Evaluation of Tall Fescue-Zoysiagrass Polystands and New Zoysiagrass Genotypes for Use in the Transition Zone

by

Mingying Xiang

B.S., Shandong Agricultural University, 2013
M.S., Oklahoma State University, 2015

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Horticulture and Natural Resources
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Abstract

Zoysiagrasses (*Zoysia* spp.) use C4 metabolism and are more drought resistant than C3 grasses. However, the long dormancy period between autumn and spring limits the use of zoysiagrass by homeowners and professional turfgrass managers. In addition, large patch has become the primary pest on zoysiagrass, and improved cultivars with good cold hardiness and large patch resistance are needed in the transition zone. Tall fescue (*Schedonorus arundinaceus* Schreb), a C3 grass, is used frequently in Kansas due to its heat and drought tolerance compared to some other C3 grasses. However, brown patch (*Rhizoctonia solani*) is the main disease limiting its growth in summer. Alternatively, mixing zoysiagrass with tall fescue may help reduce brown patch incidence. The objective of these projects were to: (1) evaluate methods for establishing a perennial mixture of seeded zoysiagrass and tall fescue; (2) determine whether a zoysiagrass/ tall fescue polystand is less susceptible to brown patch and results in improved summer quality compared to a tall fescue monostand; and (3) evaluate experimental zoysiagrass genotypes to identify one or more potential new cultivars which have high quality and tolerance to cold and large patch. I found that polystands of zoysiagrass and tall fescue were most successfully established by seeding zoysiagrass at 49 kg ha^{-1} in June and tall fescue at 392 kg ha^{-1} in September into the established zoysiagrass sward. Polystand establishment was also superior at a 1.9 cm mowing height than a 5.1 cm mowing height. The resulting mixture resulted in improved turf color in late fall and early spring compared to a zoysiagrass monostand. In addition, using a zoysiagrass-tall fescue polystand reduced brown patch by up to 21% compared to a tall fescue monostand. In the zoysiagrass breeding project, I identified ten progeny out of sixty evaluated that had better tolerance to large patch (up to 40 % less plot area affected) and

better quality compared to Meyer zoysiagrass, which is the standard cultivar used in the transition zone.

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Approved by:

Co-Major Professor
Dr. Megan Kennelly

Approved by:

Co-Major Professor
Dr. Jack Fry

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Dedication

To my mom and dad for their endless love and invaluable support throughout my undergraduate and graduate studies.

Chapter 1 - Introduction

Zoysiagrass in the Transition Zone

Zoysiagrasses (*Zoysia* spp.) are used on golf courses, lawns, and landscapes in many areas of the world where warm-season turfgrasses are grown and well-adapted. Zoysiagrass is recognized for its lower maintenance requirements, particularly when compared to cool-season grasses. Specifically, zoysiagrass requires less water, fertilizer, and pesticide inputs than cool-season grasses (Fry et al., 2008).

The transition zone is the area in between the southern part of the United States, where warm-season grasses are well adapted, and the northern region where cool-season grasses are well adapted (Dunn and Diesburg, 2004). However, neither warm- or cool-season grasses are well suited to the transition zone due to high temperatures in the summer, which are stressful to cool-season grasses, and cold winter temperatures, which can cause injury to warm-season grasses. Zoysiagrass use has generally been limited to the use of Japanese lawngrass (*Z. japonica* Steud.) in the transition zone, and the most popular cultivar is 'Meyer', which was released in 1952 (Grau, and Radko, 1951). Meyer is used on lawns and golf course tees and fairways, but must be established vegetatively, which can be costly.

Zoysiagrass-Tall Fescue Mixtures

A factor that has limited more widespread use of zoysiagrass on home lawns and golf courses in the transition zone is its extended period of dormancy. In Kansas, Meyer may appear brown from mid-October to mid-May in a home lawn. One way to overcome the extended dormancy of zoysiagrass could be to establish a mixture with a cool-season turfgrass that maintains its green color longer into autumn and greens up earlier in the spring. In moderate climates, and even in the transition zone, perennial ryegrass (*Lolium perenne* L.), a cool-season grass, is commonly overseeded into bermudagrass (*Cynodon* spp.), a warm-season grass, in order to maintain color during winter months. Attempts to overseed Meyer with cool-season grasses, however, typically fail for reasons that have been suggested by golf course superintendents, but not verified through research. First, Meyer has a relatively dense canopy that makes it difficult to get seed of cool-season turf in contact with the soil. If the Meyer canopy is disturbed aggressively using power raking or verticutting in autumn to facilitate overseeding by a cool-season grass, it usually injures the Meyer canopy so much that it performs poorly the next season, or does not survive the winter. Braun (2014) found that overseeding 'Chisholm' zoysiagrass, a dense, vegetatively established cultivar, with annual ryegrass (*Lolium multiflorum* Lam.) was unsuccessful in Wichita, KS and Manhattan, KS.

There are a few seeded zoysiagrasses that have cold hardiness that is comparable to Meyer, but are slightly coarser in leaf texture and less dense than Meyer, including 'Zenith' and 'Compadre'. The potential to establish a polystand mixture of one of these seeded zoysiagrasses and a cool-season grass is greater because they can be seeded and are less dense than Meyer, which may allow for the species to grow together more uniformly in a sward. Tall fescue (*Schedonorus arundinaceus* Schreb.) is a cool season grass with better drought and heat tolerance compared to other commonly used cool-season turfgrasses (Fry and Huang, 2004). In addition, it can be an effective candidate to mix with zoysiagrass due to their compatible texture, which would facilitate playability and aesthetics. Whether a zoysiagrass-tall fescue polystand mixture remains balanced over time depends upon the characteristics of the grasses and the cultural practices used.

Differences between zoysiagrass and tall fescue growth will influence the composition of the sward. These differences include growth habit (lateral spread), vertical shoot growth rate, root growth rate and extent of rooting, crown-internode height, leaf orientation, and competition for light, water, and nutrients (Beard, 1973). If seeded together, seed germination rate and seedling vigor are two predominant factors influencing the competitive ability of zoysiagrass and tall fescue. Murray and Morris reported successful establishment of zoysiagrass-tall fescue mixture when including tall fescue at 98 kg ha^{-1} in Maryland (Kevin Morris, personal communication). Researchers in China observed a low tall fescue population when seeding zoysiagrass at 150 kg ha^{-1} in June and tall fescue at 200 kg ha^{-1} in August (Yin et al., 2014), but additional timings and seeding rates were not examined. Additional information regarding time and rate of tall fescue seeding with zoysiagrass in establishing a polystand is needed to determine best methods for creating a balanced mixture.

After a polystand sward of zoysiagrass and tall fescue has been established, cultural practices can influence the balance of the two species. Yin et al. (2014) conducted research on managing mixtures of zoysiagrass and tall fescue with different cultivar combinations at different N rates and mowing heights. They demonstrated that a mixed stand of these two species could be maintained at a 5-cm mowing height and an annual N rate of 400 kg ha^{-1} yr^{-1} in Beijing, China. Li and Han (2008) investigated zoysiagrass-tall fescue polystand responses to different N rates and mowing heights when exposed to 70 kg wear roller traffic. They reported that zoysiagrass was favored by low traffic levels, low mowing heights (3.5 cm vs. 5.0 or 6.5 cm) and low N (0 vs. 50 or 100 kg ha^{-1}). In contrast, tall fescue was favored by high mowing (6.5 cm) and high N (100 kg ha^{-1}).

In addition to extending green color in autumn, and encouraging early spring green-up, polystand mixtures of zoysiagrass and tall fescue may offer additional benefits (Li and Han, 2008), including potential for better turf cover under a variety of environmental conditions, water savings, recovery from injury, and disease reduction. A sward containing both warm-season grasses and cool-season grasses could be better adapted to a broad range of soil and environmental conditions compared to a monostand of either species. As the soil water regimes change over time and space, the spatial distribution of roots is important in terms of water uptake and therefore, drought resistance (Smucker and Ritchie, 1993). When a mixed stand contains grass with both deep and shallow root systems, it allows the sward to take water and nutrients from different levels of the soil profile. In general, using turfgrass mixtures allows for better adaptability to a range of environmental conditions than using blends of cultivars of the same species or monostands of individual cultivars (Christians et al., 2016).

Both zoysiagrass and tall fescue have performed well when receiving limited irrigation (Fu et al., 2004; Fry and Butler, 1989). In Kansas, Meyer zoysiagrass maintained its quality when subjected to deficit irrigation levels of 80% of evapotranspiration (ET) (Fu et al., 2004). In Colorado, Rebel tall fescue had acceptable turf quality under 50% ET when irrigated every two days (Fry and Butler, 1989). Including both species in a mixture together will likely result in a drought-resistant sward compared stands of other cool-season grasses such as Kentucky bluegrass or perennial ryegrass.

Including a grass with the potential to spread laterally in a mixture can also help improve stand quality without overseeding. Zoysiagrass is rhizomatous and stoloniferous and has the potential to fill in voids in a sward where injury has occurred. Mixing tall fescue with Kentucky bluegrass (*Poa pratensis* L.), which is rhizomatous, resulted in more rapid recovery from eight weeks of simulated traffic compared to tall fescue blends in Missouri (Dunn et al., 2002).

Tall Fescue and Brown Patch Disease

Tall fescue is quite prone to the disease brown patch caused by *Rhizoctonia solani* Kühn AG-2-2 IIIB. The disease is quite common during the hot, humid weather when night temperatures exceed 20 °C and leaf wetness persists for > 10 h (Latin, 2011; Smiley et al., 2005). The susceptibility to brown patch varies among tall fescue cultivars. Cultivars such as 'Bloodhound', 'Amity', 'Rockwell', 'Rowdy' and 'Avenger II' and 'Titanium 2LS' have lower levels of susceptibility (NTEP, 2016), but none have demonstrated complete resistance to brown patch (Bokmeyer, 2009). In high quality turf areas, brown patch is controlled by applying fungicides. Using polystands of species or cultivars can decrease disease spread compared to monostands, and eliminate the need for fungicide applications to maintain turf quality. For example, seeding tall fescue with hybrid bluegrass or Kentucky bluegrass reduced brown patch disease incidence compared with monostands of tall fescue Cutulle et al. (2013). Including a species resistant to the disease in a polystand mixture, such as zoysiagrass, could also help to reduce the spread of brown patch in sward during warm, humid conditions in midsummer. More research is needed in this area.

Zoysiagrass and Large Patch Disease

In addition to Japanese Lawngrass, Manilagrass (*Zoysia matrella*) is commonly used as turf in the southern U.S., but lacks cold hardiness for use in the upper transition zone (Fry and Huang, 2004). Cooperative research between Kansas State University and Texas A&M AgriLife Research in Dallas, TX has been focused on the evaluation of *Z. japonica* x *Z. matrella* hybrids. One such hybrid was released as 'Innovation' zoysiagrass in 2017 (Chandra et al., 2017).

Innovation has a finer leaf texture and higher density than Meyer, but its cold hardiness is comparable to Meyer. This effort to develop zoysiagrass cultivars for the transition zone is continuing, and more focus is now being put on disease resistance in addition to cold hardiness and turf quality.

Large patch caused by *Rhizoctonia solani* Kühn AG 2-2 LP has become the primary pest on zoysiagrass. This fungal pathogen can also affect bermudagrass, St. Augustinegrass (*Stenotaphrum secundatum* (Walter) Kuntze), and seashore paspalum (*Paspalum vagiantum* Swartz) (Flor et al., 2017; Haygood and Martin, 1990; Latin, 2011). Large patch occurs in spring after it breaks dormancy, and in fall before it enters dormancy. Patch sizes range from a few centimeters to several meters in diameter. Disease symptoms are likely being masked during summer when temperatures favor both shoot and root growth of zoysiagrass. Without fungicide use, patch symptoms show up in the same areas every year when environmental conditions are favorable. No large patch resistant cultivar is commercially available; as such, control of the disease requires fungicides be applied in autumn and/or spring. Meyer is quite susceptible to large patch (Green et al., 1994; Obasa et al., 2013). An improved zoysiagrass cultivar with the quality characteristics and cold hardiness comparable or better than Meyer, and resistance to large patch would be well received by professional turf managers.

Objectives

More information is needed on the establishment and management of zoysiagrass-tall fescue polystands and the potential large patch resistance of new zoysiagrass genotypes. For these reasons, the objectives of my research were to: (1) evaluate methods for establishing a perennial mixture of seeded zoysiagrass and tall fescue; (2) determine whether a zoysiagrass- tall fescue polystand is less susceptible to brown patch and results in improved summer quality compared to a tall fescue monostand; and (3) evaluate experimental zoysiagrass genotypes to identify one or more potential new cultivars which have high quality and tolerance to cold and large patch.

References

Beard, J.B. 1973. Turfgrass: Science and culture. Prentice Hall, Upper Saddle River, NJ.

Bokmeyer, J.M., S.A. Bonos, and W.A. Meyer. 2009. Inheritance characteristics of brown patch resistance in tall fescue. Crop Sci. 49:2302-2308.

Braun, R. 2014. Evaluation of Colorants on Dormant 'Chisholm' zoysiagrass. MS thesis, Dept. of Horticulture and Natural Resources, Kansas State Univ., Manhattan, KS.

Chandra, A., J.D. Fry, A.D. Genovesi, M. Meeks, M.C. Engelke, Q. Zhang, D. Okeyo, J.Q. Moss, E. Ervin, X. Xiong, and S. Milla-Lewis. 2017. Registration of KSUZ 0802 zoysiagrass. J of Plant Reg. 11:100-106.

Christians, N.E., A.J. Patton, and Q.D. Law. 2016. Fundamentals of turfgrass management. John Wiley & Sons, Hoboken, NJ.

Cutulle, M.A., J.F. Derr, D. McCall, B. Horvath, and A.D. Nichols. 2013. Impact of hybrid bluegrass and tall fescue seeding combinations on brown patch severity and weed encroachment. HortScience 48:493-500.

Dunn, J. and K. Diesburg. 2004. Turf Management in the Transition Zone. Wiley, Hoboken, NJ.

Dunn, J.H, E.H. Ervin, and B.S. Fresenburg. 2002. Turf performance of mixtures and blends of tall fescue, Kentucky bluegrass, and perennial ryegrass. HortScience 37:214-217.

Flor, N.C., P.F. Harmon, K. Kenworthy, R.N. Raid, R. Nagata, and L.E. Datnoff. 2017. Screening St. Augustinegrass genotypes for brown patch and large patch disease resistance. Crop Sci. 57:S-89–S-97. doi: 10.2135/cropsci2016.06.0514

Fry, J., and J. Butler. 1989. Responses of tall and hard fescue to deficit irrigation. Crop Sci. 29:1536-1541.

Fry, J., M. Kennelly, and R. St. John. 2008. Zoysiagrass: Economic and environmental sense in the transition zone. Golf Course Mgt. 76:127–132.

Fry, J.D., and B. Huang. 2004. Applied turfgrass science and physiology. John Wiley & Sons, Hoboken, NJ.

Fu, J., J. Fry, and B. Huang. 2004. Minimum water requirements of four turfgrasses in the transition zone. HortScience 39:1740-1744.

Grau, F.V., and A.M. Radko. 1951. ‘Meyer’ (Z-52) zoysiagrass. USGA J. Turf Manag. 4:30–31.

Green, D.E., J.D. Fry, J.C. Pair, and N.A. Tisserat. 1994. Influence of management practices on Rhizoctonia large patch disease in zoysiagrass. HortScience 29:186-188.

Haygood, R.A., and S.B. Martin. 1990. Characterization and pathogenicity of species of *Rhizoctonia* associated with centipedegrass and St. Augustinegrass in South Carolina. Plant Dis. 74:510–514. doi:10.1094/PD-74-0510

Latin, R. 2011. A practical guide to turfgrass fungicides. American Phytopathological Society. APS Press, St. Paul, MN.

Li, D., and L. Han. 2008. Managing mixtures of tall fescue (*Festuca arundinacea* Schreb) and zoysiagrass (*Zoysia japonica* Steud.) for athletic turf. Korean J. Turfgrass Sci. 22:197–216.

National Turfgrass Evaluation Program. 2016. The 2012 national tall fescue test: Brown patch (warm temperature) ratings of tall fescue cultivars. National Turfgrass Evaluation Program, Beltsville, MD. <http://www.ntep.org/data/tf12/tf12_17-8/tf1217t30.txt>.

Obasa, K., J. Fry, D. Bremer, R. St John, and M. Kennelly. 2013. Effect of cultivation and timing of nitrogen fertilization on large patch disease of zoysiagrass. Plant Dis. 97:1075–1081. doi:10.1094/PDIS-10-12-0942-RE

Smiley, R.W., P.H. Dernoeden, and B.B. Clarke. 2005. Compendium of turfgrass diseases. American Phytopathological Society Press. St. Paul, MN.

Smucker, AJ.M. and J.T. Ritchie. 1993. Plant physiological responses to the soil - discussion. Int. Crop Sci. I.:747-8.

Yin, S., Q. Li, W. Liu, and D. Li. 2014. Managing tall fescue and zoysiagrass mixtures as turfgrass in the transition zone. Agron. J. 106:1-6.

Chapter 2 - Establishment and Persistence of Zoysiagrass-Tall Fescue Mixtures in the Transition Zone

This chapter has been prepared using style guidelines for Crop Science.

Abstract

Water conservation is increasingly important when selecting turfgrasses. Japanese Lawngrass (*Zoysia japonica* Steud.), a C4 grass commonly referred to as zoysiagrass, is more drought resistant than C3 grasses. However, there is some resistance to using zoysiagrass in lawns and on golf courses due to its extended period of dormancy when turf is brown. My goal was to evaluate methods for establishing a perennial mixture of seeded zoysiagrass and tall fescue (*Schedonorus arundinaceus* Schreb.), a C3 grass, which could improve quality and add winter color. The objective of this study was to evaluate mowing height, and tall fescue seeding rate and seeding month for establishment and persistence of a mixed stand with seeded zoysiagrass. Plots were arranged in a split-plot design at the Rocky Ford Turfgrass Research Center in Manhattan, KS and the Olathe Horticulture Research and Education Center, Olathe, KS. Mowing height (1.9 or 5.1 cm) was the whole-plot treatment factor and tall fescue seeding rate and seeding month were arranged in a two-way factorial in sub plots. 'Compadre' zoysiagrass was seeded in all plots at 49 kg pure live seed (PLS) ha^{-1} in June 2015. 'Corona' tall fescue was seeded in sub-plots at 98, 196, or 392 kg PLS ha^{-1} either in June 2015 with the zoysiagrass seed, or in September 2015 into established zoysiagrass. Percentage of tall fescue in the mixture was determined once in winter and summer from 2015 to 2018. Seeding tall fescue with zoysiagrass in spring generally resulted in poor tall fescue establishment and lack of uniformity, regardless of rate. Overall, seeding tall fescue at 392 kg ha^{-1} in September into established zoysiagrass and mowing at 1.9 cm provided better green color in autumn and early spring over a period of at least three years compared to other treatment combinations.

Introduction

Growing turf in the transition zone is difficult because of temperature extremes and drought. Drought is becoming an increasing issue to due lack of water availability and increasing cost of water. In the Kansas City area, the annual irrigation cost was estimated to be over $28,000 higher when managing 12 hectares of creeping bentgrass fairways compared to zoysiagrass (Fry et al., 2008). In Kansas, cost of water is making many landscape managers consider alternatives to cool-season grasses. Both cool-season and warm-season grasses grow in the transition zone, but warm-season grasses are more drought and heat resistant, and require fewer cultural inputs than cool season grasses (Du et al., 2009; Qian and Fry, 1997). Japanese Lawngrass (*Zoysia japonica* Steud.), commonly referred to as zoysiagrass, has good cold hardiness. However, there is resistance on the part of homeowners, and some golf course managers, to use zoysiagrass due to its extended period of brown color during dormancy compared to cool-season grasses. Mixing zoysiagrass with a cool-season grass, such as tall fescue (*Schedonorus arundinaceus* Schreb.), has several potential advantages. First, water savings afforded by the zoysiagrass may allow for maintenance of acceptable quality under low irrigation levels. Second, the complementary traits of each species will allow adaptation across a range of environmental conditions and inclusion of tall fescue may improve color of the sward in late fall and early spring when zoysiagrass is dormant.

Tall fescue is a candidate which mixes well with zoysiagrass because it has better drought and heat tolerance compared to other commonly used cool-season turfgrasses (Fry and Huang, 2004), and it has a leaf texture that is compatible. Seeding month for tall fescue may have an impact on establishment of a zoysiagrass-tall fescue mixture. Zoysiagrass can be seeded when the soil temperature reaches 20 to 22 °C (Patton et al., 2006). Late spring and early summer seeding is recommended in the transition zone to maximize time allowed for coverage during the summer (Beard, 1973; Johnson and Thompson, 1961; Patton et al., 2004). In Indiana and Kentucky, research showed that seeding zoysiagrass before 1 July resulted in the highest coverage in the following October; zoysiagrass attained 95% coverage 90 to 105 d after seeding (Patton et al., 2004). In contrast, tall fescue is best established when seeded in the autumn (Christians et al., 2016), but spring seeding can be effective as well (Stier and Koeritz, 2008). Murray and Morris observed successful establishment of a ‘Compadre’ (*Zoysia japonica*) zoysiagrass - ‘Rebel’ tall fescue mixture when zoysiagrass was seeded with tall fescue in early summer (Kevin Morris, personal communication).

The seeding rate of tall fescue when established as a monostand is 343 to 441 kg ha^{-1} (Christians et al., 2016). Although Murray and Morris reported successful establishment of a zoysiagrass-tall fescue mixture when including tall fescue at 98 kg ha^{-1}, there is little additional information about how tall fescue seeding rate may impact establishment and overall balance and performance of the mixed stand. When species are combined in a mixture, competitiveness can lead to changes in stand composition over time. Murray and Morris also reported that overseeding zoysiagrass annually with tall fescue at 196 to 245 kg ha^{-1} provided a desirable mixed sward (Kevin Morris, personal communication). In Missouri, researchers reported that turf-type tall fescue seeded at 90% by weight with Kentucky bluegrass (*Poa pratensis* L.) retained competitiveness in the mixture over 5 years (Hunt and Dunn, 1993). However, when tall fescue was seeded at the same ratio with perennial ryegrass (*Lolium perenne* L.), tall fescue accounted for 11% of the sward after five years compared to 89% perennial ryegrass. Limited information is available on tall fescue seeding rate to establish a balanced mixture with zoysiagrass.

Mowing height may also have an effect on the dynamics of a zoysiagrass-tall fescue mixture. In Missouri, researchers reported that mowing height influenced the composition of species in a tall fescue sward that was established with either Kentucky bluegrass or perennial ryegrass (Dunn et al., 2002). The tall fescue population increased from 53 to 59% over 2 years at a 1.9 cm mowing height, whereas no changes occurred in sward population balance at a 5.1 cm mowing height. Brede and Duich (1984) showed that when 50% Kentucky bluegrass seed by weight was used when establishing a mixture with perennial ryegrass, Kentucky bluegrass composition was 40% at a 3.8 cm mowing height, and 56% at a 1.3 cm mowing height 14 months after planting. In Italy, when seeding tall fescue and Kentucky bluegrass at the same time to establish a mixture, Kentucky bluegrass was more abundant at a lower mowing height (2.0 cm vs. 6.2 cm) (Macholino et al., 2014). However, the tall fescue population was 98 to 100% of the sample points through the whole study period and no mowing height effect was observed on the tall fescue population.

Yin et al. (2014) evaluated cultural practices on a tall fescue zoysiagrass mixture. They concluded that when seeding zoysiagrass at 147 kg ha^{-1} in June and tall fescue at 196 kg ha^{-1} in August, overseeding of tall fescue was needed the year after planting to maintain a balanced sward. More information is needed on how to best establish a zoysiagrass-tall fescue mixed sward in the transition zone and to evaluate the dynamics of the mixture over time. The objective of this study was to evaluate tall fescue seeding month and rate, and two mowing heights for establishment and persistence with Compadre zoysiagrass in Kansas.

Materials and Methods

Two identical studies were conducted at the Rocky Ford Turfgrass Research Center in Manhattan, KS (long. 39.13° N, lat. 96.36° W) and at the Olathe Horticulture Research and

Extension Center, Olathe, KS (long. 39.48° N, 95.66° W). Weather data were recorded at each location using an onsite weather station (http://mesonet.k-state.edu/) and are summarized in Figure 2.1 and 2.2. Soil type at Rocky Ford was a silty clay loam (fine, smectic, mesic Aquertic Argiudolls) with a pH of 7.3, and in Olathe, the soil type was an Oska-Martin silty clay loam with a pH of 6.9. Prior to seeding zoysiagrass at each location, soil was tilled and raked to prepare a seedbed.

At both locations, the experimental design was a split-plot with mowing height as the whole plot and the sub-plot was a factorial design with tall fescue seeding month and rate. Whole plots measured 3 by 4.5 m and were replicated four times. Sub-plots were 1.5 by 1.5 m and there were six sub-plots within each whole plot. Compadre zoysiagrass was seeded in all plots at 49 kg PLS (pure live seed) ha^{-1} in June 2015. In sub-plots, 'Corona' tall fescue was seeded at 98 kg ha^{-1}, 196 kg ha^{-1} or 392 kg ha^{-1} in June with zoysiagrass or in September, into the established zoysiagrass sward.

Manhattan, KS

Prior to seeding on 9 June 2015, seed was mixed with a natural organic fertilizer (Milorganite, Milwaukee, WI), 6–2–0 (N–P–K). Plots to be seeded with tall fescue in September received 190 g Milorganite (equivalent to 49 kg N ha^{-1}), which was mixed with the zoysiagrass seed. For plots seeded with tall fescue in June, seed of each species was mixed with 95 g Milorganite prior to seeding, and spread independently with a shaker bottle; therefore, all plots received the same amount of fertilizer in June. The seed with Milorganite mixture was applied in multiple directions to each plot. After seeding had been completed on a plot, a leaf rake was dragged over the surface to encourage seed to mix with soil. Plots were covered (Germination and Insect Blanket, A.M. Leonard, Inc., Piqua, OH) for 6 days to reduce the potential for erosion.

Immediately after seeding in June, siduron (1-(2-methylcyclohexy)-3-phenylurea) was applied at 23 kg a.i. ha^{-1}. Irrigation was applied several times daily as needed with an overhead system until two weeks after seeding. Thereafter, irrigation was applied to keep the seedbed moist. Plots were mowed at 7.5 cm across the entire plot area for the first time on 14 July 2015 to help suppress weed growth. The entire study area was mowed at 5.1 cm five weeks after seeding, which continued weekly until 27 July when the mowing whole plot treatments were initiated. After this date, plots mowed at 5.1 cm were mowed once weekly using a rotary mower, and those maintained at 1.9 cm were mowed three times weekly using a reel mower. Clippings were collected at both mowing heights.

To control broadleaf weeds in Manhattan, a mixture of Dimethylamine salt of 2, 4, -dichlorophenoxyacetic acid at 0.59 kg a.i. ha^{-1}, Dimethylamine salt of (+)-(R)-2-(2-methyl-4-chlorophenoxy) propionic acid at 0.16 kg a.i. ha^{-1} and Dimethylamine salt of dicamba at 0.06 kg a.i. ha^{-1} (PBI/Gordon Corporation, Kansas City, MO) was applied on 20 July 2015. Organic based fertilizer 15–0–8 (N–P–K) (Lebanon Seaboard Corporation, Lebanon, PA) was applied at 49 kg N ha^{-1} on 9 July 2015.

September seeding of tall fescue sub plots occurred on 17 Sept. 2015 after zoysiagrass plots were fully established. To encourage seed to soil contact, zoysiagrass in sub plots that were to receive tall fescue seed was verticut in two directions with a power rake (Billy Goat Industries Inc., Lee’s Summit, MO) with 5.0 cm knife spacing on a No. 4 setting. The power rake was pulled backwards across each plot for a total of four passes, and blades penetrated to a 0.8 cm soil cutting depth. The plots were then raked to remove material that had been removed. Tall fescue was seeded with a shaker bottle as described previously. After seeding, plots were raked with a leaf rake over the surface in two directions. Irrigation was applied several times daily by hand to autumn-seeded tall fescue plots until three weeks after seeding. Plots were not mowed for one week after seeding; thereafter, mowing was performed as described previously. Nitrogen from urea was applied to all plots at 24.5 kg N ha^{-1} on 6 Oct. 2015.

In addition, N (urea) was applied at 33 kg ha^{-1} on 12 Apr., 1 July and 12 Sept. in 2016; 10 May, 11 July, 6 Sept. in 2017; 24 May, and 5 July 2018. To control annual grassy weeds, oxadiazon, (3-[2,4-dichloro-5-(1-methylethoxy)phenyl]-5- (1,1-dimethylethyl)-1,3,4-oxadiazol-2(3H)-one) was applied at 2.94 kg a.i. ha^{-1} on 11 Apr. 2016, 3 Apr. 2017 and 23 Apr. 2018. Irrigation was applied 3 times per week to promote growth and prevent any visual drought stress.

Olathe, KS

Seeding was performed as described for Manhattan on 10 June 2015. Due to the unavailability an irrigation system, plots were irrigated daily by hand for four weeks after seeding, and no irrigation was applied thereafter. A mixture of quinclorac (3,7-dichloro-8-quinolinecarboxylic acid) at 1.3 kg a.i. ha^{-1}, sulfentrazone (N-{2,4-dichloro-5-[4-(difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1H-1,2,4-triazol-1-yl]phenyl] methanesulfonamide) at 0.16 kg a.i. ha^{-1}, 12.02% of 2,4-D (Dimethylamine salt of 2,4-dichlorophenoxyacetic acid) at 2.8 kg a.i. ha^{-1}, and 1.38% dicamba (Dimenthylamine salt of dicamba) at 0.32 kg a.i. ha^{-1} was applied to control broadleaf and grassy weeds on 18 July 2015. September seeding was conducted on 25 Sept. 2015 as described for the Manhattan study. Irrigation was applied once daily by using a hand-held hose to water the September-seeded plots until 4 weeks after seeding. On 28 Oct. 2015, a quick release fertilizer (28-0-3; Lesco Inc. Cleveland, OH) was applied at 24.5 kg N ha^{-1}. The whole plot mowing treatments were initiated on 5 Sept. 2015. Plots mowed at 5.1 cm were cut once weekly with a rotary mower, and those maintained at 1.9 cm were cut twice weekly with a reel mower. Nitrogen (urea) was applied at

33 kg ha^{-1} on 22 Apr., 30 June, and 12 Sept., in 2016; 27 May, 19 July, and 5 Sept., in 2017; and 3 May in 2018. To prevent annual grassy weeds, oxadiazon was applied at 2.94 kg a.i. ha^{-1} on 11 Apr. 2016 and 7 Apr. 2017.

Data Collection

The composition of tall fescue in each plot was determined on 11 Dec. 2015; 1 Aug. and 22 Dec. 2016; 11 July, and 30 Nov. 2017; and 20 June 2018 in Manhattan and on 4 May and 27 Dec. 2016; 19 July and 1 Dec. 2017; and 9 July 2018 in Olathe. Tall fescue incidence was determined by counting the frequency at which a tall fescue plant appeared under intersections under a grid. The grid was composed of fishing lines that were mounted on a 1.5 m x 1.5 m frame to create 196-intersections with 0.1 m between each of 14 gridlines in either direction. Any portion of a tall fescue leaf that fell under an intersection on the grid was counted as a "hit." Tall fescue composition in each plot was determined as: % tall fescue = (tall fescue count frequency/196) × 100.

Turf color was rated in late fall and early spring on a 1-9 scale, where 1 = straw brown or no color retention, and 9 = dark green (National Turfgrass Evaluation Program; Morris and Shearman, 1999). Specifically, dates on which color was rated were 8 Oct., 20 Nov., and 11 Dec., 2015; 1 Jan., 27 Feb., 10 Mar., 7 Apr., 6 May, 22 Oct., 21 Nov., and 22 Dec., 2016; 16 Mar., 14 Apr., 6 May, 29 Oct., 17 Nov., and 10 Dec., 2017; and 14 Mar., 20 Apr., and 6 May, 2018 in Manhattan. In Olathe, color was rated on 10 Nov. 2015; 21 Apr., 4 May, 21 Nov., and 27 Dec., 2016; 8 Apr., 4 Nov., and 1 Dec. 2017; and 3 May 2018.

To determine the percent green coverage using digital image analysis (DIA), four photos of each plot were taken with a Nikon D5000 digital camera (Nikon Inc., Tokyo, Japan). Debris was removed using a leaf blower before taking photos, and the camera was mounted inside a light box (0.51 m × 0.61 m × 0.56 m) at a 0.56 m height. The camera was adjusted to the setting of f-stop 5.6, 1/125 sec exposure time, 800 ISO-speed, and a focal length of 26 mm. The image format was JPEG, with an image size of 4288 × 2848 pixels and 1.5 megabytes. Images were analyzed for percent green coverage using SigmaScan Pro 5.0 (ver. 5.0 SPSS Science Marking Dept, Chicago, IL) (Richardson, 2001). The macro threshold setting was adjusted to the following setting: hue = 47 to 107 and saturation = 0 to 100. Digital images were taken in Manhattan on 18 Oct., 20 Nov., and 11 Dec., 2015; 26 Mar., 28 Apr., 22 Oct., 21 Nov., and 4 Dec., 2016; 16 Mar., 6 Apr., 6 May, 19 Oct., 30 Nov., and 14 Dec., 2017; and 20 Apr., and 21 May, 2018. In Olathe, digital images were taken on 8 Oct., 21 Nov., and 27 Dec., 2016; 8 Apr., 26 May, 7 Oct., 4 Nov., and 1 Dec., 2017; and 3 May 2018.

Data were also collected on turf quality and dark green color index. Turf quality was visually rated on a 1 to 9 scale, 1 = completely brown, 6 = minimum acceptable quality, 9 = optimum color, density, and uniformity. Dark green color index was calculated using the following equation according the results from digital image analysis:

DGCI value = [(H - 60)/60 + (1 - S) + (1 - B)]/3 (Karcher and Richardson, 2003), where H is hue, S is saturation, and B is brightness. When zoysiagrass turned dormant, the correlation between two methods was determined, using counts from the grid and digital image analysis. Data are shown in Appendix A.

Data Analysis

Data at each site were analyzed separately due to differences in data collection frequency. Mowing height, tall fescue seeding month, and tall fescue seeding rate were considered as fixed effects and block was considered as a random effect. Residual normality was tested prior to data analysis. Data were approximately normally distributed with equal variances, which met the assumptions of ANOVA (Analysis of Variance). ANOVA was tested using Proc Mixed in SAS (SAS Institute Inc., Cary, NC). Parameters were analyzed using repeated measures, with ante-independence structure ANTI (1). Pair-wise comparisons were performed to identify significant differences among means ($P \leq 0.05$). Degrees of freedom were adjusted using Satterthwaite adjustment (Satterthwaite, 1941). Eight plots of 'Meyer' zoysiagrass and turf-type tall fescue maintained at a 7.5 cm height were included off the plots as monostand standards at both locations, but data were not included in statistical analysis. Correlations among various response variables were tested using Proc Corr in SAS.

Results

Manhattan, KS

<u>Tall Fescue Incidence</u>

A mowing height × tall fescue seeding month interaction and tall fescue seeding rate main effect occurred for tall fescue incidence (Table 2.1). Averaged over tall fescue seeding rate, at a 1.9 cm mowing height, tall fescue incidence ranged from 14.9% to 53.4% for plots in which tall fescue was seeded in June, and tall fescue incidence increased over time (Figure 2.3-A). At the same mowing height, tall fescue incidence ranged from 46.7% to 87.6% in plots in which tall fescue was seeded in September. Tall fescue incidence showed an increasing trend from December 2015 to December 2016, and from July 2017 to November 2017, but generally declined from December 2016 to July 2017 and from November 2017 to June 2018.

At a 5.1 cm mowing height, tall fescue incidence ranged from 23.8% to 68.5% for June-seeded plots and from 34.4% to 78.3% for plots seeded with tall fescue in September (Figure 2.3-B). Tall fescue incidence generally increased over the three-year period. Regardless of tall fescue mowing height or seeding rate, higher tall fescue incidence occurred in plots seeded in September.

Tall fescue incidence also increased with seeding rate (Figure 2.4). Plots seeded with tall fescue at 392 kg ha^{-1} had the highest tall fescue incidence in December 2015, August 2016, and December 2016 and June 2018; however, tall fescue levels were not different than plots seeded at 196 kg ha^{-1} when evaluated in July or November 2017.

Turf Color

Significant tall fescue seeding month × tall fescue seeding rate × mowing height interactions were observed for turf color (Table 2.1). Plots seeded with tall fescue in September had better late fall and early spring color compared to those seeded with tall fescue in June at both mowing heights (Figure 2.5). The magnitude of the difference between turf color between seeding months was most noticeable at a 1.9 cm mowing height. The dates on which the low temperatures dropped below freezing in each year were 29 Oct. 2015, 10 Nov. 2016, and 27 Oct. 2017, and zoysiagrass color started to drop after those dates. On 18 Dec. 2015, 22 Dec. 2016, and 14 Dec. 2017, color ratings of monostands was 1 for zoysiagrass and 4 to 5 for tall fescue (data not shown). In comparison, the zoysiagrass-tall fescue mixtures seeded with tall fescue in September at 392 kg ha^{-1} had color on the same dates list above that ranged from 2 to 5 at both mowing heights.

In April 2017, plots mowed at 1.9 cm showed acceptable color (rating ≥ 6), which was earlier than plots mowed at 5.1 cm. At all mowing height and tall fescue seeding month treatment combinations, the highest tall fescue seeding rate had the best late fall and early spring color on many rating dates (Figure 2.6). Among the seeding rates, differences in turf color declined after summer 2016.

Green Coverage

In regard to percentage green coverage determined using digital image analysis (DIA), a tall fescue seeding rate main effect and mowing height × tall fescue seeding month interaction were observed (Table 2.1). For the main effect of tall fescue seeding rate, averaged across mowing height and tall fescue seeding month, seeding tall fescue at 392 kg ha^{-1} resulted in the highest percentage of green coverage in October, November, and December 2015 and March 2016 (Figure 2.7). There were no significant differences on later rating dates, with the exception of green coverage in plots seeded with tall fescue at 392 kg ha^{-1} being higher than those seeded at 98 kg ha^{-1} in November and December 2016 and May 2018.

Averaged over tall fescue seeding rate, plots seeded with tall fescue in September had higher green coverage in late fall and early spring at both mowing heights, with differences more pronounced at the 1.9 cm mowing height (Figure 2.8). At the 5.1 cm mowing height, plots seeded with tall fescue in September had higher green coverage on 4 of the first 8 rating dates. Starting in 2017 there were no differences in turf color between the seeding months, with the exception of November 2017. In March 2016, April 2017, and April 2018, the zoysiagrass monostand had green coverage of 13.7%, 7.7% and 3.6%, respectively (data not shown), whereas mixtures with September-seeded tall fescue had green coverage of 24.9%, 45.6%, and 29.6%, respectively, at the 1.9 cm mowing height averaged over the three seeding rates.

Correlation Between Methods

Percentage green coverage was correlated with tall fescue incidence (r = 0.58, $P < 0.001$; Figure 2.9).

Olathe, KS

Tall Fescue Incidence

The interaction of mowing height × tall fescue seeding month and tall fescue seeding month × seeding rate was significant in regard to tall fescue incidence (Table 2.1). For the mowing height × tall fescue seeding month interaction, when averaged across tall fescue seeding rates, tall fescue incidence was higher in those plots in which tall fescue was seeded in September (Table 2.2). This is consistent on all rating dates at a 1.9 cm mowing height and on four out of five rating dates at a 5.1 cm mowing height. Furthermore, when comparing tall fescue seeding month and seeding rate, plots seeded with tall fescue in September had higher tall fescue incidence than those seeded in June, with the exception of the 392 kg ha^{-1} seeding rate in May 2016 and July 2018 (Table 2.3).

Turf Color

For turf color, there was a significant tall fescue seeding month × tall fescue seeding rate × date interaction, tall fescue seeding rate × date interaction, and mowing height × date interaction (Table 2.1). Averaged across tall fescue seeding month and seeding rate, the polystands maintained at the 1.9 cm mowing height had better turf color than the 5.1 cm mowing height in May 2016, April 2017, and May 2018 (Table 2.4).

Averaged over mowing height, seeding tall fescue at 392 kg ha^{-1} in September resulted in consistently better late fall and early spring color than seeding in June, although there were no differences between the 392 kg ha^{-1} and 196 kg ha^{-1} seeding rates on most rating dates (Table 2.5). Zoysiagrass started to lose color on 13 Nov. in 2015, 13 Oct. in 2016 and 28 Oct. in 2017 (Based upon freezing temperature; Figure 2.1). Tall fescue seeded in September at 392 kg ha^{-1} extended acceptable color (> 6) to November in 2015 and resulted in acceptable color (> 6) early in April 2016.

Green Coverage

Significant tall fescue seeding month × tall fescue seeding rate and mowing height × tall fescue seeding month interactions were observed for green coverage (Table 1.1). Regardless of mowing height, higher green coverage occurred in plots in which tall fescue was seeded in September at most of the seeding rates (Table 2.6). Differences in green coverage of plots were observed for tall fescue seeding rate on 21 Nov. 2016, 8 Apr. 2017, and 4 Nov. 2017.

Regardless of seeding rate, seeding tall fescue in September, rather than June, resulted in consistently higher green coverage at 1.9 cm mowing height. However, at the 5.1 cm mowing height, plots seeded with tall fescue in September exhibited higher green coverage to June-seeded plots in November 2016, April, May, and November 2017, and May 2018 (Table 2.7). In December 2016, the zoysiagrass-tall fescue mixtures had green coverage up to 15.5%, whereas the zoysiagrass monostand had only 1.8% green coverage (data not shown). Likewise, December 2017 green coverage in the mixtures was up to 9.1%, whereas, it was 28.9% in the tall fescue monostand and 2.6% in the zoysiagrass monostand, respectively.

Correlation Between Methods

Tall fescue incidence and digital green coverage ratings were positively correlated ($r = 0.76$, $P < 0.001$; Figure 2.10).

Discussion

Mixtures composed of a seeded zoysiagrass and tall fescue were successfully established at two locations in Kansas. Cultural practices affected tall fescue incidence, visual turf color ratings, and digital color assessments.

At both locations, the highest tall fescue incidence occurred when tall fescue was seeded in September at 392 kg ha^{-1} after previously seeding zoysiagrass in June at 49 kg ha^{-1}. Bornino et al. (2010) reported perennial ryegrass coverage increased with seeding rate at 610, 1220, and

2440 kg^{-1} ha^{-1} year^{-1} when seeded into perennial ryegrass. Likewise, I observed that tall fescue incidence increased with increasing seeding rates in the zoysiagrass-tall fescue mixture. June-seeded tall fescue seemed to suffer as summer temperatures increased. The recommended time to seed tall fescue is usually in fall, and this species grows best at temperatures of 16-24 °C for shoots and 10-18 °C for roots (Fry and Huang, 2004). In addition, symptoms of damping off, likely caused by Pythium blight (*Pythium* spp.) (Smiley et al., 2005), were evident, although we did not intensively sample. In the southern US, perennial ryegrass overseeded into established bermudagrass is sometimes treated with fungicides to prevent diseases, and in some cases fungicide-treated seed is used. One of my goals was to develop systems with reduced inputs, and the plots were not treated with fungicides at any time during the study. A combination of factors likely reduced the incidence of tall fescue in June-seeded plots.

Tall fescue incidence was generally higher in plots that were seeded with tall fescue in September and mowed at 1.9 cm compared to those mowed at 5.1 cm. The lower mowing height likely allowed better tall fescue seed contact with the soil after verticutting and seeding in September. Scalping is used as a common cultural practice when bermudagrass is overseeded with cool-season grasses in the southern U.S. to increase seed-to-soil contact (McCarty, 2004).

Tall fescue incidence changed over time at both the Manhattan and Olathe locations. In Manhattan, there was a steady increase ($P < 0.001$) in the tall fescue population at the 5.1 cm mowing height from the beginning to the end of the study (Figure 2.3-B). At a 1.9 cm mowing height, even though tall fescue increased throughout the study period, the population fluctuated slightly, with a dip in July 2017 (Figure 2.3-A) but the overall trend was upward ($P \leq 0.001$). The decrease may have been due to summer physiological stress or brown patch. Despite the decrease in tall fescue incidence in July 2017, overall quality was still acceptable (See Figure

A.1 and A.2 in Appendix A). Tall fescue was still nearly 50% of the mixture, and the zoysiagrass in the stand could have been compensating for the reduced tall fescue coverage, as intended by the mixture. The mid-summer decrease is similar to observations by Yin et al. (2014), who reported a lower tall fescue coverage and shoot density in August compared to May to July and September and October in Beijing, China. In Olathe, the long-term trend was for the tall fescue population to decline from the beginning of the experiment to the end for all seeding rates, times, and both mowing heights ($P < 0.05$, except for June-seeded tall fescue at the 1.9 cm mowing height). Tall fescue is under stress in summer, and this is likely exacerbated in the hot and humid environment (average relative humidity of 67.4% to 70.2% in Manhattan and Olathe). Olathe had more precipitation from June to August in 2016 and 2017 than Manhattan (386 mm and 526 mm in Olathe in 2016 and 2017, respectively vs. 296 mm and 217 mm in Manhattan in 2016 and 2017, respectively) (Figure 2.1 and 2.2). Li and Han (2008) found that tall fescue ground coverage increased from 49% to 62 % over two years when mowed at 6.5 cm, but decreased from 49% to 39% at a 3.5 cm mowing height when averaged across N rates (0, 50, 100 kg ha^{-1}) and traffic (0, 5 or 10 passes per week). In China, establishing a zoysiagrass-tall fescue mixture by seeding zoysiagrass at 147 kg ha^{-1} in June and tall fescue in August at 196 kg ha^{-1} resulted in a low tall fescue population the next year. This required tall fescue overseeding the following autumn. If a decrease occurs, such as we observed in Olathe, occasionally overseeding the zoysiagrass-tall fescue sward with tall fescue may help maintain a balanced population over time.

Higher tall fescue incidence also influenced turf visual color ratings and digital green coverage in zoysiagrass-tall fescue polystands (Figure 2.9 and 2.10). The improvement in visual color was most noticeable in November and April, when zoysiagrass was dormant. For plots seeded with tall fescue at 392 kg ha^{-1} in September, the average increase in visual color in November was 3 rating points on the 1-9 scale compared to a monostand of zoysiagrass in Manhattan (5 vs. 2 on 20 Nov. 2015 and 21 Nov. 2016, and 4 vs. 1 on 17 Nov. 2017) and 2 or 3 rating points in Olathe (4 vs. 2 on 21 Nov. 2016, and 2 vs. 5 on 4 Nov. 2017). A similar increase in visual color was observed in April.

In addition, green coverage in November ranged from 14 to 18% higher in plots that had been seeded at 392 kg ha^{-1} in September compared to a monostand of zoysiagrass in Manhattan and 20% higher in Olathe. Similarly, green coverage in late March and early April was found to be 7 to 25% higher in Manhattan and 43% higher in Olathe. Homeowners and turfgrass managers favor green turf in late fall and spring, and avoid warm-season grass monostands that result a longer period of dormancy (Menegon et al., 2017). In this experiment, though the mixture extended the late fall and early spring color, acceptable visual color did not always occur during these months.

Tall fescue incidence and color differences among treatments at both study sites were more pronounced in 2015 and 2016 than 2017 and 2018 (Figure 2.6 and Table 2.4). Though the high seeding rate led to higher tall fescue incidence and color in the early dates, it may be possible to save money on seed if the end-user is willing to wait for a mixed stand to develop.

Across sites, seeding rates, and seeding time, plots mowed at 1.9 cm had better spring visual color than those mowed 5.1 cm, which could have been because of increased sun exposure at the lower mowing height allowing the soil to warm more quickly (Martin et al., 2001). In Italy, researchers observed an average of 10 to 18 days earlier spring green-up on bermudagrass cultivars scalped in March compared to non-scalped plots, which was associated with an increase in soil temperature under scalped turf (Rimi et al., 2011). In Georgia, Waltz et al. (2009)

reported that mowing at 7.6 cm resulted in higher organic matter accumulation in centipedegrass (*Eremochloa ophiuroides* (Munro) Hack.) compared to a 3.8 cm mowing height throughout four-year study period. The higher level of organic matter accumulation resulted in a delay in spring green-up. Similarly, in Oklahoma, earlier spring green-up was observed on seeded bermudagrass mowed at 1.3 cm (3.5 rating) compared to 3.8 cm (2.5 rating) (Martin et al., 2001).

Different end-users will have different expectations of turfgrass color and quality. Though our ratings were on the traditional NTEP scale of 1-9 with 6 = minimum, the actual "minimum" expectations of homeowners may be variable. In Maryland, researchers reported that dormant zoysiagrass could be seen when looking closely at a zoysiagrass-tall fescue polystand after zoysiagrass was dormant; however, the sward had a uniform green color at a 3 to 4.5 m distance (Kevin Morris, personal communication). Color from a distance may be a suitable measure for certain turf end-users. A next step in this research may be to survey homeowners about their opinion of a zoysiagrass monostand vs. a zoysiagrass-tall fescue polystand.

Results of this experiment demonstrate that a polystand mixture of Compadre zoysiagrass and Corona tall fescue can be successfully established in Kansas, and that the mixture can be sustained at a level that will improve spring and fall color over a period of at least three years compared to zoysiagrass monostand. More research will help determine the potential benefits of such as mixtures regarding requirements for fertilizer and pesticide inputs.

References

Beard, J.B. 1973. Turfgrass: Science and culture. Prentice Hall, Upper Saddle River, NJ.

Bornino, B.F., C.A. Bigelow, and Z.J. Reicher. 2010. Strategy and rate affects success of perennial ryegrass overseeding into bermudagrass athletic fields located on the north edge of the transition zone. Applied Turfgrass Science 7:1.

Brede, A.D., and J.M. Duich. 1984. Initial Mowing of Kentucky Bluegrass-Perennial Ryegrass Seedling Turf Mixtures. Agron. J. 76:711-714.

Christians, N.E., A.J. Patton, and Q.D. Law. 2016. Fundamentals of turfgrass management. John Wiley & Sons, Hoboken, New Jersey.

Du, H., Z. Wang, and B. Huang. 2009. Differential responses of warm-season and cool-season turfgrass species to heat stress associated with antioxidant enzyme activity. J. Amer. Soc. Hort. Sci. 134:417-422.

Dunn, J.H, E.H. Ervin, and B.S. Fresenburg. 2002. Turf performance of mixtures and blends of tall fescue, Kentucky bluegrass, and perennial ryegrass. HortScience 37:214-217.

Fry, J.D., and B. Huang. 2004. Applied turfgrass science and physiology. John Wiley & Sons, Hoboken, NJ.

Fry, J., Kennelly, M., and St. John, R. 2008. Zoysiagrass: economic and environmental sense in the transition zone. Golf Course Management. May. Pages 127-132.

Hunt, K.L. and J.H. Dunn. 1993. Compatibility of Kentucky bluegrass and perennial ryegrass with tall fescue in transition zone turfgrass mixtures. Agron. J. 85:211-215.

Johnson, C.M., and W.R. Thompson. 1961. Fall and winter seeding of lawns. Mississippi Farm Res. 24:4.

Karcher, D.E., and M.D. Richardson. 2003. Quantifying turfgrass color using digital image analysis. Crop Sci. 43:943-951.

Li, D., and L. Han. 2008. Managing mixtures of tall fescue (*Festuca arundinacea* Schreb) and zoysiagrass (*Zoysia japonica* Steud.) for athletic turf. Korean J. Turfgrass Sci. 22:197–216.

Macolino, S., G. Pignata, M. Giolo, and M.D. Richardson. 2014. Species succession and turf quality of tall fescue and Kentucky bluegrass mixtures as affected by mowing height. Crop Sci. 54:1220-1226.

Martin, D.L., G.E. Bell, J.H. Baird, C.M. Taliaferro, N.A. Tisserat, R.M. Kuzmic, D.D. Dobson, and J.A. Anderson. 2001. Spring dead spot resistance and quality of seeded bermudagrasses under different mowing heights. Crop Sci. 41:451-6.

McCarty, L.B. 2004. Overseeding. p. 465-483. In L.B. MaCarty (ed.) Best golf course management practices. 2nd ed. Pearson Education Inc., Upper Saddle, NJ.

Menegon, A., S. Macolino, J.H. McCalla, F. Rimi, and M.D. Richardson. 2017. Turf quality and species dynamics in bermudagrass and kentucky bluegrass mixtures. Agron. J. 109:1502-1509.

Morris, K.N. and R.C. Shearman. 1999. NTEP turfgrass evaluation guidelines. National Turfgrass Evaluation Program, Beltsville, Md.

Patton, A.J., G.A. Hardebeck, D.W. Williams, and Z.J. Reicher. 2004. Establishment of bermudagrass and zoysiagrass by seed. Crop Sci. 44:2160-2167.

Patton, A.J., Z.J. Reicher, A.J. Zuk, J.D. Fry, M.D. Richardson, and D.W. Williams. 2006. A guide to establishing seeded zoysiagrass in the transition zone. Appl. Turfgrass Sci. 3:1-16.

Qian, Y. and Fry, J.D. 1997. Water relations and drought tolerance of four turfgrasses. J. Amer. Soc. Hort. Sci. 122:129-133.

Richardson, M.D. 2001. Quantifying turfgrass cover using digital image analysis. Crop Sci. 41:1884–1888.

Rimi, F., S. Macolino, B. Leinauer, and U. Ziliotto. 2011. Green-up of seeded bermudagrass cultivars as influenced by spring scalping. HortTechnology 21:230-235.

Satterthwaite, F.F. 1941. Synthesis of variance. Psychometrika 6:309-316.

Smiley, R.W., P.H. Dernoeden, and B.B. Clarke. 2005. Compendium of turfgrass disease. American Phytopathological Society Press, MN.

Stier, J.C., and E.J. Koeritz. 2008. Seeding dates for tall fescue (*Festuca arundinacea* schreb.) athletic fields established in a temperate continental climate. Acta Hortic. 783:49-56 DOI: 10.17660/ActaHortic.2008.783.4

Waltz, F. 2009. Impact of annual nitrogen rate and mowing height on thatch development of ‘TifBlair’ Centipedegrass (*Eremochloa ophiuroides*) In: 2009 ASA-CSSA-SSA International Annual Meetings; Nov. 1-5, 2009; Pittsburgh, PA. https://a-c-s.confex.com/crops/2009am/webprogram/Paper53762.html

Yin, S., Q. Li, W. Liu, and D. Li. 2014. Managing tall fescue and zoysiagrass mixtures as turfgrass in the transition zone. Agron. J. 106:1-6.

Figure 2.1 Monthly average air temperature, and total precipitation from June 2015 to June 2018 in Manhattan, KS. Weather data was collected from an on-site weather station close to the research area.

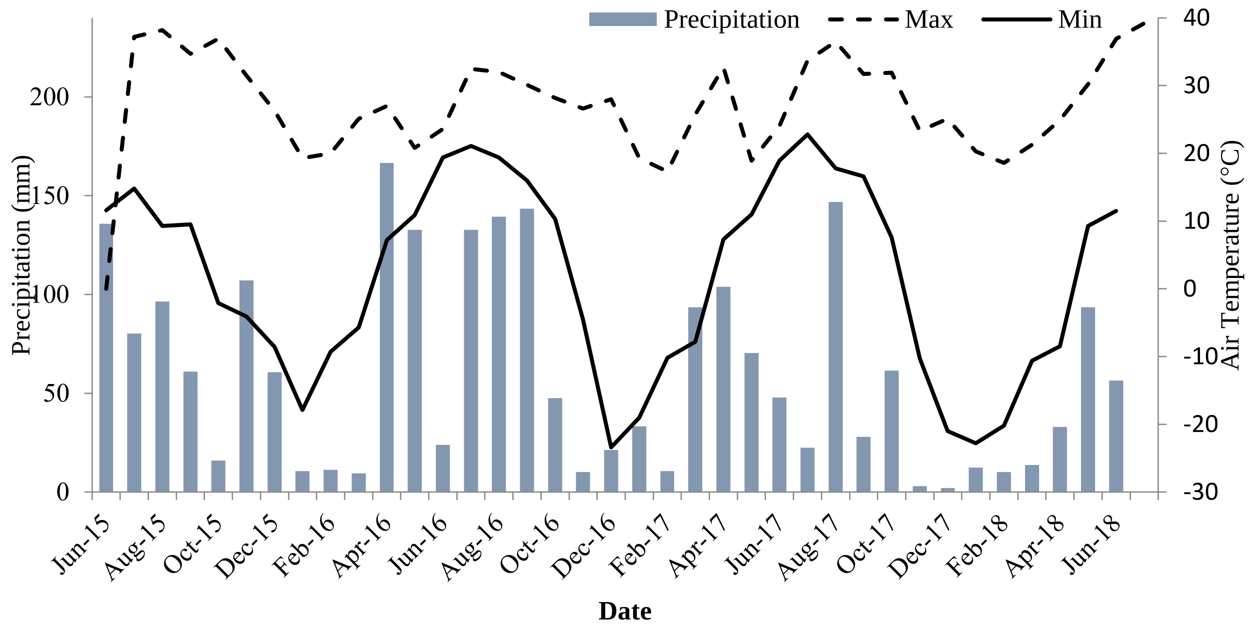


Figure 2.2 Monthly average air temperature, and total precipitation from June 2015 to June 2018 in Olathe, KS. Weather data was collected from an on-site weather station close to the research area.

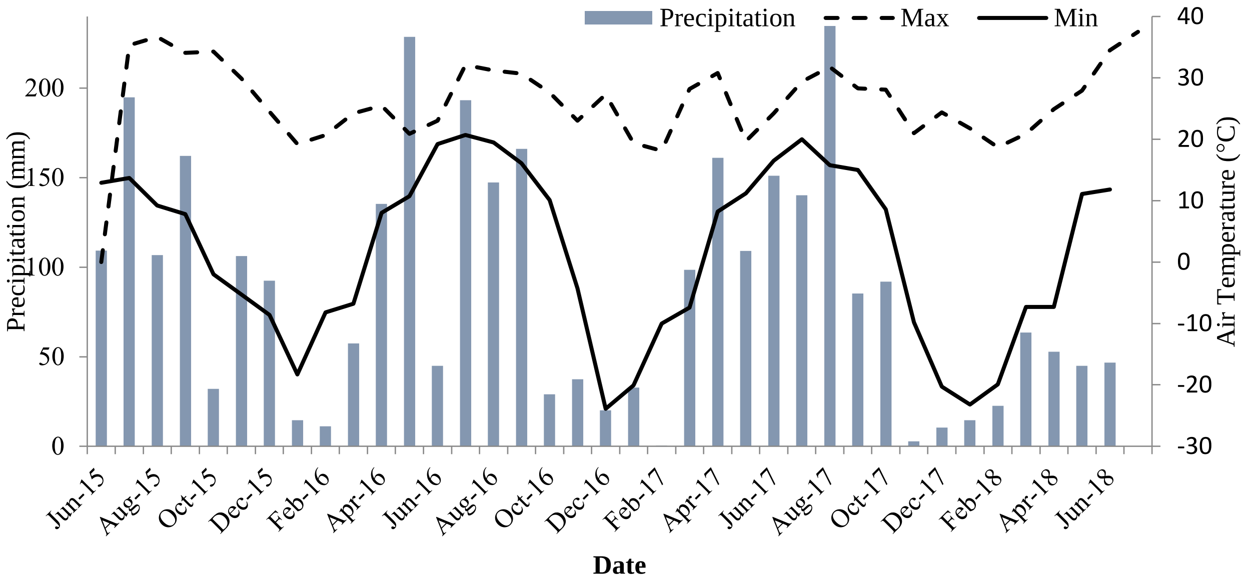
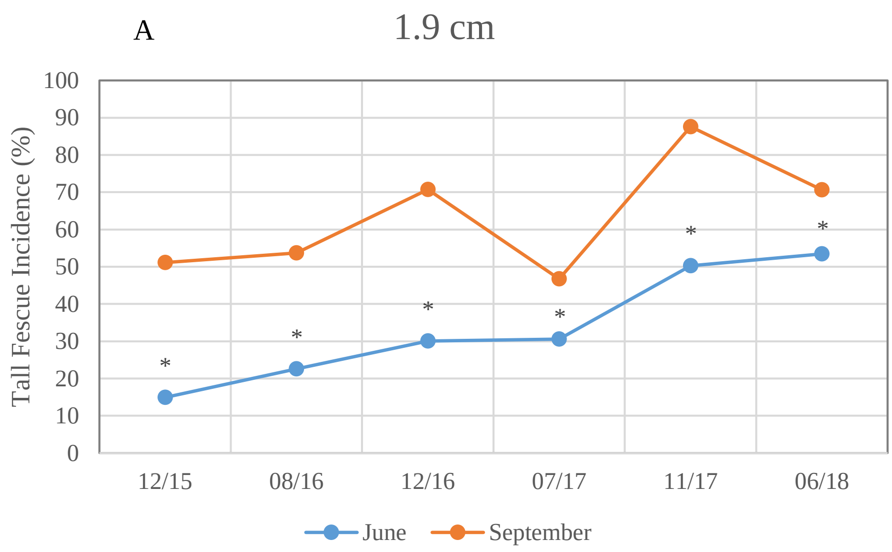
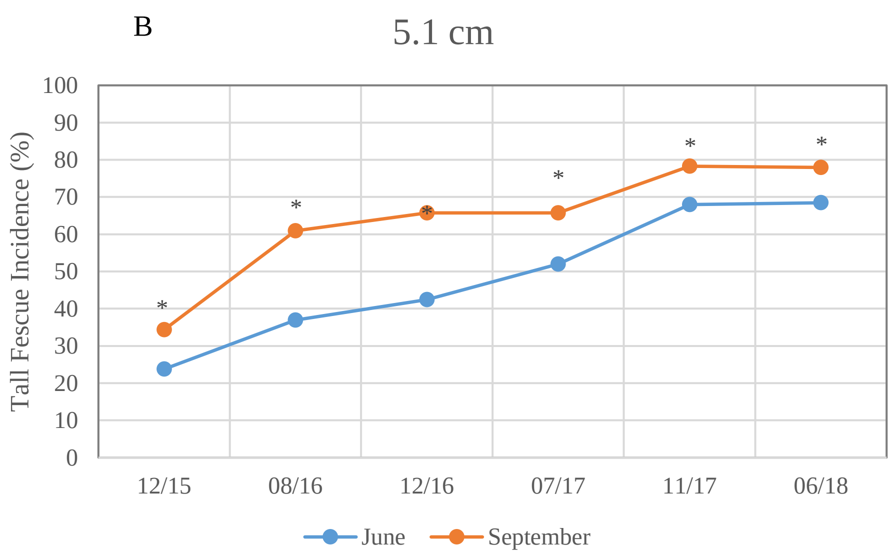


Figure 2.3 Effects of mowing height × tall fescue seeding month (June or September) interaction sliced by mowing height (1.9 or 5.1 cm) on tall fescue incidence of a zoysiagrass-tall fescue polystand in Manhattan, KS from December 2015 to June 2018.



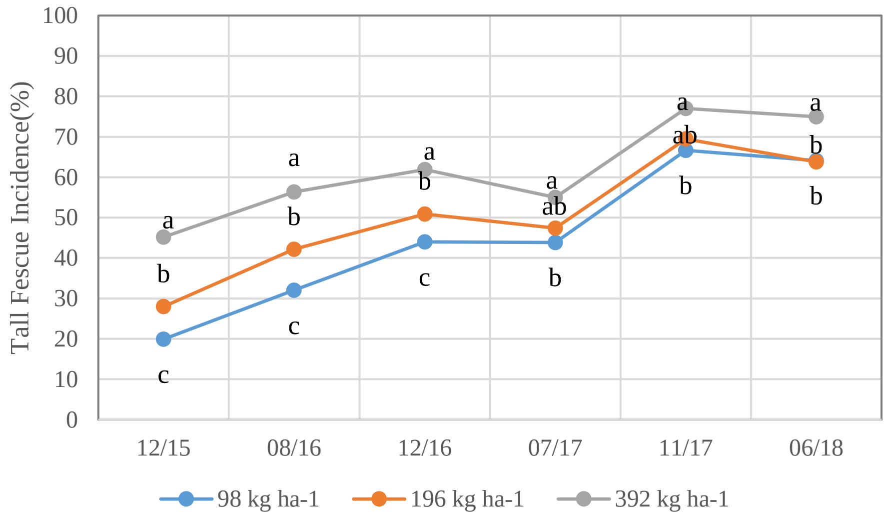


† Tall fescue incidence was determined on 11 Dec. 2015; 1 Aug. and 22 Dec., 2016; 11 July, and 30 Nov., 2017; and 20 June 2018 by counting the frequency at which a tall fescue plant appeared under intersections under a grid. The grid was on a 1.5 m x 1.5 m frame with 0.1 m between each of 14 gridlines in either direction to create 196-intersections. Any portion of a tall fescue

leaf that fell under an intersection on the grid was counted as a "hit". Tall fescue (%) = tall fescue count frequency/196 × 100).

‡ Means are averaged over four blocks and three tall fescue seeding rates (98, 196, or 392 kg ha^{-1}). An asterisk (*) indicates significant differences between tall fescue seeding month on a given month according to Fisher's Protected LSD ($P \leq 0.05$).

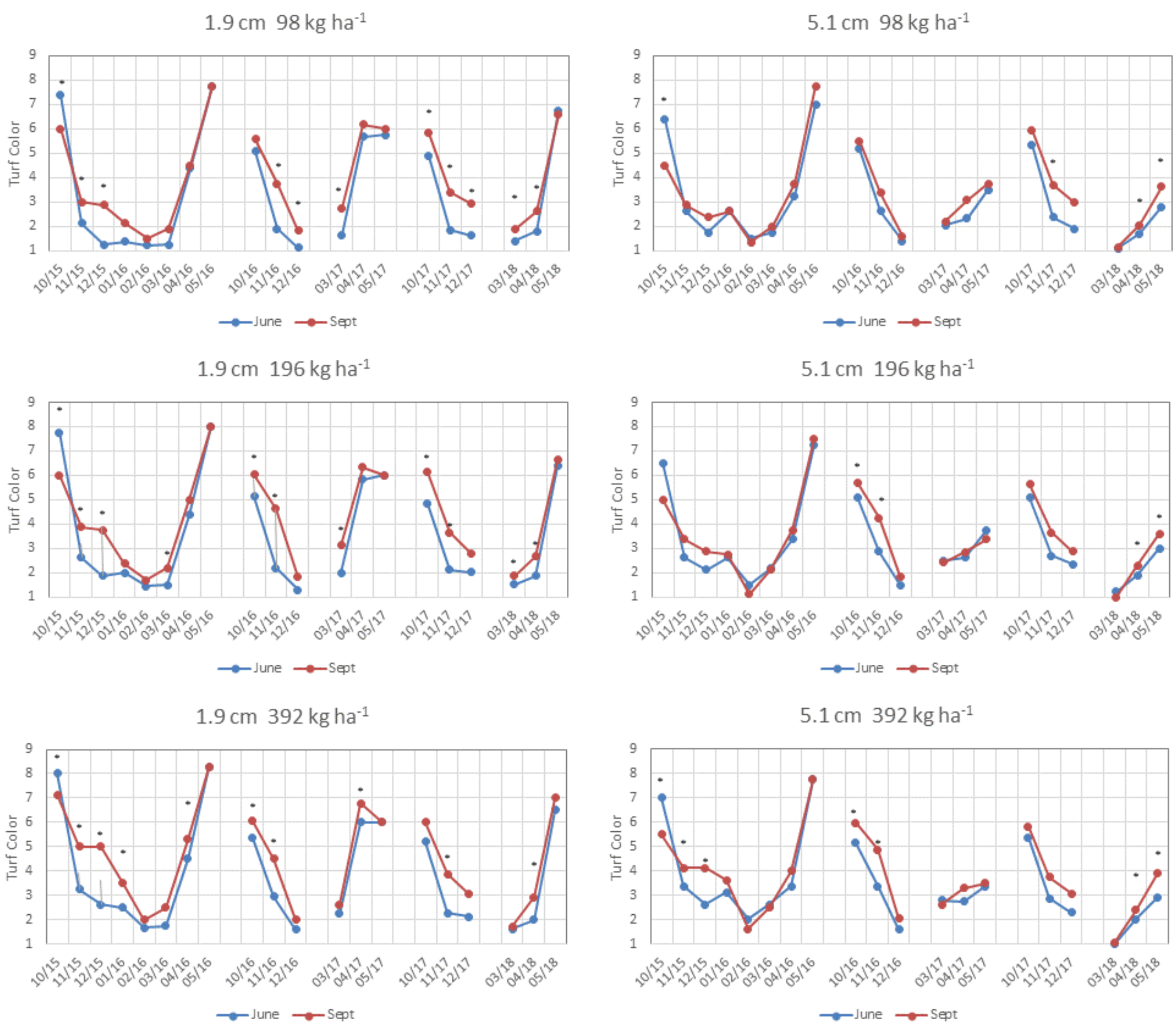
Figure 2.4 Tall fescue seeding rate main effect (98, 196, or 392 kg ha^{-1}) on tall fescue incidence in a zoysiagrass-tall fescue polystand in Manhattan, KS from December 2015 to June 2018.



† Tall fescue incidence was determined on 11 Dec. 2015; 1 Aug. and 22 Dec., 2016; 11 July, and 30 Nov., 2017; and 20 June 2018 by counting the frequency at which a tall fescue plant appeared under intersections under a grid. The grid was on a 1.5 m x 1.5 m frame with 0.1 m between each of 14 gridlines in either direction to create 196-intersections. Any portion of a tall fescue leaf that fell under an intersection on the grid was counted as a "hit". Tall fescue (%) = tall fescue count frequency/196 × 100).

‡ Means are averaged over four blocks, two mowing heights and two seeding months. Means followed by the same letter within a given month are not significantly different according to Fisher's protected LSD ($P \leq 0.05$).

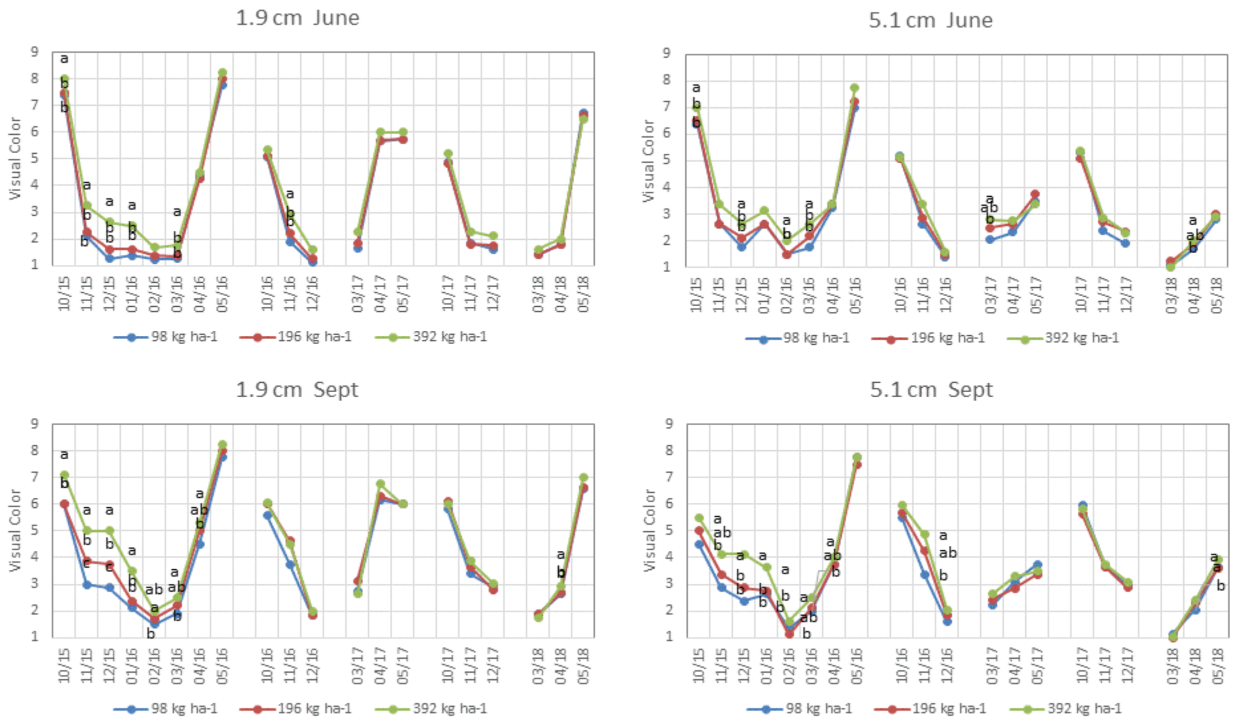
Figure 2.5 Effects of mowing height × tall fescue seeding month (June or September) × tall fescue seeding rate interaction sliced by mowing height (1.9 cm or 5.1 cm) × seeding rate (98, 196, or 392 kg ha^{-1}), on turf color of a zoysiagrass-tall fescue polystand in Manhattan, KS from October 2015 to May 2018.



† Turf color was recorded on a 1-9 scale, where 1 = straw brown or no color retention, and 9 = dark green. Data was recorded on 8 Oct., 20 Nov., and 11 Dec., 2015; 1 Jan., 27 Feb., 10 Mar., 7 Apr., 6 May, 22, Oct., 21 Nov., and 22 Dec., 2016; 16 Mar., 14 Apr., 6 May, 29 Oct., 17 Nov., and 10 Dec., 2017; and 14 Mar., 20 Apr., and 6 May 2018.

‡ Means are averaged over four blocks. An asterisk (*) indicates significant differences between tall fescue seeding month according to Fisher's Protected LSD ($P \leq 0.05$).

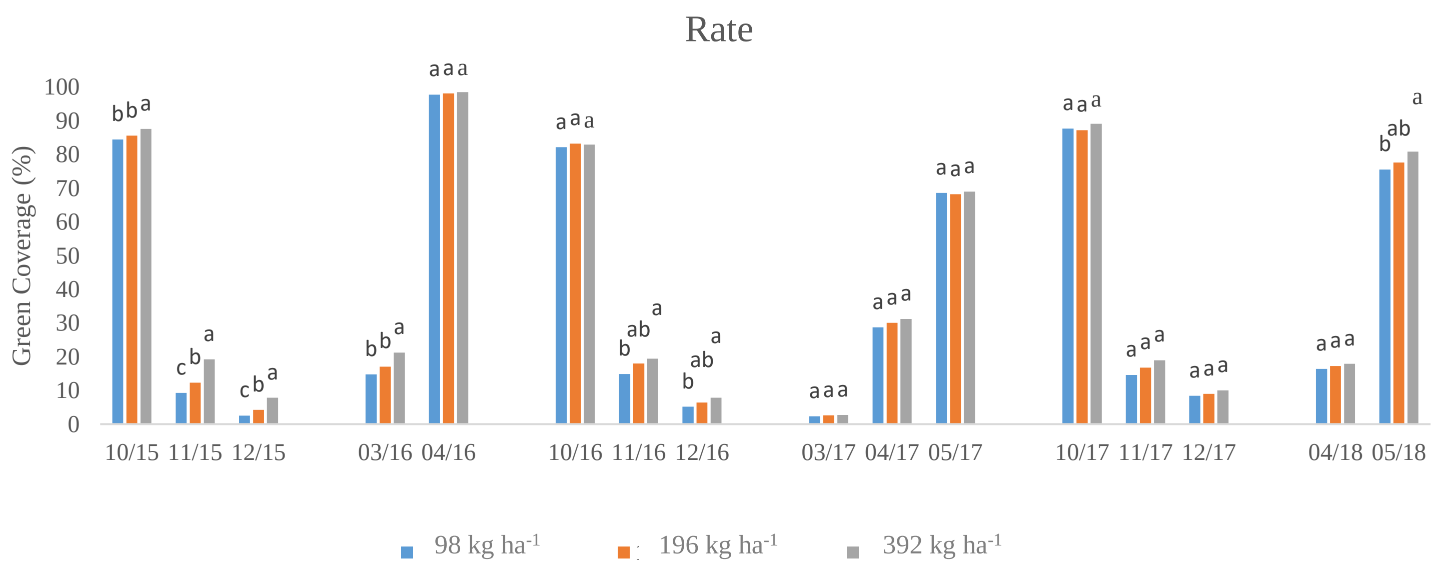
Figure 2.6 Effect of mowing height × tall fescue seeding month (June or September) × tall fescue seeding rate interaction sliced by mowing height (1.9 or 5.1 cm) × tall fescue seeding month (June or September) on turf color of a zoysiagrass-tall fescue polystand in Manhattan, KS from October 2015 to May 2018.



† Turf color was recorded on a 1-9 scale, where 1 = straw brown or no color retention, and 9 = dark green. Data was recorded on 8 Oct., 20 Nov., and 11 Dec., 2015; 1 Jan., 27 Feb., 10 Mar., 7 Apr., 6 May, 22 Oct., 21 Nov., and 22 Dec., 2016; 16 Mar., 14 Apr., 6 May, 29 Oct., 17 Nov., and 10 Dec. 2017; 14 Mar., 20 Apr., and 6 May, 2018.

‡ Means are averaged over four blocks. Means followed by the same letter in a given month are not significantly different according to Fisher's protected LSD ($P \leq 0.05$).

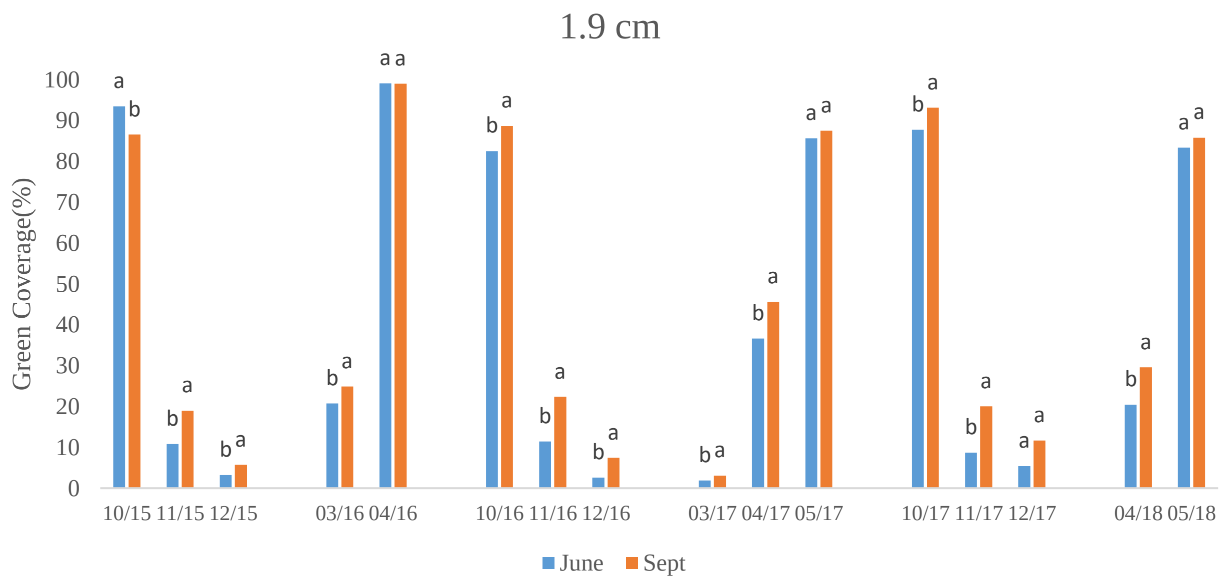
Figure 2.7 Effects of tall fescue seeding rate (98, 196, or 392 kg ha^{-1}) on green coverage by digital image analysis of a zoysiagrass-tall fescue polystand in Manhattan, KS from October 2015 to May 2018.

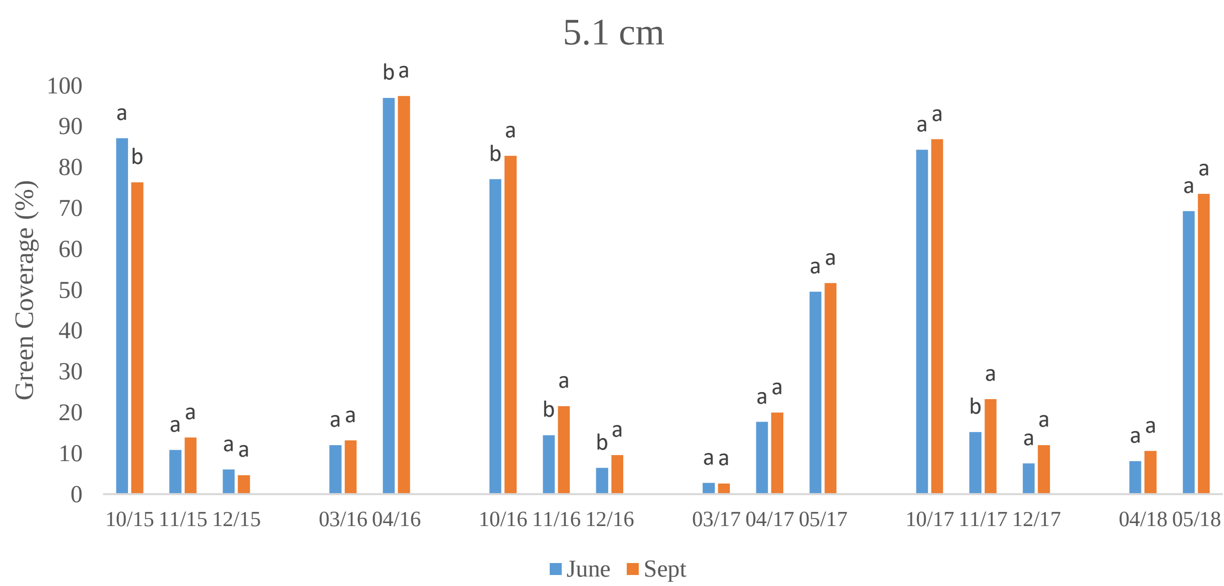


† Green coverage was determined using digital image analysis (DIA), and four photos were taken within each plot. Images were analyzed for green coverage using SigmaScan Pro 5.0. Data was recorded on 8 Oct., 20 Nov., and 11 Dec., 2015; 26 Mar., 28 Apr., 22 Oct., 21 Nov., and 4 Dec., 2016; 16 Mar., 6 Apr., 6 May, 19 Oct., 30 Nov., and 14 Dec., 2017; 20 Apr., and 21 May, 2018.

‡ Means are averaged over four blocks, two mowing heights and two tall fescue seeding months. Bars with the same letter above are not significantly different according to Fisher's protected LSD ($P \leq 0.05$).

Figure 2.8 Effects of mowing height (1.9 or 5.1 cm) × tall fescue seeding month (June or September) interaction sliced by mowing height on green coverage by digital image analysis of a zoysiagrass-tall fescue polystand in Manhattan, KS from October 2015 to May 2018.





† Green coverage was determined using digital image analysis (DIA), and four photos were taken within each plot. Images were analyzed for green coverage using SigmaScan Pro 5.0. Data was recorded on 18 Oct., 20 Nov., and 11 Dec., 2015; 26 Mar., 28 Apr., 22 Oct., 21 Nov., and 4 Dec.,

2016; 16 Mar., 6 Apr, 6 May, 19 Oct., 30 Nov., and 14 Dec., 2017; and 20 Apr., and 21 May, 2018.

‡ Means are averaged over four blocks and three tall fescue seeding rates. Bars with the same letter are not significantly different according to Fisher's protected LSD ($P \leq 0.05$).

Figure 2.9 Correlation between the green coverage using digital image analysis and tall fescue incidence using grid counts when zoysiagrass turned dormant on 11 Dec. 2015, 22 Dec. 2016, and 30 Nov. 2017 in Manhattan, KS.

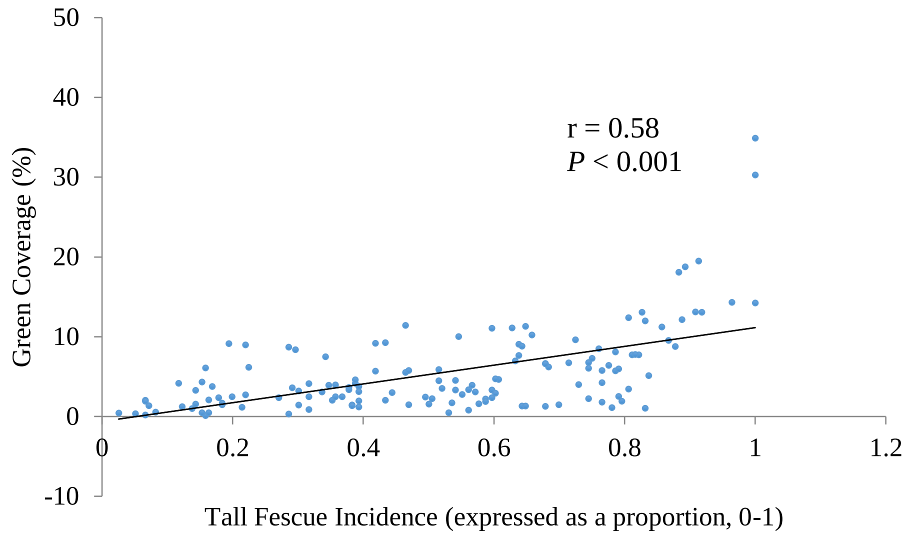


Figure 2.10 Correlation between the green coverage using digital image analysis and tall fescue incidence using grid counts when zoysiagrass turned dormant on 27 Dec. 2016 and 1 Dec. 2017 in Olathe, KS.

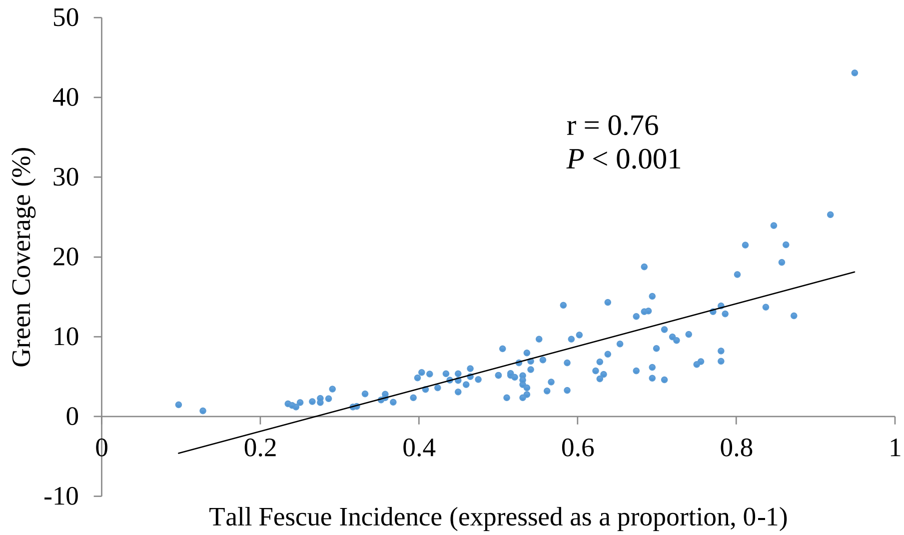


Table 2.1 Analysis of variance on the effects of mowing height (MH), tall fescue seeding month (SM), tall fescue seeding rate (SR), date, and all interactions on tall fescue (%), turf color, and green coverage of a zoysiagrass-tall fescue polystand in Manhattan and Olathe, KS.

	Manhattan, KS						Olathe, KS					
Source	df†	Tall Fescue (%)	df	Turf Color	df	Green Coverage (%)	df	Tall fescue (%)	df	Turf Color	df	Green Coverage (%)
Block	3		3		3		3		3		3	
MH	1	ns‡	1	**	1	***	1	ns	1	*	1	**
SM	1	***	1	***	1	***	1	***	1	***	1	***
MH × SM	1	***	1	***	1	**	1	*	1	ns	1	*
SR	2	***	2	***	2	***	2	***	2	**	2	**
MH × SR	2	ns	2	*	2	ns	2	ns	2	ns	2	ns
SM × SR	2	ns	2	ns	2	ns	2	**	2	ns	2	**
MH × SM × SR	2	ns	2	*	2	ns	2	ns	2	ns	2	ns
Date	5	***	19	***	15	***	4	***	8	***	8	***
MH × Date	5	***	19	***	15	***	4	***	8	***	8	***
SM × Date	5	**	19	***	15	***	4	*	8	***	8	***
MH × SM × Date	5	**	19	ns	15	ns	4	ns	8	ns	8	ns
SR × Date	10	ns	38	***	30	*	8	ns	16	*	16	ns

MH × SR × Date	10	ns	38	*	30	ns	8	ns	16	ns	16	ns
SM × SR × Date	10	ns	38	**	30	ns	8	ns	16	*	16	ns
MH × SM × SR × Date	10	ns	38	ns	30	ns	8	ns	16	ns	16	ns

† df is degree of freedom.

‡ *, **,*** significant at $P < 0.05$, 001 and 0.001, respectively.

Table 2.2 Effects of mowing height (1.9 or 5.1 cm) × tall fescue seeding month (June or September) interaction on tall fescue incidence in a zoysiagrass-tall fescue polystand in Olathe, KS from May 2016 to July 2018.

Mowing	Seeding	Tall Fescue (%)†				
height	month	5/4/16	12/27/16	7/19/17	12/1/17	7/9/18
1.9 cm	June	58b‡	46c	35c	46b	45b
1.9 cm	Sept	84a	77a	54ab	63a	58a
5.1cm	June	66b	43c	47bc	45b	39b
5.1cm	Sept	81a	65b	61a	57a	47b

† Tall fescue incidence was determined by counting the frequency at which a tall fescue plant appeared under intersections under a grid. The grid was on a 1.5 m x 1.5 m frame with 0.1 m between each of 14 gridlines in either direction to create 196-intersections. Any portion of a tall fescue leaf that fell under an intersection on the grid was counted as a "hit". Tall fescue (%) = tall fescue count frequency/196 × 100.

‡ Means are averaged over four blocks and three tall fescue seeding rates, and means with the same letter are not significantly different on a given month according to Fisher's protected LSD ($P \leq 0.05$).

Table 2.3 Effects of tall fescue seeding month (June or September) × tall fescue seeding rate (98, 196, or 392 kg ha^{-1}) interaction on tall fescue incidence of a zoysiagrass-tall fescue polystand in Olathe, KS from May 2016 to July 2018.

Seeding month	Seeding rate	Tall Fescue (%)†				
		5/4/16	12/27/16	7/19/17	12/1/17	7/9/18
June	98 kg ha^{-1}	60b‡	40b	39b	40c	41b
June	196 kg ha^{-1}	59b	41b	37b	43bc	37b
June	392 kg ha^{-1}	66b	51b	47b	52b	48ab
Sept	98 kg ha^{-1}	79a	68a	52a	58a	47ab
Sept	196 kg ha^{-1}	81a	76a	60a	63a	57a
Sept	392 kg ha^{-1}	87a	70a	60a	59a	54a

† Tall fescue incidence was determined by counting the frequency at which a tall fescue plant appeared under intersections under a grid. The grid was on a 1.5 m x 1.5 m frame with 0.1 m between each of 14 gridlines in either direction to create 196-intersections. Any portion of a tall fescue leaf that fell under an intersection on the grid was counted as a "hit". Tall fescue (%) = tall fescue count frequency/196 × 100.

‡ Means are averaged over four blocks and two mowing heights, and means with the same letter are not significantly different on a given month according to Fisher's protected LSD ($P \leq 0.05$).

Table 2.4 Mowing height main effect (1.9 or 5.1 cm) on turf color of a zoysiagrass-tall fescue polystand in Olathe, KS from November 2015 to May 2018.

Mowing	Turf Color†								
height	11/10/15	4/21/16	5/4/16	11/21/16	12/27/16	4/8/17	11/4/17	12/1/17	5/3/18
1.9 cm	4.2b‡	5.7a	6.6a	3.8a	2.1a	3.9a	4.5a	2.0a	4.7a
5.1 cm	4.6a	5.7a	6.3b	3.3a	1.9a	3.4b	3.8a	1.7a	3.0b

† Turf color was recorded on a 1-9 scale, where 1 = straw brown or no color retention, and 9 = dark green.

‡ Means are averaged over four blocks, two tall fescue seeding months and three tall fescue seeding rates, and means with the same letter are not significantly different on a given month according to Fisher's protected LSD ($P \leq 0.05$).

Table 2.5 Effects of tall fescue seeding month (June or September) × tall fescue seeding rate (98, 196, or 392 kg ha^{-1}) interaction on turf color of a zoysiagrass-tall fescue polystand in Olathe, KS from November 2015 to May 2018.

Seeding month	Rate	Turf Color†								
		11/10/15	4/21/16	5/4/16	11/21/16	12/27/16	4/8/17	11/4/17	12/1/17	5/3/18
June	98 kg ha^{-1}	2.9d‡	5.0d	6.3b	2.5c	1.6c	3.0b	3.3c	1.6d	3.6bc
June	196 kg ha^{-1}	3.3d	5.2d	6.2b	2.4c	1.3c	2.7b	3.6c	1.6d	3.3c
June	392 kg ha^{-1}	3.3d	5.2d	6.4ab	2.8c	1.5c	3.2b	3.9bc	1.7cd	3.6bc
Sept	98 kg ha^{-1}	4.9c	5.7c	6.5ab	4.0b	2.2b	4.2a	4.4ab	1.9bc	4.1ab
Sept	196 kg ha^{-1}	5.7b	6.2b	6.8a	5.0a	2.9a	4.5a	4.8a	2.3a	4.0ab
Sept	392 kg ha^{-1}	6.5a	6.8a	6.8a	4.4ab	2.7ab	4.4a	4.6a	2.0ab	4.4a

† Turf color was recorded on a 1-9 scale, where 1 = straw brown or no color retention, and 9 = dark green.

‡ Means are averaged over four blocks and two mowing heights, and means with the same letter are not significantly different on a given month according to Fisher's protected LSD ($P \leq 0.05$).

Table 2.6 Effects of tall fescue seeding month (June or September) × tall fescue seeding rate (98, 196, or 392 kg ha^{-1}) interaction on green coverage by digital image analysis of a zoysiagrass-tall fescue polystand in Olathe, KS from October 2015 to May 2018.

Seeding		Green Coverage (%)†								
month	Rate	10/8/16	11/21/16	12/27/16	4/8/17	5/26/17	10/7/17	11/4/17	12/1/17	5/3/18
June	98 kg ha^{-1}	89.1b‡	25.9c	4.7bc	40.2c	77.8bc	80.1b	30.8c	4.1c	59.9b
June	196 kg ha^{-1}	90.5ab	25.8c	3.5c	38.3c	75.0c	82.6ab	31.4c	4.0c	57.8b
June	392 kg ha^{-1}	90.9ab	32.1bc	5.2bc	41.9c	75.9c	82.3ab	37.8bc	5.8bc	60.8b
Sept	98 kg ha^{-1}	91.0ab	37.1b	10.1ab	52.1b	80.2ab	83.3ab	37.4bc	6.8ab	66.5a
Sept	196 kg ha^{-1}	91.4ab	45.0a	15.5a	60.2a	82.6a	84.8a	47.9a	9.1a	69.8a
Sept	392 kg ha^{-1}	92.6a	44.0a	13.2a	55.1ab	80.7ab	82.3ab	42.4ab	8.3a	66.3a

† Green coverage was determined using digital image analysis (DIA), four photos of each plot were taken. Images were analyzed for green coverage using SigmaScan Pro 5.0.

‡ Means are averaged over four blocks and two mowing heights, and means with the same letter are not significantly different according to Fisher's protected LSD ($P \leq 0.05$).

Table 2.7 Effects of mowing height (1.9 or 5.1 cm) × tall fescue seeding month (June or September) interaction on green coverage by digital image analysis of a zoysiagrass-tall fescue polystand in Olathe, KS from October 2015 to May 2018.

		Green Coverage (%)†								
Mowing height	Seeding month	10/8/16	11/21/16	12/27/16	4/8/17	5/26/17	10/7/17	11/4/17	12/1/17	5/3/18
1.9 cm	June	89.0b‡	29.4bc	4.4b	44.5bc	73.0c	85.0ab	39.0b	4.4b	72.5b
1.9 cm	Sept	92.5a	46.6a	15.3a	62.5a	79.6b	87.1a	49.5a	8.2a	79.6a
5.1 cm	June	91.4ab	26.5c	4.5b	35.7c	79.4b	78.3c	27.7c	4.8ab	46.5d
5.1 cm	Sept	90.9ab	37.5ab	10.6ab	49.1b	82.7a	79.9bc	35.7b	8.0ab	55.5c

† Green coverage was determined using digital image analysis (DIA), four photos of each plot were taken. Images were analyzed for green coverage using SigmaScan Pro 5.0.

‡ Means are averaged over four blocks and three tall fescue seeding rates, and means with the same letter are not significantly different according to Fisher's protected LSD ($P \leq 0.05$).

Chapter 3 - Brown Patch Occurrence in a Zoysiagrass-Tall Fescue Polystand Compared to a Tall Fescue Monostand

This chapter has been prepared using style guidelines for the journal Crop, Forage & Turfgrass Management.

Abstract

Tall fescue (*Schedonorus arundinaceus* Schreb.) is used frequently in Kansas due to its heat and drought tolerance compared to other cool-season grasses. Brown patch caused by the fungus *Rhizoctonia solani* Kühn AG-2-2 IIIB is the main disease limiting the growth of tall fescue in summer, and brown patch resistance in tall fescue cultivars is limited. Earlier research has demonstrated that polystands of zoysiagrass (*Zoysia japonica* Steud.) and tall fescue can be established successfully, with the potential to provide a quality turfgrass stand with better autumn and early spring color and reduced inputs. Our objective was to determine whether a polystand composed of a seeded zoysiagrass ('Compadre') and tall fescue ('Corona') will reduce brown patch severity while maintaining overall acceptable quality. Studies were established at the Rocky Ford Turfgrass Research Center in Manhattan, KS and Olathe Research Center, Olathe, KS in 2015. In the split plot design, natural infection by *R. solani* or a fungicide-treated control was the whole plot treatment factor, and species (tall fescue monostand and the polystand mixture) were subplots. Across both years and locations, disease severity in the tall fescue monostands was up to 27% higher than the tall fescue/zoysiagrass polystand during July through September. Turf quality was also consistently higher in the polystand compared to the monostand during peak brown patch outbreaks. Use of a tall fescue/zoysiagrass polystand is one option to reduce brown patch in transition zone lawns where the disease is common.

Introduction

Water use for landscapes has come under increasing scrutiny, and turfgrass managers and homeowners are looking for ways to maintain a quality lawn with reduced irrigation. One such way is to use warm-season rather than cool-season turfgrasses, as they generally have lower evapotranspiration rates and better drought resistance than cool-season grasses (Brain et al., 1981). Warm-season grasses lose green color in late October in Kansas, and may not green up until mid to late April. For that reason, there is interest in making swards of warm-season grasses more amenable to homeowners by considering seed mixtures of warm- and cool-season grasses.

Zoysiagrass (*Zoysia japonica* Steud.) is a warm-season grass used extensively on golf courses, and to a lesser extent, on home lawns in the transition zone. Meyer is a preferred cultivar in this region (Fry and Huang, 2004) as it exhibits good freezing tolerance (Fry and Huang, 2004; Patton and Reicher, 2007), but there are seeded cultivars of *Z. japonica* have cold hardiness comparable to Meyer (Fry and Huang, 2004). Tall fescue (*Schedonorus arundinaceus* Schreb.) is a cool-season turfgrass with better heat and drought tolerance compared to many commonly used cool-season turfgrasses. It possesses an extensive root system, and can avoid drought as long as water is available deep in the soil (Qian et al., 1997). Tall fescue is a seeded bunch grass and has a leaf texture that is comparable to seeded zoysiagrasses. These characteristics, along with its good stress tolerance, make it a promising candidate for including in mixtures with zoysiagrass.

Zoysiagrass/tall fescue mixtures were evaluated in the early 1980s at the USDA in Maryland (Kevin Morris, personal communication). Others have also demonstrated that tall fescue and zoysiagrass can be established as a seeded mixture. In China, Li and Han (2008) evaluated zoysiagrass and tall fescue mixtures under 154 lb wear roller traffic and noted that zoysiagrass was favored by low traffic, low mowing height and low N, while tall fescue was favored by high mowing, and a medium N level. Recently, in another study, we examined six methods of establishment, and of those, the best approach of the six options to establishing a mixed zoysia-tall fescue stand was to seed zoysiagrass in early summer (June of Kansas), and then interseed tall fescue in autumn (September of Kansas) (Xiang et al., 2017). More information is needed regarding how this mixture responds to disease.

Brown patch (*Rhizoctonia solani* Kühn AG-2-2 IIIB) is the main disease on tall fescue (Bonos et al., 2006; Latin, 2011; Piper and Coe, 1919) and occurs during hot, humid weather when night temperatures exceed 68 °F and leaf wetness persists for > 10 h (Smiley et al., 2005; Latin, 2011). Some tall fescue cultivars have demonstrated lower levels of susceptibility, such as 'Kentucky-31' (Yuen et al., 1994). Newer cultivars such as 'Bloodhound', 'Amity', 'Rockwell', 'Rowdy' and 'Avenger II' and 'Titanium 2LS' had statistically better ratings for brown patch than cultivars such as 'Kentucky-31', and 'Grande 3' in the 2016 NTEP evaluation conducted in Connecticut, Indiana, Kentucky, Maryland, North Carolina, and New Jersey (NTEP, 2016). However, complete resistance to brown patch in tall fescue has not been reported (Bokmeyer, 2009). When the environment is favorable for brown patch, this disease is being controlled in golf courses and the highly maintained home lawn by applying fungicides.

Mixing turfgrass species to increase host diversity may be one option to reduce disease pressure compared to monostands. For example, a study conducted in Virginia showed a mixture of tall fescue with hybrid bluegrass (*Poa pratensis* L. × *Poa arachnifera* L.) reduced brown patch in the absence of fungicides compared to monostands alone of either of species (Cutulle et al., 2013). In Missouri, researchers reported that a mixture of Kentucky bluegrass

(*Poa pratensis* L.) and perennial ryegrass exhibited about 50% less dollar spot than a monostand of perennial ryegrass (*Lolium perenne* L.) (Dunn et al., 2002). They also reported that, in the absence of fungicides, mixtures of tall fescue with other species (perennial ryegrass or Kentucky bluegrass) had less brown patch compared to a monoculture of tall fescue.

Several benefits may arise from using zoysiagrass/tall fescue mixtures. In addition to prolonging autumn color and contributing to earlier spring green-up, including tall fescue with zoysiagrass in a mixed stand may help reduce brown patch infestations on tall fescue, reducing the need for fungicides. The objective of this study was to evaluate the potential for mixtures of tall fescue and zoysiagrass to reduce infestations of brown patch compared to monostand of tall fescue.

Materials and Methods

Experiments were conducted at the Rocky Ford Turfgrass Research Center in Manhattan, KS (long. 39.13° N, lat. 96.36° W) and at the Olathe Horticulture Research and Extension Center, Olathe, KS (long. 39.48° N, lat. 95.66° W). Soil type at Rocky Ford was a silty clay loam (fine, smectic, mesic Aquertic Argiudolls) with a pH of 7.9. In Olathe, the soil type was an Oska-Martin silty clay loam with a pH of 6.9. Prior to seeding, soil was tilled and raked to prepare a seedbed.

At both locations, the experimental design was a split-plot randomized completed block design with four replicates. The main goal was to evaluate the performance of the mixture in the absence of fungicides, with comparisons to a fungicide-treated check. Therefore, preventive fungicide applications, or no preventive fungicide applications were the whole plots, and each measured 5 × 10 ft. Sub-plots consisted of: 1) a tall fescue monostand (hereafter referred to as the monostand); and 2) a zoysiagrass/tall fescue mixture (hereafter referred to as the mixture);

each measured 5 × 5 ft.

Manhattan, KS

The plot areas were treated with glyphosate (N- (phosphonomethyl) glycine, Monsanto company, St. Louis, MO) on the mixed cool-season grass sward before initiating this study. For establishment of the mixture, ‘Compadre’ zoysiagrass was seeded at 1 lb/1,000 ft^2 pure live seed (PLS) on 25 June 2015 using a shaker bottle; 3.4 oz Milorganite (Milorganite, Milwaukee, WI) 6–2–0 (N–P–K) was included in each bottle (equivalent to 0.5 lb N per 1,000 ft^2) to help with distribution of seed. ‘Corona’ tall fescue, which showed moderate tolerance to brown patch in the National Turfgrass Evaluation Program (NTEP) from 2007-2011 (NTEP, 2007-2011), was seeded at 4 lb PLS per 1,000 ft^2 mixed with 3.4 oz Milorganite in the mixture plot immediately after seeding zoysiagrass. After zoysiagrass and tall fescue had been distributed in each mixture plot, a leaf rake was dragged over each plot to increase seed-to-soil contact. Irrigation was applied several times daily with an overhead system until three weeks after seeding. Thereafter, irrigation was applied to keep the seedbed moist.

Immediately after seeding, siduron (1-(2-methylcyclohexy)-3-phenylurea) (Tupersan, Gowan Company, Yuma, AZ) was applied at 6.0 lb a.i. /acre. The plots were then covered (Germination and insect blanket, A.M. Leonard, Inc., Piqua, OH) for 6 days to help retain soil moisture and prevent soil erosion. To control broadleaf weeds, a mixture of 5.69% quinclorac (3,7-dichloro-8-quinolinecarboxylic acid; 1.0 lb a.i. /acre), 0.69% sulfentrazone (N-{2,4-dichloro-5-[4-(difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1H-1,2,4-triazol-1-yl]phenyl] methanesulfonamide; 0.1 lb a.i. /acre), 12.02% of 2,4-D (Dimethylamine salt of 2,4-dichlorophenoxyacetic acid; 2.5 lb a.i./acre), and 1.38% dicamba (Dimenthylamine salt of dicamba; 0.3 lb a.i./acre) (PBI/Gordon Corporation, Kansas City, MO) was applied on 31 July

2015. Organic based fertilizer 15–0–8 (N–P–K) (Lebanon Seaboard Corporation, Lebanon, PA) was applied at 1 lb N per 1,000 ft^2 on 9 July 2015. The plots were mowed at 1 inch beginning on 7 Aug. 2015 to help suppress weed growth.

Additional ‘Corona’ tall fescue seed was incorporated into the established mixture plots on 17 Sept. 2015. Before seeding, the plots were vertically mowed in two directions using a Billy Goat Power Rake and Overseeder (Billy Goat Industries Inc., Lee’s Summit, MO) with 1.5 inch knife spacing on a No. 4 setting to create furrows 0.3 inch deep. The power rake was pulled backwards over each plot twice in perpendicular directions, for a total of four passes per plot. The plots were then raked and debris was removed. Tall fescue seed was spread to provide PLS at 2 lb/1,000 ft^2 using a shaker bottle in perpendicular directions several times into the established mixture plot. After seeding, plots were raked with a leaf rake over the surface in two directions to help facilitate seed dropping into the furrows created. Plots newly seeded with tall fescue were watered lightly overhead three times daily for 21 days to keep the seedbed moist.

Tall fescue monostand sub-plots were established by seeding Corona tall fescue at 7 lb PLS per 1,000 ft^2 on 17 Sept. 2015. Seed was distributed in each plot using a shaker bottle as described earlier after mixing with 6.7 oz of Milorganite (equivalent to 1 lb N per 1,000 ft^2).

All plots were fertilized with urea 46–0–0 (N–P–K) at 0.5 lb N per 1,000 ft^2 on 8 Oct. 2015. In addition, N from urea was applied at 0.67 lb /1,000 ft^2 on 12 April, 1 July and 12 Sept. in 2016 and 10 May, 11 July, and 6 Sept. in 2017. Oxadiazon (3-[2,4-dichloro-5-(1-methylethoxy)phenyl]-5- (1,1-dimethylethyl)-1,3,4-oxadiazol-2(3H)-one, Bayer Environmental Science, Montvale, NJ) was applied at 3.0 lb a.i./acreon 11 Apr. 2016 and 3 Apr. 2017 to control annual grassy weeds. Turf was maintained at a 3 inch mowing height using a rotary mower and clippings were collected. During the peak brown patch season, nightly irrigation was applied from July to Sept. in 2016 and June to Sept. in 2017 to create a favorable environment for brown patch. To do this, the irrigation was scheduled to run for 10 min at 2100, 2400, 300, and 600 HR using a timer. This resulted in about 0.4 inch of irrigation each night.

Fungicide-treated whole plots were treated as follows in 2016 in Manhattan, KS: On 6 June 2016, a granular mixture of pyraclostrobin at 0.18 oz a.i. per 1,000 ft^2 + triticonazole at 0.20 oz a.i. per 1,000 ft^2 (BASF Corporation, Research Triangle Park, NC) using a shaker bottle; on 29 June, a mixture of propiconazole at 0.10 oz a.i. per 1,000 ft^2 (Lesco Spectator Ultra 1.3 fungicide, LESCO, Inc., Cleveland, OH) + azoxystrobin (Syngenta Crop Protection LLC P.O. Greensboro, NC) at 0.20 oz a.i. per 1,000 ft^2 was applied using a hand-held CO_2 sprayer equipped with two 8004EVS nozzles applied in 2.0 gal/1,000 ft^2; and on 19 July, azoxystrobin at 0.20 oz a.i. per 1,000 ft^2 was applied. In 2017, azoxystrobin at 1.0 lb /1,000 ft^2 was applied on 29 May, 19 June, 11 July, 2 Aug., and 25 Aug. using a hand-held CO_2 sprayer and previously described.

Olathe, KS

Zoysiagrass and tall fescue were seeded in the mixture plots in Olathe on 10 June 2015 using the methods described for Manhattan, with slight modifications. The original cool-season sward was treated with glyphosate in order to prepare the seedbed as described for Manhattan. Plots were irrigated using a hand-held hose each day for four weeks after seeding. Thereafter, plots were only irrigated using a hose to prevent drought stress. Otherwise, plots received only natural rainfall. To control broadleaf weeds, a mixture of 5.69% quinclorac (1.0 lb a.i. /acre), 0.69% sulfentrazone (0.1 lb a.i. /acre), 12.02% of 2,4-D (2.5 lb a.i./acre), and 1.38% dicamba (0.3 lb a.i./acre) was applied on 18 July 2015.

Additional Corona tall fescue was seeded in mixture plots as described for Manhattan on 25 Sept. 2015. On the same date, tall fescue monostand sub-plots were established as described for Manhattan. Irrigation was applied once daily by hand to mixture and monostand plots for 4 wk after planting tall fescue. On 28 Oct. 2015, a 28–0–3 (N–P–K) fast released fertilizer (LESCO Inc, Cleveland, OH) was applied to all plots at 0.5 lb N per 1,000 ft^2. Nitrogen from urea was applied at 33 kg ha^{-1} on 22 April, 30 June, and 12 Sept. in 2016 and 27 May, 19 July, and 5 Sept. in 2017. On 11 April 2016 and 7 April 2017, oxadiazon was applied at 1.0 oz a.i. per 1,000 ft^2 to prevent annual grassy weeds. The plots were maintained at a 3 inch mowing height.

A granular mixture of pyraclostrobin + triticonazole was applied at 0.18 oz a.i. per 1,000 ft^2 and 0.20 oz a.i. per 1,000 ft^2, respectively using a shaking bottle, to the fungicide-treated whole plots on 8 June. On 30 June, a granular mixture of azoxystrobin at 1.25 lb a.i. per 1,000 ft^2 + propiconazole at 3.0 lb a.i. per 1,000 ft^2 was applied using a shaking bottle. On 18 July, azoxystrobin from Heritage G at 1.24 lb a.i. per 1,000 ft^2 was applied using a shaker bottle. In 2017, azoxystrobin at 1.24 lb a.i. per 1,000 ft^2 was applied using a shaking bottle on 26 May, 16 June, 7 July, 1 Aug., and 24 Aug.

Data Collection

The percentage of tall fescue in mixture subplots was measured on 10 Dec. 2015; 14 July and 29 Dec. 2016; and 17 Nov. 2017 in Manhattan. In Olathe, the tall fescue population was determined on 11 Dec. 2015; 21 July and 27 Dec. 2016; and 27 May and 1 Dec. 2017. A 196-intersection grid that measured 5 × 5 ft with 0.3 ft between each of 14 gridlines in either direction was used to determine the amount of tall fescue in each mixture plot. Any portion of a tall fescue leaf sheath or blade that fell under an intersection on the grid was counted as a “hit”.

The composition of tall fescue in each mixture plot was calculated as: Tall fescue incidence (%) = tall fescue "hits"/196 × 100.

To evaluate brown patch severity in Manhattan, plots were rated weekly by visually estimating the percent of each plot exhibiting symptoms from 24 May to 1 Oct. 2016 and 9 June to 4 Sept. 2017; the study area in Olathe was rated every 1 to 3 wk from 1 June to 8 Oct. 2016 and 27 May to 6 Oct., 2017. Symptomatic tall fescue was routinely cultured in the lab to confirm presence of the pathogen. On 2 Sept. 2017 in Olathe, Drechslera leaf spot (*Drechslera spp.*) was detected in tall fescue. Symptoms were not distinguishable from brown patch when looking across a plot, and were included in the ratings when plots were rated on 2 Sept. and 16 Sept. 2017. Turf quality was rated monthly from May to October on a 1-9 scale, where 1 = completely brown, 6 = minimum acceptable quality, 9 = optimum color, density, and uniformity (Morris and Shearman, 1999).

Brown patch severity was also tested using digital image analysis. Four photos of each plot were taken with a Nikon D5000 digital camera (Nikon Inc., Tokyo, Japan) from July to Oct in 2016 and June to Oct in 2017. The camera was placed above each plot at 0.56 m height under a light box (0.51 m × 0.61 m × 0.56 m). The image format was JPEG, with an image size of 4288 × 2848 pixels and 1.6 megabytes. Prior to taking photographs, debris was removed by a leaf blower. Images were analyzed for percent green cover using Sigma Scan software Pro 5.0 (ver. 5.0 SPSS Science Marking Dept, Chicago, IL) (Richardson, 2001). The macro threshold settings were adjusted to the following: hue = 47 to 107 and saturation = 0 to 100. Brown patch severity was calculated as: % brown patch = 100 - % green cover.

Weather data at Manhattan and Olathe, KS were collected from weather stations on site.

Data Analysis

Due to frequency differences for data collection at each site, analysis was conducted separately for each location. Species and treatment were considered as fixed effects, and block and year were considered as random effects. Residual normality was tested. When assumptions of normality were not met, data was modified with log transformation for analysis and was back transformed for data presentation. All the reported variables were subjected to analysis of variance (ANOVA) and analyzed in Proc MIXED with repeated measures of SAS (version 9.4; SAS Institute, Cary, NC). Degrees of freedom were adjusted using the Kenward-Roger adjustment (Kenward and Roger, 2009). Mean separations were performed using pair-wise comparisons according to Fisher's protected least significant difference test at $P = 0.05$.

Species Effect on Brown Patch Disease Resistance

Comparison of Visual Assessments Versus Digital Images

There were significant correlations between the visual assessments and digital image analysis. In Manhattan the correlation coefficients were r = 0.62, $P < 0.0001$ in 2016 and r = 0.44, $P < 0.0001$ in 2017. For Olathe, the correlation coefficients were r = 0.30, $P = 0.0013$ in 2016, and r = 0.66, $P < 0.0001$ in 2017. Considering that the digital image analysis is correlated to visual assessment, results were only reported using visual assessment in this chapter.

Manhattan, KS

Tall fescue was present in 65.7, 85.1, 87.5 and 76.1% of the grid counts in Dec. 2015, July 2016, Dec. 2016, and Dec. 2017, respectively, in the fungicide-treated mixture plots and 63.0, 73.6, 74.1 and 77.3%, respectively, in the non-treated plots. Among these rating dates, higher tall fescue incidence occurred in the fungicide-treated plots than non-treated turf in July

2016 and Dec. 2016. A species × date interaction occurred for brown patch and turf quality. There was no interaction between fungicide and species, so fungicide-treated and non-treated are combined in order to compare the species main effect.

Brown patch was first observed in 2016 in late May, earlier than expected. Fungicide had not been applied at the time the disease was first observed, which minimized differences in brown patch between fungicide-treated and non-treated plots early in the experiment. Brown patch affected an average of 19% of the monostand and 6% of the mixture when disease was first observed (Figure 3.3). Higher levels of brown patch occurred in the monostand compared to the mixture on 8 of 17 dates in 2016.

In 2017, brown patch first occurred on 18 July when monostands had an average of 3% and mixtures exhibited 0.3% severity (Figure 3.3). Conditions were cooler and drier in 2017 compared to 2016, which was less conducive to brown patch. In 2016, there were with 57 nights with the low temperature above 68 °F vs. 32 nights in 2017 between May and October. Furthermore, 24.4 inch of rain fell during this period in 2016 vs. 14.8 inch in 2017 (Figure 3.1). The highest disease severity observed on any date was 19% in the monostand on 24 May 2016. In 2017 there were no differences in brown patch between the monostand and the mixture. (Figure 3.3)

Higher turf quality was observed in the mixture compared to the tall fescue monostand on 5 of 18 dates in 2016 (Figure 3.4). The monostand had quality superior to that of the mixture on only 2 of 9 dates in 2017 due to lack of brown patch. Besides one date for both years, the quality across fungicide-treated and non-treated turf in the mixture plots never dropped below a value of 6.

Olathe, KS

Months and the percentage of tall fescue observed using grid counts in the fungicide-treated polystand mixture was: Dec. 2015, 69.0%; July 2016, 47.1%; Dec. 2016, 73.6%; May 2017, 61.0%; Dec. 2017, 64.3%. In the nonfungicide treated polystand mixture, tall fescue observed using grid counts was: Dec. 2015, 73.2%; July 2016, 47.6%; Dec. 2016, 76.1%; May, 2017, 68.4%; and Dec., 2017, 44.1%. No significant differences were detected on any date when comparing tall fescue incidence in the fungicide-treated and non-fungicide treated plots. A fungicide × species × date interaction occurred for brown patch and turf quality (Table 1). Therefore data are presented separately for fungicide-treated and non-treated plots to compare the species effect. In 2016, fungicide-treated plots consistently had less brown patch than non-treated plots (Figure 3.5). In the non-fungicide treated plots, there were 4 dates out of 8 with higher disease severity in the monostand compared to the mixture, and the mixture had an average of less than 5% brown patch while there was up to 25% brown patch severity in the monostand (Figure 3.5 A). In the plots treated with fungicides, disease never exceeded 10% severity. There was one date out of eight on which the monostand had higher brown patch severity than the mixture (Figure 3.5 C).

In 2017, brown patch was first observed on 27 May, with an average of 10% in the monostands, but less than 1.5% in the mixtures in both the fungicide-treated and non-treated plots (Figure 3.5 B and D). Like in Manhattan in 2017, night temperatures were generally cooler compared to 2016. In 2017, there were 30 nights on which the low temperature was > 68 °F between May and October in 2017 compared to 61 nights in 2016. However, the precipitation between June and August 2017 totaled 20.7 inches (vs. 15.2 inches in 2016, Figure 3.2), which may have led to the increased disease pressure which approached 20% of the monostand plot area in fungicide-treated turf before 2 Sept. In addition, on the 2 and 16 Sept. rating dates, “disease severity” approached 40% because Drechslera was contributing to turf decline, mixed with some brown patch activity, and its symptoms were difficult to distinguish from brown patch when rating across entire plots. Overall, the monostand had greater brown patch severity than the mixture on 8 of 9 dates in the non-fungicide treated plots (Figure 3.5 B) and 6 out of 9 dates in the fungicide-treated plots (Figure 3.5 D).

In the absence of fungicides, turf quality was higher in mixtures compared to monostands on 3 of 8 dates in 2016 and 7 of 9 dates in 2017 (Figure 3.6 A and B). In fungicide-treated plots, there were 4 out of 8 dates in 2016 on which the mixture had better quality than the monostand (Figure 3.6 C and D). However, on 8 Oct. 2016, higher quality was observed in the monostand compared to the mixture, which resulted because the zoysiagrass in the mixture was beginning to lose green color. In the fungicide-treated plot, there was one date quality in the mixture dropped below 6 in 2016. In 2017, there were 6 out of 9 dates that the mixture had better quality than the monostand when fungicides were applied. For the mixture plot treated with fungicide, a turf quality rating lower than 6 occurred only before 15 June and after 18 August, but acceptable quality occurred during the active disease period.

Discussion

In one year at Manhattan, and in both years at Olathe, the zoysiagrass/tall fescue polystand had less brown patch than a tall fescue monostand. Others have also reported reductions in brown patch in tall fescue when using mixtures with other turfgrass species. In Missouri, mixing tall fescue with perennial ryegrass or Kentucky bluegrass reduced brown patch by up to 50% compared to using a tall fescue monostand (Dunn et al., 2002). In North Carolina, mixing Kentucky bluegrass at 5% and 10% by weight with ‘Coronado’, a brown patch-susceptible tall fescue cultivar, significantly reduced brown patch disease incidence on several rating dates (Reynolds et al, 2005). Likewise, in Virginia, mixing tall fescue with hybrid bluegrass reduced brown patch incidence by up to 21% compared to monostands of either species (Cutulle et al., 2013).

Lower levels of brown patch in the zoysiagrass-tall fescue mixture quite possibly occurred because fewer plants of the disease-susceptible species were present in the mixture plots (Wolfe, 1985). Having zoysiagrass plants interspersed among tall fescue plants could also create a barrier effect and prevent the bridging of mycelium from one plant to another (Wolfe, 1985). In Nebraska, in a tall fescue monostand, higher canopy density (measured as leaf blades per unit area and verdure dry matter) favored brown patch infection compared to cultivars with lower canopy density, possibly due to higher humidity within the canopy and the extended periods of leaf wetness (Yuen, 1994). In our study, plant density was not explicitly measured, but overall density levels in the two were comparable with no obvious differences in the density of the stand. It seems unlikely that this would have been a primary contributor to reduced brown patch in the mixture.

In addition to the polycultures of species, combining cultivars in a mixture has also been reported to suppress disease on other crops. Cox et al. (2004) demonstrated that disease severity of tan spot (*Pyrenophora tritici-repentis*) and leaf rust (*Puccinia triticina*) on wheat (*Triticum aestivum*) were both lower in the cultivar blends compared to the monocultures. Likewise, in Oregon, mixing wheat cultivars with differing susceptibility to stripe rust (*Puccinia striiformis*) was found to reduce disease severity in 27 out of 28 different cultivar blends compared to the mean of pure stands (Finckh and Mundt, 1992). Similar results have been reported on genetically modified wheat lines with different race-specific resistances to powdery mildew

(*Blumeria graminis* f.sp. *tritici*) (Zeller et al., 2012). Their study showed that plots which included two transgenetic wheat lines had less powdery mildew infection and therefore, had higher seed yield compared to the plots with one transgenic line. In Africa, the severity of angular leaf spot (*Phaeoisariopsis griseola*) was low in farmer blends of local bean (*Phaseolus vulgaris*) with supplementation of 25% or more resistant lines (Pyndji and Trutmann, 1992). In a study with oats, Leonard's models (Leonard, 1969) were generated. It predicted a logarithmic decrease between disease severity and the rate of susceptible and resistant cultivar within the mixture. Given this model, disease resistance level increases with the number of genotypes found in the mixture. However, mixing a large number of cultivars is not always practical (Mundt, 2002). For small grain crops and many other agronomic crops, mixtures include 2 to 4 varieties are common as the mixing part is likely being done by the seedsmen (Mundt, 2002).

Mixing species with comparable color and texture and diverse resistances to diseases is a feasible strategy for disease control in the turfgrass systems. Mixing hosts with different species could be one option when resistance on the potential diseases cannot be found on one desired cultivar or species. Further study is necessary to determine the mechanism whereby mixtures reduce brown patch compared to the tall fescue monostand.

References

Biran, I., B. Bravdo, I. Bushkin-Harav, and E. Rawitz. 1981. Water consumption and growth rate of 11 turfgrasses as affected by mowing height, irrigation frequency, and soil moisture. Agron. J. 73:85-90.

Bokmeyer, J.M., S.A. Bonos, and W.A. Meyer. 2009. Inheritance characteristics of brown patch resistance in tall fescue. Crop Sci. 49:2302-2308.

Bonos, S.A., B.B. Clarke, and W.A. Meyer. 2006. Breeding for disease resistance in the major cool-season turfgrasses. Annu. Rev. Phytopathol. 44:213-234.

Cox, C.M., K.A. Garrett, R.L. Bowden, A.K. Fritz, S.P. Dendy, and W.F. Heer. 2004. Cultivar mixtures for the simultaneous management of multiple diseases: Tan spot and leaf rust of wheat. Phytopathology 94:961-969.

Cutulle, M.A., J.F. Derr, D. McCall, B. Horvath, and A.D. Nichols. 2013. Impact of hybrid bluegrass and tall fescue seeding combinations on brown patch severity and weed encroachment. HortScience 48:493-500.

Dunn, J.H, E.H. Ervin, and B.S. Fresenburg. 2002. Turf performance of mixtures and blends of tall fescue, Kentucky bluegrass, and perennial ryegrass. HortScience 37: 214-217.

Finckh, M.R. and C.C. Mundt. 1992. Plant competition and disease in genetically diverse wheat populations. Oecologia 91:81–92

Fry, J.D., and B. Huang. 2004. Applied turfgrass science and physiology. John Wiley & Sons, Hoboken, NJ.

Kenward, M.G. and J.H. Roger. 2009. An improved approximation to the precision of fixed effects from restricted maximum likelihood. Computational Statistics & Data Analysis 53:2583-2595.

Latin, R. 2011. A practical guide to turfgrass fungicides. American Phytopathological Society Press. St. Paul, MN.p.186-188.

Leonard, K.J. 1969. Factors affecting rates of stem rust increase in mixed plantings of susceptible and resistant oat varieties. Phytopathology 59:1845–50.

Li, D., and L. Han. 2008. Managing mixtures of tall fescue (*Festuca arundinacea* Schreb) and zoysiagrass (*Zoysia japonica* Steud.) for athletic turf. Korean J. Turfgrass Sci. 22:197–216.

Morris, K.N. and R.C. Shearman. 1999. NTEP turfgrass evaluation guidelines. National Turfgrass Evaluation Program, Beltsville, Md. <http://www.ntep.org/pdf/ratings.pdf>

Mundt, C.C. 2002. Use of multiline cultivars and cultivar mixtures for disease management. Annu Rev Phytopathol 40:381-410.

National Turfgrass Evaluation Program. 2011. The 2006 national tall fescue test: Brown patch (warm temperature) ratings of tall fescue cultivars. National Turfgrass Evaluation Program, Beltsville, MD. <http://www.ntep.org/data/tf06/tf06_12-9/tf0612t27.txt>.

National Turfgrass Evaluation Program. 2016. The 2012 national tall fescue test: Brown patch (warm temperature) ratings of tall fescue cultivars. National Turfgrass Evaluation Program, Beltsville, MD. <http://www.ntep.org/data/tf12/tf12_17-8/tf1217t30.txt>.

Patton, A.J. and Z.J. Reicher. 2007. Zoysiagrass species and genotypes differ in their winter injury and freeze tolerance. Crop Sci. 47:1619-1627.

Piper, C.V. and H.S. Coe. 1919. Rhizoctonia in lawns and pastures. Phytopathology 9:89–92.

Pyndji, M.M., and P. Trutmann. 1992. Managing angular leaf spot on common bean in Africa by supplementing farmer mixtures with resistant varieties. Plant Dis. 76:1144-1147.

Qian, Y.L., J.D. Fry, and W.S. Upham. 1997. Rooting and drought avoidance of warm-season turfgrasses and tall fescue in Kansas. Crop Sci. 37:905-910.

Reynolds, W.C., E.L. Butler, H.C. Wetzel, A.H. Bruneay, and L.P. Tredway. 2005. Performance of Kentucky bluegrass-tall fescue mixtures in the southeastern United States. Int. Turfgrass Soc. Res. J.10:525-530.

Richardson, M.D. 2001. Quantifying turfgrass cover using digital image analysis. Crop Sci. 41:1884–1888.

Smiley, R.W., P.H. Dernoeden, and B.B. Clarke. 2005. Compendium of turfgrass diseases. American Phytopathological Society Press. St. Paul, MN.

Wolfe, M.S. 1985. The current status and prospects of multiline cultivars and variety mixtures for disease control. Annu. Rev. Phytopathol. 23:251–273.

Xiang, M., J. Fry, and M. Kennelly. 2017. Evaluating zoysiagrass-tall fescue mixtures in Kansas. 2017 Turfgrass Research. Kansas Agricultural Experiment Station. <http://newprairiepress.org/kaesrr/vol3/iss4/11/>

Yuen, G.Y., L.J. Giesler, and G.L. Horst. 1994. Influence of canopy structure on tall fescue cultivar susceptibility to brown patch disease. Crop Prot. 13:439–442.

Zeller, S.L., O. Kalinina, D.F. Flynn, and B. Schmid. 2012. Mixtures of genetically modified wheat lines outperform monocultures. Ecol Appl. 22: 1817-1826.

Figure 3.1 Monthly average air temperatures, and total precipitation from April to October in 2016 and 2017 in Manhattan, KS. Weather data was collected from an on-site weather station close to the research area.

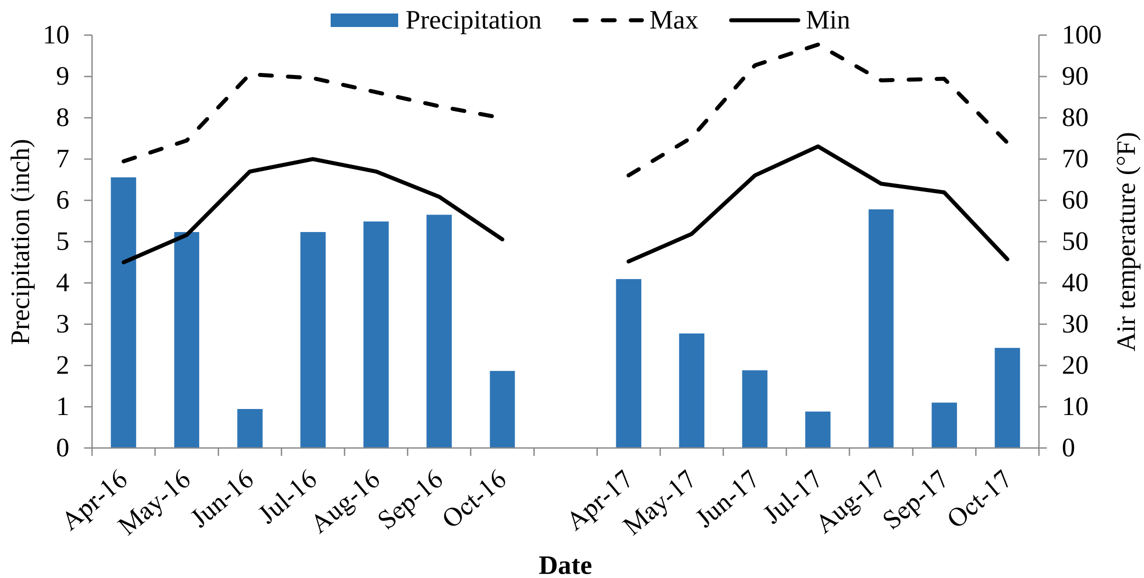


Figure 3.2 Monthly average air temperatures, and total monthly precipitation from April to October in 2016 and 2017 in Olathe, KS. Weather data was collected from an on-site weather station close to the research area.

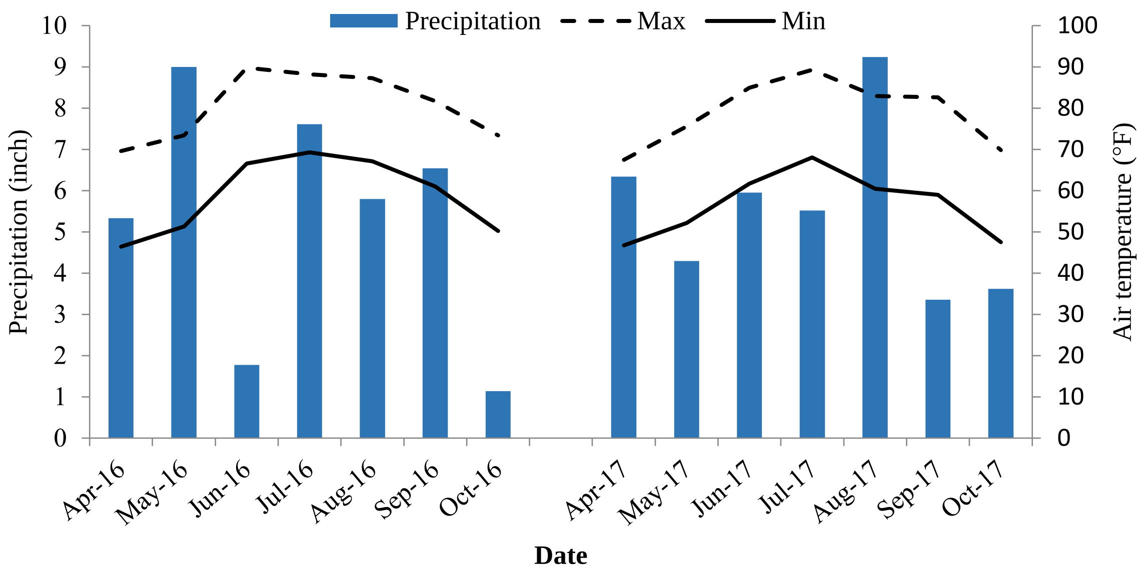


Figure 3.3 Species × date interaction for effects on brown patch in a tall fescue monostand or zoysiagrass/tall fescue mixture in Manhattan, KS in 2016 and 2017. Percentage brown patch was averaged over fungicide-treated and non fungicide-treated plots. Asterisks indicate that means between the mixture and tall fescue monostand are significantly different ($P < 0.05$). The red dots on the trend line indicate the rating dates, which correspond to the date on x-axis.

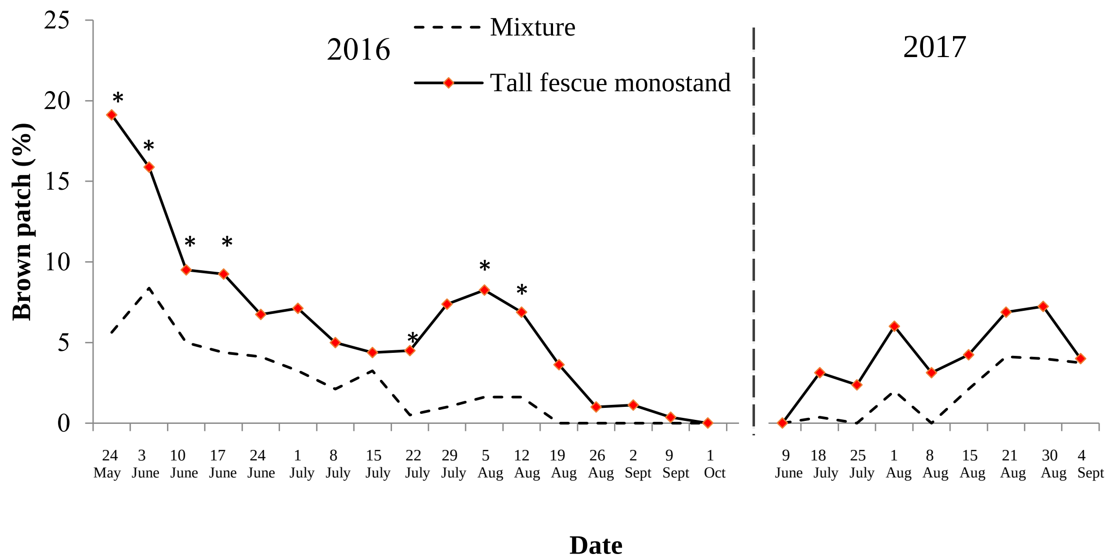


Figure 3.4 Species × date interaction for effects on turf quality in a tall fescue monostand or zoysiagrass/tall fescue mixture in Manhattan, KS in 2016 and 2017. Turf quality was averaged over fungicide-treated and non fungicide-treated plots. Asterisks indicate that means between the mixture and tall fescue monostand are significantly different ($P < 0.05$). The red dots on the trend line indicated the rating dates, which correspond to the date on x-axis. Minimal acceptable turf quality is 6, and is indicated with the blue line.

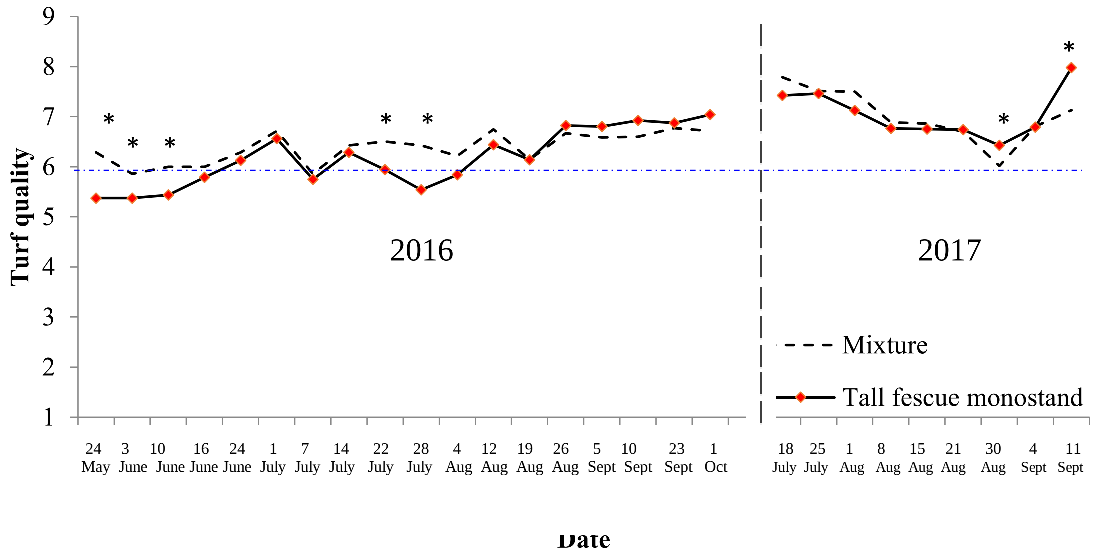
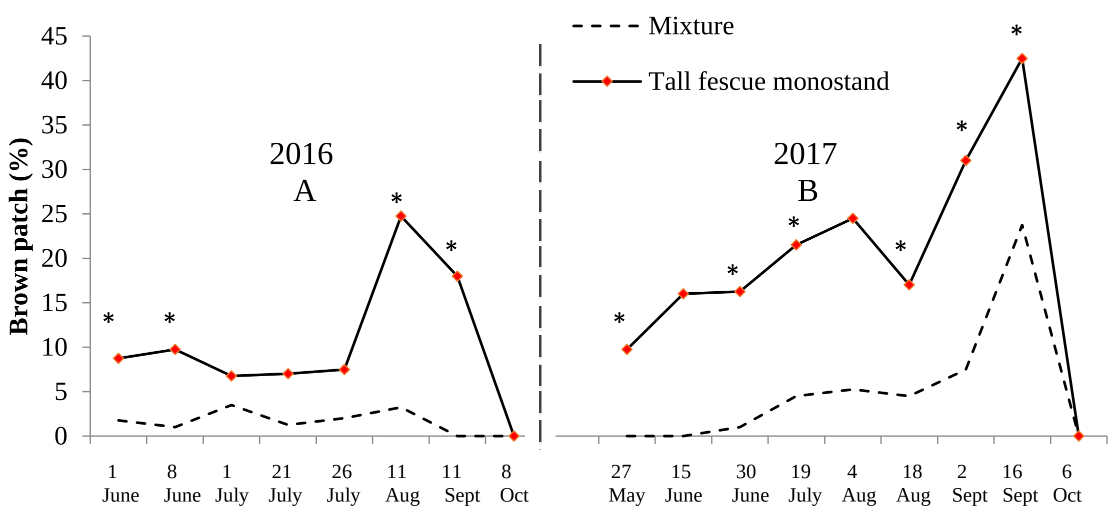


Figure 3.5 Fungicide × species × date interaction for effects on brown patch in a tall fescue monostand or zoysiagrass/tall fescue mixture in Olathe, KS in 2016 and 2017. Arrows indicate the dates when fungicide was applied. Asterisks indicate that means between the mixture and tall fescue monostand are significantly different ($P < 0.05$). The red dots on the trend line indicate the rating dates, which correspond to the date on x-axis.

Non fungicide-treated



Fungicide treated

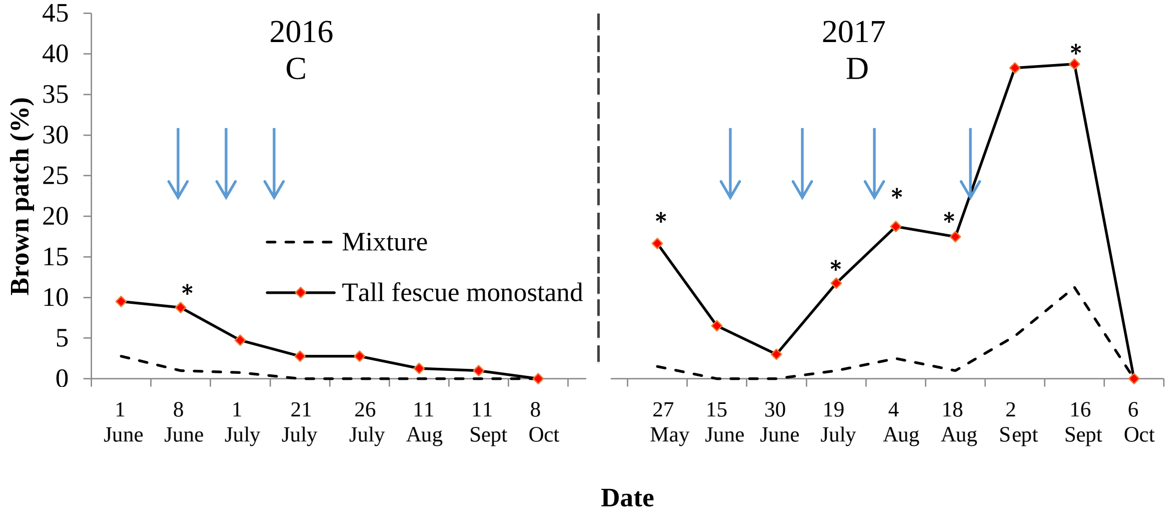
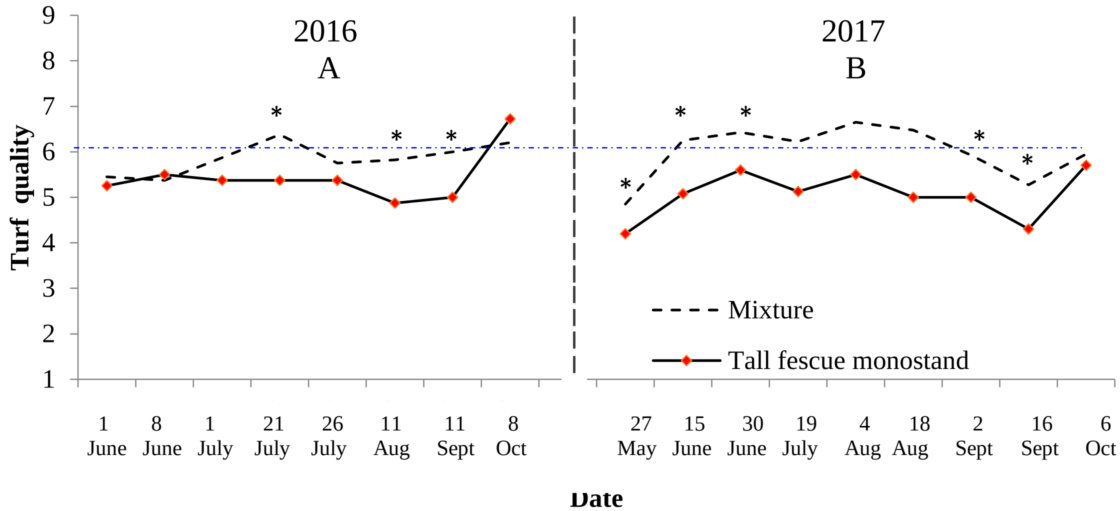


Figure 3.6 Fungicide × species × date interaction for effects on turf quality in a tall fescue monostand or zoysiagrass/tall fescue mixture in Olathe, KS in 2016 and 2017. Arrows indicate the dates when fungicide was applied. Asterisks indicate that means between the mixture and tall fescue monostand are significantly different ($P < 0.05$). The red dots on the trend line indicated the rating dates, which correspond to the date on x-axis. Minimal acceptable turf quality is 6, and is indicated with the blue line.

Non fungicide-treated



Fungicide treated

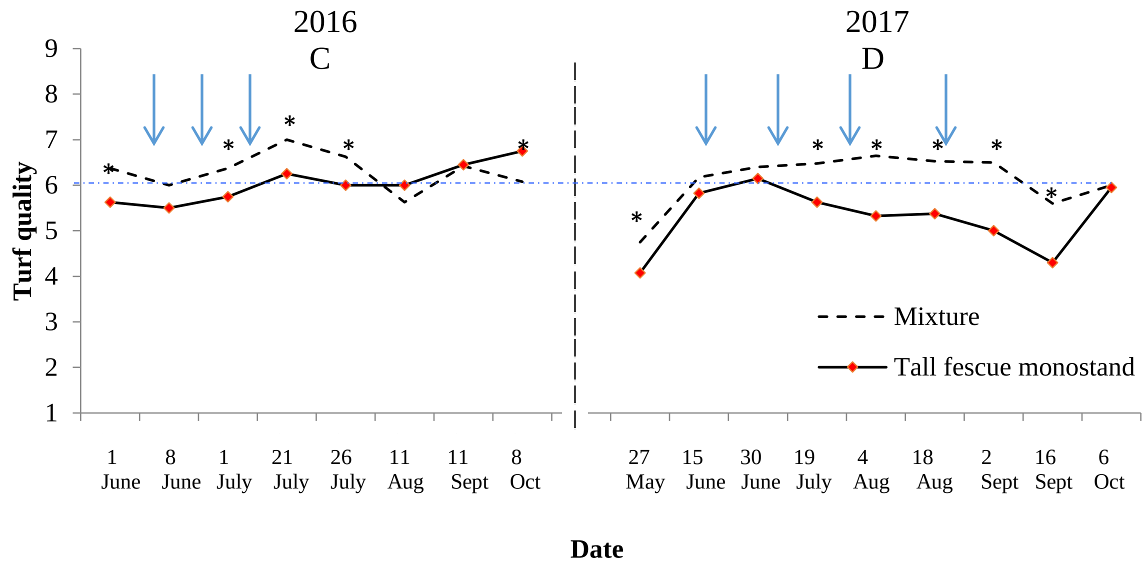


Table 3.1 Analysis of variance on the effects of treatment, species, date and their interaction on brown patch and turf quality in Manhattan and Olathe, KS.

	Manhattan, KS				Olathe, KS			
Source	df	Brown patch (%)	df	Turf quality	df	Brown patch (%)	df	Turf quality
Block	3		3		3		3	
Fungicide	1	* †	1	ns	1	** W	1	*
Species	1	**	1	ns	1	***	1	***
Fungicide × Species	1	ns	1	ns	1	ns	1	ns
Date	27	***	27	***	15	***	15	***
Fungicide × Date	27	***	27	*	15	***	15	*
Species × Date	27	***	27	***	15	***	15	***
Fungicide × Species × Date	27	ns	27	ns	15	**	15	*

† *, **,*** significant at P < 0.05, 001 and 0.001, respectively.

Chapter 4 - Screening *Zoysia* spp. for Large Patch Tolerance in the Transition Zone

This chapter has been prepared using style guidelines for Crop Science.

Abstract

Cold hardiness is the primary trait that limits the long-term survival of zoysiagrass (*Zoysia* spp.) in the transition zone. Furthermore, large patch disease caused by *Rhizoctonia solani* (AG 2-2 LP) is a serious problem on zoysiagrass. Improved cultivars with large patch resistance are desired in the transition zone, which could reduce fungicide requirements and maintenance costs. TAES 5645, a *Z. japonica* genotype that exhibited partial tolerance to large patch in preliminary studies, was used as a breeding parent and crossed with 22 cold hardy zoysiagrasses, resulting in 2,858 progeny. These progeny were evaluated for cold hardiness and agronomic traits in small non-replicated plots. Sixty progeny were identified and planted in larger, replicated plots in 2015. The plots were managed under golf course fairway conditions. In autumn 2016, *R. solani* was inoculated in plots in Manhattan, KS and Fayetteville, AR. Plots were evaluated for large patch development. KS and AR in spring 2017, 'Meyer' had >30.0% plot area affected by large patch, higher than most progeny. Progeny showed a wide range of variability in large patch tolerance. Among this group of experimental zoysiagrasses, there are promising progeny that have less susceptibility to large patch, such as TAES 6099-151, TAES 6119-179, TAES 6102-307, TAES 6099-69, and TAES 6100-146.

Introduction

Managing turfgrass in the transition zone is difficult due to temperature extremes. Zoysiagrass (*Zoysia spp.*) is attractive to turfgrass managers in the transition zone due to its heat tolerance and lower requirements for fertilizer, pesticides, and water compared to cool-season grasses. In addition, some zoysiagrass species and cultivars exhibit good cold tolerance.

Zoysiagrass is comprised of several warm-season turfgrass species native to Asia and the South Pacific. Japanese lawngrass (*Zoysia japonica* Steud.) and Manilagrass (*Zoysia matrella* L. Merr.) are the two species most widely used, and from which most cultivars have been developed. *Z. japonica* has excellent cold, heat, and drought resistance and requires fewer cultural inputs compared with cool season grasses (Beard, 1973; Fry and Huang, 2004; Fry et al., 2008).

‘Meyer’ zoysiagrass (*Z. japonica*) has been used in the U.S. transition zone for over 60 years (Fry et al., 2008). Among other characteristics, Meyer is cold hardy and has low maintenance requirements. However, it lacks the fine texture and high density found in *Z. matrella* cultivars which are used in the southern U.S. (Fry and Dernoeden, 1987). Meyer is also susceptible to large patch disease caused by *Rhizoctonia solani* Kühn (AG) 2-2 LP (Patton and Reicher, 2007).

Researchers at K-State have worked with those at Texas A&M AgriLife Research-Dallas since 2004 to develop hybrid zoysiagrasses which have cold hardiness that comparable to Meyer, but quality comparable to *Z. matrella* cultivars. From this effort, ‘Chisholm’ (*Z. japonica*) was released in 2011, breeding code DALZ 0102 (Chandra et al., 2014). After that, a finer texture cultivar, ‘Innovation’ zoysiagrass (evaluated as KSUZ 0802) was released in 2015, which is a hybrid between ‘Cavalier’ zoysiagrass (*Z. matrella*) and Chinese Common (*Z. japonica*) (Fry and Chandra, 2015).

Compared to cool season species, zoysiagrass is relatively free of disease issues. However, large patch (*Rhizoctonia solani* AG 2-2 LP) is the primary disease on zoysiagrass (Green et al., 1993), and it can significantly reduce the utility and aesthetics of the sward. The pathogen infects and colonizes zoysiagrass species in spring and fall during cool, wet conditions. The disease symptoms normally show up two to eight weeks after spring green-up and before grass enters dormancy in autumn (Green et al., 1994; Smiley et al., 2005). During infection, water soaked, reddish brown or black lesions may be present on the lower sheath tissue and the infected tillers may appear yellow-orange to orange in color. The initial symptoms start with small infected areas and can expand into off-color patches measuring several meters in diameter with orange margins (Smiley et al., 2005). Leaf sheaths can be easily pulled out from the crown after disease infection (Aoyagi et al., 1998). Large patch symptoms fade during summer months when temperatures favor shoot and root growth of zoysiagrass (Green et al., 1993). The symptoms often recur at the same locations in successive years with the expansion rate up to 1 meter annually (Aoyagi et al., 1998; Obasa et al., 2012; Smiley et al., 2005; Spurlock, 2009). Compacted soils with poor drainage favor the disease, especially when accompanied by excessive rain or irrigation (Green et al., 1993). With the spread of plant debris, clustered patches may develop around the original patch (Spurlock, 2009). Large patch can lead to a less dense turf canopy, increased weed encroachment, and reduced overall turf quality, which eventually reduces playability and aesthetics.

Cultural practices can influence large patch development. For example, raising the mowing height can suppress large patch. In Kansas, disease damage was reduced at 4.5 and 5.1

cm mowing heights compared to 1.2 or 2.5 cm (Green et al., 1994). Timing N application and sources of N fertilizers are known to affect other turf disease systems, such as brown patch in tall fescue which is caused by *R. solani* AG 1. Specifically, nitrogen fertilizer applied during summer, when brown patch is active, increases disease severity (Burpee, 1995). However, fertilizer sources and application timing have been reported as having no effect on large patch disease development. In Kansas, Obasa et al. (2013) demonstrated that Meyer zoysiagrass treated with N from urea (46-0-0) in spring and fall (90 kg $ha^{-1}year^{-1}$) when disease was active had no more large patch than turf treated with polymer-coated urea (41-0-0) during summer at the same rate. Similarly, Miller et al. (2016) reported that spring or fall nitrogen applications did not result in higher large patch development compared to summer fertilization. Research has shown variable results with other cultural practices, such as core aerification. In Arkansas, an increase in disease incidence was reported one month after core aerification when disease was active (Spurlock, 2009). They also observed an effect of spreading the inoculum and the formation of new patches. However, in KS, no effect was observed on large patch disease with annual core aerification in summer (Obasa et al., 2013). Similar results have been reported by Pan et al. (2017), who observed that aerification + top dressing did not affect large patch in MO.

Though in prior studies various cultural practices reduced large patch development, they did not provide acceptable control. To achieve acceptable control, professional turf managers commonly apply fungicides. In Kansas, one fall fungicide application, when thatch temperature ranged between 17.8 to 23.2 °C was effective in suppressing large patch compared to nontreated controls for the following spring (Obasa et al., 2017). However, cost for applications can be up to $865 ha^{-1} annually (Genovesi and Chandra, 2013). Additionally, fungicide applications vary in efficacy (Earlywine and Miller, 2015), and a follow – up, curative application may sometimes be needed. Furthermore, novel fungicide spray strategies may be required in order to achieve higher fungicide efficacy. Benelli et al. (2018) reported that applying fungicide on stems or sheaths reduced large patch severity compared with leaves in growth chamber studies, which may have implications for field application strategies. More improved cultivars with good cold hardiness and large patch tolerance are desired in the transition zone, which could reduce fungicide requirements and maintenance costs.

Previous studies demonstrated a broad range of disease severity among zoysiagrass germplasm (Flor, 2017; Obasa et al., 2012; Reicher, 2004). With the lack of full disease reduction from cultural controls, and the costs associated with fungicides, resistant varieties would be a benefit to turfgrass managers. In a preliminary study, breeders at Texas A&M developed new progeny with potential of large patch disease resistance. Researchers at Texas A&M identified one genotype of *Z. japonica*, TAES 5645, which exhibited partial tolerance to the pathogen that causes large patch in preliminary trials. This genotype was used as a breeding parent and crossed with 22 cold-hardy zoysiagrasses. Controlled hand pollinations were made using the method described by Chandra et al. (2017) at Texas A&M AgriLife Research–Dallas.

The resulting 2858 progeny were evaluated for cold hardiness and agronomic traits (establishment rate, coverage, overall quality, color and texture) in small (ranged from 0.45 m by 0.45 m to 0.9 m by 0.9 m), non-replicated plots in Manhattan, KS, West Lafayette, IN, and Dallas TX from 2012 to 2014 (Braun, 2014). From this work, 60 progeny were identified for further evaluation in larger plots (Table 4.1.). The objectives of this study were to evaluate those 60 experimental zoysiagrass genotypes and identify one or more potential new cultivars, which have tolerance to large patch.

Materials and Methods

Field experiments were conducted in Manhattan, KS (long. 39.13° N, lat. 96.36° W) and in Fayetteville, AR (36.7° N, 94.2° W) from 2015 to 2018. Soil type was a silty clay loam (fine, smectitic, mesic, Aquertic Argiudoll) with a pH of 7.3 in Manhattan and a fine-silty, mixed, mesic Typic Fragiudalt (USDA–NRCS, 2017) with an average pH of 6.2 in Fayetteville.

Site Preparation, Management and Inoculation -Manhattan, KS

Glyphosate (N- (phosphonomethyl) glycine; GlyphoMate 41, PBI/Gordon Corporation, Kansas City, MO) was applied at 4.5 kg a.i. ha^{-1} to tall fescue growing in the study area ten days prior to transplanting. Sixty experimental genotypes and eight standard entries were planted in 1.8 m by 1.8 m plots on 21 and 22 July 2015 in a randomized completed block design with three replications. Twenty-four 1.25 cm - 2.5 cm in diameter plugs were planted in each plot. Irrigation was applied 2 to 3 times daily as needed with an overhead system until two weeks after transplanting. Thereafter, irrigation was applied to promote growth. Oxadiazon (3-[2,4-dichloro-5-(1-methylethoxy)phenyl]-5- (1,1-dimethylethyl)-1,3,4-oxadiazol-2(3H)-one; Ronstar G, Bayer Environmental Science, Montvale, NJ) was applied at 2.94 kg a.i. ha^{-1} immediately after plugging to control annual grassy and broadleaf weeds. Dimethylamine salt of quinclorac (3,7-dichloro-8-quinolinecharboxylic acid; Drive XLR8, BASF Corporation, Research Triangle Park, NC) was applied at 0.9 kg a.i. ha^{-1} on 10 Aug. 2015 to control grassy weeds.

A blend of perennial ryegrass (*Lolium perenne*) cultivars was planted in the alleyways between plots in September 2015 to prevent soil erosion. Glyphosate was applied at 4.5 kg a.i. ha^{-1} on 17 Feb. 2016 when zoysiagrass was fully dormant to control winter annuals. Plots were maintained at golf course rough conditions. Beginning in Oct. 2016, plots were maintained under golf course fairway/tee conditions and mowed at 1.25 cm with reel mower. Zoysiagrass was fertilized with urea (46-0-0) in April, July, and September to provide a total of 147 kg N ha^{-1} per year in 2016 and 2017 and 49 kg N ha^{-1} in April 2018. Oxadiazon was applied at 2.94 kg a.i. ha^{-1} in the spring of 2016 and 2017 to control annual grassy and broadleaf weeds. A mixture of dithiopyr (Dimethyl 2-(difluoromethyl)-4-(2-methylpropyl)-6-(trifluoromethyl) pyridine-3, 5-dicarbothioate; Dimension, Dow AgroSciences LLC, Indianapolis, IN) at 0.56 kg a.i. ha^{-1} and Dimethylamine salt of 2, 4, -dichlorophenoxyacetic acid at 0.59 kg a.i. ha^{-1}, Dimethylamine salt of (+)-(R)-2-(2-methyl-4-chlorophenoxy) propionic acid at 0.16 kg a.i. ha^{-1} and Dimethylamine salt of dicamba at 0.06 kg a.i. ha^{-1} (Trimec, PBI/Gordon Corporation, Kansas City, MO) was applied on 30 April, 2018 to control grassy and broadleaf weeds.

On 12 Sept. 2016, after the plots were fully established, one half of each plot was inoculated with an isolate of *Rhizoctonia solani* AG 2-2 LP that was obtained from a naturally-infected zoysiagrass area at the Rocky Ford Turfgrass Research Center. A plug from the edge of the patch symptoms was collected on 7 June 2016. Several symptomatic leaf sheaths were surface sterilized in 10% bleach for one minute, rinsed in sterile water, blotted dry, and placed on water agar with 5 pieces per plate. One representative isolate was selected and hyphal tipped. The isolate was transferred to a fresh plate of one-quarter-strength potato dextrose agar every 3-4 weeks, incubating at 18 °C with a cycle of 12 hrs light, 12 hrs dark. The field inoculum was prepared as described by Obasa et al. (2013). Briefly, 150 g of oats were autoclaved in 150 ml water in 1 L jar for 30 minutes twice on two consecutive days. After cooling, on 25 Aug 2016, one half of a ¼ PDA plate was cut with a scalpel into small plugs (around 1.0 x 1.0 cm), added to each glass jar, and shaken. The jars were incubated at room temperature with shaking every 2-3 days for two weeks before use to inoculate the field plots. Each plot was inoculated in the middle on one side, chosen randomly. A furrow slice just below the thatch layer was made using a small trowel, 8-10 grams of oat kernels were inserted in each spot (Obasa et al., 2012), and the turf was tamped back down. The plots were irrigated daily for several weeks after inoculation to promote fungal infection.

The non-inoculated half of each plot was treated with flutolanil (N-[3-(1-methylethoxy)phenyl]-2-(trifluoromethyl)benzamide, ProStar 70 WG, Bayer Environmental Science, Research Triangle Park, NC) at 9.6 kg a.i. ha^{-1} on 16 Sept, 2016; 11 April, 8 May, and 7 Sept, 7, 2017; and 10 May 2018. The fungicide was applied using a CO_2 powered hand-sprayer equipped with single 8004EVS nozzle boom, which made a clean 1.5 m pass on half of each plot. The product was applied in water at 814 L ha^{-1}.

Site Management and Inoculation - Fayetteville, AR

The site management and inoculation at Fayetteville, AR were similar to Manhattan, KS with the exceptions that follow.

Glyphosate (Monsanto company, St. Louis, MO) was applied at 1.15 kg a.i. ha^{-1} monthly to the trial area in the fall of 2014 and spring of 2015 to ensure a clean seed bed. The plugs were planted on 3 July 2015 with 60 experimental genotypes and five standard entries.

In spring 2016, oxadiazon was applied at 2.94 kg a.i. ha^{-1}. Prodiamine (FarmSaver.com, LLC, Seattle, WA) pre-emergence herbicide was applied at 0.73 kg a.i. ha^{-1} in the fall 2016, and once during the spring and fall of 2017 and spring of 2018 to control annual grassy and broadleaf weeds. Winter weeds were controlled using Simazine (2-chloro-4, 6-bis (ethylamino)-s-triazine, Princep 4L, Syngenta Crop Protection, LLC Greensboro, NC) at 1.9 kg a.i. ha^{-1} and foramsulfuron (Sulfonylurea, Revolver, Bayer Environmental Science, Montvale, NJ) at 0.029 kg a.i. ha^{-1}. This herbicide application was made every January during the duration of the trial.

Once plots were established, borders were maintained using a plot edger developed at the University of Arkansas-Fayetteville. The edger directly sprays a band of glyphosate between two straight coulters spaced 30 cm apart to keep the plots from contaminating one another and remove any weeds from the border. The coulters cut any stolons and shallow rhizomes and prevent the herbicide from being translocated back into the plot.

A mixture of two isolates of *Rhizoctonia solani* AG 2-2 LP was used to develop inoculum. Each isolate was cultured separately on PDA. The source of the two isolates, BR10 and SV3, was described previously (Spurlock, 2009). To prepare the inoculum, 300 g of oats (*Avena sativa* L.) were autoclaved in 300 ml water in 2 L flasks for 30 minutes on two consecutive days. After cooling, 10-12 small plugs (1x1 cm) of *R. solani* cultures grown on PDA agar were added to the jar. The jars were incubated at room temperature, with shaking every 2-3 days, for four weeks before use to inoculate the field plots. Prior to field application, all inoculum from both isolates was thoroughly mixed and the mixture of the two isolates was used to inoculate plots. The plot was inoculated on 25 Sept. 2015 and was re-inoculated on 30 Sept. 2016.

To inoculate each plot, *R. solani* was placed just below the thatch layer using an adjustable depth plugger only in the center of each plot (Accuform Ball mark plugger, Par Aide, Lino Lakes, MN), with a diameter of 3.8 cm and set to a depth of 3.2 cm in Oct 2016. Once the plug was removed from the plot, approximately 30 ml of inoculum was placed in the hole and the plug was then replaced and secured using a round top anchor sod pin (A.M. Leonard, 241 Fox Drive, Piqua, OH). The plots were irrigated daily for several weeks after inoculation to promote fungal infection. No fungicides were applied.

Data Collection

Manhattan, KS

In KS, after the half side of each plot was inoculated, the sub plots were rated separately. Large patch was rated by visually estimating the percentage of each sub plot infected. In addition, digital images were used to determine the area of each plot affected. Digital images were taken using a Nikon D5000 digital camera with a light box (0.51 × 0.61 × 0.56 m), and leaves or clipping debris was blown away with a leaf blower when present (Alderman et al., 2017). Two digital images were taken on the inoculated side of each plot and two on the fungicide-treated side, offset and avoiding overlapping but covering the center. Thus, a set of two digital images per subplot covered 311,000 square centimeters, or 38% of each 1.8 × 0.9 m subplot. The digital images were then processed using SigmaScan Pro 5.0 (ver. 5.0 SPSS Science Marketing Dept., Chicago, IL), and results were averaged for each side. The macro threshold in SigmaScan was set according to Patton et al. (2005) with a hue between 47 and 107 and saturation between 0 and 100. The percentage of disease was determined using the equation: disease severity (%) = 100 - % green coverage. Furthermore, for each plot, the disease severity on the inoculated side was standardized according to the fungicide-treated side in order to eliminate other factors such as winter injury. The scaled digital rating was determined using the equation: relative disease severity (%) = 100 - (% green coverage on the inoculated side ⁄ % green coverage on the fungicide-treated side × 100). We attempted patch diameter measurements, but diseased areas lacked clear margins.

Fayetteville, AR

Similar to Manhattan, KS, large patch tolerance was determined by visual rating or using digital images. One digital image was taken at the center of each plot using a Canon G12 digital camera with a light box (0.51 m × 0.61 m × 0.61 m) during the disease active season. The threshold settings were set between 40 and 140 for hue and between 0 and 100 for saturation (Miller et al, 2016).

Additional Turf Parameters

Data were also collected on turf quality, spring green-up, winter kill, fall color, genetic color, and texture. Data are shown in Appendix B Tables 1-20. In addition to Fayetteville, AR; and Manhattan, KS; data were collected at Columbia, MO; Raleigh, NC; Stillwater, OK; Dallas, TX; Chicago, IL; and Blacksburg VA. The above mentioned parameters were visually rated on a 1-9 scale or on 0-100% (Morris and Shearman, 1999). For turf quality, 1 = completely brown, 6 = minimum acceptable quality, 9 = optimum color, density, and uniformity; spring green-up, 1 = straw brown, 9 = completely green; winter kill, 0 = no winter kill; fall color, 1 = straw brown or no color retention, 9 = dark green; genetic color, 1 = light green and 9 = dark green; texture, 1 = coarse and 9 = fine texture.

Data Analysis

The overall experimental design was a randomized complete block design for both locations. In Kansas, with half of each plot inoculated and the other half treated with fungicides, the experimental design also included a split-plot. Progeny was the main plot factor (1.8 m by 1.8 m), and treatment (inoculated or fungicide-treated) was the subplot factor (1.8 m by 0.9 m). Digital images analysis was recorded separately on the two separate sides and scaled as described above. Analysis of Variance (ANOVA) was tested using Proc Mixed in SAS 9.4 (SAS Institute Inc., Cary, NC) for all the one-way and two-way parameters. Residual normality was tested with Conditional Studentized Residuals using Proc Mixed prior to conducting the analysis of variance. All the data were approximately normally distributed with equal variances, which met the assumptions of ANOVA.

Results

Disease Severity Based on Visual Assessments

Correlations between visual and digital assessments were analyzed using Proc Corr in SAS 9.4 and results were variable. Since the visual estimates represent the entire plot area, those are presented here. The comparisons between methods are discussed below.

Manhattan, KS

Large patch symptoms appeared in fall 2016, starting four weeks after inoculation. On 13 Oct., large patch disease was generally low (< 10% except for Meyer) and most of the plots had no disease symptoms (Table 4.2). On that date 'Meyer' exhibited 20.3% severity, much higher than any other entry. There may have been some natural large patch infections, as we saw similar disease breakout in another nearby testing site. On 4 Nov. 2016, seven weeks after inoculation, large patch severity ranged widely. For example, seven entries had no observable disease. Twelve experimental progeny had severity > 10%, and Meyer exhibited the highest severity at 41.7%.

In spring 2017, the environmental conditions were cool and wet (Figure 4.1) with the accumulated precipitation of 41.7 mm from 17 May to 22 May, highly conducive to large patch development. Most progeny exhibited symptoms in the inoculated subplots while the fungicide-treated subplots had no evidence of disease. On 24 May 2017, disease severity in the inoculated subplots ranged from 3.3% to 60.0%, with Meyer exhibiting 33% severity (Table 4.2). Progeny TAES 6099-151, 6099-69, and 6102-307, 6099-311, 6100-146, 6099-179, and Chisholm had ≤ 10% disease severity as assessed by visual estimation.

Fall 2017 was relatively dry, especially in September when the total precipitation was only 27.9 mm comparing to 143.5 mm in September 2016 (Figure 4.1). Consequently, the disease levels were low in the first two rating dates. However, the continuous rainy weather between 3 Oct. and 6 Oct., with accumulated precipitation of 50.0 mm, resulted in favorable environmental conditions for the growth of the fungal pathogen. Large patch was active by the third rating date in Oct. 2017, and several progeny exhibited > 40% disease; TAES 6096-81 exhibited the highest severity at 84.3%. In contrast, several progeny consistently exhibited no symptoms in fall 2017, including TAES 6095-83, 6099-151, 6099-77, 6099-8, 6100-146, 6100-26, 6100-86, 6101-26, 6102-307, 6104-150, 6097-108, 6099-10, 6102-62, TAES 5645 and 6119-179.

In 2018, the spring was rather dry with precipitation between March and June totaling 196 mm (vs. 315 mm in 2017; Figure 4.1). Large patch symptoms were not clearly evident. In addition, we experienced a harsh winter in 2017, with 12 days with minimum temperature below -15 °C from December to February. Winter injury across whole plots made it difficult to assess large patch symptoms, even when comparing inoculated and non-inoculated sub-plots.

Fayetteville, AR

Large patch disease was active in spring 2017 on both rating dates (Table 4.2). Disease severity assessed visually ranged from 1.3% to 36.7% on 15 May and from 0 to 43.3% on 24 May 2017. ‘Meyer’ had 30.0% and 23.3% large patch, respectively, the highest large patch infection. There were zoysiagrass progeny which showed little or no symptoms of large patch, including TAES 6119-179, 6102-307, and 6099-69 on both rating dates.

Comparison of Visual Assessments Versus Digital Images

For Manhattan, large patch severity determined using digital image analysis is presented in Table 4.3. On 24 May 2017, the correlation between the visual assessments (Table 4.2) and raw digital rating of percentage non-green turf (Table 4.3) was r = 0.19, $P = 0.0065$. The correlation between the visual rating and the scaled digital rating (intended to control for non-green turf associated with winter injury or other stresses) was slightly higher, with r = 0.28 and $P < 0.001$. For October 2017, correlations for both the raw and scaled digital ratings (taken 18 Oct.) and visual ratings (taken 20 Oct.) were higher, with r = 0.85 and $P > 0.001$ for the raw digital % non-green turf compared to visual assessments and r = 0.89 and $P < 0.0001$ for the scaled digital ratings compared to visual assessments.

Arkansas large patch severity determined using digital image analysis is shown in Table 4.4. The correlation data for the 19 April visual rating and 20 April digital image analysis were r = 0.57 and $P < 0.0001$. The correlation data for the 15 May visual rating and 24 May digital image analysis were r = 0.27 and $P = 0.0001$.

Discussion

From 2016 to 2018, zoysiagrass progeny showed a wide range of variability in large patch tolerance in KS and AR. In Manhattan, KS, Meyer had up to 41.7% and 33.3% of the plot area affected by large patch in 2016 and 2017, respectively. Similarly, in Fayetteville, AR, Meyer had up to 30.0% severity in 2017. Some zoysiagrass progeny showed consistently low susceptibility across locations and years, such as TAES 6099-151, TAES 6119-179, TAES 6102-307, TAES 6099-69, and TAES 6100-146.

In my study, there was lack of consistent correlation between the visual disease assessment and light box digital image analysis. The two methods were evaluating different areas within plots. For example, with the light box, disease assessment captured only 38% of each sub plot, even though two pictures were taken on each half side in order to maximize the coverage. In Arkansas, only 10% of each plot was captured by the light box. However, the entire sub plot was evaluated when rating the disease visually. Other methods have been reported in field disease assessment using digital image analysis. In order to capture the whole plot, digital images were taken 1.1 to 1.8 m above the surface (Braun, 2014; Obasa et al., 2012). The drawback for this method is that it is not possible to control light levels as can be carried out using the light box and the inconsistent light conditions may affect the accuracy of the assessment. Other methods, such as measuring the average patch diameter have been reported in order to determine the large patch disease severity, but over time patch borders can become difficult to discern (Obasa et al., 2012). In this study, it was difficult to determine the edge of the patches in several progeny even at very early stages, which made determination of diameter a challenge.

In a growth chamber study, differences among St. Augustinegrass genotypes in large patch tolerance have been reported (Flor et al. 2017). In that study, researchers concluded that breeding could contribute to the resistance to large patch in St. Augustinegrass. In the related system of brown patch of cool-season turfgrasses caused by another strain of *R. solani*, brown patch susceptibility of 230 genotypes of tall fescue (*Schedonorus arundinaceum* Schreb) was evaluated in the field and none were completely resistant (Bokmeyer et al., 2009). The authors concluded that the moderate resistance that was observed was likely quantitative (with multiple resistance mechanisms), not qualitative (with a single resistance mechanism). Resistance to *R. solani* AG 2-2 IIIB in sugar beet (*Beta vulgaris* subsp. vulgaris) has also been documented as quantitative (Strausbaugh et al., 2013). Furthermore, in nine crop species, 59 cultivars, parental line and germplasm registrations have been reported with evidence of some level of tolerance to *Rhizoctonia solani* (Panella and Ruppel, 1996). In rice (*Oryza sativa* L.), resistance to sheath blight caused by *R. solani* AG1-1A is known to be quantitative, and resistance loci have been reported (Liu et al., 2013).

Among zoysiagrass, research has been conducted to evaluate variability among new progeny on their resistance to large patch disease (Flor, 2017; Obasa et al., 2012). Obasa et al. (2012) assessed 14 progeny for large patch tolerance, including crosses of *Z. japonica* (Steud.), *Z. matrella* (L.) Merr., and *Z. pacifica* (Goudswaard). All progeny tested had large patch tolerance similar to Meyer under both growth chamber and field conditions in Kansas. However, they (Obasa et al., 2012) were not evaluating progeny mentioned bred specifically for resistance to large patch disease as I did. Though Flor (2017) observed zoysiagrass progeny with better large patch tolerance than Meyer, no progeny with high large patch tolerance (≤ 20% disease severity) has been confirmed.

From this study, I have found progeny with reduced susceptibility to large patch across multiple seasons and locations. Progeny TAES 6099-151, TAES 6119-179, TAES 6102-307, TAES 6099-69, and TAES 6100-146 consistently had < 10% disease severity on all the rating dates at both locations when disease was assessed visually. Disease severity was also relatively low when assessed using the digital image analysis method.

When evaluating breeding lines, testing with multiple pathogen isolates can be important, as there can be differences in virulence or other fitness parameters. Differences in growth rates and virulence among *R. solani* 2-2 LP strains have been reported, with two isolates exhibiting higher *in vitro* growth rates also exhibiting higher virulence (Obasa, 2012). However, interactions of host genotype and isolate were not investigated in that study. Interaction between different *R. solani* AG 2-2IIIB strains and host resistance has been observed on sugar beet (Strausbaugh et al., 2013). In our study, we used only one isolate in Kansas and a mixture of two different isolates in Arkansas. We did not investigate isolate by genotype interactions. For future studies, evaluating the response of progeny to different isolates would be beneficial to the screening process.

Through this research, I have demonstrated that there are promising progeny that are less susceptible to the isolates of large patch we used in this study. The selection of new cultivars with resistance to large patch disease will be beneficial for the turfgrass managers in order to reduce the maintenance cost especially in areas where large patch disease is common.

References

Alderman, E.J., J.A. Hoyle, S.J. Keeley, and J.D. Fry. 2017. Buffalograss divot recovery as affected by nitrogen source and rate. Crop, Forage, & Turfgrass Management. 3. doi:10.2134/cftm2016.06.0044

Aoyagi, T., K. Kageyama, and M. Hyakumachi. 1998. Characterization and survival of *Rhizoctonia solani* AG 2-2 LP associated with large patch disease of *Zoysiagrass*. Plant Dis. 82:857–863. doi:10.1094/PDIS.1998.82.8.857

Beard, J.B. 1973. Turfgrass: science and culture. Prentice-Hall, Upper Saddle River, NJ.

Benelli, J.J., B.J. Horvath, A.R. Womac, B.H. Ownley, A.S. Windham, and J.C. Sorochan. 2018. Large patch (*Rhizoctonia solani* AG 2-2LP) severity on Japanese lawngrass (*Zoysia japonica*) influenced by fungicide and application target site. Crop Prot. 106:23-28.

Bokmeyer, J.M., S.A. Bonos, and W.A. Meyer. 2009a. Broad-sense heritability and stability analysis of brown patch resistance in tall fescue. HortScience 44:289–292.

Braun, R. 2014. Cultural strategies to improve zoysiagrass acceptability and performance in the transition zone. MS thesis, Dept. of Horticulture and Natural Resources, Kansas State Univ., Manhattan, KS.

Burpee, L. 1995. Interactions among mowing height, nitrogen fertility, and cultivar affect the severity of Rhizonia blight of tall fescue. Plant Dis. 79:721-726.

Chandra, A., J. Fry, M. Engelke, D. Genovesi, J. Reinert, M. Binzel, S. Metz, B. Wherley, Q. Zhang, and D. Okeyo. 2014. Registration of ‘Chisholm’ zoysiagrass. J. of Plant Reg. 9:21-26.

Chandra, A., J.D. Fry, A.D. Genovesi, M. Meeks, M.C. Engelke, Q. Zhang, D. Okeyo, J.Q. Moss, E. Ervin, X. Xiong, and S. Milla-Lewis. 2017. Registration of 'KSUZ 0802' zoysiagrass. J. of Plant Reg. 11:100-106.

Earlywine, D. and G.L. Miller. 2015. Evaluation of fungicide applications for large patch control on zoysiagrass, 2013-2014. Plant Dis and Mgt (Report No. 9) https://www.plantmanagementnetwork.org/pub/trial/PDMR/volume9/abstracts/T31.asp

Flor, N.C. 2017. Heritability estimates for large patch disease response in zoysiagrass. PhD. Dissertation. Agronomy Dept., Univ. of Florida, Gainesville, FL.

Flor, N.C., P.F. Harmon, K. Kenworthy, R.N. Raid, R. Nagata, and L.E. Datnoff. 2017. Screening St. Augustinegrass genotypes for brown patch and large patch disease resistance. Crop Sci. 57:S-89–S-97. doi: 10.2135/cropsci2016.06.0514

Fry, J. and A. Chandra. 2015. New fine-textured, cold-hardy zoysiagrass on the horizon. Golf Course Mgt. December: p. 34. http://gcmdigital.gcsaa.org/i/605433-dec-2015/35.

Fry, J., M. Kennelly, and R. St. John. 2008. Zoysiagrass: Economic and environmental sense in the transition zone. Golf Course Mgt. 76:127–132.

Fry, J.D. and P. Dernoeden. 1987. Growth of zoysiagrass from vegetative plugs in response to fertilizers. J. Amer. Soc. Hort. Sci. 112:286– 289.

Fry, J.D., and B. Huang. 2004. Applied turfgrass science and physiology. John Wiley & Sons, Hoboken, NJ

Genovesi, D. and A. Chandra. 2013. Development of large patch resistant and cold hardy zoysiagrass cultivars for the transition zone. USGA Turfgrass and environmental research online. November: Vol. 12. http://usgatero.msu.edu/v12/n1-11.pdf.

Green, D.E.II, J.D. Fry, J.C. Pair, and N.A. Tisserat. 1993. Pathogenicity of *Rhizoctonia solani*

AG 2-2 and *Ophiosphaerella herpotricha* on zoysiagrass. Plant Dis. 77:1040-1044.

Green, D.E. II, J.D. Fry, J.C. Pair, and N.A. Tisserat. 1994. Influence of management practices on large patch disease of zoysiagrass. HortScience 29:186–188.

Liu, G., Y. Jia, A. Mcclung, J.H. Oard, F.N. Lee, and J.C. Correll. 2013. Confirming QTLs and finding additional loci responsible for resistance to rice sheath blight disease. Plant Dis. 97:113-117.

Miller, G.L., D.T. Earlywine, R. Braun, J.D. Fry, and M.M. Kennelly. 2016. Influence of nitrogen source and application timing on large patch of zoysiagrass. Crop, Forage, & Turfgrass Management. 2.doi: 10.2134/cftm2015.0189

Morris, K.N. and R.C. Shearman. 1999. NTEP turfgrass evaluation guidelines. National Turfgrass Evaluation Program, Beltsville, Md.

Obasa, K, J. Fry, D. Bremer, R.S. John, and M. Kennelly. 2013. Effect of cultivation and timing of nitrogen fertilization on large patch disease of zoysiagrass, Plant Dis. 97:1075-1081.

Obasa, K. 2012. Phenotypic and genotypic characterization of *Rhizoctonia solani* isolates from zoysiagrass in Kansas. Ph.D. dissertation, Dept. of Plant Pathology, Kansas State Univ., Manhattan, KS.

Obasa, K., J. Fry, and M. Kennelly. 2012. Susceptibility of zoysiagrass germplasm to large patch caused by *Rhizoctonia solani*. HortScience, 47:1252-1256.

Obasa, K., J. Fry, D. Bremer, and M. Kennelly. 2017. Evaluation of spring and fall fungicide applications for large patch management in zoysiagrass. Int. Turfgrass Soc. Res. J. 13:191-197.

Pan, X., M.D. Richardson, S. Deng, R.J. Kremer, J.T. English, J.D. Mihail, C.E. Sams, P.C. Scharf, K.S. Veum, and X. Xiong. 2017. Effect of organic amendment and cultural practice on large patch occurrence and soil microbial community. Crop Sci. 57:2263-2272.

Panella, L., and E.G. Ruppel. 1996. Availability of germplasm for resistance against *Rhizoctonia* Spp. In *Rhizoctonia* species: taxonomy, molecular biology, ecology, pathology and disease control. Springer, Dordrecht.

Patton, A.J., K. Walker, D. McDuffee, C. Bigelow, R. Latin, and Z. Reicher. 2005. Using digital image analysis to quantify turfgrass cover and disease. https://turf.purdue.edu/report/2005/11.pdf

Patton, A.J. and Z.J. Reicher. 2007. Zoysiagrass species and genotypes differ in their winter injury and freeze tolerance. Crop Sci. 47:1619–1627.

Reicher, Z. 2004. NTEP Zoysiagrass cultivar evaluation report. p. 39-40.

Smiley, R.W., P.H. Dernoeden, and B.B. Clarke. 2005. Compendium of turfgrass disease. American Phytopathological Society Press, MN.

Spurlock, T.N. 2009. Epidemiology and etiology of zoysiagrass diseases in northwest Arkansas. MS Thesis, Department of Plant Pathology, Univ. of Arkansas. Fayetteville, AR.

Strausbaugh, C.A., I.A. Eujayl, and L. Panella. 2013. Interaction of sugar beet host resistance and *Rhizoctonia solani*. AG-2-2 IIIB Strains. Plant Dis. 97:1175-1180. doi: 10.1094/PDIS-11-12-1078-RE.

Figure 4.1 Monthly average air temperatures, and total precipitation from April 2016 to June 2018 in Manhattan, KS. Weather data was collected from an on-site weather station close to the research area.

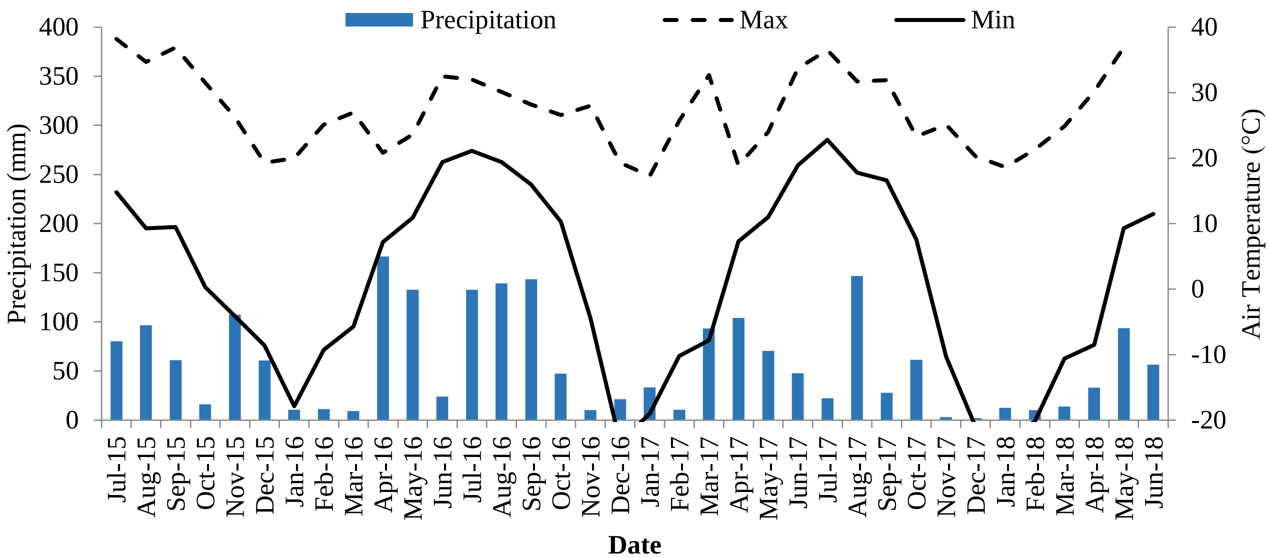


Figure 4.2 Monthly average air temperatures, and total precipitation from July 2015 to May 2018 in Fayetteville, AR.

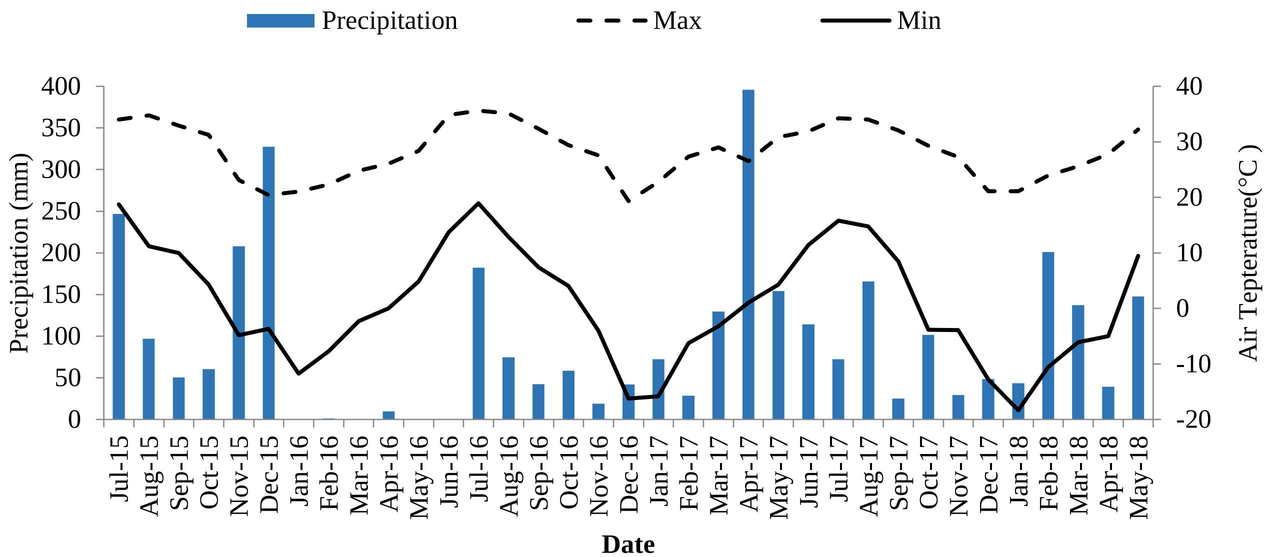


Table 4.1 Experimental zoysiagrass progeny coded family (crosses). For confidentiality, only species, and not cultivar names, are provided.

Coded Family #	Zoysiagrass Progeny Coded Family Cross Female x Male
6095	[(*Z. matrella* (L.) Merr. x *Z. matrella*) x *Z. japonica*] x *Z. japonica*
6096	(*Z. matrella* x *Z. japonica*) x *Z. japonica*
6097	(*Z. matrella* x *Z. japonica*) x *Z. japonica*
6099	*Z. japonica* x *Z. japonica*
6100	[(*Z. japonica* x *Z. pacifica* (Gaud.) Hotta & Kuroti) x *Z. japonica*] x *Z. japonica*
6101	(*Z. japonica* x *Z. matrella*) x *Z. japonica*
6102	*Z. japonica* x *Z. japonica*
6104	*Z. japonica* x *Z. japonica*
6109	(*Z. japonica* x *Z. matrella*) x *Z. japonica*
6119	*Z. japonica* x [(*Z. matrella* x *Z. matrella*) x *Z. japonica*]
6121	(*Z. matrella* x *Z. japonica*) x *Z. japonica*
6126	(*Z. matrella* x *Z. japonica*) x *Z. japonica*

Table 4.2 Percentage large patch infection of experimental zoysiagrass progeny and standard cultivars in 2016 and 2017 in Manhattan, KS and spring 2017 in Fayetteville, AR.

	Large Patch (%)							
	KS						AR	
Entry ID	10/13/16	11/4/16	5/24/17	9/24/17	9/30/17	10/20/17	4/19/17	5/15/17
6095-101	0	0	21.7	1.0	0	1.0	4.0	0.7
6095-117	0	8.3	35.0	0	0	6.7	5.0	1.7
6095-55	1.7	12.0	25.0	3.3	3.3	9.3	6.7	1.3
6095-56	0.7	5.0	42.0	2.3	16.7	7.7	3.0	1.3
6095-73	1.0	10.0	43.3	2.7	0	17.0	10.7	1.3
6095-83	0.3	2.0	18.3	0	0	0	2.0	4.0
6096-117	0	8.7	20.0	5.0	0	21.7	11.7	7.3
6096-137	0.3	9.3	36.7	1.7	3.3	15.0	18.3	7.3
6096-36	0	2.0	18.3	0	0	6.7	5.7	9.0
6096-81	4.3	14.3	38.3	28.3	33.3	84.3	28.3	43.3
6096-93	2.0	10.7	31.7	43.3	33.3	48.3	20.0	40.0
6097-108	2.7	6.7	23.3	3.3	0	0	4.7	1.3
6097-41	0	3.0	13.3	19.0	10.0	33.0	11.7	0.7
6097-50	0	5.0	21.7	1.3	1.7	20.7	6.7	2.3
6097-74	0.3	3.7	10.3	3.3	0	6.7	15.7	21.7
6097-97	2.7	12.0	28.3	51.7	36.7	31.7	4.0	2.3
6099-10	0.7	3.3	33.3	2.7	0	0	1.3	0
6099-145	0	4.0	15.7	0	0	3.3	8.0	0
6099-151	0	0.7	3.3	0	0	0	6.3	0.7
6099-232	0	5.7	28.3	10.0	6.7	3.3	10.7	21.7
6099-311	0	4.0	10.0	0	0	5.0	15.0	10.7
6099-359	0	0	18.3	0	0	5.7	6.7	3.3
6099-383	1.7	5.7	30.0	0	0	1.7	10.0	0.7
6099-388	0	2.0	19.3	18.3	23.3	56.7	15.0	10.7

6099-403	0.7	8.3	20.0	21.7	30.0	25.0	8.3	2.3
6099-447	0.3	0	14.3	0	0	1.7	5.7	1.3
6099-69	1.7	7.7	9.3	0	0	9.0	3.0	2.0
6099-77	0.7	2.0	18.3	0	0	0	1.3	0
6099-8	0	2.7	25.0	0	0	0	9.7	6.7
6100-106	1.3	16.0	35.0	7.7	0	17.7	10.0	4.7
6100-13	0.7	3.0	21.7	0	0	11.0	15.0	1.3
6100-146	0	0	10.0	0	0	0	3.3	0.7
6100-186	0	4.7	31.7	13.3	6.7	29.3	1.3	0
6100-26	0	1.3	26.7	0	0	0	2.0	9.0
6100-86	0	1.0	16.7	0	0	0	6.7	4.0
6101-117	0.7	5.0	26.7	40.0	15.0	23.3	4.7	4.7
6101-154	0	3.3	36.7	6.7	0	3.3	13.3	6.7
6101-26	0	0	31.7	0	0	0	5.0	0.7
6101-32	0	5.7	38.3	0	0	1.3	4.7	1.3
6101-52	2.0	8.0	15.3	13.3	13.3	46.7	5.7	16.7
6101-63	2.0	13.3	50.0	10.0	21.7	50.0	16.7	26.7
6101-71	2.0	6.0	31.7	16.7	21.7	21.7	9.7	17.3
6101-9	0	2.0	17.0	16.7	13.3	26.0	20.7	36.7
6102-196	0	1.3	13.3	0	0	3.3	11.7	18.3
6102-287	1.7	7.7	26.7	0	0	11.7	36.7	16.7
6102-289	0	3.0	17.7	0	0	8.3	1.3	0
6102-307	0	6.7	7.0	0	0	0	2.0	3.3
6102-47	0.7	3.0	17.0	0	0	4.3	10.7	4.0
6102-5	2.7	11.3	28.3	5.0	1.7	36.7	15.0	7.3
6102-62	0	0.3	15.0	9.3	0	0	4.0	0
6104-150	0	0	35.0	0	0	0	4.7	1.3
6109-8	0	8.7	26.7	2.7	0	8.3	5.7	4.0
6119-14	0.7	9.3	35.0	1.7	0	5.0	6.7	5.7
6119-155	0	4.0	30.0	0	0	10.0	15.0	5.7
6119-168	2.7	10.0	18.3	0	5.0	25.0	12.3	10.7

6119-179	1	3.3	10.0	0	0	0	0.7	2.3
6119-87	0.7	9.7	21.7	0	0	5.0	5.0	0.7
6121-106	3.3	23.3	20.0	21.7	16.7	46.7	16.7	10.0
6121-5	0	6.0	26.7	1.0	0	2.7	6.7	13.3
6126-71	0	6.3	16.7	0	0	1.7	13.3	6.7
Chisholm	0	1.3	10.0	10.0	10.0	18.3	6.7	10.7
El Toro	0	1.7	33.3	6.7	0	18.3	10.0	18.3
KSUZ0802	9.3	40.0	60.0	0	0	0.7	N/A	N/A
KSUZ1201	4.0	30.0	23.3	11.7	16.7	39.3	N/A	N/A
Meyer	20.3	41.7	33.3	1.7	0	8.3	30.0	23.3
TAES5645	0	0	15.0	0	0	0	N/A	N/A
Zeon	0	7.3	28.3	3.3	1.7	6.7	21.7	4.0
Zorro	0.3	6.7	43.3	4.0	0	16.7	16.7	3.3
LSD‡	4.3	13.3	27.9	19.3	20.8	22.9	12.0	16.1

† Large patch was rated visually as a percentage of the plot area affected on a 0 to 100% scale on the inoculated side of the plot in Manhattan, KS and on the whole plot in Fayetteville, AR.

‡ LSD, least significant difference between means within a column at *P* = 0.05.

Table 4.3 Large patch on experimental zoysiagrass progeny and standard cultivars as determined by digital image analysis on inoculated and fungicide-treated turf in spring and fall 2017 in Manhattan, KS.

	Percentage Non-Green Coverage†							
	24/5/17				18/10/17			
Entry ID	Fungicide -treated	Inoculated		Ratio§	Fungicide -treated	Inoculated		Ratio
6095-101	10.5	16.2		6.4	6.6	6.2		-0.4
6095-117	9.5	28.4	*	20.9	7.3	9.8		2.7
6095-55	10.0	18.2	*	9.1	8.5	11.3		3.1
6095-56	11.3	24.5	*	14.9	5.3	6.9		1.7
6095-73	12.3	22.5	*	11.6	4.3	14.1		10.2
6095-83	7.3	12.1		5.2	3.4	3.2		-0.2
6096-117	8.2	13.7		6.0	8.5	22.3		15.1
6096-137	29.1	54.4	*	35.7	7.6	14.3		7.3
6096-36	7.5	14.0		7.0	15.0	14.2		-0.9
6096-81	11.6	25.4	*	15.6	17.5	54.9	*	45.3
6096-93	11.9	34.5	*	25.7	29.0	47.2	*	25.6
6097-108	12.7	22.7		11.5	6.5	6.9		0.4
6097-41	7.7	10.1		2.6	6.2	17.1		11.6
6097-50	11.8	32.4	*	23.4	7.2	18.5		12.2
6097-74	12.0	21.1	*	10.3	12.0	14.1		2.4
6097-97	24.8	35.6	*	14.4	13.3	29.8		19.0
6099-10	9.5	19.0	*	10.5	9.2	10.5		1.4
6099-145	11.4	11.6		0.2	9.5	11.0		1.7
6099-151	10.0	15.4		6.0	10.1	9.7		-0.4
6099-232	11.9	16.5		5.2	8.6	8.4		-0.2
6099-311	34.0	46.8	*	19.4	8.6	9.3		0.8
6099-359	14.4	13.8		-0.7	13.0	16.5		4.0

6099-383	14.0	19.1		5.9	9.9	12.2		2.6
6099-388	14.4	17.6		3.7	10.0	37.4		30.4
6099-403	8.2	20.6	*	13.5	7.3	23.8		17.8
6099-447	15.0	21.4		7.5	13.9	12.3		-1.9
6099-69	8.1	11.3		3.5	14.2	13.5		-0.8
6099-77	17.0	13.5		-4.2	6.7	6.8		0.1
6099-8	15.2	26.4	*	13.2	11.1	9.1		-2.2
6100-106	8.7	16.4		8.4	19.5	22.2		3.4
6100-13	11.8	21.6	*	11.1	10.6	20.4		11.0
6100-146	13.5	22.4		10.3	15.5	15.3		-0.2
6100-186	9.2	15.2		6.6	9.2	19.7		11.6
6100-26	13.0	19.9		7.9	3.5	2.5		-1.0
6100-86	9.2	12.0		3.1	7.1	6.6		-0.5
6101-117	16.3	32.7	*	19.6	7.6	26.2	*	20.1
6101-154	19.2	23.5		5.3	8.2	9.1		1.0
6101-26	17.6	24.4		8.3	6.7	4.9		-1.9
6101-32	13.0	29.4	*	18.9	9.5	7.7		-2.0
6101-52	4.0	12.0		8.3	21.0	29.7		11.0
6101-63	17.1	24.2		8.6	22.0	44.1	*	28.3
6101-71	10.6	18.4		8.7	17.6	32.1		17.6
6101-9	3.7	13.3		10.0	12.4	17.6		5.9
6102-196	18.6	22.2		4.4	9.6	11.8		2.4
6102-287	10.3	14.6		4.8	14.9	16.6		2.0
6102-289	15.0	18.2		3.8	3.2	4.8		1.7
6102-307	6.4	13.2		7.3	12.6	12.7		0.1
6102-47	6.7	7.4		0.8	12.5	9.4		-3.5
6102-5	8.5	23.1	*	16.0	6.4	22.6		17.3
6102-62	10.1	12.7		2.9	10.5	10.0		-0.6
6104-150	19.0	29.7	*	13.2	6.6	5.6		-1.1
6109-8	11.0	20.0		10.1	8.1	10.9		3.0
6119-14	8.6	21.4	*	14.0	4.6	4.9		0.3

6119-155	10.8	23.4	*	14.1	6.1	8.0		2.0
6119-168	29.6	50.3	*	29.4	4.7	19.4		15.4
6119-179	14.1	28.7	*	17.0	3.7	4.2		0.5
6119-87	15.1	20.4		6.2	3.5	4.6		1.1
6121-106	46.7	75.9	*	54.8	5.8	36.3	*	32.4
6121-5	28.1	33.2		7.1	5.4	4.8		-0.6
6126-71	14.5	21.3		8.0	3.7	3.4		-0.3
Chisholm	8.2	15.7		8.2	9.6	18.9		10.3
El Toro	17.1	28.1	*	13.3	10.5	15.7		5.8
KSUZ 0802	7.8	17.3	*	10.3	12.7	10.5		-2.5
KSUZ 1201	8.3	8.1		-0.2	12.0	32.8	*	23.6
Meyer	11.3	22.5	*	12.6	9.7	14.0		4.8
TAES 5645	22.4	23.0		0.8	13.0	11.9		-1.3
Zeon	10.0	20.6	*	11.8	8.2	9.5		1.4
Zorro	5.0	18.4	*	14.1	7.1	15.3		8.8
LSD[‡]	13.8	13.8		15.2	14.5	14.5		18.0

[†] Large patch was determined by digital images analysis; two digital images were taken on each inoculated and fungicide-treated side of each plot and averaged. Percentage disease =100 - % green coverage.

[‡] LSD, least significant difference between means within a column at $P = 0.05$.

* Within rating dates, an asterisk indicates a significant difference between the fungicide-treated and the inoculated side.

[§] Relative disease severity was scaled and was calculated as: 100 - (% green coverage on the inoculated side ⁄ % green coverage on the fungicide-treated side × 100). The ratio was calculated in order to control for non-green turf that may have been caused by winter injury or other stresses.

Table 4.4 Large patch on experimental zoysiagrass progeny and standard cultivars as determined by digital image analysis on inoculated turf in spring 2017 in Fayetteville, AR.

	Percent Non-Green Coverage	
Entry ID	4/20/17	5/24/17
6095-101	29.5	18.2
6095-117	31.3	39.2
6095-55	37.0	35.1
6095-56	36.1	47.3
6095-73	30.5	29.0
6095-83	31.3	46.9
6096-117	33.6	22.5
6096-137	50.7	50.5
6096-36	23.2	22.2
6096-81	62.9	47.7
6096-93	52.5	41.3
6097-108	32.7	17.5
6097-41	34.6	12.5
6097-50	47.8	53.7
6097-74	38.9	23.7
6097-97	40.7	58.6
6099-10	12.0	22.9
6099-145	25.0	32.2
6099-151	25.9	32.0
6099-232	23.2	24.8
6099-311	38.3	65.9
6099-359	39.5	47.5
6099-383	31.2	33.1
6099-388	44.6	24.9
6099-403	35.9	43.3
6099-447	29.8	32.3

6099-69	22.4	24.7
6099-77	9.2	19.3
6099-8	21.9	34.3
6100-106	33.2	38.4
6100-13	25.9	27.3
6100-146	23.2	30.8
6100-186	21.4	11.7
6100-26	25.8	53.7
6100-86	35.7	41.1
6101-117	29.5	19.6
6101-154	39.8	20.3
6101-26	10.8	19.5
6101-32	19.2	18.1
6101-52	29.9	17.4
6101-63	68.3	49.4
6101-71	44.7	28.8
6101-9	36.3	22.2
6102-196	50.2	64.4
6102-287	38.5	48.4
6102-289	15.3	14.9
6102-307	30.1	34.5
6102-47	31.0	27.1
6102-5	45.9	64.8
6102-62	24.7	11.8
6104-150	37.1	39.2
6109-8	45.9	46.0
6119-14	27.9	21.4
6119-155	45.9	42.6
6119-168	30.6	17.6
6119-179	24.0	27.3
6119-87	16.5	14.1

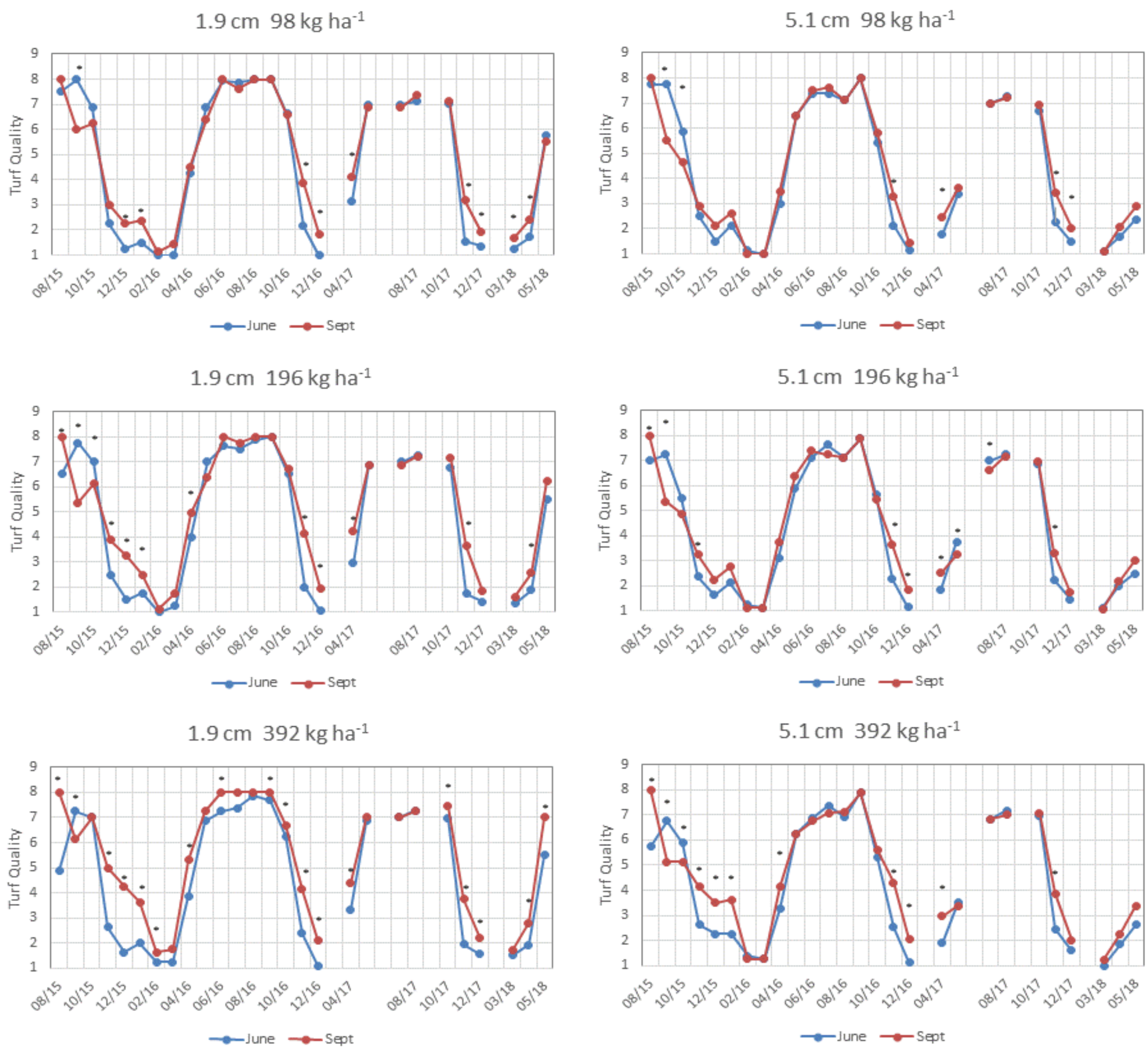
6121-106	45.4	68.1
6121-5	33.4	62.3
6126-71	26.1	21.6
Chisholm	32.0	33.7
El Toro	41.6	27.2
Meyer	54.6	45.1
Zeon	48.4	20.1
Zorro	52.9	17.5
LSD‡	13.7	16.6

† Large patch was determined by digital images analysis; one digital image was taken in the center of each plot. Percentage disease =100 - % green coverage.

‡ LSD, least significant difference between means within a column at *P* = 0.05.

Appendix A - Additional Tables and Figures for Chapter 2

Figure A.1 Effects of mowing height × tall fescue seeding month × tall fescue seeding rate interaction and sliced by mowing height × tall fescue seeding rate, on turf quality of a zoysiagrass-tall fescue polystand in Manhattan, KS from August 2015 to May 2018.

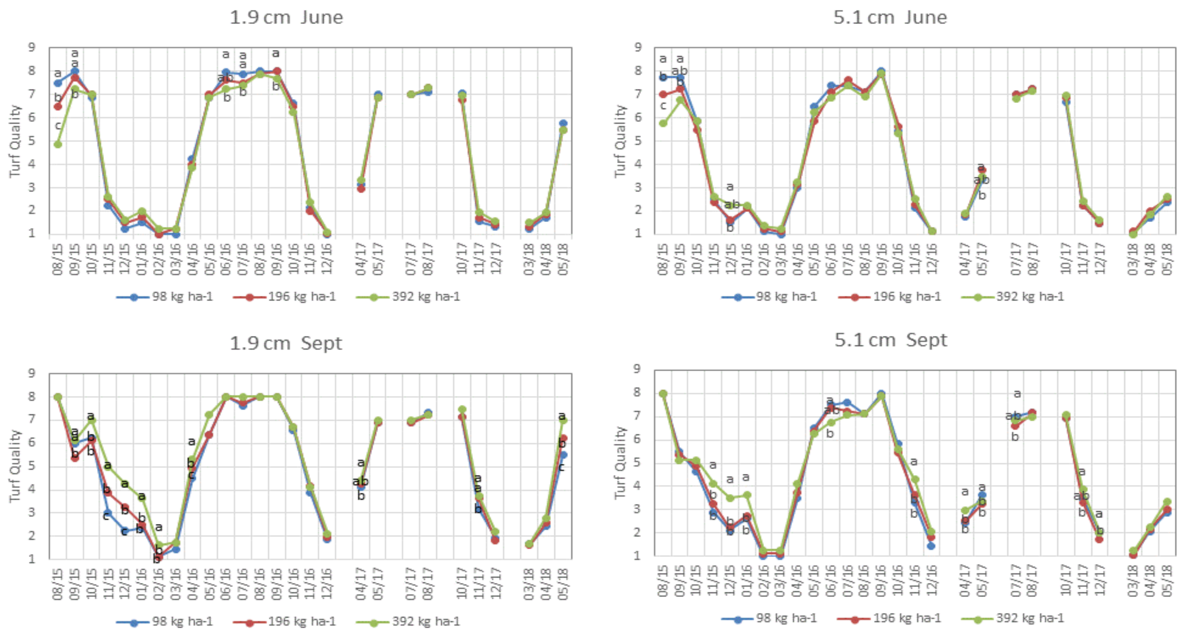


[†] Turf quality was recorded on 1 to 9 scale where 1 = completely brown, 6 = minimum acceptable quality, 9 = optimum color, density, and uniformity. Data was recorded on 24 Aug.,

19 Sept., 16 Oct., 20 Nov., and 18 Dec., 2015; 1 Jan., 27 Feb., 4 Mar., 7 Apr., 21 May, 20 June, 14 July, 12 Aug., 14 Sept., 10 Oct., 21 Nov., and 22 Dec., 2016; 6 Apr., 12 May., 31 July, 24 Aug., 19 Oct., 17 Nov., and 14 Dec., 2017; 14 Mar., 20 Apr., and 6 May 2018.

‡ Means are averaged over four blocks. An asterisk (*) indicates significant differences between seeding months according to Fisher's Protected LSD ($P \leq 0.05$).

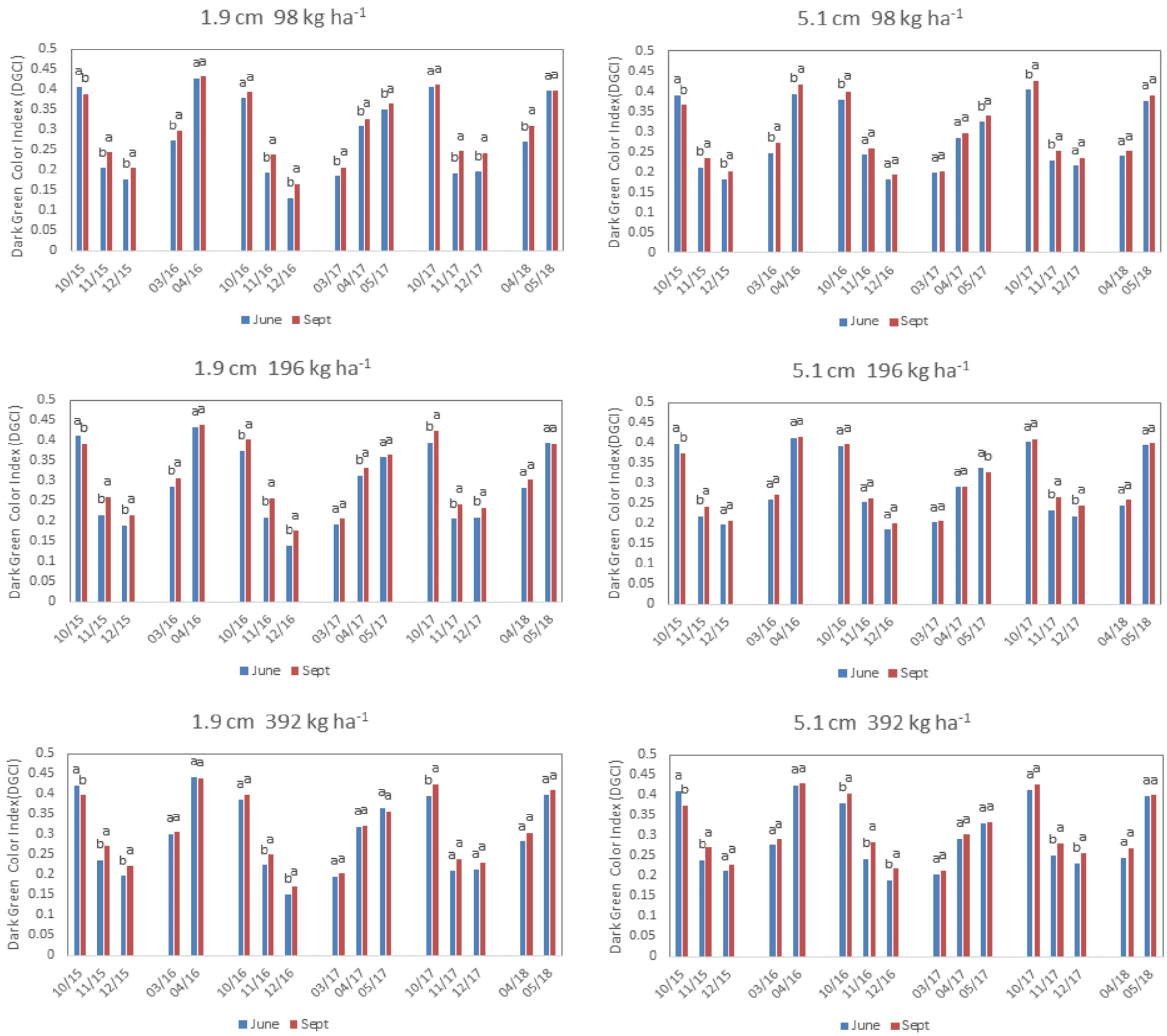
Figure A.2 Effects of mowing height × tall fescue seeding month × tall fescue seeding rate interaction and sliced by mowing height × tall fescue seeding month on turf quality of a zoysiagrass-tall fescue polystand in Manhattan, KS from August 2015 to May 2018.



† Turf quality was recorded on 1 to 9 scale where 1 = completely brown, 6 = minimum acceptable quality, 9 = optimum color, density, and uniformity. Data was recorded on 24 Aug., 19 Sept., 16 Oct., 20 Nov., and 18 Dec., 2015; 1 Jan., 27 Feb., 4 Mar., 7 Apr., 21 May, 20 June, 14 July, 12 Aug., 14 Sept., 10 Oct., 21 Nov., and 22 Dec., 2016; 6 Apr., 12 May, 31 July, 24 Aug., 19 Oct., 17 Nov., and 14 Dec., 2017; 14 Mar., 20 Apr., and 6 May 2018.

‡ Means are averaged over four blocks. Means labeled with the same letter within a given month are not significantly different according to Fisher's protected LSD ($P \leq 0.05$).

Figure A.3 Effects of mowing height × tall fescue seeding month × tall fescue seeding rate interaction and sliced by mowing height × tall fescue seeding rate on dark green color index (DGCI) of a zoysiagrass-tall fescue polystand in Manhattan, KS from October 2015 to May 2018.



[†] Dark green color index was calculated using the following equation according the results from digital image analysis using SigmaScan Pro 5.0:

DGCI value = [(H - 60)/60 + (1 - S) + (1 - B)]/3. Data was recorded on 8 Oct., 20 Nov., and 11 Dec., 2015; 26 Mar., 28 Apr., 22 Oct., 21 Nov., and 4 Dec., 2016; 16 Mar., 6 Apr., 6 May, 19 Oct., 30 Nov., and 14 Dec., 2017; 20 Apr., and 21 May, 2018.

‡ Means are averaged over four blocks, two mowing heights, two tall fescue seeding months and three tall fescue seeding rates. Means labeled with the same letter within a given month are not significantly different according to Fisher's protected LSD ($P \leq 0.05$).

Table A.1 Analysis of variance on the effects of mowing height (MH), tall fescue seeding month (SM), tall fescue seeding rate (SR), date, and all interactions on turf quality, and percentage green coverage of a zoysiagrass-tall fescue polystand in Manhattan and Olathe, KS.

	Manhattan, KS				Olathe, KS			
Source	df	Turf Quality	df	DGCI	df	Turf Quality	df	DGCI
Block	3		3		3		3	
MH	1	***[†]	1	**	1	***	1	ns
SM	1	***	1	***	1	***	1	***
MH × SM	1	***	1	*	1	Ns	1	ns
SR	2	***	2	***	2	Ns	2	ns
MH × SR	2	ns	2	ns	2	Ns	2	ns
SM × SR	2	***	2	*	2	Ns	2	**
MH × SM × SR	2	**	2	**	2	Ns	2	ns
Date	26	***	15	***	23	***	8	***
MH × Date	26	***	15	***	23	***	8	***
SM × Date	26	***	15	***	23	***	8	***
MH × SM × Date	26	ns	15	***	23	Ns	8	ns
SR × Date	52	***	30	ns	46	*	16	ns
MH × SR × Date	52	ns	30	*	46	Ns	16	ns
SM × SR × Date	52	**	30	ns	46	Ns	16	ns
MH × SM × SR × Date	52	ns	30	ns	46	Ns	16	ns

[†] *, **,*** significant at $P < 0.05$, 001 and 0.001, respectively.

Table A.2. Tall fescue seeding month main effect on turf quality of a zoysiagrass-tall fescue polystand in Olathe, KS from September 2015 to May 2018.

Seeding month	Turf Quality†																			
	9/15	11/15	4/16	5/16	6/16	7/16	8/16	9/16	10/16	11/16	12/16	4/17	5/17	6/17	7/17	9/17	10/17	11/17	12/17	5/18
June	4.5a‡	3.0b	3.2b	4.7b	5.4b	6.7b	6.8a	6.4a	6.8a	2.5b	1.3b	2.1b	4.6b	6.5a	6.8a	6.9a	6.6a	3.3b	1.6b	3.4b
Sept	3.7b	5.0a	4.6a	6.1a	6.0a	7.1a	6.7a	6.6a	6.8a	4.1a	2.4a	4.2a	5.2a	6.6a	6.7a	6.7b	6.6a	4.2a	2.0a	4.1a

† Turf quality was recorded on 1 to 9 scale where 1 = completely brown, 6 = minimum acceptable quality, 9 = optimum color, density, and uniformity. Data was recorded on 25 Sept., and 10 Nov., 2015; 21 Apr., 4 May, 8 June, 21 July, 11 Aug., 11 Sept., 8 Oct., 21 Nov., and 27 Dec., 2016; 8 Apr., 26 May, 18 June, 19 July, 2 Sept., 7 Oct., 4 Nov., and 1 Dec., 2017; and 3 May 2018.

‡ Means are averaged over four blocks, two mowing heights and three seeding rates, and means followed by the same letter are not significantly different according to Fisher's protected LSD ($P \leq 0.05$).

Table A.3. Mowing height main effect on turf quality of a zoysiagrass-tall fescue polystand in Olathe, KS from September 2015 to May 2018.

Mowing height	Turf Quality†																			
	9/15	11/15	4/16	5/16	6/16	7/16	8/16	9/16	10/16	11/16	12/16	4/17	5/17	6/17	7/17	9/17	10/17	11/17	12/17	5/18
1.9 cm	3.9a‡	3.9a	3.9a	5.6a	6.0a	7.1a	6.6a	6.6a	6.9a	3.3a	2.1a	3.4a	5.1a	6.6a	6.8a	6.9a	6.7a	4.0a	1.9a	4.5a
5.1 cm	4.3a	4.1a	3.9a	5.2a	5.4b	6.7a	6.9a	6.4a	6.7a	3.3a	1.6a	2.8a	4.7a	6.4a	6.7a	6.7a	6.5a	3.5b	1.7a	3.0b

† Turf quality was recorded on 1 to 9 scale where 1 = completely brown, 6 = minimum acceptable quality, 9 = optimum color, density, and uniformity. Data was recorded on 25 Sept., and 10 Nov., 2015; 21 Apr., 4 May, 8 June, 21 July, 11 Aug., 11 Sept., 8 Oct., 21 Nov., and 27 Dec., 2016; 8 Apr., 26 May, 18 June, 19 July, 2 Sept., 7 Oct., 4 Nov., and 1 Dec., 2017; and 3 May 2018.

‡ Means are averaged over four blocks, two tall fescue seeding months and three tall fescue seeding rates, and means followed by the same letter are not significantly different according to Fisher's protected LSD ($P \leq 0.05$).

Table A.4. Tall fescue seeding rate main effect on turf quality of a zoysiagrass-tall fescue polystand in Olathe, KS from September 2015 to May 2018.

Seeding rate	Turf Quality†																			
	9/15	11/15	4/16	5/16	6/16	7/16	8/16	9/16	10/16	11/16	12/16	4/17	5/17	6/17	7/17	9/17	10/17	11/17	12/17	5/18
98 kg ha^{-1}	4.4a‡	3.5c	3.5b	5.3a	5.4a	6.8a	6.8a	6.5a	6.8a	3.1a	1.7a	2.9a	4.9a	6.5a	6.7a	6.9a	6.6a	3.6a	1.7b	3.7ab
196 kg ha^{-1}	3.8a	4.0b	3.9a	5.3a	5.8a	6.9a	6.8a	6.6a	6.8a	3.3a	2.0a	3.2a	5.0a	6.5a	6.8a	6.8a	6.6a	3.7a	1.8ab	3.6b
392 kg ha^{-1}	4.1a	4.5a	4.2a	5.8a	5.8a	6.9a	6.8a	6.4a	6.8a	3.5a	1.8a	3.3a	4.8a	6.5a	6.7a	6.7a	6.5a	4.0a	1.9a	4.0a

† Turf quality was recorded on 1 to 9 scale where 1 = completely brown, 6 = minimum acceptable quality, 9 = optimum color, density, and uniformity. Data was recorded on 25 Sept., and 10 Nov., 2015; 21 Apr., 4 May, 8 June, 21 July, 11 Aug., 11 Sept., 8 Oct., 21 Nov., and 27 Dec., 2016; 8 Apr., 26 May, 18 June, 19 July, 2 Sept., 7 Oct., 4 Nov., and 1 Dec., 2017; and 3 May 2018.

‡ Means are averaged over four blocks, two mowing heights and two tall fescue seeding months, and means followed by the same letter are not significantly different according to Fisher's protected LSD ($P \leq 0.05$).

Table A.5. Effects of tall fescue seeding month × tall fescue seeding rate interaction on dark green color index (DGCI) of a zoysiagrass-tall fescue polystand by digital image analysis in Olathe, KS from October 2015 to May 2018.

Seeding month	Seeding rate	Dark Green Color Index (DGCI) †								
		10/16	11/16	12/16	4/17	5/17	10/17	11/17	12/17	5/18
June	98 kg ha^{-1}	0.44b‡	0.28c	0.21c	0.33b	0.36ab	0.40b	0.29c	0.21bc	0.36b
June	196 kg ha^{-1}	0.45ab	0.28c	0.20c	0.32b	0.35b	0.40b	0.29c	0.20c	0.36b
June	392 kg ha^{-1}	0.45ab	0.30b	0.21c	0.33b	0.35b	0.40b	0.31bc	0.21bc	0.36b
Sept	98 kg ha^{-1}	0.45ab	0.31b	0.23b	0.35a	0.36ab	0.41ab	0.30bc	0.22ab	0.37ab
Sept	196 kg ha^{-1}	0.46a	0.33a	0.25a	0.36a	0.37a	0.42a	0.33a	0.23a	0.38a
Sept	392 kg ha^{-1}	0.46a	0.33a	0.24ab	0.35a	0.36ab	0.41ab	0.32ab	0.22ab	0.38a

† Dark green color index was calculated using the following equation according the results from digital image analysis using SigmaScan Pro 5.0:

DGCI value = [(H - 60)/60 + (1 - S) + (1 - B)]/3, where H = hue, S = saturation, and B = brightness. Data was recorded on 8 Oct., 21 Nov., and 27 Dec. 2016; 8 Apr., 26 May, 7 Oct., 4 Nov., and 1 Dec., 2017; and 3 May 2018.

‡ Means are averaged over four blocks and two mowing heights, and means followed by the same letter on a given month are not significantly different according to Fisher's protected LSD ($P \leq 0.05$).

Table A.6. Pearson correlation coefficient for turf color, tur quality, green coverage (%), and dark green color index (DGCI) in Manhattan, KS.

Parameter	Turf Color	Turf Quality	Green Coverage (%)	Dark Green Color Index
Turf Color†	1			
Turf Quality‡	0.91***	1		
Green Coverage (%)§	0.85***	0.83***	1	
Dark Green Color Index¶	0.76 ***	0.76***	0.96***	1

† Turf color was recorded on a 1-9 scale, where 1 = straw brown or no color retention, and 9 = dark green.

‡ Turf quality was recorded on 1 to 9 scale where 1 = completely brown, 6 = minimum acceptable quality, 9 = optimum color, density, and uniformity.

§ Green coverage was determined using digital image analysis (DIA), and four photos were taken within each plot. Images were analyzed for percent green coverage using SigmaScan Pro 5.0.

¶ Dark green color index was calculated using the following equation according the results from digital image analysis using SigmaScan Pro 5.0:

DGCI value = [(H - 60)/60 + (1 - S) + (1 - B)]/3, where H = hue, S = saturation, and B = brightness.

*** Indicates significant of correlation at *P* = 0.001.

Table A.7. Pearson correlation coefficient for turf color, turf quality, green coverage (%), and dark green color index (DGCI) in Olathe, KS.

Parameter	Turf Color	Turf Quality	Green Coverage (%)	Dark Green Color Index
Turf Color†	1			
Turf Quality‡	0.92***	1		
Green Coverage (%)§	0.80***	0.78***	1	
Dark Green Color Index¶	0.78 ***	0.76***	0.96***	1

† Turf color was recorded on a 1-9 scale, where 1 = straw brown or no color retention, and 9 = dark green.

‡ Turf quality was recorded on 1 to 9 scale where 1 = completely brown, 6 = minimum acceptable quality, 9 = optimum color, density, and uniformity.

§ Green coverage was determined using digital image analysis (DIA), and four photos were taken within each plot. Images were analyzed for percent green coverage using SigmaScan Pro 5.0.

¶ Dark green color index was calculated using the following equation according the results from digital image analysis using SigmaScan Pro 5.0:

DGCI value = [(H - 60)/60 + (1 - S) + (1 - B)]/3, where H = hue, S = saturation, and B = brightness.

*** Indicates significant of correlation at *P* = 0.001.

Appendix B - Additional Tables and Figures for Chapter 4

Table B.1 Turf quality of experimental zoysiagrass progeny and standard cultivars in 2016 and 2017 in Fayetteville, AR.

	Turf Quality†								
Entry ID	4/22/16	5/24/16	6/13/16	7/18/16	8/24/16	9/22/16	6/7/17	7/7/17	8/4/17
6095-101	7.0	7.5	7.5	7.2	7.0	7.5	6.7	7.0	6.7
6095-117	7.7	8.2	7.5	7.3	7.0	7.3	6.3	7.0	6.3
6095-55	5.8	6.2	6.5	7.0	6.3	7.8	6.3	7.3	7.3
6095-56	7.8	8.5	7.8	7.2	7.0	7.3	6.3	7.0	6.3
6095-73	7.2	7.8	7.5	7.3	7.3	8.3	6.7	7.3	6.7
6095-83	8.0	8.5	8.3	8.2	7.0	8.0	7.3	8.0	8.3
6096-117	6.3	6.7	6.2	7.0	7.0	7.7	6.7	7.3	7.0
6096-137	7.2	7.2	6.0	6.7	7.0	5.8	7.0	7.3	7.3
6096-36	7.0	8.5	7.2	6.7	7.0	5.5	6.0	7.0	6.0
6096-81	6.5	6.5	7.3	7.5	7.0	8.5	7.3	8.0	8.3
6096-93	5.0	6.3	5.8	6.5	7.0	6.0	6.3	7.0	6.3
6097-108	6.7	6.8	7.5	6.8	6.7	7.2	6.7	7.0	7.0
6097-41	6.7	6.8	7.3	7.3	7.3	7.0	6.3	7.3	6.3
6097-50	5.7	7.2	6.8	7.0	6.3	6.8	6.3	6.7	6.7
6097-74	6.3	6.7	7.3	7.0	7.0	7.2	6.3	7.0	6.3

6097-97	6.0	6.2	5.5	6.0	6.7	6.7	6.7	7.0	7.0
6099-10	6.0	7.2	7.3	7.5	7.3	8.5	6.7	7.0	6.3
6099-145	5.8	6.7	6.2	6.2	7.3	8.0	7.0	8.0	7.7
6099-151	6.3	6.2	6.0	5.8	6.7	7.0	5.7	6.3	5.3
6099-232	6.0	6.5	6.7	7.8	7.3	8.5	6.7	7.0	6.3
6099-311	7.7	6.7	6.0	6.3	6.7	7.0	6.7	7.0	7.0
6099-359	8.3	7.3	6.5	5.5	6.3	6.3	6.3	7.0	7.0
6099-383	6.7	7.5	7.2	6.7	7.0	7.3	7.0	7.3	7.3
6099-388	6.2	7.3	7.5	7.2	7.3	7.0	6.7	7.7	7.0
6099-403	6.2	7.5	6.7	6.8	7.0	7.3	6.7	7.0	6.7
6099-447	6.7	8.0	7.7	7.3	7.3	7.7	6.7	7.3	6.7
6099-69	7.3	7.5	6.7	6.8	7.3	6.8	6.7	7.3	6.7
6099-77	5.8	6.5	6.5	6.7	7.0	7.7	7.0	7.3	7.3
6099-8	7.5	7.3	6.3	6.3	6.7	7.7	6.7	7.3	7.3
6100-106	5.8	5.7	5.5	6.8	6.3	8.2	6.3	7.3	7.3
6100-13	6.2	6.5	6.5	7.3	6.7	7.8	6.7	7.0	7.0
6100-146	5.5	6.2	6.5	8.2	6.7	7.0	5.7	6.0	5.0
6100-186	6.7	7.7	7.0	6.5	6.7	6.7	6.0	6.7	6.0
6100-26	6.3	7.2	6.8	7.2	7.0	6.8	6.7	7.0	6.7
6100-86	5.3	6.5	6.7	8.0	7.0	8.0	6.7	7.7	7.3
6101-117	7.5	7.5	6.5	6.0	6.7	6.3	6.3	6.7	6.3
6101-154	7.2	7.7	7.7	7.5	7.3	7.7	7.7	8.0	8.3

6101-26	7.0	8.0	6.8	6.7	7.0	7.0	6.0	6.7	5.7
6101-32	6.2	7.0	7.2	7.5	7.0	6.8	6.7	7.0	6.7
6101-52	7.0	7.5	7.7	7.2	6.3	7.3	6.7	7.0	7.3
6101-63	6.5	6.8	7.3	7.8	7.3	7.3	7.0	7.7	7.3
6101-71	6.8	6.5	6.8	8.2	7.0	7.7	6.7	7.3	7.0
6101-9	7.0	6.7	7.3	7.2	6.7	7.5	7.0	7.3	7.7
6102-196	6.5	5.8	6.0	6.2	6.7	7.2	7.0	7.3	7.7
6102-287	7.5	7.3	7.0	7.0	7.3	7.7	7.7	8.0	8.3
6102-289	6.5	6.5	6.8	7.5	7.3	8.2	7.7	8.3	8.7
6102-307	7.2	6.8	6.8	7.2	6.7	6.8	6.3	6.7	6.3
6102-47	6.3	7.5	6.8	7.8	7.0	7.3	7.0	7.7	7.7
6102-5	7.2	7.2	6.8	6.8	6.7	6.5	6.0	7.0	6.3
6102-62	6.0	7.0	7.5	7.8	7.0	7.0	6.3	7.0	6.3
6104-150	6.2	6.7	6.7	6.8	6.7	7.2	6.7	7.0	7.0
6109-8	5.8	6.7	6.2	7.0	7.0	7.5	7.0	7.3	7.3
6119-14	7.5	7.2	6.8	6.7	7.0	7.5	7.0	7.3	7.3
6119-155	6.8	7.0	6.7	6.3	7.7	6.3	7.7	8.3	8.3
6119-168	7.5	7.7	7.8	8.0	6.7	7.8	6.7	7.3	7.3
6119-179	8.3	7.5	6.7	6.0	7.0	7.5	7.0	7.3	7.3
6119-87	6.7	7.2	6.5	6.5	6.7	7.7	6.7	7.3	7.3
6121-106	7.2	7.3	5.7	6.0	7.0	7.0	7.0	7.3	7.3
6121-5	7.2	7.0	6.5	6.8	7.0	7.3	7.0	7.0	7.0

6126-71	7.0	7.5	7.3	7.3	7.7	8.2	7.3	8.0	7.7
Chisholm	7.7	7.8	8.0	6.7	7.0	6.8	6.0	6.7	5.7
El Toro	8.0	8.3	7.5	6.2	7.0	7.3	6.0	6.3	5.3
Meyer	6.2	7.0	6.8	7.3	7.0	8.7	7.0	7.3	7.3
Zeon	7.0	7.2	7.0	7.0	7.0	6.8	7.7	7.7	8.3
Zorro	6.7	7.3	6.5	6.0	7.0	6.5	7.0	7.7	7.7
LSD‡	0.8	1.0	0.7	0.9	0.8	0.7	0.9	0.9	1.4

† Turf quality was rated on the whole plots on a scale of 1-9 (1 = dead; 6 = minimally acceptable quality; 9 = optimum color, density, texture, and uniformity); n = 3.

‡ LSD, least significant difference between means within a column at *P* = 0.05.

Table B.2 Turf quality of experimental zoysiagrass progeny and standard cultivars in 2016 in Manhattan, KS.

	Turf Quality†	
Entry ID	09/10/16	10/09/16
6095-101	6.7	6.7
6095-117	6.7	6.7
6095-55	6.0	6.0
6095-56	7.0	7.3
6095-73	7.0	7.0
6095-83	6.7	7.0
6096-117	6.3	5.7
6096-137	6.3	6.7
6096-36	7.0	6.0
6096-81	5.7	5.0
6096-93	5.7	5.3
6097-108	7.0	7.0
6097-41	7.3	7.3
6097-50	7.3	6.3
6097-74	7.0	6.3
6097-97	4.7	4.7
6099-10	7.3	6.3
6099-145	7.0	7.0
6099-151	6.7	6.3
6099-232	4.0	4.7
6099-311	7.0	6.7
6099-359	6.3	6.0
6099-383	6.3	6.3
6099-388	7.0	6.0
6099-403	4.0	4.0
6099-447	6.7	6.3

6099-69	7.0	6.3
6099-77	6.0	6.3
6099-8	6.7	6.7
6100-106	6.3	6.0
6100-13	6.3	6.3
6100-146	6.7	6.0
6100-186	7.0	6.7
6100-26	7.0	7.3
6100-86	6.7	7.3
6101-117	6.7	7.0
6101-154	7.0	6.3
6101-26	6.7	6.3
6101-32	7.3	6.7
6101-52	7.0	6.0
6101-63	6.0	5.3
6101-71	6.7	6.0
6101-9	6.7	6.3
6102-196	7.7	6.3
6102-287	6.7	6.3
6102-289	6.7	6.7
6102-307	7.0	6.7
6102-47	4.7	5.3
6102-5	5.7	6.0
6102-62	7.3	6.7
6104-150	7.0	6.7
6109-8	6.7	6.3
6119-14	6.7	6.7
6119-155	7.3	7.3
6119-168	6.0	7.0
6119-179	7.0	6.3
6119-87	7.0	7.0

6121-106	6.7	6.7
6121-5	6.3	6.7
6126-71	7.0	7.7
Chisholm	6.0	6.3
El Toro	6.3	6.3
Meyer	6.7	5.7
Zeon	7.0	7.3
Zorro	6.3	6.7
LSD‡	1.3	1.1

† Turf quality was rated on the whole plots on a scale of 1-9 (1 = dead; 6 = minimally acceptable quality; 9 = optimum color, density, texture, and uniformity); n = 3.

‡ LSD, least significant difference between means within a column at $P = 0.05$.

Table B.3 Turf quality of the zoysiagrass progeny and standard cultivars on both the fungicide-treated and the inoculated sides of the plots in 2017 in Manhattan, KS.

	Turf Quality†																			
	4/26/17			5/25/17			6/23/17			7/23/17			8/28/17			9/30/17			10/30/17	
Entry ID	Fungicide-treated	Inoculated		Fungicide-treated	Inoculated		Fungicide-treated	Inoculated		Fungicide-treated	Inoculated		Fungicide-treated	Inoculated		Fungicide-treated	Inoculated		Fungicide-treated	Inoculated
6095-101	4.2	2.7	*	6.0	5.0		7.8	7.5		7.3	7.5		7.3	7.5		8.0	8.0		6.3	6.3
6095-117	4.7	2.8	*	5.8	4.5	*	8.3	8.3		7.8	7.8		7.2	7.2		8.0	8.0		6.3	5.3
6095-55	3.2	2.7		5.7	4.7		7.6	7.5		6.5	7.7	*	7.2	7.5		8.0	7.7		5.8	4.8
6095-56	3.2	2.5		5.5	4.8		7.7	6.8	*	7.3	7.3		7.8	8.0		8.0	7.7		6	5.2
6095-73	3.2	2.3	*	5.9	4.8		8.5	8.5		7.7	7.7		8.2	8.2		8.0	7.7		6.2	4.2
6095-83	3.2	2.5		6.0	5.3		8.2	7.8		7.5	7.5		8.3	8.3		8.0	8.0		6.3	6.3
6096-117	4.3	3.2	*	6.0	5.0		7.7	6.2	*	7.3	7.1		7.3	7.8		8.0	7.7		6.2	4.2
6096-137	2.2	1.5		4.2	3.3		6.6	6.1		6.7	6.7		7.3	7.3		8.0	7.7		5.8	4
6096-36	3.5	3.3		6.2	5.6		7.6	7.6		7.7	7.7		7.3	7.3		8.0	8.0		5.7	5.3
6096-81	4.8	2.7	*	5.8	4.2	*	7.7	6.9	*	7.7	8.3		6.6	6.8		8.0	6.0	*	5.5	2.2
6096-93	4.7	3.0	*	5.7	3.7		5.7	5.7		5.0	5.5		5.5	5.8		7.0	5.3	*	4.8	3.2
6097-108	3.5	2.8		5.9	4.2	*	8.0	7.7		8.0	7.8		7.5	7.7		8.0	8.0		5.8	5.5
6097-41	4.3	3.2	*	6.7	5.7		7.2	7.2		7.0	7.0		6.8	7.7	*	8.0	7.0	*	6.2	4.5
6097-50	3.3	2.8		5.7	4.5		8.2	7.8		7.5	7.5		7.8	7.7		8.0	7.3		5.3	4.2
6097-74	4.3	3.3	*	6.0	5.7		7.9	7.9		7.2	7.2		6.7	7.0		7.8	7.8		5.5	4.7
6097-97	2.7	1.5	*	4.3	3.5		5.7	5.0		6.0	5.2		6.7	5.0	*	7.3	5.7	*	5.2	3.7
6099-10	3.8	3.2		6.3	5.6		7.6	7.3		7.5	7.5		7.8	7.8		8.0	8.0		6.5	5.3
6099-145	3.7	2.8	*	6.3	5.8		8.0	7.5		7.8	7.8		7.6	7.5		8.0	8.0		6	5.8
6099-151	4.2	3.5		6.3	5.7		8.0	8.0		7.3	7.3		6.9	6.9		8.0	8.0		5.8	5.5

6099-232	4.2	3.0	*	5.7	4.7		6.7	6.2		6.8	6.8		7.3	7.3		7.7	7.3		5.3	5.3
6099-311	2.2	2.0		4.0	3.8		7.2	6.5		7.7	7.3		7.7	7.3		7.7	7.7		5.8	5.2
6099-359	4.3	4.0		5.3	6.7	*	8.0	7.4		7.5	7.5		7.8	7.7		7.8	7.8		6	4.8
6099-383	3.8	3.2		5.5	4.3		6.7	6.5		6.3	6.3		7.0	7.3		8.0	8.0		5.8	5.2
6099-388	2.0	1.7		6.4	5.2		8.5	8.5		7.3	7.3		7.5	7.5		8.0	6.3	*	6	3.3
6099-403	2.0	1.7		3.7	3.6		6.0	4.8	*	6.3	6.3		6.5	6.8		7.0	6.3		5.8	3.8
6099-447	3.0	3.0		5.2	5.2		7.7	6.5	*	7.3	6.7		7.0	7.0		8.0	8.0		5.7	5.2
6099-69	3.5	2.8		6.8	6.0		7.8	7.8		7.3	7.3		8.0	8.0		8.0	8.0		5.7	4.8
6099-77	2.8	3.2		6.0	5.2		7.6	7.4		7.2	7.2		7.2	7.5		8.0	8.0		6	5.8
6099-8	4.3	3.5	*	5.8	4.8		8.2	8.2		7.5	7.7		7.5	7.5		8.0	8.0		5.8	5.5
6100-106	5.3	3.2	*	6.3	5.0	*	7.9	7.2		7.2	7.2		7.0	7.2		7.7	7.3		4.5	4
6100-13	3.2	2.0	*	5.9	4.3	*	8.2	8.0		7.7	7.7		7.8	7.8		8.0	7.7		5.8	4.7
6100-146	3.2	2.7		5.7	5.3		7.7	7.8		7.8	7.8		7.2	6.8		8.0	8.0		5.8	5.3
6100-186	3.3	2.3	*	6.3	5.0	*	7.9	7.9		7.7	7.7		8.2	8.2		8.0	7.3		5.8	4.2
6100-26	1.8	1.7		5.0	4.5		7.5	7.5		8.0	8.0		7.7	7.7		8.0	8.0		6.3	6.3
6100-86	4.3	3.7		6.9	5.5	*	7.6	7.6		7.5	7.5		7.7	7.7		8.0	8.0		5.7	5.7
6101-117	2.3	1.7		5.7	4.5		8.0	7.3		7.5	7.5		7.5	7.5		8.0	6.7	*	5.5	3.7
6101-154	2.2	1.7		5.5	4.2	*	8.2	6.8	*	8.0	8.0		7.0	7.3		8.0	8.0		5.7	5.2
6101-26	3.0	3.0		5.5	5.1		6.8	7.5		7.0	7.0		7.8	7.8		8.0	8.0		6	6
6101-32	3.3	2.2	*	5.3	4.2		7.3	7.2		7.0	7.0		7.5	7.5		8.0	8.0		6.2	6.2
6101-52	6.3	3.5	*	7.7	6.0	*	8.2	7.2		7.3	7.5		7.2	7.5		7.7	7.0		4.8	3.2
6101-63	5.7	2.8	*	6.8	4.2	*	6.3	6.3		5.7	6.2		6.8	6.8		7.3	6.3	*	5.2	3
6101-71	5.7	4.2	*	7.7	4.9	*	7.3	7.5		7.5	8.0		7.3	7.5		8.0	6.7	*	5.3	3.8
6101-9	6.3	5.3	*	7.3	6.0	*	7.8	5.7	*	6.0	5.8		6.3	7.7	*	7.3	7.3		5	4.2
6102-196	2.8	3.0		5.5	5.0		8.0	7.7		7.7	7.3		7.7	7.8		7.8	7.8		6.2	4.5
6102-287	4.3	3.0		6.5	5.6		8.5	8.5		7.5	7.5		7.7	7.8		8.0	8.0		5.7	4.7

6102-289	2.0	1.8		4.8	4.2		7.4	7.4		7.5	7.2		7.8	7.5		8.0	8.0		6.3	5.3	
6102-307	3.7	3.5		6.3	6.6		7.7	7.7		7.2	7.2		7.2	7.2		7.0	7.0		5.8	5.8	
6102-47	4.0	3.5		6.7	5.8		7.8	7.8		6.8	6.8		7.7	7.7		8.0	8.0		5.7	5	
6102-5	4.7	2.3	*	7.0	4.3	*	7.6	7.6		7.3	7.5		8.0	7.7		8.0	7.3		6.3	4.3	*
6102-62	4.2	3.8		6.7	6.0		7.8	7.7		7.3	7.3		7.3	7.2		7.3	7.3		5.3	5.3	
6104-150	1.5	1.3		4.5	4.2		7.8	7.2		7.7	7.7		7.3	7.3		8.0	8.0		6	6	
6109-8	3.5	2.8		5.7	4.8		7.8	7.8		7.8	7.8		7.5	7.7		8.0	8.0		5.8	5.3	
6119-14	3.8	2.3	*	5.8	4.5	*	7.8	7.0		7.5	7.5		7.3	7.3		8.0	8.0		6.2	6	
6119-155	2.0	1.7		6.0	4.3	*	7.6	7.3		7.5	7.5		7.2	7.2		8.0	8.0		6	5.3	
6119-168	2.3	2.0		4.2	3.7		8.0	7.1	*	8.0	8.0		7.5	7.5		8.0	7.7		6	4.7	*
6119-179	3.2	2.3	*	6.2	4.3	*	8.0	7.2	*	7.7	7.7		7.3	7.5		8.0	8.0		5.7	5.2	
6119-87	2.5	2.0		5.8	4.8		8.2	7.5		8.0	8.0		8.3	8.3		8.0	8.0		6.3	5.5	
6121-106	1.5	1.3		3.3	3.2		6.2	5.8		7.3	7.3		7.2	7.2		8.0	6.3	*	6	3.5	*
6121-5	2.7	3.0		4.0	3.8		7.1	6.5		7.7	7.5		7.0	7.0		8.0	8.0		6	5.5	
6126-71	2.3	1.8		4.8	4.3		8.4	7.9		8.7	8.7		8.5	8.5		8.0	8.0		6	5.7	
Chisholm	4.8	3.7	*	6.7	5.2	*	6.8	6.3		7.2	7.2		7.3	7.3		8.0	7.7		5.7	4.7	
El Toro	2.7	2.0		5.3	4.2		7.2	7.2		7.0	7.0		7.5	7.7		7.7	7.7		5.7	4.5	*
KSUZ 0802	4.3	2.8	*	6.7	5.0	*	8.0	8.0		7.2	7.3		7.2	7.3		7.8	7.8		5.8	5.8	
KSUZ 1201	4.2	3.7		5.8	5.9		8.0	7.7		7.7	7.7		7.7	7.7		8.0	7.0	*	5.5	4	*
Meyer	4.7	2.8	*	5.8	4.7		6.7	6.2		6.2	6.3		7.0	7.5		7.7	7.7		5.8	5	
TAES 5645	2.5	2.5		5.4	4.7		6.5	6.5		7.0	6.7		6.8	6.6		7.2	7.2		5.3	5.3	
Zeon	3.2	2.2	*	5.7	4.2	*	7.5	7.0		7.0	7.0		6.3	6.8		8.0	7.7		5.5	4.8	
Zorro	4.3	2.7	*	7.0	5.0	*	7.3	6.5	*	6.3	6.2		7.0	7.3		8.0	7.7		6.3	4.7	*
LSD‡	1.1	1.1		1.3	1.3		1.4	1.4		1.3	1.3		1.0	1.0		0.8	0.8		1	1	

† Turf quality was rated on each side of the plot on a scale of 1-9 (1 = dead; 6 = minimally acceptable quality; 9 = optimum color, density, texture, and uniformity); n = 3.

‡ LSD, least significant difference between means within a column at $P = 0.05$.

* Within each rating date, entries followed by a star in the inoculated column indicates a significant ($P = 0.05$) difference between fungicide-treated and nontreated (inoculated) turf.

Table B.4 Turf quality of experimental zoysiagrass progeny and standard cultivars in 2016 and 2017 in West Lafayette, IN.

	Turf Quality†							
Entry ID	7/31/16	8/22/16	9/23/16	5/16/17	6/16/17	7/31/17	9/29/17	10/20/17
6095-101	5.3	6.3	7.7	6.0	6.3	6.7	7.0	7.7
6095-117	6.0	6.7	6.7	6.0	6.0	6.3	6.7	7.7
6095-55	3.3	3.7	5.3	3.7	4.3	5.0	5.3	6.7
6095-56	6.0	6.3	7.0	5.0	5.0	5.7	6.3	8.3
6095-73	6.7	6.7	7.7	5.0	5.3	6.0	6.7	8.0
6095-83	5.3	6.7	7.3	5.3	6.7	7.0	6.0	8.7
6096-117	5.7	6.0	7.7	7.3	6.7	7.3	6.0	6.7
6096-137	5.0	5.7	6.7	3.7	4.0	5.3	6.0	7.3
6096-36	6.7	6.3	6.7	5.7	6.0	6.7	6.3	6.3
6096-81	5.3	6.7	7.7	7.0	7.3	7.7	4.7	5.3
6096-93	5.7	5.3	7.0	5.0	4.3	5.0	6.3	6.0
6097-108	4.7	5.7	6.7	5.0	5.7	6.0	6.3	7.0
6097-41	6.0	6.0	7.0	6.0	6.0	7.0	6.0	7.0
6097-50	3.7	4.7	6.7	4.0	4.7	5.3	6.3	6.7
6097-74	5.0	6.0	6.7	6.0	5.3	6.0	5.7	6.7
6097-97	4.7	5.0	6.0	3.7	3.7	3.7	5.7	5.3
6099-10	5.3	6.7	7.7	6.7	6.3	7.3	6.3	6.3

6099-145	6.3	6.0	7.0	5.3	5.7	6.3	6.7	7.7
6099-151	5.3	5.7	6.0	5.3	5.0	5.7	6.7	6.0
6099-232	4.0	4.7	7.0	7.0	6.3	7.7	6.3	7.3
6099-311	5.3	6.0	7.0	4.7	4.7	5.0	6.0	6.3
6099-359	6.3	5.3	7.0	5.0	5.0	6.0	6.7	6.7
6099-383	5.7	6.0	7.0	5.0	6.0	6.7	6.7	8.0
6099-388	6.0	6.0	7.7	4.7	5.0	6.3	7.0	6.7
6099-403	5.3	6.3	7.7	3.0	3.7	4.3	6.0	6.3
6099-447	5.7	6.3	7.0	5.3	5.3	5.3	5.7	6.3
6099-69	6.0	6.7	7.0	5.7	5.7	5.7	5.7	6.7
6099-77	5.3	6.0	7.0	5.3	5.7	5.7	6.3	7.0
6099-8	5.7	6.7	6.7	5.3	5.3	6.3	6.3	7.3
6100-106	3.3	4.0	6.0	4.7	4.0	5.0	5.7	5.7
6100-13	6.3	6.3	7.3	5.0	5.0	5.7	7.0	7.0
6100-146	5.7	6.3	7.3	6.0	5.7	7.3	6.3	7.0
6100-186	6.0	6.0	7.3	5.7	6.0	6.7	7.7	7.7
6100-26	5.0	5.7	7.0	5.0	6.0	7.3	7.3	7.3
6100-86	5.0	5.7	7.7	6.0	6.3	8.0	6.3	7.0
6101-117	6.0	6.3	7.7	4.3	5.7	6.0	6.7	7.0
6101-154	5.0	6.0	7.7	3.7	5.3	7.0	6.7	7.3
6101-26	6.0	6.7	6.7	5.7	6.3	7.0	7.3	7.0
6101-32	5.3	6.7	8.0	5.7	6.3	7.0	7.3	7.3

6101-52	6.7	6.7	6.7	4.7	5.3	5.3	4.7	5.7
6101-63	6.0	6.0	7.0	5.7	5.0	5.7	6.0	6.3
6101-71	5.3	6.0	7.3	7.0	7.0	7.7	6.3	7.3
6101-9	6.0	6.7	7.7	6.0	6.7	6.0	5.7	5.7
6102-196	5.7	6.0	6.7	5.0	5.0	5.3	6.3	6.3
6102-287	5.7	6.0	7.3	5.3	5.7	5.3	5.3	6.3
6102-289	3.7	5.0	7.0	3.0	4.0	5.0	6.0	7.0
6102-307	5.7	6.0	7.0	6.3	6.0	6.7	6.7	7.7
6102-47	5.0	6.0	7.0	6.3	6.3	6.7	7.0	8.0
6102-5	5.3	6.3	7.0	5.7	6.3	6.3	7.3	7.3
6102-62	6.3	6.7	7.0	7.0	6.0	6.0	6.3	6.0
6104-150	3.0	3.3	4.7	1.7	2.0	2.7	6.0	5.0
6109-8	5.3	5.7	6.7	5.3	5.3	6.7	6.3	7.0
6119-14	5.3	6.0	7.0	4.7	5.7	6.0	5.0	7.7
6119-155	3.7	4.7	6.7	3.3	4.3	5.0	6.7	6.7
6119-168	5.7	6.0	7.3	4.0	5.0	5.7	6.3	7.7
6119-179	6.3	6.0	7.0	6.0	5.7	6.7	6.0	8.0
6119-87	5.3	6.3	7.3	5.7	6.3	6.7	7.3	8.3
6121-106	4.7	5.7	6.7	2.7	4.0	5.3	5.3	6.0
6121-5	6.7	6.0	6.7	5.7	5.7	5.7	6.3	7.3
6126-71	4.7	6.0	7.3	4.7	5.0	6.3	6.3	7.7
Chisholm	7.0	5.7	6.0	5.7	6.3	6.0	5.3	6.3

El Toro	6.0	5.3	5.7	4.0	5.0	4.3	5.0	5.3
KSUZ 0802	5.3	6.3	6.7	7.7	6.7	7.0	6.3	7.0
KSUZ 1201	6.0	6.0	7.3	8.0	7.7	7.3	7.7	8.0
Meyer	5.7	5.7	7.0	6.0	5.3	6.0	5.0	5.7
TAES 5645	4.7	5.7	6.0	3.0	5.0	5.7	6.0	6.3
Zeon	5.0	6.0	7.0	6.0	6.0	6.0	5.7	6.7
Zorro	4.7	5.0	6.3	5.7	5.7	7.0	6.0	6.3
LSD‡	1.3	1.2	1.1	1.5	1.3	1.6	1.8	1.3

† Turf quality was rated on the whole plots on a scale of 1-9 (1 = dead; 6 = minimally acceptable quality; 9 = optimum color, density, texture, and uniformity); n = 3.

‡ LSD, least significant difference between means within a column at $P = 0.05$.

Table B.5 Turf quality of experimental zoysiagrass progeny and standard cultivars in 2016 and 2017 in Columbia, MO.

	Turf Quality†											
Entry ID	5/15/16	6/20/16	7/15/16	8/19/16	9/20/16	10/15/16	11/16/16	7/05/17	8/07/17	9/05/17	10/3/17	11/7/17
6095-101	1.7	3.0	6.3	7.3	8.0	8.0	8.0	8.0	8.3	8.3	8.3	8.0
6095-117	1.0	1.7	4.3	6.0	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3
6095-55	1.0	1.7	3.7	5.7	6.0	6.0	6.0	6.7	7.0	7.0	7.0	6.7
6095-56	1.3	2.3	5.7	7.0	8.0	8.0	8.0	7.7	7.7	7.7	7.7	7.3
6095-73	2.0	3.0	6.3	7.7	8.0	8.0	8.0	8.0	8.0	8.0	8.0	7.7
6095-83	1.0	2.3	5.0	6.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.3
6096-117	2.0	2.7	5.3	7.3	8.0	8.0	8.0	7.7	7.7	7.7	7.7	7.7
6096-137	2.0	2.7	5.7	6.7	7.7	7.7	7.7	7.0	7.0	7.7	7.0	7.0
6096-36	2.3	3.7	7.0	8.0	8.0	8.0	8.0	8.3	8.3	8.3	8.3	8.0
6096-81	2.0	3.0	6.3	7.3	8.0	8.0	8.0	8.3	8.3	8.3	8.3	8.3
6096-93	1.3	2.3	4.7	6.0	7.3	7.3	7.3	7.0	7.0	7.3	7.0	7.0
6097-108	2.0	3.0	6.0	7.0	8.0	8.0	8.0	7.7	7.7	7.7	7.7	7.7
6097-41	1.7	3.0	5.0	7.3	8.0	8.0	8.0	7.7	7.7	7.7	7.7	7.7
6097-50	1.3	2.3	5.3	6.0	6.7	6.7	6.7	7.0	7.3	7.3	7.3	7.3
6097-74	1.7	2.7	4.7	6.3	7.0	7.0	7.0	6.7	7.0	7.3	7.0	7.0
6097-97	1.3	2.7	4.7	6.3	7.0	7.0	7.0	7.3	7.3	7.3	7.3	7.0
6099-10	1.0	2.3	5.3	7.0	8.0	8.0	8.0	8.7	8.7	8.7	8.7	8.0

6099-145	2.0	2.7	6.7	7.3	8.0	8.0	8.0	8.0	8.0	8.3	8.3	8.0
6099-151	1.3	2.7	6.3	7.3	7.7	7.7	7.7	7.0	7.3	7.3	7.3	7.3
6099-232	2.0	3.0	6.7	7.7	8.0	8.0	8.0	8.3	8.3	8.3	8.3	7.7
6099-311	1.3	3.0	5.7	7.0	8.0	8.0	8.0	7.3	7.3	7.3	7.3	7.3
6099-359	1.7	3.0	5.7	7.7	7.7	7.7	7.7	8.3	8.3	8.3	8.3	8.0
6099-383	1.3	2.7	5.0	6.7	7.3	7.3	7.3	7.3	7.7	7.7	7.7	7.7
6099-388	1.3	2.3	4.3	6.7	7.3	7.3	7.3	7.0	7.0	7.0	7.0	7.0
6099-403	1.3	3.0	5.7	6.3	7.0	7.0	7.0	7.3	7.3	7.7	7.3	7.0
6099-447	1.3	2.7	6.3	7.0	8.0	8.0	8.0	7.0	7.3	7.7	7.3	7.3
6099-69	2.3	3.7	6.3	7.7	8.0	8.0	8.0	7.7	8.0	8.0	8.0	7.7
6099-77	1.0	2.7	5.0	6.7	7.7	7.7	7.7	7.3	7.3	7.3	7.3	7.3
6099-8	1.7	3.7	6.3	7.7	8.0	8.0	8.0	7.0	7.0	7.0	7.0	7.0
6100-106	1.0	1.7	2.7	5.3	5.3	5.3	5.3	6.3	6.3	6.3	6.3	6.3
6100-13	2.7	3.3	6.7	7.3	8.0	8.0	8.0	7.7	7.7	7.7	7.7	7.3
6100-146	1.0	2.3	6.0	6.3	8.0	8.0	8.0	7.3	7.3	8.0	8.0	8.0
6100-186	1.3	3.0	6.0	7.0	7.7	7.7	7.7	8.3	8.3	8.3	8.3	8.0
6100-26	1.7	3.7	6.7	7.7	8.0	8.0	8.0	8.3	8.3	8.3	8.3	8.0
6100-86	1.3	3.3	6.0	7.0	8.0	8.0	8.0	8.3	8.3	8.3	8.3	8.0
6101-117	2.3	3.3	6.7	7.7	8.0	8.0	8.0	6.7	7.3	7.3	7.3	7.0
6101-154	1.3	2.7	6.0	6.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
6101-26	2.7	3.7	6.7	7.7	8.0	8.0	8.0	7.3	7.3	7.7	7.7	7.7
6101-32	2.3	3.7	6.0	7.3	8.0	8.0	8.0	8.3	8.3	8.3	8.3	8.3

6101-52	1.7	3.0	6.0	7.0	7.7	7.7	7.7	8.0	8.0	8.3	8.0	7.7
6101-63	1.3	2.7	5.0	6.3	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
6101-71	1.7	3.0	6.0	6.7	7.7	7.7	7.7	7.3	7.3	7.7	7.3	7.3
6101-9	1.7	3.0	6.3	7.3	8.0	8.0	8.0	8.3	8.3	8.3	8.3	8.0
6102-196	1.7	3.0	5.7	7.0	7.7	7.7	7.7	7.7	7.7	8.3	7.7	7.3
6102-287	1.3	2.7	5.0	6.3	7.3	7.3	7.3	7.7	7.7	7.7	7.7	7.3
6102-289	2.0	3.0	5.0	7.0	8.0	8.0	8.0	7.0	7.3	7.3	7.3	7.3
6102-307	2.3	3.0	5.3	7.3	8.0	8.0	8.0	7.3	7.3	7.3	7.3	7.3
6102-47	1.0	1.7	2.7	4.3	5.7	5.7	5.7	6.0	6.7	6.7	6.7	6.7
6102-5	1.7	2.7	5.7	7.7	8.0	8.0	8.0	7.7	7.7	7.7	7.7	7.3
6102-62	1.3	2.7	6.0	7.3	8.0	8.0	8.0	7.0	7.3	7.3	7.3	7.3
6104-150	1.3	3.0	5.0	6.7	7.7	7.7	7.7	7.7	8.0	8.0	8.0	7.7
6109-8	1.7	3.0	6.0	7.0	7.7	7.7	7.7	8.0	8.0	8.0	8.0	8.0
6119-14	1.3	3.0	6.3	7.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
6119-155	1.7	3.0	6.0	7.3	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.3
6119-168	1.3	3.3	5.7	7.0	7.7	7.7	7.7	7.3	7.3	7.3	7.3	7.3
6119-179	2.3	3.7	7.3	7.7	8.0	8.0	8.0	8.0	8.0	8.0	8.0	7.3
6119-87	1.3	3.0	5.3	6.3	7.3	7.3	7.3	8.0	8.0	8.3	8.3	8.0
6121-106	2.0	2.7	5.7	7.3	8.0	8.0	8.0	7.7	7.7	8.0	7.7	7.3
6121-5	1.3	2.7	5.0	6.3	7.3	7.3	7.3	7.7	7.7	7.7	7.7	7.7
6126-71	1.7	3.7	6.3	7.0	7.7	7.7	7.7	8.0	8.0	8.0	8.0	7.7
Chisholm	2.7	3.3	6.7	7.3	8.0	8.0	8.0	7.0	7.0	7.0	7.0	7.0

El Toro	2.3	3.7	7.0	8.0	8.0	8.0	8.0	7.7	7.7	7.7	7.7	7.7
Meyer	1.3	2.0	5.0	6.3	7.3	7.3	7.3	7.3	7.3	7.7	7.7	7.7
Zeon	1.7	3.0	5.7	7.0	8.0	8.0	8.0	7.0	7.0	7.0	7.0	7.0
Zorro	2.3	3.0	6.7	7.7	8.0	8.0	8.0	7.3	7.3	7.3	7.3	7.0
LSD‡	0.8	0.9	1.4	1.0	0.9	0.9	0.9	1.3	1.2	1.1	1.1	0.9

† Turf quality was rated on the whole plots on a scale of 1-9 (1 = dead; 6 = minimally acceptable quality; 9 = optimum color, density, texture, and uniformity); n = 3.

‡ LSD, least significant difference between means within a column at *P* = 0.05.

Table B.6 Turf quality of experimental zoysiagrass progeny and standard cultivars in 2016 and 2017 in Raleigh, NC.

	Turf Quality†									
Entry ID	7/29/16	8/23/16	9/23/16	10/27/16	5/18/17	6/18/17	7/20/17	8/16/17	9/21/17	10/18/17
6095-101	7.7	8.0	8.0	7.3	6.7	7.3	8.0	8.7	8.3	8.0
6095-117	7.3	7.7	8.0	7.0	6.0	7.0	7.7	8.3	8.3	8.0
6095-55	5.7	6.7	7.3	7.3	6.7	7.0	7.7	7.7	7.7	7.3
6095-56	8.0	8.0	8.0	8.0	6.7	7.3	8.0	8.3	8.7	8.3
6095-73	7.7	7.7	7.7	8.0	6.3	7.3	8.3	8.3	8.0	8.3
6095-83	7.7	7.7	8.0	7.0	7.0	7.7	8.0	8.3	8.0	8.0
6096-117	4.0	5.0	6.0	6.0	5.3	5.3	7.0	7.0	7.0	6.7
6096-137	8.0	8.7	9.0	7.7	4.3	6.0	7.7	7.0	7.7	7.7
6096-36	6.3	8.0	8.0	7.0	7.3	8.0	7.0	7.7	7.3	7.0
6096-81	6.3	7.3	7.0	6.3	5.7	6.3	7.0	7.7	7.0	6.7
6096-93	3.7	4.7	4.7	4.3	4.0	4.3	5.0	5.3	5.3	5.0
6097-108	8.0	8.0	8.0	7.3	7.7	8.3	7.7	8.0	8.0	7.7
6097-41	7.3	7.7	7.7	7.0	7.0	8.0	8.0	7.7	7.7	6.7
6097-50	6.7	7.7	7.7	7.0	5.7	6.7	7.7	7.7	7.3	7.0
6097-74	7.7	8.0	8.0	7.7	6.7	8.0	7.7	7.7	7.3	6.7
6097-97	6.7	7.7	7.7	7.0	5.7	6.3	6.7	6.7	6.7	6.7
6099-10	7.7	7.7	7.7	7.0	7.7	8.0	7.7	8.3	8.0	7.3

6099-145	7.3	8.0	8.0	7.0	6.0	6.7	7.0	8.0	8.0	7.7
6099-151	8.0	8.7	8.3	7.0	6.7	7.7	8.0	8.0	8.0	7.7
6099-232	5.3	6.3	7.0	7.0	6.7	7.0	7.7	8.0	7.7	7.3
6099-311	7.7	8.0	8.0	7.3	5.7	7.0	8.0	8.0	7.3	7.3
6099-359	8.0	8.0	8.0	7.0	6.3	7.3	7.0	7.0	7.3	7.0
6099-383	7.7	8.0	7.7	7.0	5.0	6.0	6.7	7.0	7.0	6.3
6099-388	7.3	8.0	8.7	7.7	5.7	7.0	7.3	7.7	7.7	7.3
6099-403	5.5	7.5	6.0	5.7	4.0	4.7	6.3	7.3	7.3	7.0
6099-447	7.7	7.7	7.7	7.0	6.3	7.3	8.0	8.0	8.0	7.7
6099-69	7.3	8.0	8.0	7.3	6.0	7.0	7.7	8.0	7.7	7.3
6099-77	6.3	7.0	7.7	7.3	6.3	6.7	7.7	7.7	7.3	7.0
6099-8	7.7	8.0	8.0	7.0	6.7	7.7	8.0	8.0	8.0	7.3
6100-106	4.0	5.0	5.7	5.7	5.0	5.7	6.7	7.3	7.3	6.7
6100-13	7.3	8.0	8.0	7.3	7.0	8.0	8.3	8.0	8.0	8.3
6100-146	6.3	7.7	7.7	7.0	6.3	6.3	7.3	7.3	7.3	7.3
6100-186	8.0	8.0	8.0	8.0	7.0	7.7	7.7	8.0	8.0	7.7
6100-26	8.3	8.3	8.7	7.7	6.3	6.7	7.7	7.7	7.7	7.7
6100-86	6.7	7.7	7.7	7.0	7.3	7.7	7.7	8.3	8.3	7.7
6101-117	7.7	8.0	8.0	8.0	6.0	7.0	8.3	8.3	8.3	7.7
6101-154	8.0	8.3	8.0	8.0	4.7	5.7	8.3	8.3	9.0	9.0
6101-26	7.3	8.0	8.0	7.0	6.3	7.0	7.7	7.7	7.7	7.0
6101-32	8.0	8.7	8.7	8.0	5.7	6.7	7.7	8.0	8.7	8.3

6101-52	7.7	8.0	8.0	7.0	7.3	6.7	7.0	7.0	6.3	6.0
6101-63	7.0	7.7	7.7	6.3	6.3	6.7	6.7	6.7	6.0	5.7
6101-71	5.0	6.7	7.0	6.3	6.7	7.3	8.3	8.0	7.3	6.7
6101-9	6.3	7.0	7.3	7.0	7.0	7.3	7.7	8.0	7.7	7.7
6102-196	7.3	8.0	8.0	7.0	5.7	7.7	8.0	8.0	7.7	7.3
6102-287	7.3	8.0	8.0	7.3	6.0	7.0	7.3	8.0	7.3	7.0
6102-289	8.0	8.7	9.0	8.3	4.7	6.0	7.7	8.0	8.3	8.3
6102-307	8.0	8.0	8.0	7.0	8.0	8.0	8.0	8.0	7.7	7.3
6102-47	7.3	8.0	8.0	7.3	5.7	6.7	8.0	8.0	8.0	8.0
6102-5	7.3	8.0	8.0	7.0	6.3	7.3	7.0	8.0	7.0	7.0
6102-62	7.0	7.3	7.7	7.0	7.0	7.3	8.0	8.0	8.0	7.7
6104-150	7.0	7.7	8.0	7.3	5.7	6.3	7.3	7.7	8.0	8.0
6109-8	7.3	7.7	8.0	7.3	7.3	7.3	7.3	7.3	7.7	7.3
6119-14	8.0	8.7	8.7	7.7	6.7	7.3	8.0	8.7	8.7	8.0
6119-155	7.3	8.3	8.3	8.0	5.3	6.3	8.0	8.7	8.0	8.0
6119-168	7.0	8.0	8.3	7.7	5.0	6.0	7.3	8.3	8.3	7.7
6119-179	7.3	8.0	8.0	7.0	7.3	8.0	8.0	8.0	8.0	8.0
6119-87	7.3	7.7	7.7	7.7	5.7	6.3	6.7	7.3	7.3	7.0
6121-106	8.0	8.0	8.0	7.0	5.0	6.3	7.0	8.0	8.0	7.7
6121-5	8.0	8.0	8.0	7.0	5.3	6.0	7.0	7.7	8.0	8.0
6126-71	8.0	8.0	8.3	8.0	5.0	6.3	7.3	8.3	8.0	7.7
Chisholm	7.0	7.0	7.3	7.0	6.7	7.0	6.7	7.0	7.0	7.0

El Toro	6.7	7.3	7.7	7.0	6.0	7.0	7.0	8.0	8.0	7.7
Meyer	4.7	6.3	6.7	6.0	5.3	5.7	6.3	6.3	6.0	6.0
Zeon	7.3	8.7	8.7	7.7	6.0	7.7	8.3	8.0	8.0	7.7
Zorro	7.3	9.0	9.0	8.0	4.7	7.0	8.3	8.0	8.3	8.0
LSD‡	1.2	0.8	0.8	0.8	1.0	1.0	1.0	0.9	1.0	0.9

† Turf quality was rated on the whole plots on a scale of 1-9 (1 = dead; 6 = minimally acceptable quality; 9 = optimum color, density, texture, and uniformity); n = 3.

‡ LSD, least significant difference between means within a column at *P* = 0.05.

Table B.7 Turf quality of experimental zoysiagrass progeny and standard cultivars in 2016 and 2017 in Stillwater, OK.

	Turf Quality†												
Entry ID	5/19/16	6/15/16	7/16/16	8/30/16	9/17/16	10/12/16	5/5/17	6/5/17	7/5/17	8/2/17	9/7/17	10/10/17	11/13/17
6095-101	7.0	6.3	6.0	5.3	5.3	5.3	7.7	8.0	6.7	7.7	7.0	7.3	6.3
6095-117	7.3	6.3	6.0	6.0	5.7	5.3	6.3	7.7	7.0	7.7	8.0	7.7	6.0
6095-55	6.0	6.0	6.0	5.3	5.7	5.3	5.7	6.7	6.7	7.3	7.3	7.3	6.7
6095-56	7.3	6.7	6.3	5.7	5.3	5.7	6.0	7.3	6.7	7.3	7.0	7.0	6.3
6095-73	6.7	6.7	6.7	7.0	6.7	6.0	7.0	8.0	6.7	7.0	7.7	8.0	6.7
6095-83	6.3	6.7	7.0	5.0	5.0	5.0	8.3	8.0	6.7	8.0	7.3	7.3	6.0
6096-117	6.0	5.7	6.0	6.7	6.3	5.7	7.3	7.3	7.3	6.7	7.3	7.3	5.7
6096-137	6.3	5.7	5.0	6.3	6.0	6.0	7.3	7.0	6.7	7.3	6.7	6.3	6.3
6096-36	6.7	5.7	5.3	5.3	5.3	5.7	6.7	7.3	6.3	7.0	6.3	6.7	5.7
6096-81	5.7	6.0	6.7	6.3	6.0	6.3	3.7	5.7	6.0	7.0	6.7	6.7	5.3
6096-93	4.7	5.0	4.0	6.3	6.7	6.3	5.7	6.3	6.3	6.7	5.7	6.7	5.0
6097-108	7.0	7.3	7.0	6.0	5.7	5.7	7.3	8.0	7.7	7.7	7.3	7.0	6.0
6097-41	7.0	6.3	6.0	6.0	6.3	6.0	8.0	7.7	7.0	7.3	7.0	6.7	5.7
6097-50	6.0	5.7	6.0	7.0	6.3	5.7	6.0	7.7	7.0	7.3	6.7	7.3	6.3
6097-74	6.3	6.7	6.0	6.0	5.7	5.7	7.7	8.0	7.3	7.7	7.3	7.0	6.3
6097-97	6.3	6.0	7.0	6.0	6.0	5.7	6.0	7.0	7.0	7.3	7.0	6.7	6.0
6099-10	7.0	6.7	7.3	6.7	6.3	6.0	8.0	7.7	7.0	7.7	7.3	7.7	6.3

6099-145	8.0	7.7	7.3	4.7	4.3	4.3	7.7	8.0	7.3	7.7	7.3	7.7	6.7
6099-151	6.0	6.0	5.3	5.7	5.7	5.7	5.7	7.3	7.3	7.3	6.7	7.0	5.3
6099-232	5.0	4.7	5.3	4.7	4.7	4.7	8.3	7.7	7.0	7.3	7.0	6.7	5.7
6099-311	7.0	5.7	5.3	5.7	5.7	5.7	6.0	7.3	7.3	7.3	6.7	7.0	6.7
6099-359	7.3	6.7	6.3	7.0	6.7	6.3	6.3	7.7	7.0	7.3	6.7	7.3	6.7
6099-383	8.0	6.7	6.0	7.3	6.7	6.3	8.7	8.0	7.0	7.3	7.7	7.3	6.7
6099-388	7.3	6.3	5.7	6.7	6.3	6.0	6.7	8.0	7.0	7.3	6.7	7.3	7.0
6099-403	6.3	6.3	6.3	7.0	6.7	6.0	7.0	7.7	7.0	7.7	7.0	7.3	6.3
6099-447	6.7	6.0	6.3	6.3	6.3	6.7	7.7	7.3	7.0	7.0	7.0	6.7	6.0
6099-69	7.7	7.0	6.7	6.3	6.7	6.3	8.0	7.3	7.0	7.7	7.0	7.3	5.7
6099-77	7.3	7.3	7.3	5.0	5.0	5.0	8.0	7.7	7.0	8.0	8.0	7.3	6.7
6099-8	7.0	7.0	6.0	6.7	6.3	6.0	6.7	7.3	7.0	7.3	6.7	7.0	5.7
6100-106	5.7	5.7	6.7	5.7	6.0	5.7	6.3	7.0	6.7	7.0	7.7	7.0	5.3
6100-13	6.3	6.0	6.3	5.7	5.7	6.0	8.0	8.0	6.7	6.7	7.7	7.0	6.0
6100-146	7.0	6.0	6.0	6.0	5.3	5.7	8.3	7.7	6.7	7.3	5.7	6.3	4.7
6100-186	7.3	6.7	5.7	6.0	6.0	5.7	7.0	7.3	7.7	8.0	7.7	7.3	7.0
6100-26	6.3	6.3	6.3	6.0	5.7	5.3	7.0	7.7	7.0	7.3	7.0	7.0	6.0
6100-86	6.3	6.0	6.7	6.3	6.3	6.0	7.7	7.7	7.7	7.3	8.0	7.3	6.0
6101-117	7.0	6.3	6.3	6.0	5.7	5.7	6.7	6.7	7.0	7.3	6.7	7.3	6.0
6101-154	7.7	7.7	7.7	6.0	6.3	5.7	7.3	8.0	8.0	8.0	7.0	8.0	7.0
6101-26	6.3	6.0	6.3	5.7	5.0	5.3	7.7	8.0	7.3	7.3	7.3	6.3	6.0
6101-32	7.0	7.0	5.7	6.3	6.3	6.0	8.3	8.0	8.0	7.7	7.3	7.7	6.0

6101-52	6.0	5.7	6.7	7.0	6.7	6.3	6.0	6.0	7.0	7.7	7.7	7.0	5.0
6101-63	6.0	6.0	5.3	6.3	6.3	6.3	6.0	6.7	7.3	7.3	7.0	6.3	5.3
6101-71	5.3	5.7	5.7	6.0	6.0	5.7	7.0	7.3	7.3	7.3	7.0	7.0	5.7
6101-9	6.0	5.7	6.3	4.7	4.7	4.7	7.0	7.7	7.3	7.3	7.7	7.3	6.0
6102-196	6.0	6.3	6.0	6.0	6.0	5.7	7.0	8.0	7.0	7.7	6.3	7.0	6.0
6102-287	6.3	7.0	6.0	6.3	6.0	5.7	6.7	7.3	7.0	7.7	7.0	7.0	6.0
6102-289	6.3	5.3	6.0	5.7	5.7	5.3	8.3	8.0	7.3	7.0	6.3	6.7	6.0
6102-307	6.7	6.0	5.7	5.7	6.0	5.7	8.7	7.3	7.0	6.7	7.0	6.7	6.0
6102-47	6.7	7.0	6.0	5.7	5.7	5.7	8.0	8.0	6.7	7.3	6.7	7.0	6.0
6102-5	7.3	6.7	6.0	5.7	5.7	5.7	7.3	8.0	7.0	7.3	7.0	6.7	5.7
6102-62	7.0	7.3	7.7	6.3	6.3	6.0	8.0	8.0	7.3	8.0	8.0	7.0	6.0
6104-150	6.7	5.7	5.7	6.3	6.0	5.7	7.0	7.7	6.7	7.7	6.7	6.3	6.0
6109-8	6.3	6.7	6.7	6.0	5.7	5.7	6.7	8.0	7.3	7.7	7.7	7.3	6.7
6119-14	7.0	5.7	6.3	6.3	6.0	5.7	7.0	7.3	7.0	7.7	7.0	7.3	6.7
6119-155	6.7	7.3	6.0	5.0	5.0	5.0	6.3	7.7	7.7	7.3	7.3	7.3	7.0
6119-168	7.3	6.3	6.0	6.0	6.0	6.0	7.7	8.0	6.7	7.3	7.0	7.0	6.3
6119-179	7.7	7.0	6.3	6.0	5.7	5.7	7.0	7.7	8.0	8.0	7.7	7.3	7.0
6119-87	5.3	5.7	6.0	6.7	6.3	5.7	7.7	8.0	7.7	7.3	8.0	8.0	7.0
6121-106	7.0	6.7	6.0	6.3	6.3	6.0	5.0	6.3	7.0	7.3	7.0	6.7	6.3
6121-5	8.0	7.3	7.3	6.3	6.0	5.3	6.0	7.7	8.0	7.7	7.7	7.3	6.7
6126-71	6.3	7.0	7.0	6.7	6.0	6.0	8.7	8.0	8.0	8.0	7.7	7.7	7.0
Chisholm	5.7	5.0	5.3	5.7	5.7	5.3	2.7	2.3	6.0	6.7	7.0	6.3	5.0

El Toro	6.7	5.7	5.7	6.7	6.3	5.3	5.0	5.7	6.0	7.3	7.0	6.7	5.3
Meyer	5.3	5.3	6.0	6.0	5.7	5.7	6.3	7.0	7.0	7.3	6.7	6.7	6.0
Zeon	6.3	6.3	5.7	5.7	5.7	5.7	6.7	7.7	7.0	7.7	7.3	7.7	7.0
Zorro	6.3	6.3	5.7	6.0	6.0	5.7	7.3	8.0	6.7	7.0	7.3	8.0	6.3
LSD‡	1.2	1.2	1.0	1.4	1.2	1.0	1.4	0.9	0.8	0.9	0.8	0.9	0.8

† Turf quality was rated on the whole plots on a scale of 1-9 (1 = dead; 6 = minimally acceptable quality; 9 = optimum color, density, texture, and uniformity); n = 3.

‡ LSD, least significant difference between means within a column at *P* = 0.05.

Table B.8 Turf quality of experimental zoysiagrass progeny and standard cultivars in 2016 and 2017 in Dallas, TX.

	Turf Quality†										
Entry ID	4/11/16	5/26/16	6/17/16	7/12/16	8/1/16	9/9/16	5/4/17	6/6/17	7/10/17	8/3/17	9/5/17
6095-101	5.7	5.3	6.3	8.3	7.0	6.7	6.0	5.7	6.0	4.3	3.0
6095-117	5.7	6.3	7.7	8.3	7.3	7.0	5.3	5.3	5.3	4.0	2.7
6095-55	4.7	5.3	7.0	7.7	7.0	7.7	4.7	6.0	6.0	4.0	3.0
6095-56	5.0	5.7	7.0	6.7	6.7	5.3	4.7	5.7	6.3	5.0	4.7
6095-73	5.3	6.0	6.7	8.0	7.3	6.0	5.3	6.0	6.0	3.3	2.7
6095-83	6.3	6.3	7.7	8.3	7.3	6.7	6.7	7.3	8.0	6.7	6.7
6096-117	3.7	5.0	7.0	6.3	5.7	4.3	3.7	4.7	4.7	2.3	1.0
6096-137	5.0	6.0	6.7	7.0	6.3	5.7	5.3	5.0	5.7	2.7	1.7
6096-36	5.3	5.7	6.3	5.7	5.3	5.0	3.3	5.0	4.0	2.3	2.3
6096-81	3.0	4.0	5.3	5.7	5.3	4.7	3.7	4.0	3.7	2.7	2.3
6096-93	3.3	4.0	5.0	4.7	4.0	3.7	2.3	3.3	2.7	1.7	2.0
6097-108	5.0	5.3	6.3	7.3	6.7	5.7	5.3	5.7	6.3	3.3	3.0
6097-41	5.3	6.3	7.7	7.7	7.0	7.0	4.7	5.7	5.0	2.3	2.0
6097-50	4.7	4.7	6.3	6.7	6.0	5.7	4.0	5.0	4.0	2.3	2.0
6097-74	6.0	5.7	7.3	7.3	7.0	6.7	5.7	6.0	6.3	3.0	2.0
6097-97	4.7	4.7	6.3	5.3	4.3	4.7	4.7	4.7	4.3	2.0	1.3
6099-10	4.7	4.7	6.7	6.7	6.0	5.3	4.7	5.3	5.7	4.0	3.7

6099-145	5.3	5.7	7.0	8.3	6.7	7.7	6.7	6.3	7.3	4.0	3.3
6099-151	5.7	6.3	7.0	5.7	6.0	6.3	5.0	6.0	5.7	3.7	2.7
6099-232	6.0	5.3	7.0	6.7	6.0	6.3	4.0	5.7	5.0	2.7	2.3
6099-311	4.3	5.0	6.0	6.0	6.0	5.0	5.3	5.3	5.0	2.7	1.7
6099-359	5.0	6.0	7.7	7.0	6.3	6.0	5.7	5.3	5.0	3.0	2.7
6099-383	5.7	6.3	8.3	7.7	6.7	7.0	4.3	5.3	5.7	3.3	3.7
6099-388	4.3	5.3	8.3	7.0	6.7	6.0	4.0	4.3	5.0	3.0	1.3
6099-403	3.3	2.7	3.0	4.7	5.0	5.0	5.3	5.3	5.0	3.7	3.0
6099-447	6.0	6.3	7.3	7.0	7.0	6.7	4.3	5.0	4.3	2.3	2.0
6099-69	4.7	6.0	7.3	7.3	6.7	7.0	5.0	6.7	7.0	4.3	3.7
6099-77	5.0	4.7	5.7	5.7	5.3	4.3	5.0	6.0	6.7	3.3	2.7
6099-8	5.0	5.7	7.7	7.7	6.7	6.3	6.0	5.7	6.0	4.7	3.7
6100-106	3.0	3.3	4.7	6.7	5.3	5.3	4.0	4.0	5.0	3.0	2.3
6100-13	5.7	6.3	8.3	7.7	7.0	7.0	5.3	5.0	4.0	2.3	2.0
6100-146	4.3	4.3	6.0	7.3	6.7	6.0	5.3	5.7	7.0	3.3	3.3
6100-186	6.0	6.0	7.3	7.3	7.3	7.3	5.7	6.3	6.7	3.7	3.0
6100-26	4.3	5.0	6.3	6.0	5.7	5.7	4.3	4.7	5.3	3.0	1.7
6100-86	5.3	5.0	6.7	7.3	6.7	5.3	4.7	5.7	5.7	3.0	2.0
6101-117	4.7	5.3	6.3	6.0	4.7	3.3	3.7	5.3	6.0	2.7	2.3
6101-154	5.3	6.3	8.0	8.7	7.7	7.3	6.7	7.0	7.7	5.0	5.3
6101-26	5.3	6.0	7.7	7.3	7.0	6.3	5.0	5.7	6.0	2.7	3.0
6101-32	5.0	5.7	7.3	7.3	6.3	6.3	6.7	6.0	7.0	4.3	5.3

6101-52	4.7	5.3	7.0	7.0	6.0	6.3	3.7	4.3	3.7	2.7	2.0
6101-63	4.0	5.0	6.3	6.7	5.7	5.0	3.3	4.0	4.0	1.7	1.3
6101-71	5.0	5.7	7.0	8.0	6.7	6.3	3.3	4.7	5.7	3.3	2.3
6101-9	5.0	5.3	7.0	6.3	6.3	5.7	4.3	4.7	4.3	2.3	2.0
6102-196	5.0	5.0	6.7	6.7	6.0	6.3	4.0	4.7	3.7	2.0	2.0
6102-287	4.7	5.3	6.7	7.0	6.7	7.7	5.0	5.3	6.3	3.7	3.7
6102-289	4.7	4.3	6.7	7.0	6.7	6.3	6.7	7.3	7.7	4.3	2.7
6102-307	5.0	5.3	6.3	6.7	6.7	6.7	5.7	6.0	6.7	3.3	2.7
6102-47	4.7	4.0	5.0	6.3	6.0	6.0	5.7	6.3	6.7	2.7	2.7
6102-5	5.7	5.3	6.7	6.7	6.3	5.7	4.3	5.0	4.7	2.7	1.7
6102-62	4.0	4.7	4.7	7.0	6.3	5.7	5.7	6.7	6.0	4.7	2.7
6104-150	6.0	6.7	8.0	7.3	7.0	7.3	3.3	4.7	4.3	3.3	3.0
6109-8	4.7	4.7	6.7	6.3	5.7	6.0	4.0	4.7	3.7	3.0	2.7
6119-14	6.7	6.0	7.7	7.7	7.0	7.7	7.3	6.3	6.3	4.3	3.3
6119-155	5.0	6.0	7.3	6.3	6.7	5.7	4.7	4.3	5.7	3.0	1.7
6119-168	6.3	6.3	8.0	8.0	8.0	7.7	7.3	7.0	8.7	6.3	5.3
6119-179	6.7	6.7	7.7	7.7	6.7	7.0	6.3	6.3	6.3	4.0	2.7
6119-87	5.0	5.3	6.7	6.7	6.7	7.3	6.0	6.0	5.7	3.7	2.0
6121-106	5.3	5.0	7.0	4.7	4.3	3.7	3.3	3.7	3.7	2.0	1.0
6121-5	5.7	5.0	7.0	6.0	5.0	6.0	5.3	5.0	3.3	2.3	1.7
6126-71	7.7	6.3	8.0	7.0	6.3	6.7	5.0	5.0	4.7	3.0	1.7
Chisholm	6.3	7.3	8.0	7.3	7.3	7.0	6.3	7.3	7.7	5.3	4.3

El Toro	6.3	7.7	9.0	7.7	7.3	8.7	5.7	7.0	6.7	5.3	4.7
KSUZ 0802	5.7	6.3	8.0	8.0	7.0	7.3	5.3	6.0	5.3	2.0	2.0
KSUZ 1201	6.3	6.7	7.3	7.7	7.0	6.7	4.0	4.7	5.3	2.3	2.0
Meyer	3.0	4.7	5.7	5.3	5.0	4.3	3.3	4.0	3.7	2.0	2.0
TAES 5645	5.3	5.3	6.3	6.3	5.7	5.3	3.3	3.7	2.7	1.7	1.3
Zeon	5.3	6.7	8.0	6.7	6.0	7.0	5.7	5.0	5.7	3.3	3.0
Zorro	5.7	6.3	8.0	7.3	7.0	6.7	4.7	4.3	5.3	2.0	1.7
LSD‡	1.7	1.5	1.6	1.4	1.4	2.2	1.4	1.3	1.8	1.5	1.8

† Turf quality was rated on the whole plots on a scale of 1-9 (1 = dead; 6 = minimally acceptable quality; 9 = optimum color, density, texture, and uniformity); n = 3.

‡ LSD, least significant difference between means within a column at *P* = 0.05.

Table B.9 Turf quality of experimental zoysiagrass progeny and standard cultivars in 2016 and 2017 in Chicago, IL.

	Turf Quality†	
Entry ID	8/20/16	8/30/17
6095-101	5.7	5.0
6095-117	5.7	6.3
6095-55	5.3	6.0
6095-56	6.0	6.7
6095-73	5.7	5.7
6095-83	6.3	5.3
6096-117	6.3	3.7
6096-137	6.7	6.3
6096-36	5.7	6.3
6096-81	5.7	4.3
6096-93	4.7	5.7
6097-108	5.3	4.7
6097-41	6.3	5.3
6097-50	6.0	6.3
6097-74	6.0	6.3
6097-97	6.0	4.7
6099-10	5.3	6.0
6099-145	6.3	5.0
6099-151	5.7	5.7
6099-232	5.7	3.7
6099-311	6.0	6.3
6099-359	6.3	5.7
6099-383	6.3	7.3
6099-388	5.3	5.7
6099-403	6.0	6.3

6099-447	6.3	6.0
6099-69	6.3	7.3
6099-77	6.3	4.0
6099-8	5.7	6.0
6100-106	6.3	4.3
6100-13	6.3	6.3
6100-146	6.3	5.7
6100-186	5.0	5.0
6100-26	5.7	6.0
6100-86	6.3	6.7
6101-117	6.0	6.7
6101-154	5.7	5.7
6101-26	5.7	6.0
6101-32	5.7	6.7
6101-52	5.3	5.7
6101-63	6.0	5.0
6101-71	6.0	5.3
6101-9	5.3	5.3
6102-196	6.0	7.0
6102-287	5.3	5.3
6102-289	6.0	3.0
6102-307	5.7	6.3
6102-47	6.2	5.3
6102-5	4.7	7.7
6102-52	6.5	5.3
6104-150	6.3	3.3
6109-8	6.0	7.0
6119-14	6.0	6.7
6119-155	5.7	5.7
6119-168	6.7	6.0
6119-179	7.0	7.0

6119-87	6.0	5.3
6121-106	5.7	5.3
6121-5	6.7	6.3
6126-71	6.3	6.7
KSUZ0802	6.0	6.3
KSUZ1201	4.0	6.7
Meyer	6.0	5.0
TAES5645	6.3	7.0
Zorro	6.7	5.3
LSD‡	1.3	1.7

† Turf quality was rated on the whole plots on a scale of 1-9 (1 = dead; 6 = minimally acceptable quality; 9 = optimum color, density, texture, and uniformity); n = 3.

‡ LSD, least significant difference between means within a column at $P = 0.05$.

Table B.10 Turf quality of experimental zoysiagrass progeny and standard cultivars in 2016 in Blacksburg, VA.

	Turf Quality†	
Entry ID	9/30/16	11/08/16
6095-101	7.2	7.2
6095-117	7.2	7.3
6095-55	6.5	6.7
6095-56	7.5	7.7
6095-73	7.2	7.3
6095-83	7.8	7.5
6096-117	6.7	6.7
6096-137	7.5	7.4
6096-36	7.0	7.2
6096-81	6.7	6.8
6096-93	6.3	6.5
6097-108	7.0	7.0
6097-41	7.2	7.2
6097-50	6.7	7.0
6097-74	6.7	6.7
6097-97	5.7	5.7
6099-10	6.5	6.7
6099-145	7.0	7.2
6099-151	7.0	7.2
6099-232	6.3	6.5
6099-311	6.7	6.7
6099-359	7.5	7.7
6099-383	6.8	6.8
6099-388	6.7	6.7
6099-403	5.8	6.0

6099-447	7.0	7.0
6099-69	7.8	7.8
6099-77	6.8	6.8
6099-8	6.8	7.0
6100-106	5.2	5.5
6100-13	6.8	7.0
6100-146	6.7	6.5
6100-186	6.8	6.8
6100-26	7.0	6.8
6100-86	6.8	6.7
6101-117	7.0	7.0
6101-154	7.0	7.0
6101-26	7.7	7.7
6101-32	7.2	7.0
6101-52	8.0	7.8
6101-63	7.3	7.2
6101-71	6.8	6.8
6101-9	6.8	6.8
6102-196	6.8	6.8
6102-287	7.0	6.8
6102-289	6.7	6.8
6102-307	7.3	7.2
6102-47	7.0	7.0
6102-5	7.3	7.3
6102-62	7.2	7.3
6104-150	6.7	6.7
6109-8	6.8	6.8
6119-14	7.2	7.6
6119-155	7.2	7.3
6119-168	6.8	6.8
6119-179	7.0	7.3

6119-87	6.8	6.8
6121-106	6.5	6.7
6121-5	7.3	7.0
6126-71	6.8	6.7
Chisholm	7.2	7.3
El Toro	7.5	7.0
Meyer	6.8	6.8
Zeon	6.8	7.0
Zorro	6.5	6.5
LSD[‡]	0.8	0.8

[†] Turf quality was rated on the whole plots on a scale of 1-9 (1 = dead; 6 = minimally acceptable quality; 9 = optimum color, density, texture, and uniformity); n = 3.

[‡] LSD, least significant difference between means within a column at $P = 0.05$.

Table B.11 Spring green-up of experimental zoysiagrass progeny and standard cultivars in 2016 in Fayetteville, AR; Manhattan, KS; Columbia, MO; Raleigh, NC; Stillwater, OK; and Dallas, TX.

	Spring Green-up†					
	AR	KS	MO	NC	OK	TX
Entry ID	4/20/16	5/5/16	4/1/16	3/24/16	3/11/16	3/15/16
6095-101	6.3	4.0	2.7	3.3	6.0	8.0
6095-117	7.3	3.3	2.0	2.7	5.3	5.7
6095-55	5.7	2.3	1.7	5.3	5.7	5.0
6095-56	9.0	3.3	2.3	4.0	6.0	4.7
6095-73	8.0	6.0	1.7	4.3	6.3	6.7
6095-83	8.0	2.7	2.0	3.3	6.0	5.7
6096-117	6.0	2.3	3.0	2.0	4.7	3.7
6096-137	5.0	4.0	2.0	2.0	5.7	5.3
6096-36	5.3	4.3	3.3	1.3	3.0	1.3
6096-81	6.7	4.3	4.3	3.0	5.0	3.3
6096-93	4.0	3.7	1.7	1.7	4.0	3.7
6097-108	5.3	5.7	1.7	3.3	6.0	5.0
6097-41	7.3	4.0	1.7	3.0	5.7	6.0
6097-50	4.3	5.3	1.7	4.7	6.0	7.0
6097-74	5.7	6.7	1.7	4.3	6.0	6.7
6097-97	4.3	1.3	3.7	4.3	5.0	6.0
6099-10	5.7	4.3	1.7	2.3	5.7	3.7
6099-145	4.0	5.0	3.3	5.7	7.3	7.0
6099-151	4.3	4.7	2.3	4.7	6.0	6.7
6099-232	4.7	2.7	2.7	2.7	4.3	5.7
6099-311	4.7	8.0	2.7	2.3	6.0	4.7
6099-359	5.7	6.7	3.0	2.7	6.3	6.0
6099-383	5.0	2.7	2.0	5.7	6.0	7.7

6099-388	4.3	4.3	1.3	3.0	6.7	6.0
6099-403	4.7	2.0	1.7	2.5	6.0	6.3
6099-447	5.7	5.0	3.7	4.7	5.3	8.0
6099-69	6.3	5.3	2.3	3.7	5.3	4.7
6099-77	4.3	5.0	1.0	5.0	6.0	4.0
6099-8	4.7	4.7	2.0	4.0	6.0	6.0
6100-106	5.3	3.0	1.7	2.0	5.7	4.3
6100-13	4.7	6.3	3.0	3.0	6.3	5.3
6100-146	6.0	5.3	1.0	2.3	4.7	3.0
6100-186	6.0	5.0	1.7	2.3	6.0	5.7
6100-26	5.0	4.3	1.7	2.0	5.3	5.3
6100-86	4.3	5.3	1.3	3.7	6.0	6.7
6101-117	6.7	5.7	3.0	2.7	6.0	4.7
6101-154	5.3	3.7	1.7	2.3	6.0	6.3
6101-26	6.3	4.3	3.0	3.0	5.3	6.0
6101-32	5.0	5.3	2.7	2.3	5.0	5.3
6101-52	7.3	5.3	3.0	2.3	3.0	3.7
6101-63	5.7	3.3	1.7	2.3	4.0	4.7
6101-71	6.7	3.7	3.0	3.7	5.7	5.7
6101-9	6.7	4.3	3.3	2.3	5.3	6.3
6102-196	4.7	6.0	2.7	4.7	6.3	6.0
6102-287	5.3	4.7	1.7	4.7	6.7	7.0
6102-289	5.0	4.7	2.3	4.0	5.7	7.0
6102-307	5.0	4.7	2.3	2.3	4.0	4.0
6102-47	5.0	2.0	1.0	4.0	6.7	6.3
6102-5	5.3	2.3	2.7	2.7	6.0	6.3
6102-62	5.0	4.0	3.0	3.0	5.3	3.7
6104-150	4.7	3.7	1.7	1.0	4.3	6.3
6109-8	5.3	3.3	2.0	2.0	5.0	4.3
6119-14	6.3	3.3	2.7	4.0	6.0	8.0
6119-155	5.0	4.7	2.0	2.0	6.3	7.3

6119-168	5.3	4.7	1.3	3.0	6.3	8.0
6119-179	6.0	7.7	3.7	3.0	5.7	8.0
6119-87	5.0	6.0	1.7	5.3	6.0	6.0
6121-106	4.3	5.7	2.0	3.0	6.3	6.7
6121-5	5.7	6.0	1.7	3.0	5.3	5.7
6126-71	5.7	4.3	2.0	4.0	6.7	8.0
Chisholm	6.0	5.7	3.7	3.0	5.0	5.0
El Toro	7.0	8.7	3.0	2.3	4.3	6.3
KSUZ 0802	N/A	2.3	N/A	N/A	N/A	5.0
KSUZ 1201	N/A	4.3	N/A	N/A	N/A	5.3
Meyer	6.7	3.7	2.0	2.3	4.3	2.7
TAES 5645	N/A	4.3	N/A	N/A	N/A	6.3
Zeon	6.7	4.3	1.0	3.0	5.0	6.0
Zorro	6.3	4.0	2.7	2.0	5.3	6.0
LSD‡	1.2	2.4	1.4	1.1	1.0	2.3

† Spring green-up was rated on a 1-9 scale (1 = brown; 9 = fully green); n = 3.

‡ LSD, least significant difference between means within a column at *P* = 0.05.

Table B.12 Spring green-up of experimental zoysiagrass progeny and standard cultivars in 2017 in Fayetteville, AR; Manhattan, KS; West Lafayette, IN; Columbia, MO; Raleigh, NC; Stillwater, OK; and Dallas, TX.

	Spring Green-up†						
	AR	KS	IN	MO	NC	OK	TX
Entry ID	5/4/17	4/14/17	4/21/17	4/21/17	04/20/17	3/13/17	03/28/17
6095-101	6.3	4.2	6.0	4.3	6.3	4.3	4.3
6095-117	7.7	4.0	5.3	5.0	6.3	4.7	2.7
6095-55	2.7	4.3	4.3	3.7	6.7	3.3	3.0
6095-56	7.7	3.2	4.7	4.0	6.0	4.7	3.3
6095-73	7.0	2.3	4.0	4.3	6.3	4.0	2.7
6095-83	7.3	3.5	5.0	5.3	7.0	5.0	4.3
6096-117	6.0	4.2	6.3	4.7	7.3	3.3	2.3
6096-137	7.3	2.0	2.7	2.7	4.0	3.3	3.3
6096-36	8.7	3.3	4.7	4.7	9.0	3.0	1.3
6096-81	4.3	4.0	6.0	4.7	7.3	2.3	2.0
6096-93	6.7	4.2	4.3	5.7	6.0	2.3	1.7
6097-108	5.3	3.0	5.0	4.3	8.0	4.3	3.3
6097-41	4.3	4.3	5.0	5.0	7.7	4.7	3.7
6097-50	5.3	3.2	5.0	4.3	6.3	4.0	3.0
6097-74	4.7	5.2	6.0	4.3	7.3	4.7	3.7
6097-97	4.7	3.2	3.0	4.7	5.7	3.0	2.7
6099-10	5.0	3.7	5.7	5.0	7.7	6.3	2.3
6099-145	6.0	4.0	5.3	3.7	6.3	5.3	4.7
6099-151	5.3	4.3	5.7	4.7	7.3	3.3	4.0
6099-232	4.0	4.2	6.3	4.3	8.0	5.0	2.7
6099-311	6.0	2.0	4.0	3.7	5.3	3.7	3.3
6099-359	6.7	4.0	4.7	3.7	7.0	4.7	3.3
6099-383	7.0	4.0	6.0	4.3	5.7	6.3	3.3

6099-388	6.7	2.0	3.7	3.7	5.7	4.7	2.7
6099-403	6.3	2.5	2.3	3.7	5.7	4.3	3.0
6099-447	7.0	3.7	5.7	4.3	5.7	4.3	3.3
6099-69	6.3	2.6	5.0	4.0	6.3	5.3	2.7
6099-77	6.3	3.0	5.0	6.0	6.3	5.3	4.0
6099-8	7.7	4.0	5.3	3.7	6.7	6.0	3.7
6100-106	3.0	6.2	6.3	5.0	7.0	4.3	2.3
6100-13	5.0	3.2	4.7	3.7	6.7	5.0	3.0
6100-146	4.0	2.7	5.0	4.0	7.0	4.0	3.0
6100-186	7.3	3.7	5.3	4.3	7.3	4.7	2.7
6100-26	6.3	2.0	3.7	2.7	6.0	3.3	2.3
6100-86	4.3	3.3	5.3	4.3	6.7	4.7	2.3
6101-117	6.7	2.5	4.3	3.0	6.3	3.7	2.0
6101-154	6.7	2.1	4.0	3.3	4.7	4.0	4.0
6101-26	7.7	3.3	5.3	3.3	7.0	6.0	4.3
6101-32	6.0	3.5	5.7	3.7	6.0	5.3	3.7
6101-52	6.0	4.7	3.7	6.7	9.0	2.3	2.3
6101-63	4.7	5.0	6.3	6.3	8.0	2.3	2.0
6101-71	2.3	4.8	7.0	5.3	8.0	4.0	2.3
6101-9	5.7	5.7	7.0	6.7	8.7	4.3	2.3
6102-196	5.0	3.5	5.0	3.7	6.0	5.7	2.7
6102-287	6.0	3.7	6.0	4.3	6.7	4.3	2.7
6102-289	5.3	1.8	3.0	4.0	4.7	4.7	3.7
6102-307	5.0	3.8	6.0	4.7	8.7	4.0	2.3
6102-47	6.0	4.2	6.0	5.7	5.7	5.0	3.7
6102-5	6.7	4.7	5.3	3.7	6.3	4.3	2.7
6102-62	6.3	4.2	6.0	5.7	8.0	5.3	3.7
6104-150	5.0	1.2	1.3	2.3	4.0	4.3	2.0
6109-8	4.3	3.3	4.3	4.3	6.0	2.7	2.0
6119-14	6.0	4.2	4.0	4.3	6.0	3.0	4.3
6119-155	6.3	1.8	2.3	3.3	5.3	3.0	3.0

6119-168	7.0	2.3	3.7	3.7	5.0	4.3	5.0
6119-179	7.7	3.0	5.7	3.3	7.0	4.7	4.0
6119-87	6.3	2.5	5.0	4.3	6.3	4.3	3.3
6121-106	7.7	1.8	2.7	3.0	4.7	2.3	3.0
6121-5	7.0	3.2	6.0	6.3	5.7	2.7	3.7
6126-71	6.0	2.2	3.7	3.3	4.3	6.0	3.3
Chisholm	8.0	5.2	6.3	4.7	7.7	4.7	3.7
El Toro	8.7	3.0	3.3	2.7	6.7	3.0	3.7
KSUZ 0802	N/A	3.8	7.0	N/A	N/A	N/A	3.3
KSUZ 1201	N/A	4.3	7.7	N/A	N/A	N/A	2.3
Meyer	4.7	5.8	6.3	6.3	7.0	2.3	1.7
TAES 5645	N/A	1.3	2.0	N/A	N/A	N/A	2.0
Zeon	6.3	3.2	5.3	4.7	6.7	3.0	3.7
Zorro	7.3	3.7	5.7	3.7	6.0	2.7	2.7
LSD‡	2.1	1.2	1.5	1.3	1.1	1.6	1.1

† Spring green-up was rated on a 1-9 scale (1 = brown; 9 = fully green); n = 3.

‡ LSD, least significant difference between means within a column at $P = 0.05$.

Table B.13 Winter kill of experimental zoysiagrass progeny and standard cultivars in 2016 in West Lafayette, IN.

	Winter Kill†
Entry ID	5/18/16
6095-101	45.0
6095-117	26.7
6095-55	85.0
6095-56	45.0
6095-73	56.7
6095-83	58.3
6096-117	26.7
6096-137	68.3
6096-36	23.3
6096-81	30.0
6096-93	33.3
6097-108	53.3
6097-41	58.3
6097-50	86.7
6097-74	30.0
6097-97	61.7
6099-10	56.7
6099-145	48.3
6099-151	23.3
6099-232	48.3
6099-311	58.3
6099-359	63.3
6099-383	38.3
6099-388	73.3
6099-403	43.3
6099-447	38.3

6099-69	43.3
6099-77	46.7
6099-8	18.3
6100-106	43.3
6100-13	23.3
6100-146	58.3
6100-186	31.7
6100-26	51.7
6100-86	55.0
6101-117	33.3
6101-154	66.7
6101-26	26.7
6101-32	51.7
6101-52	25.0
6101-63	28.3
6101-71	26.7
6101-9	16.7
6102-196	45.0
6102-287	46.7
6102-289	81.7
6102-307	31.7
6102-47	50.0
6102-5	48.3
6102-62	28.3
6104-150	99.0
6109-8	36.7
6119-14	53.3
6119-155	95.0
6119-168	63.3
6119-179	41.7
6119-87	35.0

6121-106	70.0
6121-5	18.3
6126-71	68.3
Chisholm	20.0
El Toro	65.0
KSUZ0802	26.7
KSUZ1201	10.0
Meyer	11.7
TAES5645	81.7
Zeon	66.7
Zorro	73.3
LSD‡	24.5

† Winter injury was rated on a 0 to 100% scale; n = 3.

‡ LSD, least significant difference between means within a column at *P* = 0.05.

Table B.14 Winter kill of experimental zoysiagrass progeny and standard cultivars in 2017 in West Lafayette, IN; Columbia, MO; Raleigh, NC; Stillwater, OK; and Dallas, TX.

	Winter Kill†				
	IN	MO	NC	OK	TX
Entry ID	5/16/17	5/19/17	05/18/17	4/18/17	04/19/17
6095-101	1.7	16.7	1.7	1.0	16.7
6095-117	3.3	18.3	0.0	10.0	33.3
6095-55	3.3	40.0	1.7	23.3	35.0
6095-56	8.3	28.3	0.0	6.7	18.3
6095-73	13.3	18.3	0.0	6.7	23.3
6095-83	5.0	20.0	0.0	0.0	11.7
6096-117	0.0	13.3	0.0	1.7	43.3
6096-137	36.7	48.3	23.3	6.7	25.0
6096-36	5.0	1.7	0.0	6.7	55.0
6096-81	0.0	5.0	0.0	58.3	53.3
6096-93	25.0	8.3	10.0	33.3	70.0
6097-108	5.0	25.0	0.0	1.7	26.7
6097-41	1.7	16.7	0.0	0.0	21.7
6097-50	16.7	21.7	1.7	18.3	36.7
6097-74	0.0	18.3	0.0	0.0	25.0
6097-97	45.0	8.3	1.7	11.7	36.7
6099-10	0.0	1.7	0.0	0.0	41.7
6099-145	5.0	20.0	0.0	0.0	16.7
6099-151	1.7	20.0	0.0	18.3	23.3
6099-232	0.0	18.3	0.0	0.0	30.0
6099-311	10.0	33.3	1.7	21.7	28.3
6099-359	8.3	28.3	0.0	11.7	20.0
6099-383	8.3	31.7	3.3	0.0	33.3
6099-388	18.3	43.3	0.0	13.3	40.0
6099-403	43.3	41.7	16.7	6.7	20.0

6099-447	8.3	36.7	0.0	1.7	35.0
6099-69	3.3	28.3	0.0	0.0	28.3
6099-77	3.3	1.7	0.0	0.0	8.3
6099-8	3.3	40.0	0.0	3.3	30.0
6100-106	13.3	8.3	1.7	10.0	38.3
6100-13	13.3	40.0	0.0	0.0	31.7
6100-146	0.0	11.7	0.0	0.0	18.3
6100-186	1.7	11.7	0.0	6.7	28.3
6100-26	10.0	50.0	0.0	6.7	38.3
6100-86	0.0	6.7	0.0	0.0	36.7
6101-117	18.3	58.3	0.0	3.3	43.3
6101-154	30.0	41.7	13.3	0.0	20.0
6101-26	3.3	40.0	1.7	1.7	18.3
6101-32	5.0	28.3	5.0	0.0	21.7
6101-52	23.3	3.3	0.0	20.0	41.7
6101-63	1.7	6.7	0.0	21.7	53.3
6101-71	0.0	3.3	0.0	8.3	35.0
6101-9	0.0	5.0	0.0	8.3	36.7
6102-196	3.3	33.3	0.0	0.0	43.3
6102-287	1.7	18.3	3.3	18.3	33.3
6102-289	40.0	51.7	21.7	5.0	23.3
6102-307	0.0	8.3	0.0	0.0	30.0
6102-47	0.0	10.0	0.0	0.0	25.0
6102-5	1.7	26.7	0.0	1.7	35.0
6102-62	0.0	5.0	0.0	0.0	23.3
6104-150	92.3	50.0	0.0	0.0	66.7
6109-8	5.0	20.0	0.0	13.3	61.7
6119-14	16.7	15.0	1.7	3.3	8.3
6119-155	38.3	38.3	10.0	8.3	46.7
6119-168	18.3	36.7	15.0	0.0	8.3
6119-179	0.0	25.0	0.0	3.3	10.0

6119-87	3.3	26.7	0.0	0.0	21.7
6121-106	60.0	48.3	10.0	41.7	35.0
6121-5	0.0	10.0	13.3	23.3	21.7
6126-71	18.3	46.7	11.7	0.0	33.3
Chisholm	0.0	6.7	0.0	6.7	5.0
El Toro	36.7	63.3	0.0	13.3	35.0
KSUZ 0802	0.0	100.0	N/A	N/A	N/A
KSUZ 1201	0.0	100.0	N/A	N/A	N/A
Meyer	10.0	5.0	0.0	41.7	73.3
TAES 5645	46.7	100.0	N/A	N/A	N/A
Zeon	6.7	35.0	3.3	6.7	28.3
Zorro	10.0	43.3	10.0	6.7	35.0
LSD‡	17.9	19.3	7.2	15.9	19.7

† Winter injury was rated on a 0 to 100% scale; n = 3.

‡ LSD, least significant difference between means within a column at $P = 0.05$.

Table B.15 Fall color of experimental zoysiagrass progeny and standard cultivars in 2016 in Manhattan, KS; Columbia, MO; Raleigh, NC; Stillwater, OK; Dallas, TX; and Blacksburg, VA.

	Fall Color†					
	KS	MO	NC	OK	TX	VA
Entry ID	11/12/16	11/16/16	10/27/16	11/16/16	11/11/16	12/15/16
6095-101	6.0	6.3	6.3	5.7	4.0	1.0
6095-117	6.0	6.7	6.3	5.7	3.3	1.3
6095-55	5.3	4.3	6.3	6.3	4.0	1.7
6095-56	5.3	6.3	6.7	5.7	2.7	1.3
6095-73	5.7	5.7	7.3	5.3	3.3	2.0
6095-83	6.0	5.7	7.0	6.0	4.7	1.7
6096-117	3.7	4.0	5.7	6.3	2.0	1.7
6096-137	4.7	5.3	5.7	5.0	2.3	1.0
6096-36	3.0	3.7	5.7	3.0	2.3	1.0
6096-81	3.7	4.3	4.3	5.3	2.3	1.7
6096-93	3.7	4.3	3.7	4.7	1.3	1.3
6097-108	6.0	6.3	6.7	7.0	2.0	1.3
6097-41	5.0	6.7	6.0	5.0	4.0	1.7
6097-50	5.7	5.0	6.0	6.7	3.0	2.0
6097-74	5.0	5.3	6.7	4.0	2.7	1.3
6097-97	5.3	6.0	5.0	5.7	2.3	2.0
6099-10	4.0	4.3	6.3	5.0	2.7	1.0
6099-145	5.0	5.7	5.7	6.0	3.7	1.3
6099-151	5.0	5.3	6.0	5.5	2.7	1.7
6099-232	5.0	5.0	6.3	6.7	3.0	1.3
6099-311	6.0	6.3	5.7	6.0	3.3	1.3
6099-359	5.0	5.7	5.0	5.0	3.0	1.7
6099-383	5.3	5.7	5.0	6.7	3.0	1.3
6099-388	5.3	5.7	6.3	5.3	3.0	1.7
6099-403	5.0	5.7	6.0	5.3	3.3	1.7

6099-447	4.3	4.7	6.3	6.7	3.0	2.0
6099-69	4.7	3.7	6.0	7.0	2.7	1.7
6099-77	4.7	4.0	6.3	4.7	2.7	2.7
6099-8	5.3	4.7	5.7	5.7	2.7	2.0
6100-106	3.0	4.7	5.7	5.3	3.0	2.3
6100-13	5.7	6.0	6.0	4.7	3.3	1.7
6100-146	4.0	5.0	6.3	6.0	3.0	1.0
6100-186	4.7	6.0	6.0	6.3	3.3	2.0
6100-26	5.3	5.7	6.0	5.0	3.0	1.0
6100-86	4.7	5.0	6.7	5.7	2.3	1.0
6101-117	4.3	4.0	6.7	6.3	1.3	1.7
6101-154	5.0	5.7	6.7	5.0	3.3	1.0
6101-26	4.7	3.7	5.0	8.0	2.0	1.0
6101-32	4.0	5.0	6.0	4.0	3.0	1.7
6101-52	2.0	3.3	5.7	3.7	2.0	1.0
6101-63	3.3	3.3	5.0	6.7	2.0	1.7
6101-71	2.0	3.0	6.3	5.3	2.3	1.7
6101-9	4.3	4.3	5.7	6.7	2.3	1.7
6102-196	5.3	5.7	5.0	6.3	2.7	1.7
6102-287	5.0	4.0	6.3	6.3	2.7	1.7
6102-289	5.3	6.0	7.7	6.7	4.3	1.0
6102-307	4.0	5.0	6.0	6.7	3.3	1.7
6102-47	4.3	4.7	6.3	5.3	3.7	1.0
6102-5	5.0	5.3	5.3	7.3	3.3	1.0
6102-62	4.3	4.3	6.3	5.7	3.3	1.3
6104-150	4.7	6.0	6.0	4.7	4.7	1.7
6109-8	4.0	4.7	6.0	2.7	2.3	1.3
6119-14	5.0	6.3	6.0	5.0	4.0	1.7
6119-155	5.7	6.3	5.7	7.0	3.7	1.0
6119-168	5.3	6.0	7.0	5.7	3.7	1.5
6119-179	5.7	5.7	6.3	5.3	4.0	1.7

6119-87	5.3	6.0	6.3	5.7	4.3	2.0
6121-106	5.7	7.0	5.3	4.0	2.7	1.3
6121-5	6.0	6.0	5.3	3.7	3.3	1.3
6126-71	5.7	7.0	7.3	7.7	4.3	1.0
Chisholm	4.3	5.3	5.3	3.7	4.0	1.7
El Toro	4.7	4.3	6.3	3.7	4.7	1.3
KSUZ 0802	3.3	N/A	N/A	N/A	2.3	N/A
KSUZ 1201	4.0	N/A	N/A	N/A	3.0	N/A
Meyer	2.7	4.0	6.0	5.7	2.0	3.3
TAES 5645	4.7	N/A	N/A	N/A	2.7	N/A
Zeon	5.0	5.3	5.3	4.0	3.7	1.3
Zorro	4.7	5.7	5.3	4.0	4.3	1.7
LSD‡	1.1	1.1	1.0	1.8	1.2	1.1

† Fall color was rated on a 1-9 scale (1 = straw or brown, no color retention; 9 = dark green); n = 3.

‡ LSD, least significant difference between means within a column at *P* = 0.05.

Table B.16 Fall color of experimental zoysiagrass progeny and standard cultivars in 2017 in West Lafayette, IN; Columbia, MO; Raleigh, NC; Stillwater, OK; Dallas, TX; and Chicago, IL.

	Fall Color†					
	IN	MO	NC	OK	TX	IL
Entry ID	10/20/17	11/13/17	11/15/17	11/20/17	11/14/17	10/17/17
6095-101	8.7	6.7	6.3	8.0	1.7	6.3
6095-117	8.7	6.0	7.0	8.0	2.3	6.3
6095-55	7.7	4.7	6.7	8.0	2.0	6.0
6095-56	8.0	6.3	7.0	8.0	4.0	6.3
6095-73	8.7	6.3	7.0	8.0	2.3	6.0
6095-83	8.7	5.7	8.0	7.7	4.0	6.3
6096-117	7.7	4.7	4.0	7.0	1.0	6.3
6096-137	7.3	5.7	5.0	7.3	1.3	5.7
6096-36	6.0	5.0	4.0	6.7	1.3	6.0
6096-81	6.7	5.7	4.3	7.3	2.0	6.7
6096-93	7.0	5.0	2.0	7.7	1.0	6.0
6097-108	7.3	6.3	6.7	7.3	2.7	6.0
6097-41	8.0	6.0	6.7	8.0	1.0	5.7
6097-50	7.7	5.3	6.3	8.0	2.0	6.0
6097-74	7.7	5.7	5.7	7.3	2.0	6.0
6097-97	6.0	5.3	5.7	7.3	1.7	5.0
6099-10	6.3	5.0	5.0	7.7	1.7	7.0
6099-145	7.3	6.0	5.7	7.5	2.3	6.0
6099-151	7.0	5.3	5.7	8.0	1.7	4.7
6099-232	8.0	6.0	6.3	8.0	2.0	6.0
6099-311	7.0	6.0	6.3	8.0	2.3	6.3
6099-359	7.0	6.0	5.0	6.7	3.0	4.7
6099-383	8.0	5.7	4.7	6.7	2.7	5.3
6099-388	7.7	6.0	5.7	8.0	1.3	5.0
6099-403	7.7	5.7	6.7	8.0	1.7	5.7

6099-447	6.7	5.0	5.3	8.0	1.3	6.0
6099-69	7.0	5.0	5.0	8.0	1.3	5.3
6099-77	7.0	4.3	6.7	7.7	1.7	5.0
6099-8	8.3	5.0	5.7	7.7	2.3	4.7
6100-106	6.0	5.7	2.7	8.0	2.0	6.0
6100-13	7.7	6.0	6.0	7.3	2.0	5.3
6100-146	7.0	5.3	5.0	8.0	2.3	5.3
6100-186	8.0	6.0	6.3	7.0	2.3	5.3
6100-26	7.7	6.0	5.3	6.3	2.3	4.7
6100-86	7.7	5.7	4.7	8.0	1.3	5.7
6101-117	7.7	5.0	6.7	7.3	1.3	6.7
6101-154	8.0	5.7	7.3	7.0	3.7	4.7
6101-26	7.3	5.3	6.3	7.0	2.3	5.3
6101-32	7.7	5.3	5.7	6.3	1.7	6.3
6101-52	4.7	5.0	3.7	6.3	1.0	6.3
6101-63	6.3	5.0	4.0	6.7	1.0	5.3
6101-71	7.0	4.7	4.0	7.7	1.3	6.3
6101-9	7.7	5.3	6.0	8.0	1.3	6.7
6102-196	7.0	5.7	6.0	7.0	1.7	4.7
6102-287	6.7	4.7	4.7	8.0	1.3	5.3
6102-289	8.7	6.0	7.7	7.3	3.3	5.3
6102-307	8.0	5.0	5.3	7.7	2.0	4.7
6102-47	8.0	5.0	5.7	7.3	1.3	5.0
6102-5	7.7	5.7	4.3	7.0	1.7	5.0
6102-62	7.3	5.0	7.0	7.7	1.0	5.3
6104-150	7.7	6.0	7.0	7.7	2.3	5.3
6109-8	7.0	5.0	5.0	7.7	1.7	5.0
6119-14	8.0	6.3	6.7	8.0	2.7	5.7
6119-155	8.0	6.3	7.0	8.0	2.3	5.0
6119-168	9.0	5.7	6.0	8.0	3.3	5.3
6119-179	8.3	6.0	6.7	7.7	2.3	6.0

6119-87	8.3	6.3	6.3	8.0	2.3	5.3
6121-106	7.7	7.0	6.3	8.0	2.0	4.7
6121-5	7.7	6.0	6.3	7.3	2.3	5.3
6126-71	8.7	7.0	7.3	8.0	2.3	6.0
Chisholm	6.7	5.7	5.0	6.7	1.3	4.7
El Toro	5.3	5.0	5.7	6.3	3.7	6.0
KSUZ 0802	6.3	N/A	N/A	N/A	1.0	N/A
KSUZ 1201	8.0	N/A	N/A	N/A	1.3	N/A
Meyer	6.7	4.7	4.7	7.0	1.7	6.3
TAES 5645	6.7	N/A	N/A	N/A	1.3	N/A
Zeon	7.0	5.0	6.0	8.0	2.7	6.0
Zorro	8.0	5.7	5.3	8.0	2.0	6.0
LSD‡	1.3	1.1	1.2	0.7	1.4	0.9

† Fall color was rated on a 1-9 scale (1 = straw or brown, no color retention; 9 = dark green); n = 3.

‡ LSD, least significant difference between means within a column at $P = 0.05$.

Table B.17 Genetic color of experimental zoysiagrass progeny and standard cultivars in 2016 in Fayetteville, AR; Manhattan, KS; Columbia, MO; Raleigh, NC; Stillwater, OK; and Dallas, TX.

	Genetic Color†					
	AR	KS	MO	NC	OK	TX
Entry ID	8/24/16	7/6/16	5/15/16	8/23/16	7/26/16	6/29/16
6095-101	7.3	7.0	4.0	6.0	5.7	7.3
6095-117	6.7	7.3	3.7	6.7	6.7	5.7
6095-55	7.0	7.0	3.3	6.3	7.3	6.7
6095-56	7.0	7.0	2.7	6.3	7.3	6.0
6095-73	8.0	6.3	4.3	6.0	6.7	6.7
6095-83	7.7	7.7	4.7	6.7	7.3	7.0
6096-117	7.7	7.0	5.3	7.0	7.0	7.0
6096-137	7.7	6.7	7.0	5.7	5.0	8.0
6096-36	7.7	6.3	5.0	5.0	4.0	7.3
6096-81	8.0	6.7	3.7	6.0	7.0	7.7
6096-93	7.0	6.0	4.7	4.7	5.0	6.3
6097-108	6.7	6.3	3.7	6.0	7.0	6.3
6097-41	7.0	7.0	3.3	6.3	7.0	6.0
6097-50	7.3	7.0	3.3	6.0	5.7	5.7
6097-74	7.0	6.7	4.0	6.3	5.7	6.0
6097-97	6.7	7.3	4.0	5.0	6.3	6.3
6099-10	7.7	6.7	2.7	6.3	7.7	6.3
6099-145	7.7	6.0	4.0	5.7	6.3	6.7
6099-151	7.0	7.0	4.0	6.0	6.3	6.7
6099-232	8.0	7.0	4.0	6.0	7.3	6.7
6099-311	7.0	6.0	4.3	6.0	5.3	7.7
6099-359	7.0	6.0	4.0	6.0	6.3	6.3
6099-383	7.3	7.0	5.3	6.0	5.7	6.7
6099-388	7.7	6.3	4.3	6.0	6.0	7.7
6099-403	7.3	7.0	3.0	6.0	6.0	7.0

6099-447	7.7	6.7	3.3	7.0	8.0	6.0
6099-69	7.7	5.7	4.3	5.3	5.7	6.7
6099-77	7.3	6.7	4.0	6.3	7.3	6.7
6099-8	7.7	6.3	5.0	6.0	6.0	6.0
6100-106	7.7	7.0	3.3	6.7	7.3	6.7
6100-13	7.7	6.0	5.0	6.0	6.0	7.0
6100-146	7.3	6.3	4.7	6.0	6.7	7.3
6100-186	7.0	6.3	4.0	5.7	6.0	7.3
6100-26	7.3	6.0	6.0	6.0	6.3	7.3
6100-86	8.0	7.0	4.0	6.0	7.7	7.3
6101-117	7.0	5.7	5.7	6.0	6.0	7.0
6101-154	8.0	7.0	5.3	5.3	6.3	7.3
6101-26	8.0	6.0	3.0	5.3	5.7	6.0
6101-32	7.3	7.0	5.7	6.0	6.3	6.7
6101-52	7.3	6.0	5.3	6.3	7.0	7.0
6101-63	7.7	7.0	4.7	6.7	6.7	7.0
6101-71	8.0	7.0	4.0	7.0	7.0	7.0
6101-9	7.3	7.0	5.0	5.7	7.0	7.0
6102-196	7.3	6.0	3.7	6.0	6.3	6.3
6102-287	7.7	5.7	3.3	6.0	6.7	6.0
6102-289	7.7	7.0	6.0	6.3	7.3	7.7
6102-307	8.0	7.0	4.3	6.0	6.0	7.0
6102-47	7.7	7.0	3.3	6.0	6.0	6.3
6102-5	7.0	6.7	4.7	5.0	5.7	6.0
6102-62	7.0	6.7	2.7	5.7	6.7	5.3
6104-150	7.7	6.7	3.0	6.0	6.0	6.3
6109-8	7.3	6.7	4.0	6.0	7.0	6.0
6119-14	7.7	7.0	5.7	6.0	6.7	7.3
6119-155	7.3	6.0	5.7	5.3	5.3	7.7
6119-168	8.0	6.7	4.7	6.0	5.7	6.3
6119-179	7.0	6.3	4.7	5.7	6.0	7.0

6119-87	7.0	7.0	5.7	6.0	6.3	7.0
6121-106	7.3	6.0	4.7	5.7	5.0	7.3
6121-5	6.7	6.3	3.7	6.0	6.0	6.7
6126-71	7.7	7.0	5.3	6.3	6.7	7.0
Chisholm	6.7	5.7	1.0	4.7	7.3	4.7
El Toro	6.3	6.0	1.0	6.7	6.0	5.0
KSUZ 0802	N/A	7.0	N/A	N/A	N/A	7.0
KSUZ 1201	N/A	7.3	N/A	N/A	N/A	7.0
Meyer	7.7	7.0	4.3	6.7	4.3	6.7
TAES 5645	N/A	6.3	N/A	N/A	N/A	6.3
Zeon	8.0	7.0	7.3	6.0	5.3	8.0
Zorro	7.7	7.0	7.7	6.0	5.0	8.0
LSD	0.8	0.8	1.2	0.7	1.0	0.8

† Genetic color was rated on a 1-9 scale (1 = brown/straw/dead; 9 = dark green); n = 3.

‡ LSD, least significant difference between means within a column at *P* = 0.05.

Table B.18 Genetic color of experimental zoysiagrass progeny and standard cultivars in 2017 in Fayetteville, AR; Manhattan, KS; Columbia, MO; Raleigh, NC; Stillwater, OK; Dallas, TX; and Chicago, IL.

	Genetic Color†						
	AR	KS	MO	NC	OK	TX	IL
Entry ID	8/4/17	6/23/17	7/5/17	7/18/17	8/13/17	6/14/17	8/30/17
6095-101	7.3	6.6	8.0	5.7	6.7	6.3	6.3
6095-117	7.0	6.9	7.3	6.3	7.0	5.7	6.7
6095-55	7.3	6.5	7.0	6.0	7.0	5.7	6.7
6095-56	7.7	7.3	7.7	6.3	6.3	6.0	7.0
6095-73	8.0	6.5	8.0	6.3	7.0	6.3	6.3
6095-83	8.0	6.7	7.7	6.3	7.7	7.0	6.3
6096-117	8.3	6.7	7.7	6.0	7.0	5.7	6.3
6096-137	7.3	6.7	7.0	6.0	6.3	5.0	6.0
6096-36	8.0	6.1	8.3	5.0	6.0	4.3	6.0
6096-81	8.7	7.4	8.3	6.0	7.3	5.3	6.3
6096-93	7.0	5.2	7.0	4.3	6.0	4.7	6.0
6097-108	7.0	7.1	7.7	5.7	7.0	6.3	6.0
6097-41	7.3	6.7	7.7	6.0	7.0	6.0	5.7
6097-50	8.0	6.3	7.0	5.3	6.7	5.3	5.7
6097-74	7.0	6.2	7.0	6.0	7.0	6.3	6.7
6097-97	7.0	6.9	7.3	5.0	6.7	5.0	5.3
6099-10	8.3	6.9	8.7	7.0	7.3	5.7	7.3
6099-145	7.3	6.5	8.0	4.7	7.0	5.3	6.0
6099-151	7.3	6.4	7.0	6.0	7.0	5.3	5.3
6099-232	8.7	6.3	8.3	6.0	7.3	5.7	6.3
6099-311	7.0	6.9	7.3	6.3	6.3	5.0	6.7
6099-359	7.3	6.3	8.3	5.7	6.7	5.7	5.3
6099-383	7.7	6.3	7.3	5.7	6.3	5.0	6.0

6099-388	8.3	6.2	7.0	6.0	6.7	5.3	6.0
6099-403	7.3	6.6	7.3	6.0	6.7	5.7	6.3
6099-447	8.0	6.7	7.0	6.7	7.3	6.0	6.3
6099-69	8.3	6.4	7.7	5.3	6.3	5.7	5.7
6099-77	7.0	6.7	7.3	6.0	7.3	5.0	5.7
6099-8	8.0	6.4	7.0	6.0	6.0	5.7	5.3
6100-106	8.3	7.6	6.3	6.7	8.0	5.7	6.7
6100-13	7.7	6.7	7.7	5.7	6.3	5.0	6.0
6100-146	7.7	6.6	7.3	6.0	6.3	5.3	6.0
6100-186	7.3	6.3	8.3	5.7	7.0	5.7	6.0
6100-26	8.0	6.2	8.3	5.7	6.7	5.3	5.7
6100-86	8.0	6.7	8.3	6.7	8.0	6.0	6.0
6101-117	7.3	6.2	6.7	5.7	7.0	5.3	7.0
6101-154	8.7	6.5	7.7	6.0	6.7	5.7	5.3
6101-26	7.7	6.2	7.3	6.0	7.0	5.0	6.0
6101-32	7.7	6.5	8.3	6.0	6.0	4.7	6.7
6101-52	8.0	7.1	8.0	6.0	7.7	6.0	7.3
6101-63	7.7	6.7	7.7	7.0	7.7	5.7	5.7
6101-71	8.3	7.3	7.3	7.0	7.3	6.0	7.0
6101-9	7.7	6.8	8.3	5.7	7.3	5.7	7.3
6102-196	8.0	6.7	7.7	6.0	6.7	4.3	5.3
6102-287	7.7	6.6	7.7	5.7	7.3	5.7	6.0
6102-289	8.0	6.9	7.0	6.3	6.7	7.0	6.3
6102-307	8.7	6.4	7.3	5.7	6.7	5.3	5.7
6102-47	7.3	6.8	6.0	5.7	6.7	5.3	5.3
6102-5	7.3	5.9	7.7	4.7	6.7	4.3	5.7
6102-62	7.7	6.4	7.0	6.0	7.0	6.0	6.0
6104-150	7.7	6.4	7.7	5.7	6.7	5.3	6.3
6109-8	7.7	6.4	8.0	5.3	6.7	5.0	6.0
6119-14	8.0	7.0	8.0	6.0	7.3	5.0	6.3
6119-155	8.0	6.3	7.7	6.0	6.7	4.7	6.0

6119-168	8.0	6.5	7.3	6.0	6.7	6.3	5.7
6119-179	7.3	6.6	8.0	5.7	7.0	6.0	6.7
6119-87	7.7	6.6	8.0	5.7	7.7	4.7	6.3
6121-106	7.0	6.2	7.7	5.3	6.7	3.7	5.3
6121-5	7.0	6.4	7.7	6.0	6.7	4.0	6.0
6126-71	8.3	7.3	8.0	6.0	7.0	5.3	6.3
Chisholm	7.0	5.6	7.0	4.7	7.7	5.0	5.3
El Toro	6.7	6.7	7.7	6.3	7.3	6.0	6.0
KSUZ 0802	N/A	6.6	N/A	N/A	N/A	5.3	N/A
KSUZ 1201	N/A	7.0	N/A	N/A	N/A	6.7	N/A
Meyer	7.7	6.8	7.3	6.7	6.7	6.0	7.0
TAES 5645	N/A	5.8	N/A	N/A	N/A	4.0	N/A
Zeon	8.0	6.2	7.0	6.0	6.3	5.3	6.0
Zorro	8.3	6.5	7.3	6.0	6.0	6.7	7.0
LSD‡	1.3	0.8	1.2	0.7	0.8	0.9	1.2

† Genetic color was rated on a 1-9 scale (1 = brown/straw/dead; 9 = dark green); n = 3.

‡ LSD, least significant difference between means within a column at *P* = 0.05.

Table B.19 Texture of experimental zoysiagrass progeny and standard cultivars in 2016 in Fayetteville, AR; Manhattan, KS; Columbia, MO; Raleigh, NC; Stillwater, OK; and Dallas, TX.

	Texture†					
	AR	KS	MO	NC	OK	TX
Entry ID	8/24/16	7/6/16	5/15/16	8/23/16	7/28/16	6/29/16
6095-101	6.7	6.0	4.0	7.3	3.7	7.3
6095-117	7.0	6.3	3.7	7.3	3.3	5.7
6095-55	7.0	6.0	3.3	8.0	4.7	6.7
6095-56	7.0	6.0	2.7	7.3	6.0	6.0
6095-73	7.0	7.0	4.3	7.7	5.0	6.7
6095-83	7.3	7.0	4.7	7.0	6.0	7.0
6096-117	7.0	7.0	5.3	7.0	3.3	7.0
6096-137	8.0	7.7	7.0	9.0	7.3	8.0
6096-36	7.3	6.3	5.0	8.0	6.3	7.3
6096-81	7.0	6.0	3.7	7.3	3.7	7.7
6096-93	7.0	7.0	4.7	7.3	4.7	6.3
6097-108	6.0	5.7	3.7	7.0	5.0	6.3
6097-41	6.7	5.0	3.3	7.0	5.3	6.0
6097-50	7.0	6.0	3.3	7.3	4.7	5.7
6097-74	6.7	5.7	4.0	7.3	5.3	6.0
6097-97	6.3	5.0	4.0	7.0	5.0	6.3
6099-10	6.3	6.0	2.7	7.0	5.3	6.3
6099-145	6.7	5.7	4.0	7.0	6.0	6.7
6099-151	6.7	5.7	4.0	8.3	5.3	6.7
6099-232	7.3	7.3	4.0	8.0	4.0	6.7
6099-311	7.0	6.3	4.3	8.0	5.3	7.7
6099-359	7.3	5.3	4.0	8.0	5.0	6.3
6099-383	7.3	6.3	5.3	8.3	5.0	6.7
6099-388	7.3	6.3	4.3	8.0	5.0	7.7
6099-403	7.3	6.0	3.0	8.0	5.3	7.0

6099-447	7.0	5.7	3.3	7.0	4.0	6.0
6099-69	7.3	6.3	4.3	8.0	5.7	6.7
6099-77	7.0	7.3	4.0	7.7	4.7	6.7
6099-8	6.7	5.7	5.0	8.0	4.7	6.0
6100-106	6.7	5.3	3.3	7.7	3.3	6.7
6100-13	7.0	6.3	5.0	8.0	5.0	7.0
6100-146	7.0	6.0	4.7	7.7	4.7	7.3
6100-186	7.0	5.3	4.0	7.3	5.7	7.3
6100-26	7.3	6.7	6.0	8.0	5.3	7.3
6100-86	7.3	7.3	4.0	7.3	4.7	7.3
6101-117	7.3	6.3	5.7	8.0	5.7	7.0
6101-154	7.3	7.0	5.3	7.7	7.0	7.3
6101-26	7.0	6.3	3.0	7.0	5.0	6.0
6101-32	7.3	7.0	5.7	8.3	6.0	6.7
6101-52	7.3	7.0	5.3	8.7	5.3	7.0
6101-63	7.7	6.3	4.7	8.0	4.0	7.0
6101-71	7.3	6.7	4.0	8.0	5.0	7.0
6101-9	7.0	7.0	5.0	7.7	4.7	7.0
6102-196	6.7	5.7	3.7	7.7	4.3	6.3
6102-287	7.0	5.0	3.3	7.3	4.7	6.0
6102-289	8.0	7.3	6.0	9.0	4.3	7.7
6102-307	7.0	6.3	4.3	8.0	5.0	7.0
6102-47	7.7	6.3	3.3	7.7	7.0	6.3
6102-5	7.0	6.0	4.7	8.0	5.3	6.0
6102-62	6.7	6.7	2.7	6.7	6.0	5.3
6104-150	7.3	4.3	3.0	7.0	5.7	6.3
6109-8	7.0	5.3	4.0	7.3	4.0	6.0
6119-14	8.0	7.0	5.7	8.0	4.0	7.3
6119-155	8.0	7.3	5.7	9.0	6.0	7.7
6119-168	7.0	6.7	4.7	8.0	5.0	6.3
6119-179	7.0	6.0	4.7	7.7	5.0	7.0

6119-87	7.0	6.0	5.7	7.7	5.3	7.0
6121-106	7.7	7.0	4.7	8.0	5.3	7.3
6121-5	7.0	6.7	3.7	8.0	5.0	6.7
6126-71	7.3	6.3	5.3	8.0	5.0	7.0
Chisholm	6.0	3.0	1.0	6.0	4.3	4.7
El Toro	6.0	4.0	1.0	6.0	4.3	5.0
KSUZ 0802	N/A	6.7	N/A	N/A	N/A	7.0
KSUZ 1201	N/A	5.7	N/A	N/A	N/A	7.0
Meyer	7.3	5.3	4.3	7.0	4.3	6.7
TAES 5645	N/A	6.0	N/A	N/A	N/A	6.3
Zeon	8.0	8.0	7.3	9.0	7.0	8.0
Zorro	7.7	7.7	7.7	9.0	6.3	8.0
LSD‡	0.7	1.0	1.2	0.6	1.0	0.8

† Leaf texture was rated on a 1-9 scale (1 = coarsest; 9 = finest); n = 3.

‡ LSD, least significant difference between means within a column at $P = 0.05$.

Table B.20 Texture of experimental zoysiagrass progeny and standard cultivars in 2017 in Fayetteville, AR; Manhattan, KS; West Lafayette, IN; Columbia, MO; Raleigh, NC; Stillwater, OK; Dallas, TX; and Chicago, IL.

	Texture†							
	AR	KS	IN	MO	NC	OK	TX	IL
Entry ID	8/4/17	6/23/17	7/31/17	6/21/17	7/18/17	7/28/17	6/6/17	8/30/17
6095-101	7.7	7.2	6.0	7.0	6.7	7.0	6.0	6.3
6095-117	8.0	6.4	5.3	6.7	6.7	7.0	5.7	6.7
6095-55	7.0	6.8	6.3	7.0	7.0	6.0	6.0	6.3
6095-56	7.3	6.5	6.0	7.3	7.0	7.0	6.3	6.3
6095-73	7.7	7.2	6.3	7.3	7.3	6.3	6.7	6.0
6095-83	7.3	7.3	6.0	7.0	7.0	7.0	6.7	6.0
6096-117	8.0	7.4	6.3	7.0	6.7	6.0	7.0	7.0
6096-137	8.7	7.6	7.3	8.0	8.0	8.0	7.0	7.3
6096-36	7.7	7.0	6.0	7.0	6.7	7.3	7.0	6.0
6096-81	7.7	6.8	6.0	7.0	6.7	7.3	7.0	6.0
6096-93	8.3	6.5	5.3	7.0	6.0	7.0	6.7	7.0
6097-108	8.0	6.4	5.3	6.7	6.3	6.0	6.0	6.3
6097-41	6.7	6.4	5.0	7.0	7.0	7.0	6.0	6.3
6097-50	7.3	6.6	5.3	7.0	6.7	7.3	6.3	7.3
6097-74	8.0	6.6	5.3	7.0	6.7	6.3	6.3	6.7
6097-97	6.7	6.0	5.0	7.0	6.0	6.0	5.7	5.7
6099-10	7.0	6.1	5.0	7.0	7.0	6.0	5.7	5.7
6099-145	8.0	6.6	5.3	6.7	6.7	7.0	6.0	6.0
6099-151	7.7	7.1	5.0	7.0	7.0	7.0	6.0	6.3
6099-232	7.7	6.6	6.0	7.0	7.0	6.0	6.3	6.0
6099-311	8.0	7.4	5.7	7.0	7.0	7.0	6.0	6.0
6099-359	8.0	6.6	5.3	7.0	7.0	6.0	6.0	6.7
6099-383	7.0	7.2	6.0	7.3	7.7	7.0	7.0	7.0
6099-388	7.7	7.2	6.0	7.7	7.7	6.7	7.0	6.3

6099-403	8.0	6.4	5.0	7.0	6.7	6.3	6.0	6.7
6099-447	7.0	6.4	5.0	7.0	7.0	6.0	6.0	6.3
6099-69	8.0	7.2	5.0	7.0	7.0	6.7	5.7	6.7
6099-77	8.3	7.0	6.0	7.0	7.0	6.0	6.7	6.0
6099-8	7.7	7.0	5.7	7.0	7.0	6.0	6.0	7.0
6100-106	7.7	6.7	5.7	7.0	7.0	5.3	6.3	6.0
6100-13	8.0	7.4	6.0	7.3	7.7	6.7	6.0	6.7
6100-146	8.3	6.5	6.3	7.7	7.3	6.0	7.0	6.0
6100-186	7.7	6.1	5.7	7.0	7.0	6.0	6.3	6.3
6100-26	7.3	7.3	6.7	7.7	7.0	6.3	7.0	7.3
6100-86	7.7	6.8	6.0	7.0	7.0	6.0	7.0	6.7
6101-117	7.7	7.3	6.3	7.7	7.3	6.0	6.7	7.7
6101-154	7.7	7.2	7.0	7.3	7.3	8.0	7.0	6.7
6101-26	8.3	6.7	6.0	7.0	7.0	6.7	6.0	6.0
6101-32	8.0	7.2	6.0	7.7	7.7	7.0	7.0	7.0
6101-52	8.0	7.0	6.7	8.0	8.0	7.0	7.0	7.3
6101-63	7.7	6.7	5.0	7.0	6.7	6.0	7.0	6.3
6101-71	8.0	6.9	6.0	7.3	7.0	6.7	6.7	6.7
6101-9	8.0	6.6	6.0	7.3	6.7	6.3	6.7	6.3
6102-196	8.0	6.6	4.7	7.0	7.0	5.0	6.0	6.3
6102-287	8.0	6.6	5.0	7.0	6.3	5.7	5.7	6.3
6102-289	7.0	7.2	7.0	8.7	8.0	7.7	7.0	6.0
6102-307	8.3	7.2	6.0	7.0	7.0	7.0	7.0	7.0
6102-47	8.3	7.3	6.0	7.0	7.0	8.0	6.3	6.0
6102-5	7.7	6.6	5.0	7.0	6.0	6.0	5.7	6.3
6102-62	7.7	6.3	4.7	7.0	7.0	6.0	6.0	6.0
6104-150	7.3	6.4	4.7	7.0	6.0	6.0	6.0	6.0
6109-8	8.0	6.1	5.0	7.0	7.0	6.0	6.0	6.0
6119-14	7.7	7.2	6.3	8.0	8.0	6.7	7.0	7.7
6119-155	8.0	7.8	7.0	8.7	8.3	7.7	7.0	7.3
6119-168	8.0	7.0	6.0	7.7	7.3	6.3	6.7	7.0

6119-179	7.3	6.6	6.0	7.0	7.3	6.0	6.3	7.0
6119-87	7.7	7.1	6.0	7.7	7.3	6.7	6.7	6.7
6121-106	7.7	7.2	6.0	7.0	7.0	7.0	6.3	6.7
6121-5	7.3	7.4	5.7	7.0	6.7	6.0	5.7	6.3
6126-71	7.0	7.2	6.3	7.0	7.3	7.0	6.3	6.7
Chisholm	6.3	5.0	3.3	6.0	5.0	5.7	5.0	5.3
El Toro	6.3	5.5	3.0	6.0	6.0	5.0	5.0	5.0
KSUZ 0802	N/A	7.6	6.7	N/A	N/A	N/A	7.0	N/A
KSUZ 1201	N/A	6.6	6.3	N/A	N/A	N/A	6.7	N/A
Meyer	6.7	7.0	5.0	7.0	6.3	5.0	6.3	6.7
TAES 5645	N/A	6.6	5.0	N/A	N/A	N/A	6.3	N/A
Zeon	8.3	7.9	7.7	8.7	9.0	8.0	8.0	8.0
Zorro	8.0	8.2	8.0	9.0	9.0	8.0	8.0	7.7
LSD‡	1.3	0.7	0.6	0.6	0.6	0.5	0.6	0.8

† Leaf texture was rated on a 1-9 scale (1 = coarsest; 9 = finest); n = 3.

‡ LSD, least significant difference between means within a column at P = 0.05.