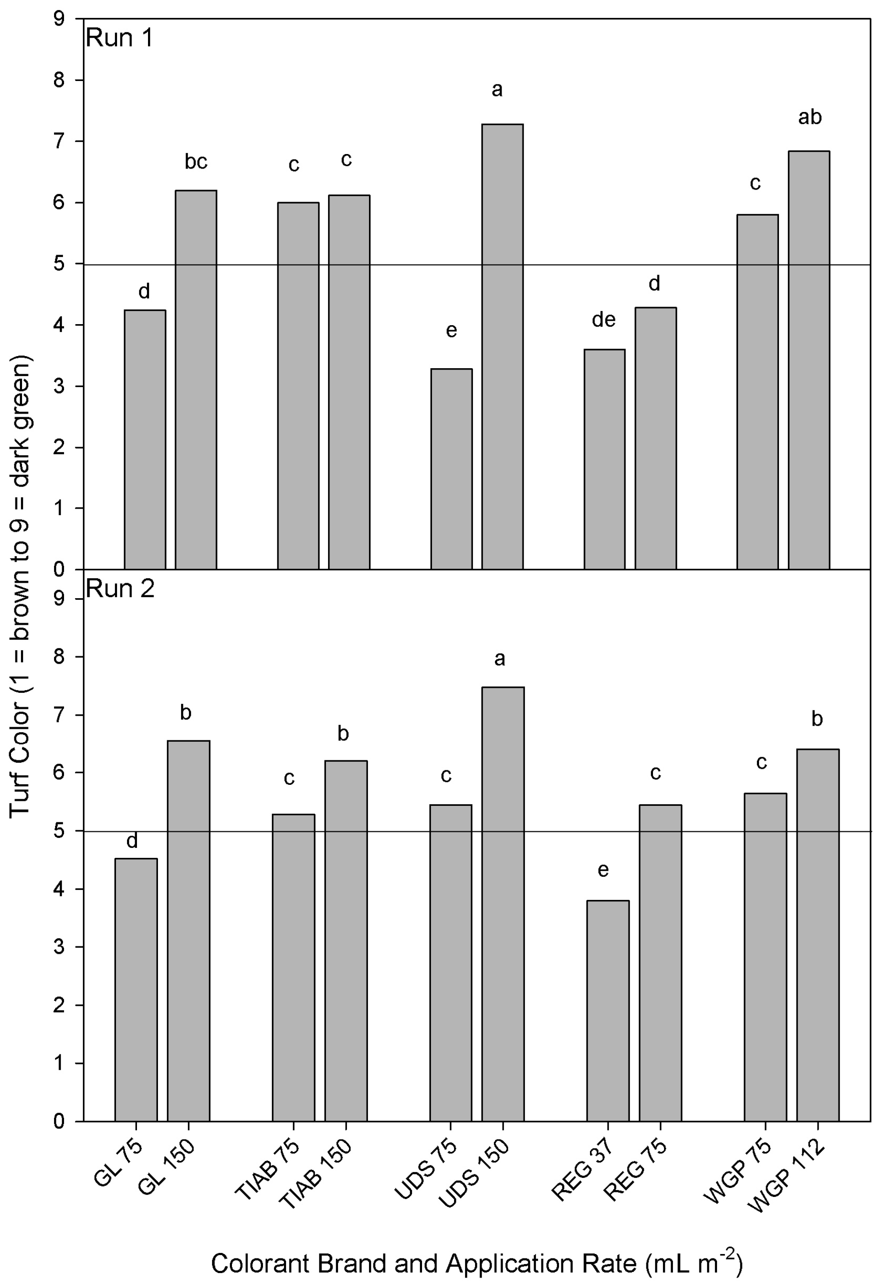
† Values with the same letter within each date column are not statistically different according to Fisher's $LSD_{0.05}$ test.

Table 9. The turfgrass surface temperature and height of new growth during spring green-up of Miniverde bermudagrass and Diamond zoysiagrass following the application of a colorant (16 November 2009). Surface temperature data represent the mean of nine measurements from November – March 2009. Spring green-up data represent the mean of three measurements from 24 March – 7 April 2010.

Application rate (mL m^{-2})	Turf surface temperature (°C) and New growth (mm) measurements†			
	bermudagrass		zoysiagrass	
	Temp.	Growth	Temp.	Growth
187	15.2 a	6.7 a	15.4 a	7.2 a
140	14.9 a	6.2 b	15.0 b	7.0 a
94	14.8 a	6.2 b	14.7 c	6.4 b
Untreated	12.9 b	5.2 c	12.7 d	4.9 c
LSD ($_{0.05}$)	0.81	0.41	0.48	0.51
CV%	3.0	7.9	1.8	9.5

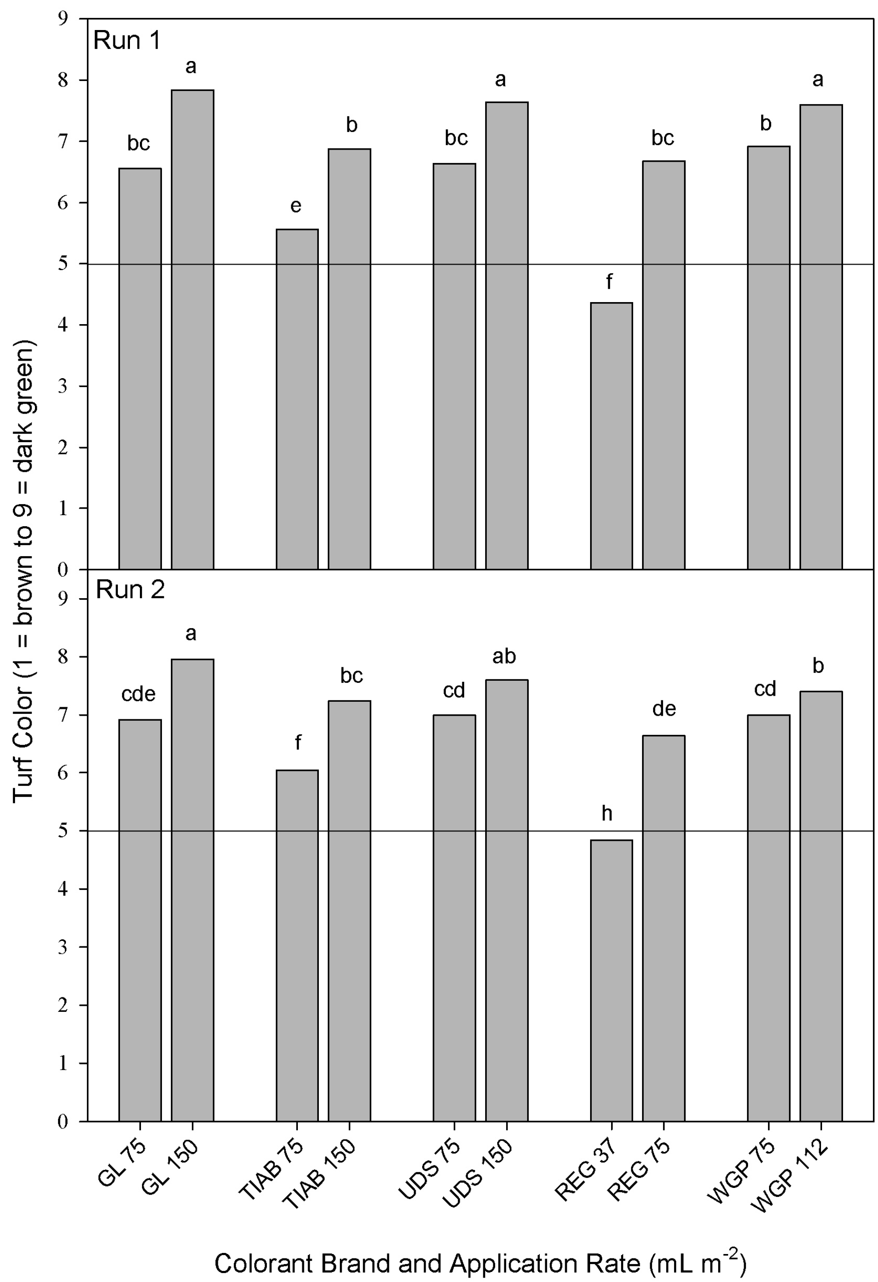
† Values with the same letter within each date column are not statistically different according to Fisher's $LSD_{0.05}$ test.

Figure 1. Effect of colorant application rate on Miniverde bermudagrass turf color. Run 1 data represent the mean of five rating weeks over the initial application (November 2008 to January 2009). Run 2 data represent mean of five rating weeks over the second application (January 2009 to March 2009). Horizontal line is an indicator of acceptable quality. Values with the same letter are not significantly different according to Fisher's $LSD_{0.05}$ test. Abbreviations: GL: Green Lawnger, TIAB: Turf in a Bottle, UDS: Ultradwarf Super, REG: Regreen, WGP: Wintergreen Plus.



Run 1
Run 2
Turf Color (1 = brown to 9 = dark green)
9
8
7
6
5
4
3
2
1
0
d
bc
c
c
e
a
de
d
c
ab
b
c
b
c
a
e
c
c
b
GL 75
GL 150
TIAB 75
TIAB 150
UDS 75
UDS 150
REG 37
REG 75
WGP 75
WGP 112
Colorant Brand and Application Rate (mL m-2)

Figure 2. Effect of colorant application rate on Diamond zoysiagrass turf color. Run 1 data represent the mean of five rating weeks over the initial application (November 2008 to January 2009). Run 2 data represent mean of five rating weeks over the second application (January 2009 to March 2009). Horizontal line is an indicator of acceptable quality. Values with the same letter are not significantly different according to Fisher's $LSD_{0.05}$ test. Abbreviations: GL: Green Lawnger, TIAB: Turf in a Bottle, UDS: Ultradwarf Super, REG: Regreen, WGP: Wintergreen Plus.


Run 1
Run 2
bc
a
e
b
bc
a
f
bc
b
a
cde
a
f
bc
cd
ab
h
de
cd
b
Turf Color (1 = brown to 9 = dark green)
GL 75
GL 150
TIAB 75
TIAB 150
UDS 75
UDS 150
REG 37
REG 75
WGP 75
WGP 112
Colorant Brand and Application Rate (mL m-2)