

Zoysiagrass grow-in, thatch management, weed control, and selection of quality genotypes in the
U.S. transition zone

by

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B.S., Kansas State University, 2018
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AN ABSTRACT OF A DISSERTATION

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Department of Horticulture and Natural Resources
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Abstract

Zoysiagrass (*Zoysia* spp.) is a warm-season (C₄) turfgrass species that provides a dense, uniform, high-quality playing surface with excellent heat, drought, pest, and wear tolerance compared to many other cool-season turfgrass species. ‘Meyer’ zoysiagrass is commonly used on golf course fairways, tee boxes, and bunker faces in the U.S. transition zone due to enhanced drought tolerance compared to Kentucky bluegrass and improved cold hardiness compared to bermudagrass. ‘Innovation’ zoysiagrass is a newer cultivar that exhibits finer leaf texture and improved density compared to Meyer, but minimal research has been reported on the cultivar since its commercial release. Zoysiagrass, though maintained with reduced inputs for some sites, is intensively maintained on golf courses and athletic fields, and often times home lawns; therefore, thatch accumulation can occur. Further, zoysiagrass is generally established vegetatively by sod, plugs, or sprigs. Because of the slow rate of zoysiagrass establishment, weed competition within the sward often occurs. Summer annual weeds such as crabgrass (*Digitaria* spp.) and goosegrass (*Eleusine indica* (L.) Gaertn.) can affect the growth and establishment of zoysiagrass. Following establishment, bermudagrass (*Cynodon* spp. L.C. Rich.), is one of the problematic weeds within zoysiagrass swards because of the physiological similarities and therefore lack herbicide options for control. Within the last two decades, zoysiagrass breeding programs in the U.S. have focused their efforts on developing new zoysiagrass hybrids that have increased drought, freezing, and pest tolerance, exhibit finer leaf texture, enhanced rooting, and a faster rate of establishment. Therefore, the objectives of this dissertation were to: 1) determine the influence of aerification intensities on thatch levels, rooting, and turfgrass quality of Innovation zoysiagrass; 2) evaluate how nitrogen rate and mowing height influence the establishment rate, turf quality, thatch accumulation, and post-harvest root strength of

experimental hybrid 'DALZ 1808', Innovation, and Meyer zoysiagrass from sprigs; 3) evaluate how commonly used herbicides affect the weed encroachment, establishment, and rooting of Innovation zoysiagrass when applied immediately following sprigging; 4) investigate a new commercially available herbicide for its effects on bermudagrass control and zoysiagrass safety; and 5) evaluate a set of sixty-nine experimental zoysiagrass hybrids to identify potential for commercial release. Research herein suggests moderate aerification (10 to 27% core removal) can reduce organic matter and increase rooting, while also enhancing turf quality and color compared to nonaerified turf. Nitrogen rate and mowing height can affect thatch accumulation and post-harvest rooting of zoysiagrass; however, the effects from nitrogen rate and mowing height differences vary by zoysiagrass cultivar. Oxadiazon (liquid formulation) can reduce weed pressure and hasten zoysiagrass establishment when applied immediately following sprigging. Sequential applications of a new herbicide containing trifloxysulfuron-sodium and a proprietary safener (metcamifen) tank-mixed with fluazifop-P-butyl can suppress bermudagrass >95% without causing injury to zoysiagrass. Finally, the zoysiagrass breeding study indicates that several experimental entries show promise across a range of environments, with multiple elite experimental lines exhibiting adaptability in the transition zone. The findings within this dissertation will provide insight for turfgrass practitioners on strategic management of zoysiagrass within the transition zone and beyond.

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Dedication

To my Jodi, thank you for going on this journey with me.

Chapter 1 - Introduction

Zoysiagrass in the Transition Zone

The United States transition zone is a region between subtropical and temperate climates that rests between the northern and southern regions. The U.S. transition zone includes 300 to 700 miles north to south between the cool northern region, and the southern warm, humid region (Dunn and Diesburg, 2004). Cool-season grasses are naturally adapted to the northern region, while warm-season grasses are adapted to the southern region. Within the transition zone, both warm- and cool-season grasses can establish and grow; however, neither warm- or cool-season species are completely adapted year-round. Cool-season turfgrass species begin to deteriorate during hot, dry periods in the summer months, while warm-season grass species go into dormancy during the winter months in the transition zone. Zoysiagrass (*Zoysia* spp. Willd.) was introduced to the United States in 1892, and as of 2015 it was estimated zoysiagrass covered 10,375 hectares throughout the U.S. (Patton et al., 2017a). Zoysiagrass is a warm-season turfgrass species that is often used on golf course fairways, tee boxes, and bunker faces in the U.S. transition zone because of the dense, uniform, high-quality playing surface with excellent heat, drought, pest, and wear tolerance this species provides compared to many cool-season turfgrass species.

‘Meyer’ zoysiagrass was released in 1951 and is preferred by golf course superintendents in the transition zone due to its drought tolerance compared to Kentucky bluegrass (*Poa pratensis*) in the summer months, and improved cold hardiness compared to bermudagrass (*Cynodon dactylon*) in the winter months. Few zoysiagrass cultivars have been commercially-released that outperform Meyer in the transition zone.

‘Innovation’ zoysiagrass, an interspecific hybrid crossed between *Zoysia matrella* and *Zoysia japonica*, was released in 2015 as an alternative for Meyer in the transition zone because

of its fine texture and cold tolerance (Chandra et al., 2017). Innovation zoysiagrass is established at sod producers, often by sprigs, and then harvested and laid at end-user sites where the mature sod is maintained. Limited research has been conducted on Innovation zoysiagrass since its release; therefore, information is needed on how core cultivation can impact thatch after sod is laid, and which herbicides can be most effectively used at the time of sprigging. Further, other cultural practices used by zoysiagrass producers need to be evaluated for their influence on cultivar grow-in, turf quality, and rooting after sod is laid. In addition, bermudagrass commonly encroaches zoysiagrass swards, and evaluation of a newly released herbicide used to suppress bermudagrass is needed to better provide guidelines for its use. Finally, there have been many experimental zoysiagrass genotypes evaluated over the past several years across multiple states, and there is a need to identify the top performing experimental genotypes for future commercial release.

Turfgrass Cultural Practices

Intensively maintained turf refers to swards that receive regular applications of fertilizer, supplemental irrigation, and frequent mowing. Because of these practices, thatch accumulation can occur. A thatch layer is composed of dead organic residues, and living roots, stems, and crowns of the turfgrass system, as well as other microbes and organisms in various states of life and decay (Gaussoin et al., 2013). It is believed that thatch accumulates due to a higher rate of organic matter production and slower rate of decomposition (Beard, 1973; Turgeon, 1979).

Another problem that occurs in turfgrass systems is compaction. Turfgrass swards, especially on golf courses and athletic fields, experience heavy foot and cart traffic which results in soil compaction. Compaction can injure or sometimes kill turfgrass since the pore space in soil is essential to root function because of the oxygen that they contain (Grant, 1993).

Turfgrass managers are able to effectively reduce thatch accumulation and alleviate compaction with cultivation. Cultivation is often used in agriculture and refers to soil tillage; a practice that is not desirable in established, perennial turfgrass swards. However, cultivation in the turfgrass industry refers to a number of mechanical processes that can be used to loosen the soil, reduce compaction and thatch, or groom the surface (Christians et al., 2017). One of the most effective cultivation processes is core aerification. With this practice, hollow tines are inserted into the turfgrass canopy and remove a core of soil from the sward. By removing the core, soil is loosened and a variety of factors are increased including: gas exchange, root growth, and water infiltration. Tine size, depth, and spacing are important variables in acceptable thatch and compaction reduction. The practice of core aerification, that creates 20 to 40 holes/ft² penetrating 2 to 3 inches deep, has been found to be beneficial for both athletic fields and home lawns (Trappe and Patton, 2008). However, implementing aerification or similar cultivation practices can remove a substantial amount of the surface area when performed multiple times throughout the year. Currently, there is no research on how aerification intensity affects thatch accumulation, rooting depth, and overall turf quality of Innovation zoysiagrass.

The practice of mechanical mowing began almost 200 years ago (Hall, 1994), and has since become the predominant cultural practice in turfgrass systems. There are numerous studies that have investigated the influence of nitrogen rates and mowing height on many turfgrass species (Bush et al., 2000; Calvache et al., 2017; Dernoeden et al., 1993; Patton et al., 2010; Shearman et al., 1980). Previous studies have reported that mowing at a higher height of cut can increase thatch accumulation on Kentucky bluegrass (Dunn et al., 1981a; Shearman et al., 1980); and nitrogen rate and source may have only a minimal effect on thatch accumulation (Dunn et al., 1981b; White & Dickens, 1984). However, many of these previous studies have focused on

the visual turf quality of cool-season grass species, with minimal reports on how nitrogen rates and mowing height influence thatch accumulation in zoysiagrass swards (Patton et al., 2010; Schwartz et al., 2018).

During zoysiagrass establishment at the sod producer, the mowing height of cut is often higher than the traditional height of cut used to maintain zoysiagrass golf course fairways (D. McFadden, personal observation). The cultural practices used during establishment at the sod producer could play a critical role in the post-harvest transplant health of the zoysiagrass. End-users receiving zoysiagrass with large amounts of thatch accumulation would likely need to implement additional strategies after the sod is laid, including aerifying, verticutting, topdressing, or increased irrigation. Therefore, identifying strategies at the sod producer that will influence the rate of zoysiagrass establishment, decrease the amount of thatch accumulation, and increase post-harvest transplant rooting could save turfgrass managers time and money by producing a better quality zoysiagrass.

Use of Herbicides During Zoysiagrass Establishment

Zoysiagrass is generally established with vegetative planting; most commonly by sod, sprigs, or plugs and has a slow rate of establishment compared to other warm-season species (Patton et al., 2017). In the U.S. transition zone, zoysiagrass is commonly sprigged or plugged in the early summer, when summer annual weeds such as crabgrass (*Digitaria* spp.) and goosegrass (*Eleusine indica*) are emerging. During establishment from plugs, growth can be hastened when preemergence herbicides are applied to reduce the competition from crabgrass and goosegrass (Fry et al., 1986). However, many preemergence herbicides can reduce rooting and establishment of zoysiagrass when applied at or around the time of plugging or sprigging (Carroll et al., 1996; Engel et al., 1968; Fry et al., 1986).

Ronstar (oxadiazon 3-[2,4-dichloro-5-(1-methylethoxy)phenyl]-5-(1,1-dimethylethyl)-1,3,4-oxadiazol-2(3H)-one), a protoporphyrinogen (protox) inhibitor, is a commonly used preemergence herbicide that can be applied at the time of zoysiagrass establishment from sprigs or plugs for the control of annual grasses and broadleaf weeds (Environmental Science US Inc., 2011). However, Ronstar underwent a registration review by the United States Environmental Protection Agency (U.S. EPA) in 2021. In 2022, the U.S. EPA released registration changes that reduces the number of applications allowed in a year and the rate of active ingredient that is allowed per acre. Ronstar is also now limited to use on only 30% of the whole golf course area (including fairways, tees, greens, and roughs; EPA 2022). Because of these new restrictions, it is important to investigate alternative preemergence and postemergence herbicides that can be used at the time of zoysiagrass sprigging when weed control is critical for proper establishment of the sward.

Suppression of Bermudagrass in Zoysiagrass

Bermudagrass establishes rapidly and produces a vigorous, dense sward of turf with a deep root system (McCarty and Miller, 2002). Because of these growth characteristics, bermudagrass is extremely difficult to control in turfgrass systems, ornamental beds, agronomic crops, and pastures (Brown et al., 1985; Ferrell et al., 2005; Newman et al., 2003). When bermudagrass invades a sward of desired turfgrass, the quality of the sward generally declines due to the differences in growth habit, color, and texture (Johnson and Carrow, 1995). Bermudagrass is one of the most problematic weeds within zoysiagrass swards; and because of the physiological similarities between bermudagrass and zoysiagrass there are limited selective herbicides available to control bermudagrass without causing injury to zoysiagrass (Johnson, 1987; Johnson, 1992; Dernoeden, 1989).

Fluazifop-p-butyl (Fusilade II), an acetyl CoA carboxylase (ACCase) inhibitor, is a selective herbicide for the control of grass weeds that can be applied up to 6 fl oz/acre during a single application (Syngenta Professional Products, 2022). Favorable results of bermudagrass suppression have often been reported after three to four applications of fluazifop-P-butyl; however, unacceptable injury to zoysiagrass can occur. In Georgia, fluazifop-P-butyl was found to control Tifway bermudagrass (>99%) after three applications, but caused excessive injury to Emerald zoysiagrass one month following application (Johnson, 1987). Similarly, in Fayetteville, AR and Auburn, AL, fluazifop-P-butyl averaged 83% bermudagrass suppression 28 days after three sequential applications, but injured Meyer and ‘Zorro’ zoysiagrass (Patton et al., 2017b). Recognition (Syngenta Professional Products), a new herbicide for the control of certain broadleaf, sedge, and grass weeds in turf, containing trifloxysulfuron-sodium and a proprietary safener (metcamifen) entered the market in 2023. Herbicide safeners are designed to improve enzyme activity within a desired plant species for protection from herbicidal injury without causing a reduction in efficacy on the target weed species (Davies and Caseley, 1999). Recognition can be tank-mixed with Fusilade II for the control of bermudagrass in zoysiagrass turf; and because of new label guidelines, single applications of Fusilade II can be applied up to 24 fl. oz/acre when tank-mixed with Recognition.

Research is needed to determine if Recognition tank-mixed with Fusilade II controls bermudagrass without injuring zoysiagrass. There is also a need to evaluate how spring-applied and fall-applied treatments at high and low rates of the combination affect bermudagrass suppression and zoysiagrass injury.

Zoysiagrass Breeding Advancements

Zoysiagrass breeding is thought to have started in the 1940's in Beltsville, MD by creating new germplasm using open pollination, irradiation, and directed crosses (Hanson, 1965). Because of early breeding work, Meyer, 'Emerald', and 'El Toro' were commercially released in 1951, 1955, and 1984, respectively (Patton et al., 2017). Today, these three cultivars are prevailing selections for use in adapted regions. In 1980, Texas A&M University initiated a zoysiagrass breeding program at the Dallas Experiment Station (Engelke and Murray, 1989). Because of these breeding efforts, several high quality zoysiagrass cultivars were released including Zorro, 'Cavalier', 'Chisholm', and 'Palisades' (Engelke et al., 2002a; Engelke and Reinert, 2003; Chandra et al., 2015; Engelke et al., 2002b). Most of the cultivars indicated above are well adapted to the southern climates, with poor adaptability to the U.S. transition zone, with Chisholm as the exception.

Within the last two decades, zoysiagrass breeding programs in the U.S. have focused their efforts on developing progeny that exhibit finer leaf texture, enhanced rooting and drought tolerance, increased pest tolerance, and increased growth rates (Patton et al., 2017a). A collaborative effort amongst Texas A&M, Kansas State, and Purdue Universities began in 2012 to evaluate 2,858 new zoysiagrass progeny (Braun et al., 2022). Because of this, 'DALZ 1808' was identified as a top 10 best overall performer across all locations. DALZ 1808 has not been commercially released for production, however, there is a need to evaluate this promising cultivar to determine how nitrogen rates and mowing height affects the quality, thatch accumulation, and rooting before commercialization.

In addition, from the 2,858 zoysiagrass progeny investigated by Braun et al. (2022), a single release has been identified, 'DALZ 1701'. Following that experiment, another study sponsored by the United States Golf Association (USGA) was initiated to evaluate performance

of several thousand genotypes in Texas, Indiana, and Kansas. After initial evaluation, a set of sixty-nine hybrids were selected based on their superior performance from 2018 to 2020. There is a need to collect data on these top performers by evaluating many traits used to characterize turfgrasses (establishment rate, turf quality, genetic color, leaf texture, fall color retention, spring greenup, and winter injury) to determine if one or several of these experimental hybrids have potential for commercial release. The USGA also sponsored trials beginning in 2021 to identify top performing experimental zoysiagrass hybrids at seven locations across the United States.

Objectives

Numerous research studies have been conducted on zoysiagrass throughout the years. However, because of the recent commercialization of Innovation and the potential for future commercialization of DALZ 1808, there is a need to investigate how these cultivars are affected by cultural practices and herbicide applications. Therefore, the objectives of the research highlighted within this dissertation were to: (1) determine the influence of aerification on the quality, thatch levels, and rooting depth of Innovation zoysiagrass; (2) determine the influence of nitrogen rates and mowing height on the establishment rate, quality, thatch levels, and rooting strength of Innovation and DALZ 1808 compared to Meyer zoysiagrass; (3) evaluate the effects of commonly used preemergence herbicides on Innovation zoysiagrass at the time of sprigging; 4) evaluate the effectiveness of trifloxysulfuron-sodium + metcamifen (Recognition) when combined with fluazifop-p-butyl (Fusilade II) for bermudagrass suppression in Meyer zoysiagrass; and 5) identify top performing zoysiagrass genotypes evaluated across multiple states in a recent USGA sponsored trial.

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Chapter 2 - Aerification effects on thatch, rooting, and quality of 'Innovation' zoysiagrass

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Abstract

Aerification is a common practice used to reduce thatch accumulation and soil compaction which are two common issues turfgrass managers experience on golf courses, sports fields, and home lawns. Thatch accumulation is detrimental to turfgrass swards when allowed to buildup in excess. Minimal research has focused on 'Innovation' zoysiagrass and the effects of aerification intensity on turf quality and rooting depth. Therefore, a three-year field study was conducted in Olathe, KS to determine the influence of aerification intensities on thatch levels, rooting, and turfgrass quality of Innovation zoysiagrass. Treatments included no aerification, moderate aerification, and intensive aerification. Moderate aerification removed 27%, 10%, and 10.5% of the experimental plot in 2020, 2021, and 2022, respectively. Intensive aerification removed 54%, 20%, and 21% of the experimental plot in 2020, 2021, and 2022, respectively. Treatments were assessed by measuring organic matter (% by weight), root weight at different depths, turf quality, and turf color. There was a decrease in organic matter in the surface 1-in when turfgrass was intensively aerified compared to turfgrass that was not aerified. Non-aerified turf averaged ~16% organic matter, whereas intensively aerified turf averaged 11.7% organic matter. Zoysiagrass receiving moderate aerification significantly enhanced rooting at the 0-3, 3-6, and 6-9 cm depths below the soil surface compared to non-aerified turf. Research herein suggests moderately aerifying (removing 10% to 27% of the surface area) Innovation zoysiagrass can reduce organic matter and increase rooting, while also enhancing turf quality and color compared to non-aerified turf. Intensively aerifying (removing 21% to 54% of the surface area) Innovation zoysiagrass during the summer months might impede healthy growth of the zoysiagrass sward, as zoysiagrass quality was significantly reduced after intensive aerification treatments compared to non-aerified treatments.

Introduction

Aerification is a common practice used to reduce thatch accumulation and soil compaction; two issues turfgrass managers experience on golf courses, sports fields, and home lawns. Thatch is an intermingled organic layer of living and dead shoots, stems, and roots that develop between the zone of green vegetation and the soil surface (Beard, 1973; Ledebauer and Skogley, 1967). When the growth production rate of a turfgrass system exceeds its decomposition rate, thatch accumulation occurs (Murray and Juska, 1977). Thatch accumulation is detrimental to turfgrass swards when allowed to buildup in excess. Issues related to thatch accumulation include susceptibility to mower scalping (Barton et al., 2009), vulnerability to pest injury (Potter and Braman, 1991), and susceptibility to drought and freezing (Happ, 2004).

Turfgrass swards, especially on golf courses and athletic fields, experience heavy traffic which results in soil compaction. Traffic stress adversely affects turfgrass quality by reducing its growth and development largely due to soil compaction (Sharath et al., 2017). These compacted areas can injure or sometimes kill turfgrass since the pore space in soil is essential to root function because of the oxygen that they contain (Grant, 1993). Soil compaction reduces water, heat, and gas exchange (Grable and Siemer, 1968; Linn and Doran, 1984; Willis and Raney, 1971), while increasing bulk density, water retention, and soil strength (O'Neil and Carrow, 1983). Decreasing bulk density, a relative measure of soil compaction, increases soil macroporosity; which allows for optimum root growth in turfgrass systems (Fry and Huang, 2004).

Turfgrass managers utilize different cultivation methods to relieve compaction and reduce thatch accumulation in turfgrass systems. Cultivation is often used in agriculture and refers to soil tillage; a practice that is not desirable in established, perennial turfgrass swards.

However, cultivation in the turfgrass industry refers to a number of mechanical processes that can be used to loosen the soil, reduce compaction and thatch, or groom the surface (Christians et al., 2017). By employing aerification, or core removal strategies, soil physical properties improve in several ways. One of the most effective cultivation processes is core aerification, also referred to as hollow tine aerification. With this practice, hollow tines are inserted into the turfgrass canopy and then remove a core of soil from the sward and leave a soil plug on top of the canopy. Plugs are typically allowed to dry on the surface and then broken up by vertical mowing or dragging. By removing the core, soil is loosened and a variety of factors are increased including: gas exchange, root growth, and water infiltration. Tine size, depth, and spacing are important variables in acceptable thatch and compaction reduction. The practice of core aerification, with > 2-inch diam. tines that create 20 to 40 holes ft⁻², has been found to be beneficial for both athletic fields and home lawns (Trappe and Patton, 2008). However, implementing aerification or similar cultivation practices causes soil disruption and can remove a substantial amount of the surface area when performed multiple times throughout the year.

Research demonstrates that employing hollow tine aerification can increase water infiltration and reduce soil bulk density (McCarty et al., 2007; Murphy et al., 1993), while also reducing and controlling thatch (Brauen et al., 1998; Malleshaiah et al., 2018). Previous research on aerification benefits has focused on water infiltration, thatch control, and turfgrass quality (Atkinson et al., 2012; McCarty et al., 2007; Murphy et al., 1993; Wiecko et al., 1993). Further, previous hollow tine aerification studies have reported contrasting results on plant rooting affects (Murphy et al., 1993; Smith, 1979). Minimal research has focused on ‘Innovation’ zoysiagrass (*Zoysia japonica* × *Z. matrella*) and the effects of aerification intensity on turf quality and

rooting depth. Therefore, the objective of this research was to determine the influence of aerification intensities on thatch levels, rooting, and turfgrass quality of Innovation zoysiagrass.

Materials and methods

A field study was conducted at the Olathe Horticulture Research and Extension Center in Olathe, KS (long. 39.48° N, lat. 95.66° W) in 2020 (Year 1), 2021 (Year 2) and 2022 (Year 3) to determine the effects of aerification intensity on reducing thatch in Innovation zoysiagrass, and its impact on turf quality and rooting. The study was performed on a sward of Innovation zoysiagrass that was sodded in 2019. At the time of sodding, thatch depth was approximately one inch throughout the sward. The experiment was arranged in a randomized complete block design with three replicates. Plots measured 5-ft x 15-ft and replications were separated by a 2-ft border. Treatments were induced to the same experimental plots for each year of the experiment. Treatments included no aerification, moderate aerification, and intensive aerification. The number of cores and tine size varied by experimental year; however, intensive aerification treatments had twice as many cores pulled per plot compared to moderately aerified plots for each year of the experiment (Figure 2.1). Moderate aerification treatments had 63 cores ft⁻², 60 cores ft⁻², and 42 cores ft⁻² pulled in 2020, 2021, and 2022, respectively. Moderate aerification removed 27%, 10%, and 10.5% of the experimental plot in 2020, 2021, and 2022, respectively. Intensive aerification treatments had 126 cores ft⁻², 120 cores ft⁻², and 84 cores ft⁻² pulled in 2020, 2021, and 2022, respectively. Intensive aerification removed 54%, 20%, and 21% of the experimental plot in 2020, 2021, and 2022, respectively. Aerification date, core cultivator, core depth, and tine diameter details are shown in Table 2.1.

Following aerification, a steel mat was evenly dragged over individual plots to break up soil on cores lying on the canopy and smooth the turfgrass surface. Plots were maintained at a

0.75-inch height of cut; irrigation was only applied when the zoysiagrass sward began to visibly show significant drought stress.

Measurements and statistical analysis

Treatments were assessed by measuring organic matter (% by weight), root weight at different depths, visual turf quality, and visual turf color. Thatch was evaluated by determining total organic matter. Organic matter levels were determined by pulling two cores measuring 2-inches in diameter by 1-inch deep from each plot on September 24, 2020, October 18, 2021, and September 26, 2022. Shoots above thatch and soil and roots below thatch were removed. Each sample was oven dried at 220°F +/- 5°F, for more than 24 hours. Each dried sample was weighed and then ashed at 1,067°F for 6 h at the International Sports Turf Research Center lab in Lenexa, KS, USA. The ashed samples were weighed and the loss on ignition organic matter content weights were calculated using Method 1 of ASTM F1647 (ASTM International).

On the same dates mentioned above, three cores measuring 1-inch in diameter were sampled from three random areas in each plot and the profile separated into 0-3 cm, 3-6 cm, 6-9 cm and 9-12 cm from below the shoot system (Figure 2.2). Root zone material from the samples were placed on a sieve and soil was washed from the roots. Roots were then placed in individual paper bags and dried for approximately 48 h in an electric drying oven (Thermo Scientific, Model 658, Marietta, OH, USA) at 150°F. After the 48 h, dried roots were weighed to determine the weight of roots within each depth for each aerification treatment.

Turf quality was visually rated on a 1 to 9 scale with 1 representing dead turf and 9 representing optimum color, density, and uniformity. Turf color was visually rated on a 1 to 9 scale with 1 representing no color retention and 9 representing dark green color. Turf quality and turf color of plots were rated biweekly throughout each growing season.

Organic matter content, root weights across depths, turf quality, and turf color measurements were subjected to ANOVA using the Glimmix procedure in SAS (version 9.4, SAS Institute Inc.). Experiment year was included, and data were combined when a significant year x aerification intensity interaction ($P \leq 0.05$) was not observed. Means were separated according to Tukey's HSD test ($\alpha = .05$) when the F tests were significant ($P \leq 0.05$).

Results and discussion

Organic matter data had no year x aerification intensity interaction, therefore means were combined across year. There was a decrease in organic matter in the surface 1-in when turfgrass was intensively aerified compared to turfgrass that was not aerified (Table 2.2). Nonaerified turf averaged ~16% organic matter, whereas intensively aerified turf averaged 11.7% organic matter throughout the three year study. Moderately aerified turf had a reduction in organic matter compared to nonaerified turf, but was not significantly lower; however, it was statistically similar to intensively aerified turf. A previous study investigating renovation techniques on mature kikuyugrass found hollow tine aerification and verticutting decreased organic matter content over a 24 month period compared to topdressing or hollow tine aerification + topdressing; however, treatments still had unacceptable organic matter content (~20%; Barton et al., 2009). Similarly, a study conducted in Georgia found that core aerification conducted once or twice a year did not have an impact on thatch reduction in Tifway bermudagrass (Carrow et al., 1987).

Dry root sample data showed no significant effect for experiment year x aerification intensity interactions when data were analyzed. Therefore, data over years were combined and analyzed by rooting depth. Rooting was enhanced in treatments receiving moderate aerification at all measured depths (except 9-12 cm) compared to nonaerified turf (Table 2.3). Root weights

in intensively aerified treatments were statistically similar to moderate aerification and nonaerified treatments. Treatments receiving moderate aerification significantly enhanced rooting at the 0-3, 3-6, and 6-9 cm depths below the soil surface (Figure 2.2). Similarly, Sharath et al. (2018) reported that Manilagrass (*Zoysia matrella*) receiving hollow tine aerification treatments had an average root volume of 3.95 cm³, whereas Manilagrass receiving no aerification had a root volume of 1.48 cm³.

The impact of aerification intensity on turf quality is critical to turf managers and has to be considered as they determine appropriate strategies. Turf quality evaluation with experiment year x aerification intensity interaction had a significant effect for June when data were combined across years, so July and August turf quality data are presented. Treatments receiving intensive aerification had significantly lower turf quality than treatments that did not receive aerification (Table 2.4). This was likely due to the amount of injury incurred on intensive aerification treatments. Under conditions evaluated throughout this three year study, turf quality was significantly reduced when zoysiagrass was intensively aerified (20% to 54% of surface area impacted) compared to nonaerified turf. Throughout July and August in 2020-2022, intensively aerified treatments averaged below minimally acceptable turf quality (<6.0). Similarly, in Clemson, SC, turf quality of TifEagle bermudagrass decreased to unacceptable levels (<7.0) for four weeks following treatments when aerification impacted 15% and 25% of the surface area regardless of frequency (Atkinson et al., 2012).

Turf color data were combined across years, as there was no significant effect for experiment year x aerification intensity interactions. Turf color was significantly higher in intensively aerified treatments compared to nonaerified treatments in June, July, and August; intensively aerified treatments averaged 7.7, 7.8, and 7.6 respectively, throughout these summer

months (Table 2.2). Turf color was enhanced in April to May when core aerification was induced twice per year on Tifway bermudagrass (Carrow et al., 1987). Similar to this previous report, spring greenup was hastened in intensively aerified turf compared to nonaerified turf the following spring after aerification treatments were induced (Data not shown; Figure 2.3).

Research herein suggests moderately aerifying Innovation zoysiagrass can reduce organic matter and increase rooting, while also enhancing turf quality and color compared to nonaerified turf. Intensively aerifying Innovation zoysiagrass during the summer months might impede healthy growth of the zoysiagrass sward. Future research is needed to evaluate how aerification timing and frequency affect Innovation zoysiagrass quality, organic matter accumulation, and rooting depth. Further, future research should investigate how increasing the aerification depth affects the root growth and development at deeper lengths.

Figure 2.1 Experimental plots receiving intensive aeration (a); moderate aeration (b); or no aeration (c) immediately following aeration on 8 July 2022 in Olathe, KS.

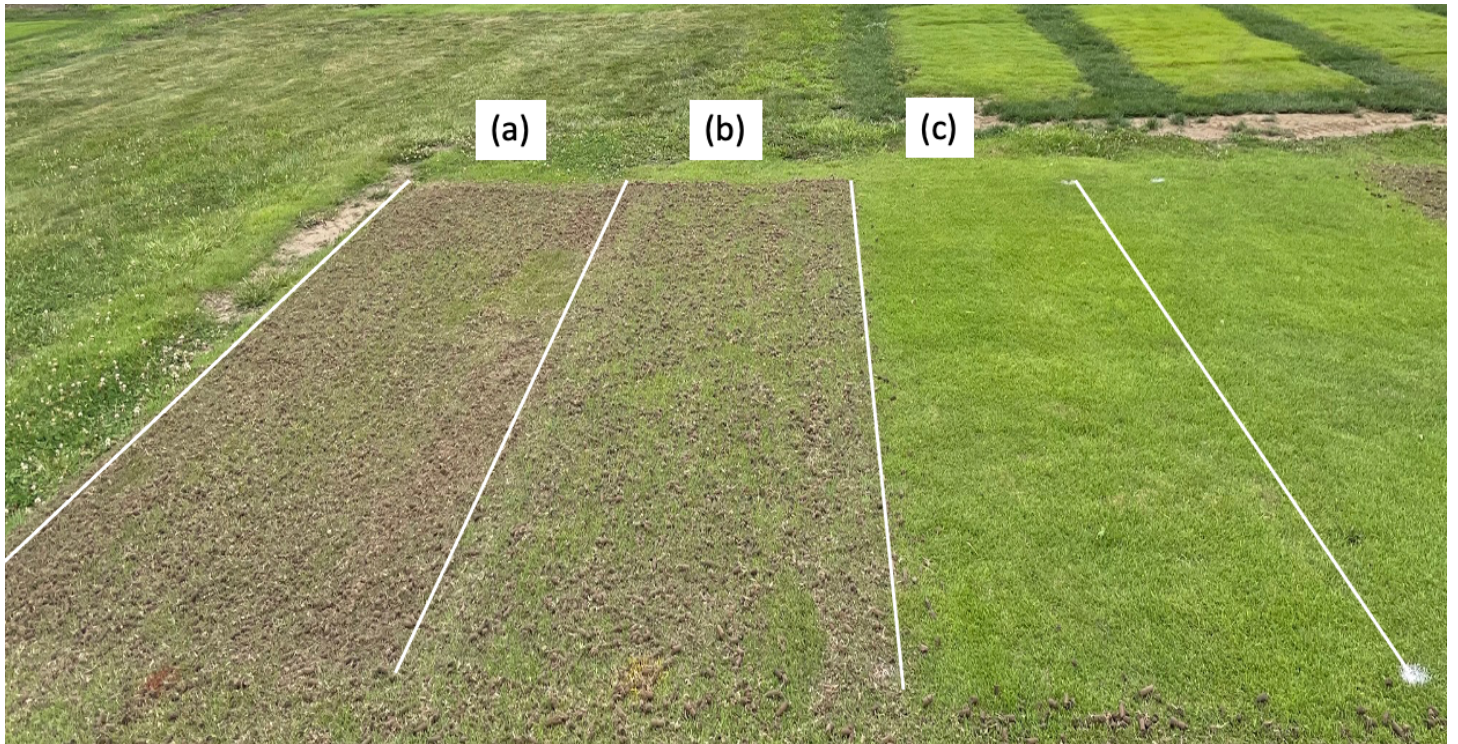


Table 2.1 Aerification date and aerifier details for each year of the study in Olathe, KS.

Aerification information	2020	2021	2022
Aerification date	June 26	June 21	July 8
Core cultivator	John Deere Aercore 800	Ryan Greensaire 24	Verti-Core 1600
Manufacturer	Deere and Company, Moline, IL, USA	Clark Equipment Co., Johnson Creek, WI, USA	Redexim North America, Valley Park, MO, USA
Core depth	2.5-inch	2.0-inch	2.5-inch
Tine diameter	5/8-inch	1/4-inch	3/8-inch

Moderate aerification removed 27%, 10%, and 10.5% of the experimental plot in 2020, 2021, and 2022, respectively. Intensive aerification removed 54%, 20%, and 21% of the experimental plot in 2020, 2021, and 2022, respectively.

Figure 2.2 Core samples of nonaerified turf (a,d); moderately aerified turf (b,e); and intensively aerified turf (c,f) at the time of removal from experimental plots (left) and following a 48 h oven dry down period (right).



Table 2.2 Effect of aerification intensity on thatch (organic matter to a 1-in depth) three months after treatment in 2020-2022

Aerification intensity ^a	Organic matter (%) ^b
None	15.9 a ^c
Moderate	13.5 ab
Intensive	11.7 b

^a Moderate aerification treatments had 63 cores ft⁻², 60 cores ft⁻², and 42 cores ft⁻² pulled in 2020, 2021, and 2022, respectively. Intensive aerification treatments had 126 cores ft⁻², 120 cores ft⁻², and 80 cores ft⁻² pulled in 2020, 2021, and 2022, respectively.

^b Organic matter was determined by pulling two cores 2-inches in diameter and 1-inch deep from each plot on September 24, 2020, October 18, 2021, and September 26, 2022. Each sample was oven dried at 220°F +/- 5°F, for more than 24 hours. Each dried sample was weighed and then ashed at 1,067°F for 6 h. The ashed samples were weighed and the loss on ignition organic matter content weights were calculated.

^c Means followed by the same letter are not significantly different according to Tukey's HSD ($P \leq 0.05$). Means are averages over two core samples, three replications, and three experimental years, n = 18.

Table 2.3 Effect of aerification on root dry weights in 2020-2022.

Aerification intensity ^b	Sample depth (cm) ^a			
	0-3	3-6	6-9	9-12
	Weight (mg) ^c			
None	450b ^d	41b	10b	8 ^e
Moderate	836a	114a	50a	14
Intensive	651ab	98ab	31ab	16

^a Three cores (2.54 cm diam. to 12 cm depth) were pulled at random from each experimental plot on September 24, 2020, October 18, 2021, and September 26, 2022.

^b Moderate aerification treatments had 63 cores ft⁻², 60 cores ft⁻², and 42 cores ft⁻² pulled in 2020, 2021, and 2022, respectively. Intensive aerification treatments had 126 cores ft⁻², 120 cores ft⁻², and 80 cores ft⁻² pulled in 2020, 2021, and 2022, respectively.

^c Root weight of oven-dried root samples after 48 h in an electric drying oven at 150°F.

^d Means followed by the same letter in a column are not statistically different according to Tukey's Honest Significant Different ($P < 0.05$). Means are averages over replication, core samples, and experimental year, $n = 27$.

^e Samples at the 9-12 cm depth were not significantly different.

Table 2.4 Effect of Aerification Intensity on Turf Quality and Turf Color in 2020-2022

Aerification Treatment ^c	Turf Quality ^a		Turf Color ^b		
	July	August	June	July	August
None	7.2a ^d	6.9a	6.1b	6.5b	6.2b
Moderate	7.1ab	6.4ab	7.0ab	7.2ab	6.9ab
Intensive	5.9b	5.9b	7.7a	7.8a	7.6a

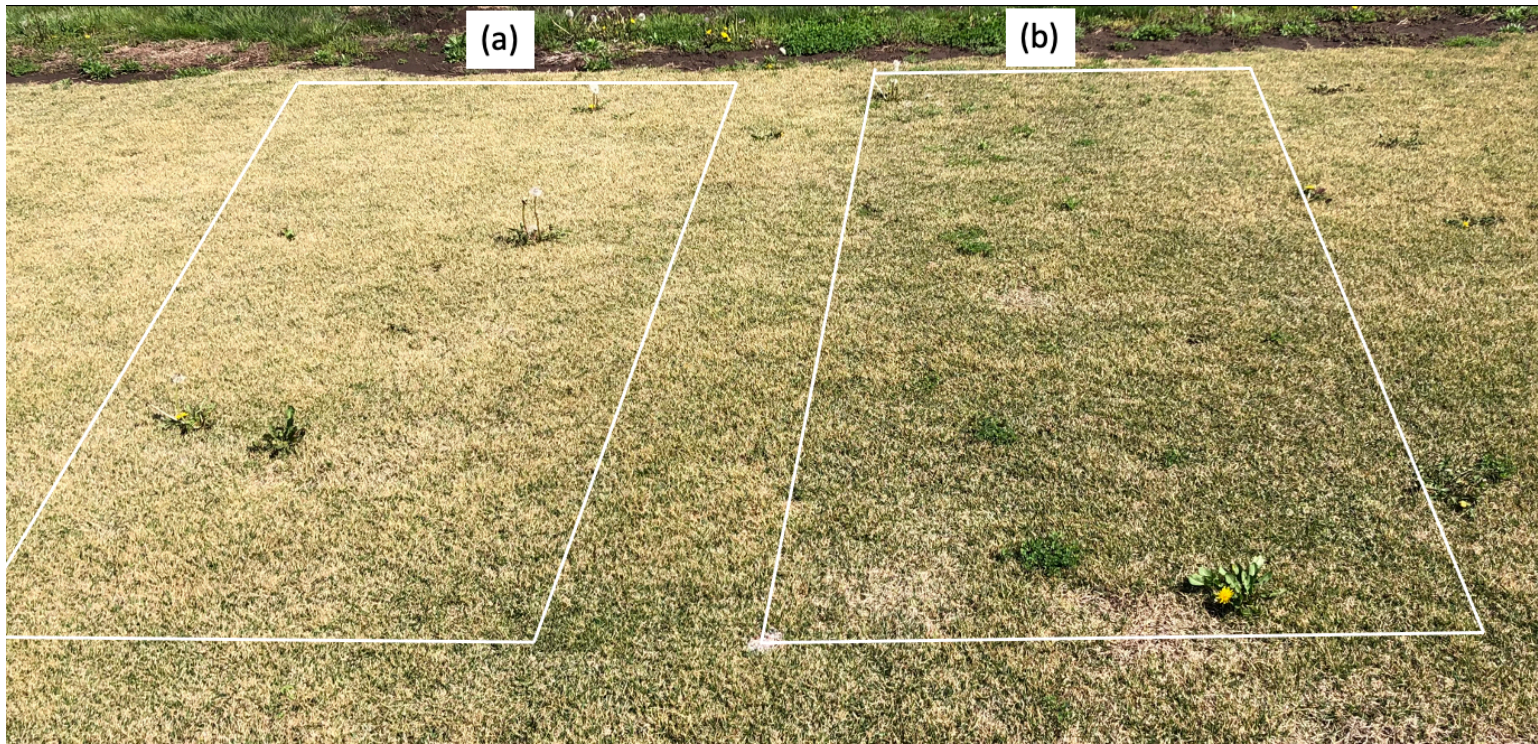
^a Turf quality was rated visually on a 1 to 9 scale on which 1 = dead; 6 = minimally acceptable; 9 = optimum color, density, uniformity, and texture.

^b Turf color was rated visually on a 1 to 9 scale on which 1 = brown/straw color; 9 = dark green.

^c Moderate aerification treatments had 63 cores ft⁻², 60 cores ft⁻², and 42 cores ft⁻² pulled in 2020, 2021, and 2022, respectively. Intensive aerification treatments had 126 cores ft⁻², 120 cores ft⁻², and 80 cores ft⁻² pulled in 2020, 2021, and 2022, respectively.

^d Means followed by the same lower case letter in a column are not significantly different ($P < 0.05$). Means are averages over three replications and three experimental years, n = 9.

Figure 2.3 Differences in spring greenup between nonaerified turf (a); and intensively aerified turf (b) on 29 April 2021 in Olathe, KS.



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Chapter 3 - Nitrogen and mowing height effects on zoysiagrass grow-in, thatch accumulation, and post-harvest rooting

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Abstract

During zoysiagrass establishment at the sod producer, the mowing height of cut is often higher than the traditional height of cut used to maintain zoysiagrass on golf course fairways, and nitrogen is frequently applied to hasten establishment. There is a need to investigate how cultural practices used during zoysiagrass establishment from sprigs affects thatch accumulation during the critical establishment period and the post-harvest health of the zoysiagrass. Identifying strategies at the sod producer that will decrease the amount of thatch accumulation during zoysiagrass establishment and increase post-harvest rooting could save turfgrass managers time and money by producing a better quality zoysiagrass. A field study was conducted in Olathe, KS from 2021 to 2023 to evaluate how nitrogen rate rates (77 kg N ha^{-1} or 175 kg N ha^{-1} annually) and mowing height (1.9 cm or 3.8 cm height of cut) influence establishment rate, turf quality, thatch accumulation, and post-harvest root strength of ‘DALZ 1808’, ‘Innovation’, and ‘Meyer’ zoysiagrass from sprigs. At 12, 14, and 16 months after sprigging, DALZ 1808 and Meyer had significantly higher turf quality compared to Innovation. Innovation zoysiagrass mowed at 3.8 cm HOC had significantly more thatch compared to all other treatments (17.87 mm); whereas, DALZ 1808 treatments had thatch levels below 10 mm regardless of mowing height or nitrogen rate. The peak force needed to uproot treatments was highest in Meyer zoysiagrass maintained at 3.8 cm HOC and fertilized with 175 kg N ha^{-1} . The results from this study indicate that recommended mowing height and annual nitrogen rate for a reduction in thatch accumulation and better turf quality and post-harvest rooting differs depending on zoysiagrass cultivar.

Introduction

Zoysiagrass (*Zoysiagrass* spp. Willd) is commonly established by sod, sprigs, or plugs (Patton et al., 2017). Sodding zoysiagrass is often very costly; therefore, a cost-effective alternative is to broadcast or row-plant vegetative sprigs. There are numerous studies that have investigated the establishment rate of several zoysiagrass genotypes from sprigs (Richardson and Boyd, 2001; Stiglbauer et al., 2009; Zhang et al., 2021). Further, the effects of nitrogen rate and mowing height on zoysiagrass has also been well documented (Dunn et al., 1981a; Patton et al., 2010; Schwartz et al., 2018). However, many of these previous studies have focused on the visual turf quality, with minimal reports on how nitrogen rates and mowing height influence thatch accumulation and post-harvest root strength in zoysiagrass swards. Previous studies have reported that mowing at a higher height of cut can increase thatch accumulation on Kentucky bluegrass (*Poa pratensis*; Dunn et al., 1981b; Shearman et al., 1980); and nitrogen rate and source has no or minimal effect on thatch accumulation in zoysiagrass (Dunn et al., 1981a) and bermudagrass (*Cynodon dactylon*; White & Dickens, 1984).

A thatch layer is composed of dead organic residues, and living roots, stems, and crowns of the turfgrass system, as well as other microbes and organisms in various states of life and decay (Gaussoin et al., 2013). Thatch accumulation can occur in intensively maintained swards of turfgrass that receive regular applications of fertilizer, supplemental irrigation, and frequent mowing. During zoysiagrass establishment at the sod producer, the mowing height of cut is often higher than the traditional height of cut used to maintain zoysiagrass on golf course fairways and nitrogen is frequently applied to hasten establishment (D. McFadden, personal obs.). There is a need to investigate how cultural practices used during zoysiagrass establishment from sprigs affects thatch accumulation during the critical establishment period. Furthermore, the cultural

practices used during establishment at the sod producer could play a critical role in the post-harvest health of the zoysiagrass. End-users receiving zoysiagrass with large amounts of thatch accumulation would likely need to implement additional strategies after the sod is laid, including aerifying, verticutting, or increased irrigation. Therefore, identifying strategies at the sod producer that will decrease the amount of thatch accumulation during zoysiagrass establishment and increase post-harvest rooting could save turfgrass managers time and money by producing a better quality zoysiagrass.

Limited research has been conducted on new genotypes, such as Innovation zoysiagrass and a promising experimental line DALZ 1808, on the thatch accumulation and post-harvest root strength following establishment from sprigs. Therefore, the objective of this research study was to evaluate how nitrogen rate and mowing height influence establishment rate, turf quality, thatch accumulation, and post-harvest root strength of DALZ 1808, Innovation, and Meyer zoysiagrass from sprigs.

Materials and Methods

Grow-in

A field study was conducted at the Olathe Horticulture Research and Extension Center in Olathe, KS (long. 39.48° N, lat. 95.66° W) from 2021 to 2023 to determine the effects of nitrogen rate and mowing height on the rate of grow-in, thatch accumulation, and post-harvest rooting of three zoysiagrass genotypes. In 2021, the experiment was initially arranged in a strip-plot design with four replicates. Plots measured 1.8 m x 3.0 m with 0.61 m borders between genotypes. Prior to study initiation, the site previously contained a cool-season turfgrass mixture. The study area was tilled, and soil dragged to leave a uniform surface of bare soil. DALZ 1808 sod was collected from experimental plots in Manhattan, KS on 10 June 2021 that had been

established by plugs in July of 2015 and then maintained at 1.9 cm height of cut (HOC). Innovation and Meyer were harvested from the Olathe Horticulture Research and Extension Center on 11 June 2021. Prior to harvest, Innovation was established by sod in June of 2019 and Meyer was established in 2015 and then maintained at 1.9 cm HOC. Sod was broken up into sprigs using a sprigger (Figure 3.1; Sprig Master II; Sprigger's Choice, Inc.; Dawson, GA, USA) and manually scattered uniformly into designated experimental plots at a 1:10 ratio (0.09 m² of sod spread over a 0.92 m² area) and then covered with 1.27 cm of top soil on 11 June 2021. Immediately following sprigging, Ronstar was applied at a rate of 75 kg N ha⁻¹ along with a starter fertilizer (18-10.6-0 [N-P-K]) applied at a rate of 11 kg N ha⁻¹ followed by supplemental irrigation (Figure 3.1). Treatments in 2021 included three zoysiagrass genotypes (DALZ 1808, Innovation, and Meyer), and two nitrogen rates (77 kg N ha⁻¹ and 175 kg N ha⁻¹ annually). On 20 August 2021 the entire trial area was mowed to 6.35 cm HOC.

During the summer of 2022, the trial was rearranged to a strip-split plot design to incorporate two mowing height treatments (1.9 cm and 3.8 cm HOC). Genotype was the vertical strip, nitrogen treatment was the horizontal strip, and mowing treatments were the sub-plots nested within each intersection for twelve total treatments replicated four times (Figure 3.2).

Post-Harvest Rooting

Twenty-four months following sprigging, sod was cut 30.48 cm wide at a 2.54 cm depth using a sod cutter (Jr. Sod Cutter; Ryan Turf; Clark Equipment Co.; Johnson Creek, WI, USA). Sod was then cut to 15.24 cm in diameter using a hole cutter (15.24 cm standard golf hole cutter; ParWest Turf; Huntington Beach, CA, USA) and then placed into circular plastic frames (rooting sieves) with a mesh screen in the bottom measuring 20.98 cm in diameter with a 0.2 cm hole diameter in the bottom screen. Eight plugs from each treatment were placed into the rooting

sieves for a total of 96 rooting sieves for each experimental run. Within each rooting sieve, soil was distributed around each plug so that it was fully surrounded; approximately 450 grams of soil was applied. On 26 June 2023 the 96 rooting sieves were placed onto an area of bare soil that had been tilled and dragged for uniformity. Immediately prior to placing the rooting sieves onto the soil surface, 11 kg N ha⁻¹ was applied using a starter fertilizer (18-10.6-0 [N-P-K]). Fifteen days after planting, 48 of the 96 rooting sieves were detached from the soil to determine the peak force needed detach the roots from the soil. Thirty days following planting, the final 48 rooting sieves were detached from the soil using the same methods as the fifteen day treatments. On 26 July 2023 the experiment was repeated using the same methods as experimental run 1.

Measurements and statistical analysis

In 2021 and 2022, treatments were assessed by measuring visual turf quality, percent establishment, large patch occurrence, and handheld normalized difference vegetative index (NDVI) readings. Turf quality was rated on a 1 to 9 scale with 1 representing dead turf and 9 representing optimum color, density, and uniformity. Establishment was rated on a 0 to 100% scale with 0% representing no turf cover within the experimental plot and 100% representing full cover and complete establishment of the plot. In the fall of 2022 large patch occurred within experimental plots. Large patch, caused by *Rhizoctonia solani* Kuhn AG 2-2, occurred naturally in the experimental area in 2022. Disease severity was visually evaluated on a percent scale where 0.092 m² of diseased area equaled 4% large patch. Normalized difference vegetation index (NDVI) measurements are often used as an indicator of plant health status for many crops (Atshan et al., 2018; Straw et al., 2016; Chapman and Barreto, 1997). Measurements range from -1.0 to 1.0, with higher values indicating greater plant health. Handheld NDVI (FieldScout CM

1000 NDVI Meter, Spectrum Technologies, Aurora, IL, USA) readings were recorded in 2022 following 95% establishment of all experimental plots.

On 30 May 2023, two 5.08 cm diam. plugs were removed from each experimental plot. Thatch depth was measured (in millimeters) at two random locations by starting at the soil surface to the top of the thatch (where turfgrass crowns are visible) using a digital caliper, and the average of the two measurements recorded. Thatch samples were then washed to remove roots and any soil media below the thatch surface, and shoots above the thatch layer were removed (Figure 3.3). Samples were then placed in an electric drying oven (Model 658; Thermo Scientific; Marietta, OH, USA) at 65.6°C for 48 hours. Following the 48 hour period, dry weight of each sample was recorded (in grams).

For the post-harvest rooting study conducted in the summer of 2023, turf quality was visually rated immediately prior to detaching the rooting sieves from the soil at each date. A digital force gauge was placed onto each rooting sieve using 1.27 cm hooks attached to three 0.48 cm vinyl coated galvanized steel cables that attached to the bottom of the digital force gauge (Figure 3.4; DFX II Series Digital Force Gauge; Chatillon Force Measurement; Florida, USA). Uniform tension was applied at a constant rate until the rooting sieve detached free from the soil, similar to methodology used by Dest and Ebdon (2017). The peak kilograms of force needed to detach the rooting sieves from the soil was recorded.

Each of the above measurements were subjected to analysis of variance (ANOVA) using the Glimmix procedure in SAS (version 9.4, SAS Institute Inc.). Experimental run was included for post-harvest rooting data, and data were combined when experimental run was not significant ($P \leq 0.05$). Means were separated according to Tukey's HSD test ($\alpha = .05$) when the F tests were significant ($P \leq 0.05$).

Results

2021-2022 Grow-in

All treatments reached over 50% establishment by 13 weeks after sprigging regardless of nitrogen rate (Figure 3.4). DALZ 1808 receiving 175 kg N ha⁻¹ annually was the only treatment to average 95% establishment 15 weeks after sprigging. All other treatments did not reach 95% establishment until the following summer (data not shown). However, there were no significant differences in grow-in on any rating date based on cultivar or N level.

Following complete establishment of all experimental plots, mowing treatments were induced on 28 March 2022. Genotype x nitrogen rate x mowing height interactions were insignificant for turf quality across all rating dates (Table 3.1). The effect of genotype was significant at every rating date throughout the study. At 12, 14, and 16 months after sprigging, DALZ 1808 and Meyer had significantly higher turf quality compared to Innovation (Table 3.2). Twelve months after sprigging, DALZ 1808 had an average turf quality of 7.4 across replications regardless of nitrogen rate and mowing height; whereas, Innovation had an average turf quality of 6.2. Sixteen months after sprigging, in October 2022, Innovation quality began to decline (4.8) as it entered winter dormancy; whereas DALZ 1808 and Meyer maintained acceptable turf quality (6.8 and 6.3, respectively).

Large patch occurred within the trial area in the fall of 2022. Though not part of the experimental design, a visual large patch rating was taken to anecdotally compare if specific treatments had more large patch occurrence compared to others. On average, Innovation mowed at 3.8 cm had a trend of more diseased area within the experimental plot compared to all other treatments (Table 3.4). When averaged across genotypes and nitrogen rates, large patch occurrence was higher in 3.8 cm HOC experimental plots (9.1% large patch) compared to 1.9 cm

HOC plots (3.4% large patch). Large patch inoculations were not part of the study, but these anecdotal trends provide baseline information for future targeted studies.

There were no significant effects for genotype x nitrogen rate x mowing height on NDVI readings (Table 3.3). NDVI averaged 0.86 in DALZ 1808 experimental plots; significantly higher than Meyer plots (Table 3.5). NDVI readings were also higher in experimental plots receiving 175 kg N ha⁻¹ annually and plots mowed at 3.8 cm.

2023 Post-Harvest Rooting

Genotype x mowing height was significant for caliper thatch-depth measurements (Table 3.3). Innovation mowed at 3.8 cm had significantly more thatch compared to all other treatments (17.87 mm; Table 3.6). DALZ 1808 was the only genotype in this study that had thatch levels below 10 mm; 1.9 cm and 3.8 cm HOC averaged 8.79 mm, and 9.52 mm of thatch, respectively. Meyer treatments averaged around 12.2 mm of thatch regardless of mowing height.

The three-way interaction of genotype x nitrogen rate x mowing height was significant for the oven-dried thatch samples taken from the 5.08 cm plugs (Table 3.3). The treatment resulting in the highest oven-dried thatch weight was Innovation receiving low nitrogen (77 kg N ha⁻¹ annually) mowed at 1.9 cm (4.32 grams of oven-dried thatch; Table 3.7). Alternatively, Innovation receiving high nitrogen (175 kg N ha⁻¹ annually) mowed at 3.8 cm averaged 2.48 grams of thatch, significantly lower than the treatment stated above. The treatments with the lowest oven-dried thatch weight were DALZ 1808 receiving the low annual rate of nitrogen mowed at the low HOC and DALZ 1808 receiving the high annual rate of nitrogen mowed at the high HOC, with 2.37 grams and 2.43 grams of thatch, respectively. Meyer zoysiagrass had an average oven-dried thatch weight between 3.00 and 3.91 grams across all nitrogen rate x mowing height treatments.

Experimental run was significant for both the 15 d and 30 d root strength measurements for the post-harvest rooting strength study (Table 3.8). Therefore, root strength measured at 15 d following planting is presented separately by experiment. There were significant treatment effects for experimental run 2, so data presented are from experimental run 2 only. For the 15 d root strength measurement in experimental run 1, Meyer treatments receiving 77 kg N ha⁻¹ annually mowed at 1.9 cm had the highest peak kgs of force needed to detach the rooting sieve from the soil (5.1 kgs of force; Table 3.9). For the same experimental run, Innovation receiving 175 kg N ha⁻¹ annually mowed at 3.8 cm had an average peak force of 1.49 kgs to detach the rooting sieve. For experimental run 2, the treatment that had the highest average peak force needed to detach the rooting sieve was Meyer receiving 175 kg N ha⁻¹ annually mowed at 3.8 cm when root strength was measured 15 d after planting. At 30 d after planting for experimental run 2, the same treatment stated above (Meyer receiving 175 kg N ha⁻¹ annually mowed at 3.8 cm) had the highest peak force needed to detach the rooting sieve from the soil (26.85 kgs of force; Fig. 3.5; Table 3.10). All treatments needed above 19.05 kgs of force to detach the rooting sieve, except for Innovation receiving 77 kg N ha⁻¹ annually mowed at 1.9 cm and DALZ 1808 receiving 77 kg N ha⁻¹ annually mowed at 3.8 cm; both treatments averaged 15.08 kgs of force and 16.07 kgs of force, respectively.

Experimental run was insignificant for both the 15 d and 30 d turf quality rating for the post-harvest rooting strength study (Table 3.8). Therefore, data are combined across experimental run and presented by the 15 d and 30 d interval. At 15 d following planting, each treatment had a turf quality between 4.3 and 6.1 (Table 3.11). Turf quality increased for all treatments at 30 d following planting, Meyer receiving 77 kg N ha⁻¹ annually mowed at 1.9 cm

had the highest average turf quality (7.3). However, no treatment was significantly different when turf quality was rated 30 d following planting.

Discussion

This study was conducted to identify if nitrogen rate and mowing height have an effect on thatch accumulation and post-harvest rooting strength, and turf quality on different zoysiagrass genotypes. Zoysiagrass genotype played a major role in how nitrogen rate and mowing height affects thatch accumulation, quality, and rooting strength of newly established sod. For example, when averaged across nitrogen treatments, Innovation zoysiagrass mowed at 3.8 cm had statistically accumulated more thatch than Innovation treatments mowed at 1.9 cm (Table 3.6). Similar results were reported by Dunn et al. (1981) for Meyer zoysiagrass; mowing at 1.9 cm compared to 3.8 cm decreased thatch content by 13 to 25%. In contrast, when measured by weight instead of depth, Innovation mowed at 1.9 cm and receiving 77 kg N ha⁻¹ annually had an average dry thatch weight of 4.32 grams (Table 3.7). This weight was significantly higher than the average dry thatch weight of Innovation mowed at 3.8 cm receiving the same nitrogen rate annually (3.08 grams).

Mowing height and the genotype x mowing height interaction had more of an influence on thatch depth and thatch weight compared to nitrogen rate or the genotype x nitrogen rate interaction (Table 3.3). DALZ 1808 and Meyer treatments had similar thatch depths when mowed at 1.9 cm and 3.8 cm. However, Innovation mowed at 1.9 cm had an average thatch depth of 3.3 mm, lower than Innovation mowed at 3.8 cm.

The effects of nitrogen rate and mowing height on large patch occurrence in zoysiagrass has not been well documented. A study was conducted in Fayetteville, AR to study the influence of nitrogen fertility and mowing height on the growth of ‘El Toro’, ‘Cavalier’, and Meyer

zoysiagrass from sprigs; the authors noted that large patch was present in experimental plots, but there was no clear relationship between mowing height, nitrogen rate, and cultivar on large patch occurrence (Patton et al., 2010). In this study, we observed a trend that large patch was highest in Innovation plots mowed at 3.8 cm compared to all other treatments (Table 3.4) In contrast, Green et al. (1994) found that Meyer zoysiagrass mowed at 1.2 cm and 2.5 cm had more large patch disease development and progression compared to Meyer mowed at 4.5 cm or 5.1 cm. Our anecdotal results suggest that mowing height effects on large patch disease and progression may vary by zoysiagrass cultivar, and more targeted studies with inoculations as part of the design would be useful.

Digital force gauges and load cells have been used in previous studies to determine the leaf tensile strength of zoysiagrass (Zhang et al., 2018), and the effects of traffic and soil compaction on Kentucky bluegrass rooting (Dest and Ebdon, 2017). Root tensile strength is a parameter used to identify how turfgrass roots mobilize in the soil (Lateh et al., 2011). The peak force it took to detach rooting sieves from the soil 15 days after planting was significantly higher in experimental run 2 compared to experimental run 1. The peak force needed to detach rooting sieves from the soil was significantly higher at 30 d following planting compared to 15 d. The peak force needed to detach the rooting sieves from the soil 30 d after planting was higher in Meyer zoysiagrass treatments receiving increased rates of nitrogen compared to treatments receiving the lower rate of nitrogen in this study. Meyer zoysiagrass fertilized with 175 kg N ha⁻¹ annually and mowed at 3.8 cm had an average peak kgs of force of 15.65 (15 d; expt. 2) and 26.85 (30 d; expt. 2), the highest kgs of force needed to detach the rooting sieves from the soil compared to all other treatments (Tables 3.9, 3.10).

In summary, the experimental zoysiagrass genotype DALZ 1808 had the fastest establishment rate regardless of nitrogen rate; reaching > 90% establishment 15 weeks after sprigging was done at a 1:10 ratio (0.09 m⁻² of sod spread over a 0.92 m⁻² area). However, growth differences were not statistically different. DALZ 1808 and Meyer treatments had similar turf quality throughout the first sixteen month following sprigging. Twenty-three months after sprigging, DALZ 1808 had numerically accumulated the least amount of thatch compared to Meyer and Innovation regardless of nitrogen rate; statistical differences between DALZ 1808 and Meyer were not significant. Innovation treatments that were maintained at 1.9 cm HOC and received 77 kg N ha⁻¹ annually had a reduction in root strength compared to Meyer zoysiagrass maintained at 3.8 cm HOC and fertilized with 175 kg N ha⁻¹ annually when rooting sieves were detached from the soil at 30 d following planting. Future research should focus on how irrigation amounts, nitrogen source, and mowing height impact thatch accumulation in zoysiagrass cultivars when maintained on sites over years.

Figure 3.1 Sprigger used to break up sod from DALZ 1808, Innovation, and Meyer zoysiagrass into stolons (A); Oxadiazon being applied to trial area immediately following sprigging on June 11, 2021 in Olathe, KS (B).



Figure 3.2 Trial map of treatments within the study. Study was arranged in a strip-split plot design with zoysiagrass genotype as the vertical strip, nitrogen treatments as the horizontal strip, and mowing height treatments as the sub-plots nested within each intersection.



Figure 3.3 Thatch measurements of 5.08 cm diam. plug samples. Sample plug after initial thatch measurement (A); sample after shoot and root material were removed (B); washed sample after soil media was removed (C); and dried sample after a 48-hr oven dry-down period at 65°C.

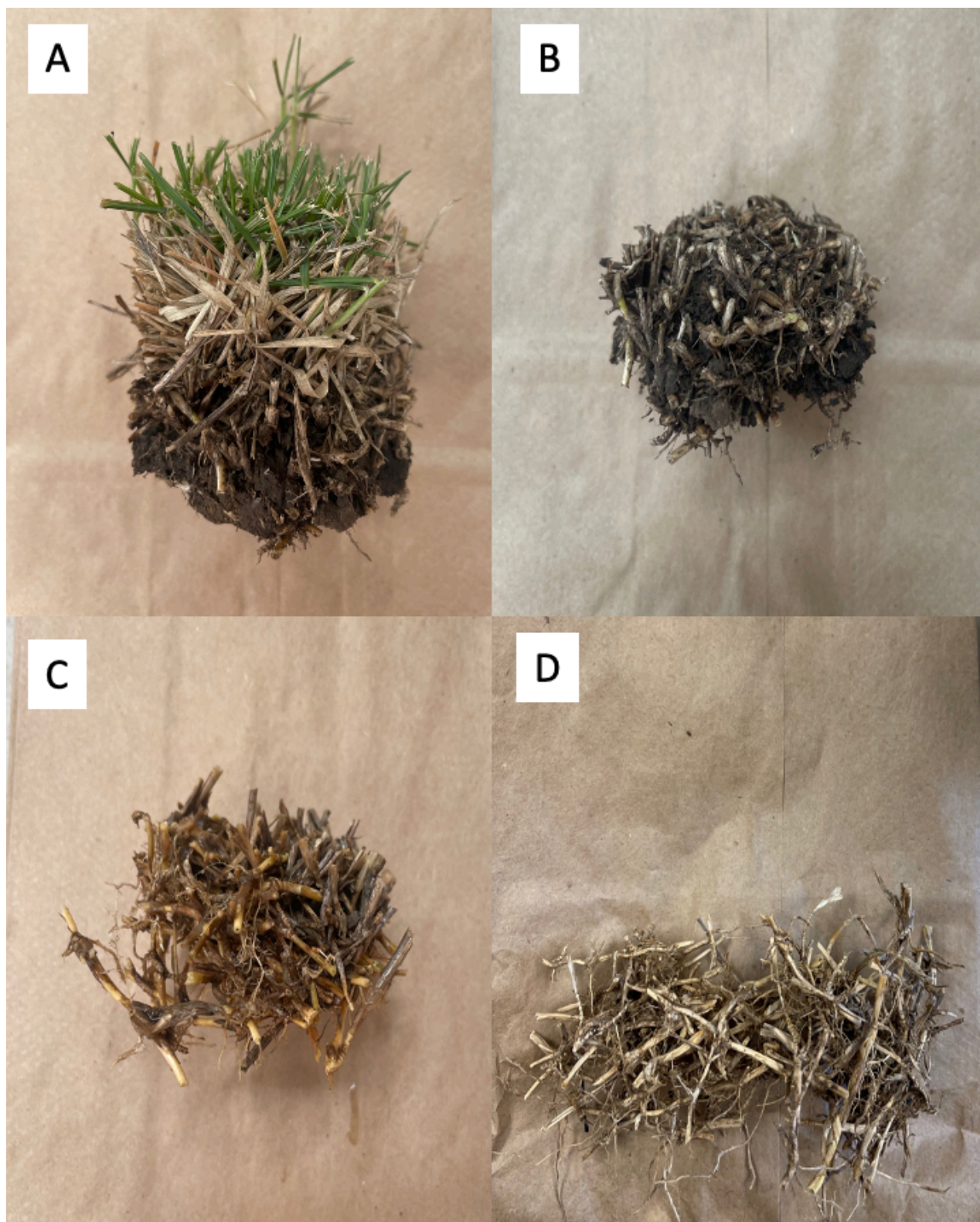


Figure 3.4 Percent establishment of genotypes receiving either 77 kg N ha⁻¹ annually or 175 kg N ha⁻¹ annually at intervals following sprigging in 2021 in Olathe, KS. No statistical differences were observed among cultivars.

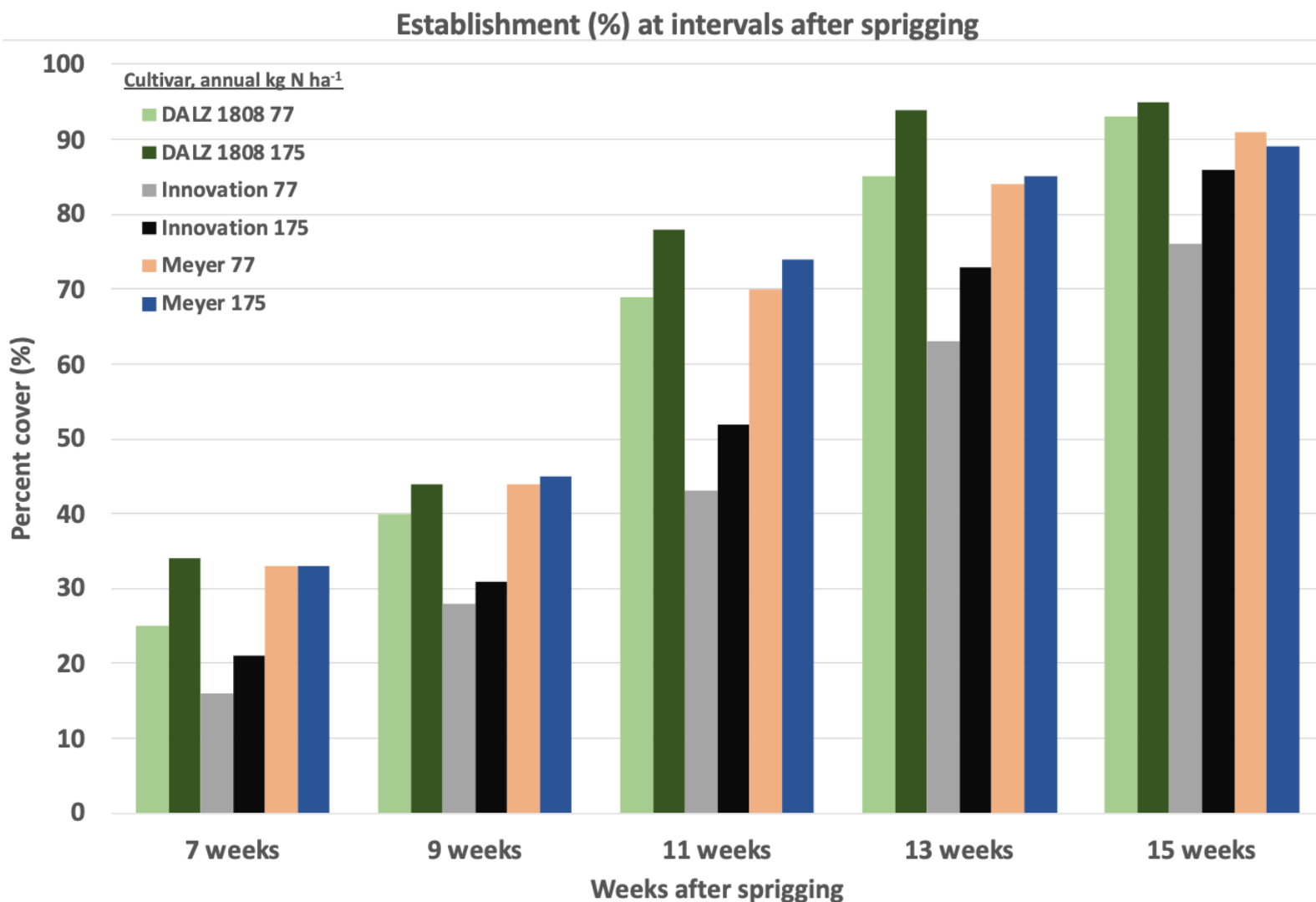


Table 3.1 Analysis of variance on the effects of genotype (G), nitrogen rate (N), mowing height (M), and all interactions on turf quality at intervals after sprigging in Olathe, KS.

	df	Months after sprigging		
		12	14	16
G	2	**	*	***
N	1	ns	ns	ns
M	1	ns	ns	*
G*N	2	**	ns	ns
G*M	2	ns	ns	ns
N*M	1	ns	ns	ns
G*N*M	2	ns	ns	ns

df = degrees of freedom (same for all measured variables).

*, **, *** significant at P -value < 0.05, 0.001, and 0.0001, respectively.

ns = not significant

Table 3.2 Turf quality at intervals after zoysiagrass sprigging in Olathe, KS.

Genotype	Turfgrass quality ^a				
	Months after sprigging ^b				
	2	4	12	14	16
DALZ 1808	5.5 a ^c	6.0 ab	7.4 a	6.8 a	6.8 a
Innovation	4.1 b	5.0 b	6.2 b	6.2 b	4.8 b
Meyer	5.1 ab	6.3 a	7.0 a	6.8 a	6.3 a

^a Turf quality was rated visually on a 1 to 9 scale on which 1 = dead; 6 = minimally acceptable; 9 = optimum color, density, uniformity, and texture.

^b Sprigging was done at a 1:10 ratio (0.09 m⁻² of sod spread over a 0.92 m⁻² area) on 11 June 2021.

^c Means followed by the same lower case letter in a column are not significantly different ($P < 0.05$). Means are averages over replication, nitrogen rate, and mowing height n = 16.

Table 3.3 Analysis of variance on the effects of genotype (G), nitrogen rate (N), mowing height (M), and all interactions on NDVI, and thatch measurements (depth at harvest and oven-dried weight) in Olathe, KS.

	df	NDVI	Thatch depth (mm)	Thatch weight (grams)
G	2	*	*	*
N	1	*	ns	ns
M	1	*	ns	***
G*N	2	ns	ns	ns
G*M	2	ns	*	**
N*M	1	ns	ns	*
G*N*M	2	ns	ns	*

df = degrees of freedom (same for all measured variables).

*, **, *** significant at P -value < 0.05, 0.001, and 0.0001, respectively.

ns = not significant

Table 3.4 Main effect of genotype x mowing height on large patch occurrence in 2022 in Olathe, KS.

Genotype	Mowing ht. ^a (cm)	Large patch ^b (%)
DALZ 1808	1.9	0.6
	3.8	1.9
Innovation	1.9	8.9
	3.8	19.8
Meyer	1.9	0.6
	3.8	5.6

^a Mowing ht. refers to treatments which were mowed twice weekly at 1.9 cm HOC or once weekly at 3.8 cm HOC throughout the growing season.

^b Large patch was visually evaluated on a percent scale where 0.09 m⁻² of diseased area equaled 4% large patch in the fall of 2022 to anecdotally compare large patch occurrence within experimental plots.

Table 3.5 Main effect of genotype, nitrogen rate, and mowing height on NDVI readings in 2022 in Olathe, KS.

Genotype	NDVI ^a	Nitrogen ^b		Mowing Ht. ^c	
		(kg)	NDVI	(cm)	NDVI
DALZ 1808	0.86 a ^d	77	0.82 b ^e	1.9	0.82 b ^f
Innovation	0.84 ab				
Meyer	0.82 b	175	0.86 a	3.8	0.86 a

^a NDVI = normalized difference vegetation index

^b Nitrogen refers to treatments which received either 77 kg N ha⁻¹ annually or 175 kg N ha⁻¹ annually.

^c Mowing ht. refers to treatments which were mowed twice weekly at 1.9 cm HOC or once weekly at 3.8 cm HOC throughout the growing season.

Main effect of genotype^d, nitrogen rate^e, and mowing height^f on NDVI; means followed by the same lower case letter in a column are not significantly different ($P < 0.05$).

Table 3.6 Effect of genotype x mowing height on thatch layer depth in 2023 in Olathe, KS.

Genotype	Mowing ht. ^a (cm)	Thatch depth (mm) ^b
DALZ 1808	1.9	8.79 c ^c
	3.8	9.52 c
Innovation	1.9	14.57 b
	3.8	17.87 a
Meyer	1.9	12.17 bc
	3.8	12.15 bc

^a Mowing ht. refers to treatments which were mowed twice weekly at 1.9 cm HOC or once weekly at 3.8 cm HOC throughout the growing season.

^b On 30 May 2023, two 5.08 cm diam. plugs were removed from each experimental plot. Thatch depth was measured at two random locations by starting at the soil surface to the top of the thatch (where turfgrass crowns are visible) using a digital caliper.

^c Means followed by the same lower case letter are not significantly different ($P < 0.05$). Means are averages over replication and nitrogen rate, n = 8.

Table 3.7 Effect of genotype x nitrogen rate x mowing height on oven-dried thatch weight in 2023 in Olathe, KS.

Genotype	Nitrogen ^a (kg)	Mowing ht. ^b (cm)	Thatch dry weight (grams) ^c
DALZ 1808	77	1.9	2.37 b ^d
	175	3.8	2.43 b
	175	1.9	2.96 ab
	77	3.8	2.86 ab
Innovation	77	1.9	4.32 a
	175	3.8	2.84 b
	175	1.9	3.63 ab
	77	3.8	3.08 ab
Meyer	77	1.9	3.56 ab
	175	3.8	3.00 ab
	175	1.9	3.91 ab
	77	3.8	3.43 ab

^a Nitrogen refers to treatments which received either 77 kg N ha⁻¹ annually or 175 kg N ha⁻¹ annually.

^b Mowing ht. refers to treatments which were mowed twice weekly at 1.9 cm HOC or once weekly at 3.8 cm HOC throughout the growing season.

^c Thatch dry weights were recorded after a 48-hour oven dry-down period at 65°C. Weight includes the samples of two 5.08 cm diam. plugs that the thatch layer was collected from.

^d Means followed by the same lower case letter are not significantly different ($P < 0.05$). Means are averages over replication, n = 4.

Table 3.8 Analysis of variance on the effects of genotype (G), nitrogen rate (N), mowing height (M), experimental run (Expt.), and all interactions on zoysiagrass root strength (kgs force), and turf quality in 2023 in Olathe, KS.

	df	15 d after planting		30 d after planting	
		Root strength	Turf quality	Root strength	Turf quality
G	2	*	ns	ns	ns
N	1	ns	ns	ns	ns
M	1	ns	ns	ns	ns
Expt.	1	**	ns	**	ns
G*N	2	ns	ns	ns	ns
G*M	2	*	ns	ns	ns
N*M	1	ns	*	ns	ns
G*N*M	2	*	***	ns	*
G*Expt.	2	*	ns	ns	ns
M*Expt.	1	***	*	ns	ns
N*Expt.	1	ns	ns	ns	ns
G*N*M*Expt.	7	***	**	ns	ns

df = degrees of freedom (same for all measured variables).

*, **, *** significant at P -value < 0.05, 0.001, and 0.0001, respectively.

ns = not significant

Table 3.9 The effect of genotype x nitrogen rate x mowing height on root strength (kgs of force) needed to detach rooting sieves from the soil 15 days after planting in 2023 in Olathe, KS.

Genotype	Nitrogen ^b (kg)	Mowing ht. ^c (cm)	Root Strength ^a (kgs of force)	
			Expt. 1	Expt. 2
DALZ 1808	77	1.9	2.65 ab ^d	8.17 b
	175	3.8	2.77 ab	4.54 b
	175	1.9	2.26 ab	7.44 b
	77	3.8	2.62 ab	5.71 b
Innovation	77	1.9	3.60 ab	3.36 b
	175	3.8	1.49 b	4.72 b
	175	1.9	3.00 ab	3.67 b
	77	3.8	2.69 ab	8.51 ab
Meyer	77	1.9	5.10 a	4.53 b
	175	3.8	3.10 ab	15.63 a
	175	1.9	3.24 ab	5.83 b
	77	3.8	2.51 ab	8.46 ab

^a A digital force gauge was used to determine the peak kilograms of force needed to uproot individual experimental sieves 15 d after planting.

^b Nitrogen refers to treatments which received either 77 kg N ha⁻¹ annually or 175 kg N ha⁻¹ annually.

^c Mowing ht. refers to treatments which were mowed twice weekly at 1.9 cm HOC or once weekly at 3.8 cm HOC throughout the growing season.

^d Means followed by the same lower case letter in a column are not significantly different ($P < 0.05$). Means are averages over replication, n = 4.

Figure 3.5 Meyer zoysiagrass receiving 175 kg N ha⁻¹ annually mowed at 3.8 cm HOC detached from soil at 30 d following planting (A); Digital force gauge attached to rooting sieve to measure kgs of peak force needed to detach sieve from soil (B).

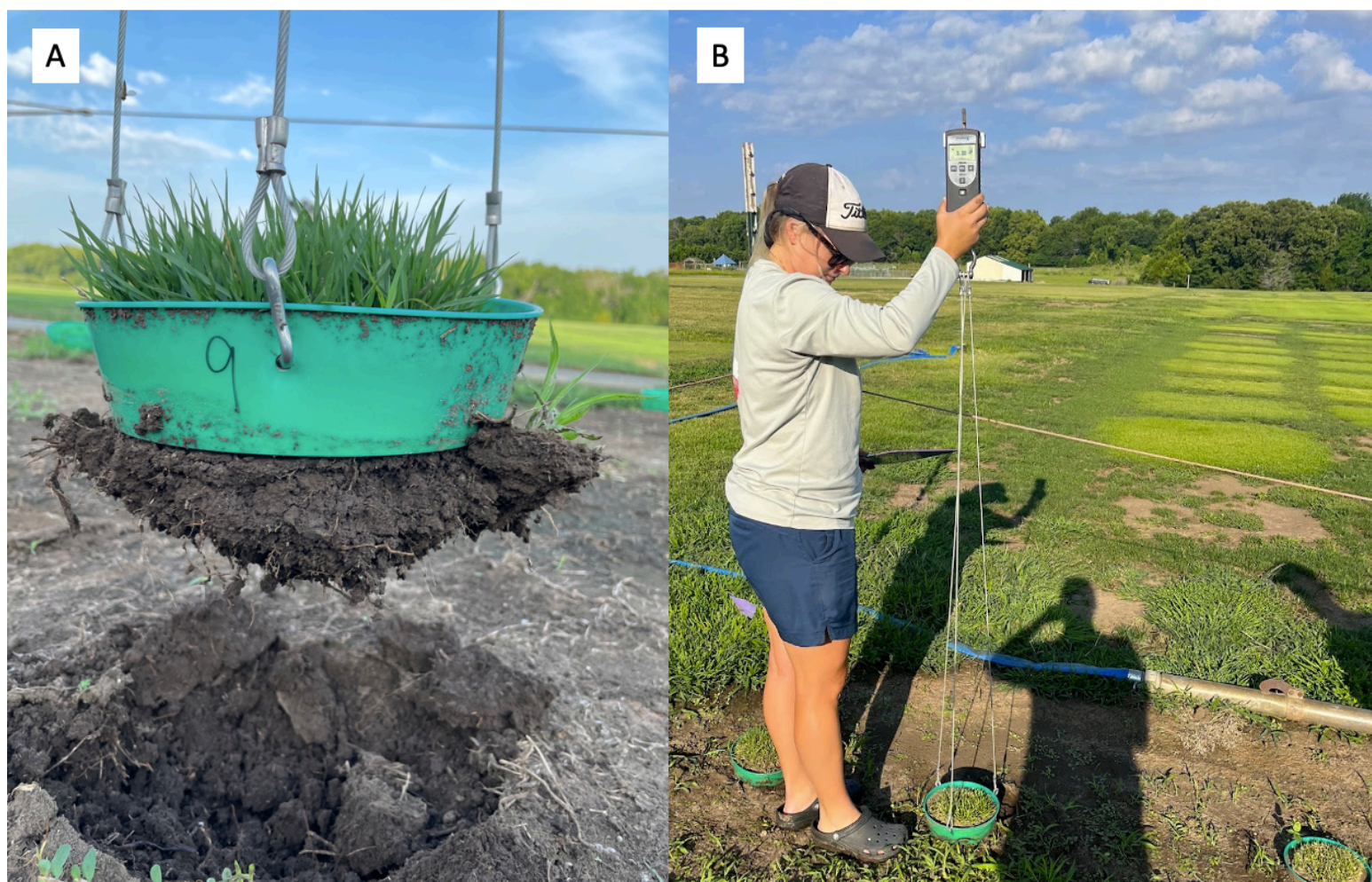


Table 3.10 The effect of genotype x nitrogen rate x mowing height on root strength (kgs of force) needed to detach rooting sieves from the soil 30 days after planting in experimental run 2 in 2023 in Olathe, KS.

Genotype	Nitrogen ^a (kg)	Mowing ht. ^b (cm)	Root strength ^c (kgs of force)
DALZ 1808	77	1.9	21.99 ab
	175	3.8	19.10 ab
	175	1.9	22.13 ab
	77	3.8	16.07 ab
Innovation	77	1.9	15.08 b
	175	3.8	19.66 ab
	175	1.9	19.94 ab
	77	3.8	20.76 ab
Meyer	77	1.9	24.73 ab
	175	3.8	26.85 a
	175	1.9	25.59 ab
	77	3.8	23.50 ab

^a Nitrogen refers to treatments which received either 77 kg N ha⁻¹ annually or 175 kg N ha⁻¹ annually.

^b Mowing ht. refers to treatments which were mowed twice weekly at 1.9 cm HOC or once weekly at 3.8 cm HOC throughout the growing season.

^c A digital force gauge was used to determine the peak kilograms of force needed to uproot individual experimental sieves 30 d after planting.

^d Means followed by the same lower case letter in a column are not significantly different ($P < 0.05$). Means are averages over replication, n = 4.

Table 3.11 The effect of genotype x nitrogen rate x mowing height on turf quality at 15 and 30 days following planting.

Genotype	Nitrogen ^b (kg)	Mowing ht. ^c (cm)	Turf quality ^a	
			15 d	30 d
DALZ 1808	77	1.9	5.1 ab ^d	5.9 a
	175	3.8	5.1 ab	5.9 a
	175	1.9	6.1 a	6.8 a
	77	3.8	5.5 ab	6.1 a
Innovation	77	1.9	4.3 b	5.3 a
	175	3.8	4.3 b	5.5 a
	175	1.9	5.4 ab	6.0 a
	77	3.8	5.5 ab	5.9 a
Meyer	77	1.9	5.9 ab	7.3 a
	175	3.8	5.9 ab	6.0 a
	175	1.9	5.5 ab	6.1 a
	77	3.8	4.8 ab	5.5 a

^a Turf quality of experimental sieves was rated visually on a 1 to 9 scale on which 1 = dead; 6 = minimally acceptable; 9 = optimum color, density, uniformity, and texture at 15 d and 30 d following planting.

^b Nitrogen refers to treatments which received either 77 kg N ha⁻¹ annually or 175 kg N ha⁻¹ annually.

^c Mowing ht. refers to treatments which were mowed twice weekly at 1.9 cm HOC or once weekly at 3.8 cm HOC throughout the growing season.

^d Means followed by the same lower case letter in a column are not significantly different ($P < 0.05$). Means are averages over experimental run and replication, n = 8.

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Chapter 4 - Identifying herbicides for using during ‘Innovation’ zoysiagrass establishment from sprigs

This chapter has been prepared using style guidelines for submission to *Crop, Forage, and Turfgrass Management*

Abstract

In the U.S. transition zone, zoysiagrass (*Zoysia* spp. Willd) is commonly sprigged during the early summer when soil temperatures aid in establishment and growth of the warm-season species. However, crabgrass (*Digitaria* spp.) and goosegrass (*Eleusine indica*), two problematic summer annual grassy weeds, emerge during the same time sprigging is recommended. Because of new restrictions for oxadiazon (Ronstar G), there is a need to investigate alternative options for weed control that can be used at the time of zoysiagrass sprigging. Therefore, a study was initiated in 2021-2022 and replicated in 2022-2023 in Olathe, KS to evaluate how commonly used preemergence herbicides affect the weed encroachment, establishment, and rooting of Innovation zoysiagrass when applied immediately following sprigging. At four months following sprigging, the liquid formulation of oxadiazon was the only treatment to reach 50% cover. Twelve months following sprigging, liquid oxadiazon-treated plots averaged 84% establishment; whereas indaziflam-treated plots averaged 12% establishment. Many of the treatments reduced weed pressure within experimental plots compared to the untreated control. Liquid oxadiazon-, s-metolachlor-, prodiamine-, and indaziflam-treated plots had < 5% weed emergence at three months following sprigging. Prodiamine-treated plots had significantly reduced the amount of grassy weed encroachment (1%), but did not control broadleaf weeds (33%) within experimental plots. Alternatively, simazine reduced the emergence of broadleaf weeds (8%), but did not control grassy weeds (24%). There was < 5% emergence of broadleaf and grassy weeds in liquid oxadiazon-, and 2,4-D + quinclorac + dicamba + sulfentrazone-treated plots. The root length of granular oxadiazon-, and simazine-treated stolons was 25.0 mm, and 23.5 mm, respectively, whereas indaziflam-, dithiopyr-, and prodiamine-treated stolons had an average root length of 6.0 mm, 6.2 mm, and 6.8 mm, respectively. Innovation zoysiagrass plots treated with liquid

oxadiazon decreased weed pressure within experimental plots and did not affect establishment or root length and number of roots on new stolons. This study indicates that the liquid formulation of oxadiazon has potential for use at the time of zoysiagrass sprigging without impeding establishment.

Introduction

Sodding zoysiagrass (*Zoysia* spp. Willd) gives an instant turf canopy—similar to laying carpet. When zoysiagrass is established by sod, the sward has a more competitive edge against weeds as the healthy turfgrass can choke out unwanted invaders; however, sodding is very costly compared to plugging or sprigging (Fagerness, 2001). Sprigs and plugs are used as a more cost-effective option to establish zoysiagrass vegetatively. Over two years is generally required to reach complete establishment of the sward from plugs (Portz et al., 1981) with similar establishment times from sprigs (Dernoeden and Carroll, 1992), leaving the area open for weed invasion during grow-in. Therefore, weed control is critical during zoysiagrass establishment from plugs or sprigs.

In the transition zone, zoysiagrass is commonly sprigged during the early summer when soil temperatures aid in establishment and growth of this warm-season species. However, crabgrass (*Digitaria* spp.) and goosegrass (*Eleusine indica*), two problematic summer annual grassy weeds, emerge during the same time sprigging is recommended. Zoysiagrass growth can be hastened when preemergence herbicides are applied to reduce competition of annual grassy weeds (Fry et al., 1986); although, many preemergence herbicides can affect the rooting and establishment of zoysiagrass when applied at or around the time of plugging or sprigging (Carroll et al., 1996; Engel et al., 1968; Fry et al., 1986).

Ronstar (oxadiazon) is a commonly used granular preemergence herbicide that can be applied at the time of zoysiagrass establishment from sprigs or plugs for the control of annual grasses and broadleaf weeds (Environmental Science US Inc., 2011). However, Ronstar underwent a registration review by the United States Environmental Protection Agency (U.S. EPA) in 2021. Ronstar is also now limited to use on only 30% of the whole golf course area

(including fairways, tees, greens, and roughs) and the number of applications allowed in a year and the rate of active ingredient that is allowed per acre were also reduced (EPA, 2022). Because of new restrictions, there is a need to investigate alternative options for weed control that can be used at the time of zoysiagrass sprigging. Therefore, the objective of this research was to evaluate how commonly used preemergence herbicides affect the weed emergence, establishment, and rooting of ‘Innovation’ zoysiagrass when applied immediately following sprigging.

Materials and methods

A field study was conducted at the Olathe Horticulture Research and Extension Center in Olathe, KS (long. 39.48° N, lat. 95.66° W) in 2021-2022 (Expt. 1) and repeated in 2022-2023 (Expt. 2) on a separate sward to determine the effects of herbicides on the establishment of Innovation zoysiagrass when applied after sprigging. The experiment was arranged in a randomized complete block design with four replicates. The site previously contained a cool-season turfgrass mixture. Prior to trial initiation, the trial area was scalped and tilled, and a drag mat was used to uniformly spread the soil on the surface. Innovation sod was collected from an existing sward at the Olathe Horticulture Research and Extension Center and sod was broken up into sprigs using a sprigger (Sprig Master II; Sprigger’s Choice, Inc.; Dawson, GA, USA). Four equally spaced 2-inch deep furrows were created for sprigs to be evenly spread into each 4-ft x 8-ft experimental plot, and an equal number of sprigs were distributed within each experimental plot using a 1:10 ratio (1 ft² of sod spread over a 10 ft² area) and then covered with 0.5 in. of top soil on 9 July 2021 (Expt. 1; Figure 4.1) and 7 June 2022 (Expt. 2).

Immediately following sprigging, seven single-active ingredient preemergence herbicides were applied to designated plots (Table 4.1). One postemergence herbicide treatment was

included in this study, but the application of this treatment was not made until weeds began to emerge within the experimental plots (2 August 2021, Expt. 1; 8 July 2022, Expt. 2). Herbicides were applied using a carbon dioxide (CO₂)-pressurized, handheld spray boom (R&D Sprayers, Opelousas, LA, USA) equipped with four flat-fan nozzles (8003; TeeJet Technologies, Springfield, IL, USA) on 10-inch spacing calibrated to deliver 43 gal/acre at 37 PSI. Fertilizer and sequential herbicide applications were made throughout both runs of the experiment; fertilizer and herbicide application timings for each experimental run are presented in Table 4.2.

Measurements and statistical analysis

Throughout both experimental runs, treatments were assessed by visually estimating percent zoysiagrass establishment, turf vigor, turf color, and weed cover. A handheld normalized difference vegetation index (NDVI) meter was used to determine the green index of each plot. Establishment was rated on a 0 to 100% scale with 0% representing no turf cover with the experimental plot and 100% representing full cover and complete establishment of the plot. Establishment was rated monthly for four months following sprigging during Expt. 1 and 2, with two more establishment ratings at twelve and fifteen months following sprigging. Turf vigor was rated similar to NTEP (National Turfgrass Evaluation Program) guidelines for seedling vigor, which reflects the speed in which the area develops into mature sod by estimating ground cover and plant height. Turf vigor was visually rated on a 1 to 9 scale (1 = dead; 6 = acceptable; and 9 = maximum vigor). Turf color was rated on a 1 to 9 scale (1 = brown/straw/dead; 9 = dark green). Throughout Expt. 1 and Expt. 2 the predominant weeds within the study area were crabgrass, common lespedeza (*Lespedeza* sp.), and white clover (*Trifolium repens*). Weed cover was rated on a 0 to 100% scale with 0% representing no weeds within the experimental plot and 100% representing complete weed cover of the experimental plot. In Expt. 2, weed cover was

rated to identify the number of broadleaf weeds and grassy weeds within each experimental plot. Handheld NDVI (FieldScout CM 1000 NDVI Meter, Spectrum Technologies, Aurora, IL, USA) readings were recorded in Expt. 1 only. NDVI measurements are often used as an indicator of plant health status for many crops (Atshan et al., 2018; Straw et al., 2016; Chapman and Barreto, 1997). Measurements range from -1.0 to 1.0, with higher values indicating greater plant health. The FieldScout CM1000 NDVI Meter senses light at wavelengths of 600 nm and 840 nm to approximate plant health. NDVI measurements were taken at three random locations within each plot and the average recorded.

One month following sequential applications of preemergence herbicide treatments, root length and total root number were determined by sampling three stolons within each experimental plot and the average recorded. A digital caliper was used to measure the root length by pulling up stolons from the soil, and then counting the total number of roots growing from the second to last node on the stolon. Newest stolons were chosen within each plot for these measurements.

Results

Establishment data were combined across experimental runs, as experiments were not significantly different (Table 4.3). Treatment x Experiment interactions were significant for all rating dates; however, data are presented combined across experimental run because of similarities. At one month following sprigging, the only treatments that allowed Innovation zoysiagrass to reach >12% establishment within experimental plots were the untreated control, both granular and liquid oxadiazon treatments, and the postemergence herbicide treatment containing 2,4-D + quinclorac + dicamba + sulfentrazone (POST; Table 4.4). At four months following sprigging, the liquid formulation of oxadiazon was the only treatment to reach 50%

cover; all other treatments were significantly lower. One year after sprigging, many treatments had hindered establishment of the zoysiagrass sprigs. Indaziflam-treated plots averaged 12% establishment at 12 months following sprigging, while liquid oxadiazon-treated plots averaged almost 84% establishment (Figure 4.2). The granular formulation of oxadiazon had the second highest establishment rate at 64% twelve months after sprigging when combined across both experimental runs.

Weed pressure throughout both experiments was high, as many of the plots had areas void of turf. Experiment was significant for weed cover rated at three and ten months, but not significant at twelve months following sprigging (Table 4.5). Therefore, weed cover data are presented separately by experiment for the three and ten month post-sprigging rating dates, and presented by treatment x experiment for the twelve month post-sprigging rating date. Three months after sprigging in 2021 (Expt. 1), many of the treatments reduced weed coverage within experimental plots compared to the untreated control. Liquid oxadiazon-, s-metolachlor-, proflumicarb-, and indaziflam-treated plots had < 5% weed emergence at three months following sprigging in Expt. 1 (Table 4.6). There was significantly higher weed pressure in 2022 (Expt. 2) three months following sprigging. The untreated control averaged 90% weed cover within experimental plots. In Expt. 2, indaziflam was the only treatment to have < 5% weed cover within experimental plots three months following sprigging. Alternatively, at ten months following sprigging, weed pressure was higher in Expt. 1 compared to Expt. 2. All treatments, with the exception of indaziflam-treated plots, had over 20% weed cover within the experimental plots at ten months following sprigging in Expt. 1. When data were combined across experimental run, liquid oxadiazon-, indaziflam-, and POST-treated plots had < 10% weed cover at twelve months following sprigging.

Prodiamine-treated plots had significantly reduced the amount of grassy weeds (1%), but did not control broadleaf weeds (33%) within experimental plots (Table 4.7). Alternatively, simazine reduced the number of broadleaf weeds (8%), but did not control grassy weeds (24%). There was < 5% cover of broadleaf and grassy weeds in liquid oxadiazon-, and POST-treated plots.

Experimental run was not significant for turf vigor rated at two months following sprigging; however, it was significant for turf vigor rated at twelve months following sprigging (Table 4.5). Turf vigor data recorded at two months following sprigging were combined across experimental run, and presented separately by experiment for data recorded at twelve months following sprigging. Turf vigor was highest for liquid oxadiazon-treated sprigs at two months following sprigging when data were combined across experimental runs (Table 4.8). Because of the increased weed pressure in untreated control plots, turf vigor was significantly reduced (2.4 vigor). Liquid oxadiazon was the only treatment to have a turf vigor above 5 at two months following sprigging, which was still below the acceptable vigor of 6. Twelve months following sprigging, turf vigor reached acceptable levels for many of the treatments in Expt. 1. Granular oxadiazon-, and liquid oxadiazon-treated sprigs had turf vigor of 7.3 and 7.5, respectively. Twelve months following sprigging in Expt. 2, liquid oxadiazon-treated sprigs had a turf vigor of 7.8, significantly higher than all other treatments.

Turf color was rated two months following sprigging for both experimental runs. Experiment was significant (Table 4.5), so data are presented separately by experimental run. In Expt. 1, turf color was similar for all treatments (Table 4.9). Granular oxadiazon-, and POST-treated sprigs had an average turf color of 6.3 and 6.0, respectively, no other treatment had an average turf color > 6.0. At two months following sprigging in Expt. 2, all treatments had an

average turf color > 6.0 with the exception of prodiamine-treated sprigs. Liquid oxadiazon-, and simazine-treated sprigs had the highest turf color, with an average of 7.3.

NDVI measurements in Expt. 1 did not reach a green index above 0.40 in experimental plots for any treatment at intervals following sprigging (Table 4.10). On 27 August 2021 (two months following sprigging), POST-, and granular oxadiazon-treated plots had an average NDVI of 0.36 and 0.34, respectively. On the same date, indaziflam-, and simazine-treated plots had an average NDVI of 0.23; significantly lower than POST-treated plots. Untreated control data were removed before analysis, as the green index of experimental plots was mainly from crabgrass emergence and not zoysiagrass.

Experiment was not significant for root length and root number measurements (Table 4.5). Therefore, data are presented combined across experimental run. The root length of granular oxadiazon-, and simazine-treated stolons was 25.0 mm, and 23.5 mm, respectively (Table 4.11). Indaziflam-, dithiopyr-, and prodiamine-treated stolons had an average root length of 6.0 mm, 6.2 mm, and 6.8 mm, respectively. All treatments had an average root number of 1 to 2 on new stolons (Table 4.11). Following root measurements within experimental plots in Expt. 1, sample stolons were clipped and photos were taken to present the visual rooting differences between treatments (Figure 4.3).

Discussion

At three months following sprigging, weed pressure was much higher for many treatments in Expt. 2 compared to Expt. 1. Granular oxadiazon-, simazine-, and POST-treated plots averaged 87%, 86%, and 82% weed emergence within plots at three months following sprigging in Expt. 2. Whereas in Expt. 1, the same treatments stated above averaged 7%, 30%, and 11% weed emergence, respectively, within experimental plots. Summer annual weeds have

similar emergence patterns each year within a specific geographical location (Baskin and Baskin, 1988; Hartzler et al., 1999). Summer annual weeds germinate in the spring and early summer, grow to maturity throughout the summer, and set seed in the fall before ultimately dying by the first hard frost (Radosevich et al., 1997). Air and soil temperatures could have played a role in the drastic weed emergence differences, as temperature is reported to be the main environmental factor controlling weed germination and emergence (Baskin and Baskin, 1988). The three month weed emergence ratings were taken eleven months apart (6 October 2021, Expt. 1; 7 Sept. 2022, Expt. 2). At the three month weed emergence rating in Expt. 1, the average high and low air temperature was 78°F and 58°F, respectively, and the high and low 2 in. soil temperature was 78°F and 66°F, respectively. Whereas, at the three month weed emergence rating in Expt. 2, the average high and low air temperature was 88°F and 59°F, respectively, and the high and low 2 in. soil temperature was 87°F and 71°F, respectively. These factors likely played a role in the emergence differences observed at the three month post-sprigging rating date.

Granular oxadiazon (Ronstar G) can be applied to zoysiagrass immediately prior to or immediately after sprigging according to label guidelines. Previous studies have reported zoysiagrass safety when granular oxadiazon was applied around the time of seeding sprigging (Fry et al., 1986 Patton et al., 2007) and after establishment (Johnson and Carrow, 1999). Throughout Expt. 2, granular oxadiazon-treated plots had reduced weed control efficacy and a reduction in turf vigor compared to Expt. 1.

Liquid oxadiazon (Ronstar Flo) has no labeled guidelines for application at the time of zoysiagrass sprigging. The Ronstar Flo label allows an application of the product at the time of bermudagrass establishment from sprigs for the control of crabgrass, goosegrass, and annual sedge (*Cyperus compressus* L.; Environmental Science US, 2021). Results from this study

indicate that Ronstar Flo applied at 1.85 fl. oz/1,000 ft² immediately following sprigging reduced weed pressure and increased the rate of establishment compared to untreated sprigs. Begitschke et al. (2018a) found that liquid oxadiazon applied one day following ‘Latitude 36’ planting increased the number of days required to reach 50% establishment, and reduced root length and root mass. The differences in establishment and rooting of zoysiagrass and bermudagrass after an application of liquid oxadiazon should be investigated further in the future.

Indaziflam (Specticle Flo) applied immediately after sprigging significantly reduced Innovation zoysiagrass establishment. The Specticle Flo product label restricts application until 16 months after seeding or sprigging of turf (Environmental Science US, 2020). Weed emergence within indaziflam-treated plots was minimal, however, sprig establishment was hindered and turf vigor, and root length was significantly reduced. A previous study conducted by Gómez de Barreda et al. (2013) reported similar results, with fall-applied indaziflam at 70 and 140 g ai ha⁻¹ significantly increasing the amount of nonrooted sprigs and reducing establishment when zoysiagrass was sprigged the spring following applications. Alternatively, a two-year field study at Mississippi State University found that indaziflam applied one day following sprigging of ‘Latitude 36’ bermudagrass did not affect the grow-in time or tensile strength of the sod (Begitschke et al., 2018). Results herein indicate that indaziflam should not be applied at the time of sprigging for proper establishment of Innovation zoysiagrass.

S-metolachlor (Pennant MAGNUM) applied immediately after sprigging had significantly lower establishment compared to untreated zoysiagrass one month after sprigging. Establishment rated at two, three, four, and twelve months after sprigging resulted in similar establishment rates of s-metolachlor-treated plots compared to untreated plots. The Pennant

MAGNUM product label recommends that seeding or overseeding of desirable turfgrasses be postponed to four months before or after the application of this product (Syngenta Professional Products, 2015a). Root length and root number on new stolons were similar to untreated zoysiagrass stolons after the application of this product. Although rooting of s-metolachlor-treated sprigs were comparable to untreated sprigs, s-metolachlor-treated plots reached 47% establishment twelve months following sprigging. Similarly, in Georgia, s-metolachlor applied at 4.4 kg ha⁻¹ reduced 'TifEagle' bermudagrass sprig cover after twelve weeks compared to untreated bermudagrass (McCullough et al., 2012).

Simazine (Princep Liquid) had increased weed pressure within experimental plots compared to other treatments at intervals following sprigging. However, simazine-treated zoysiagrass sprigs had longer roots on new stolons compared to indaziflam-, dithiopyr-, and prodiamine-treated sprigs. Simazine-treated experimental plots averaged 53% establishment at twelve months following sprigging. The Princep Liquid label does not have specific guidelines for product use at the time of zoysiagrass sprigging, but there is an advisory statement informing applicators that temporary slowing of growth and yellowing may occur on newly sprigged turfgrass (Syngenta Professional Products, 2018). A previous study reported that a single application of simazine applied at 1 lb acre⁻¹ immediately after sprigging centipedegrass and St. Augustinegrass controlled grassy weeds without affecting establishment of both warm-season turfgrass species (Johnson, 1973). When simazine was applied to Latitude 36 hybrid bermudagrass plugs 1 d after planting, root length was unaffected at four weeks following application (Begitschke et al., 2018b). Results from this study indicate that simazine applied at the highest label rate for warm-season turfgrasses did not effectively reduce weed pressure in experimental plots, however rooting of Innovation zoysiagrass stolons was unaffected.

Dithiopyr (Dimension 2EW) treated plots had similar levels of establishment compared to untreated zoysiagrass at intervals following sprigging. Untreated zoysiagrass did not reach over 37% establishment by twelve months following sprigging, mainly due to the increased weed emergence within the plots limiting lateral growth. Dithiopyr-treated plots reached 29% establishment at twelve months following sprigging. Twelve months after sprigging in Expt. 1 and Expt. 2 there was 32% and 31% weed emergence, respectively, within dithiopyr-treated experimental plots. Therefore, weed competition was not likely a limiting factor for the slow establishment of dithiopyr-treated sprigs. The Dimension 2EW label restricts the application of this product until newly established turf have developed a good root system and uniform stand, and have received at least two mowings (Corteva Agriscience, 2021). A previous study by Carroll et al. (1996) reported that oxadiazon increased Meyer zoysiagrass coverage compared to dithiopyr, and dithiopyr significantly reduced Meyer root growth. These results align with our results, as dithiopyr-treated Innovation sprigs had an average root length of 6 mm, significantly lower than oxadiazon-treated sprigs.

Prodiamine (Barricade 65WG) applied immediately after sprigging had similar establishment rates as dithiopyr-treated zoysiagrass at all intervals following sprigging. Prodiamine-treated plots had adequate grassy weed control, but had the highest number of broadleaf weeds within experimental plots compared to all other treatments (33%). Prodiamine also reduced the root length of new stolons, and had an average root number of less than 2. An application of prodiamine has been shown to reduce the root mass and turfgrass density of Kentucky bluegrass (Hummel et al., 1990), and the root length and root dry weight of tall fescue (*Festuca arundinacea*; Han et al., 1995). The Barricade 65WG label has no mention of application timing after zoysiagrass sprigging. However, the label indicates that applications can

be made on newly-sprigged or plugged bermudagrass, but newly-sprigged bermudagrass stolon rooting may be temporarily slowed (Syngenta Professional Products, 2015b). Previous studies have reported that an application of prodiamine at or around the time of hybrid bermudagrass sprigging have resulted in reduced cover of the sward (Begitschke et al., 2018b; Brosnan et al., 2014; McCarty and Weinbrecht, 1997). Results herein indicate that Barricade 65WG causes a reduction in root length, and hinders establishment of Innovation zoysiagrass from sprigs.

2,4-D + quinclorac + dicamba + sulfentrazone (Q4 Plus) applied on Innovation zoysiagrass one month following sprigging increased establishment rate compared to untreated zoysiagrass. At twelve months following sprigging, there was < 10% weed emergence within Q4 Plus-treated plots in Expt. 1 and Expt. 2. Root length of new stolons in Q4 Plus-treated plots averaged 19 mm in length, whereas untreated zoysiagrass had an average root length of 16 mm. Further, at two months following sprigging in Expt. 1, Q4 Plus-treated plots had the highest NDVI values compared to all other treatments. The Q4 Plus herbicide label indicates that applications of this product to newly sprigged turfgrass should be delayed until three to four weeks after sprigging (PBI Gordon Corporation, 2019). In both experimental runs, the application of this POST treatment was delayed until one month following sprigging when weeds began to emergence in the experimental plots. There have been several studies that have investigated the effects of quinclorac applied at the time of sprigging of warm-season turfgrass species (Brecke et al., 2010; Carroll et al., 1996; Dernoeden and Carroll, 1992). However, no previous research was found on the effects of 2,4-D + quinclorac + dicamba + sulfentrazone on zoysiagrass sprigs. Results from this study indicate that an application of 2,4-D + quinclorac + dicamba + sulfentrazone made four weeks following sprigging has minimal effects on the establishment and rooting of Innovation zoysiagrass.

Overall, liquid oxadiazon applied on Innovation zoysiagrass immediately following sprigging had nearly complete establishment twelve months following sprigging. Liquid oxadiazon also decreased weed pressure within experimental plots and did not affect root length and number of roots on new stolons. As applications of the granular formulation of oxadiazon become more restricted for use, the liquid formulation has potential for use at the time of zoysiagrass sprigging. Future research should investigate how preemergence herbicides affect the establishment of other zoysiagrass cultivars from sprigs, and determine how differing rates of liquid oxadiazon affect the establishment of Innovation zoysiagrass.

Figure 4.1 Experimental plots immediately following sprigging and preemergence herbicide applications on 9 July 2021 (Expt. 1) in Olathe, KS.



Table 4.1 Herbicide formulations and rates used in replicated field trials in Olathe, KS from 2021-2023.

Common name	Trade name	Manufacturer	Rate/ 1,000 ft ⁻²	Lbs a.i./ 1,000 ft ⁻²
Oxadiazon (granular)	Ronstar G	Environmental Science US, LLC, Research Triangle Park, NC, USA	3.37 lbs	0.067
Oxadiazon (liquid)	Ronstar Flo	Environmental Science US, LLC, Research Triangle Park, NC, USA	1.85 fl. oz	0.046
Indaziflam	Specticle Flo	Environmental Science US, LLC, Research Triangle Park, NC, USA	0.22 fl. oz	0.001
S-metolachlor	Pennant MAGNUM	Syngenta Crop Protection, LLC, Greensboro, NC, USA	0.95 fl. oz	0.057
Simazine	Princep Liquid	Syngenta Crop Protection, LLC, Greensboro, NC, USA	1.47 fl. oz	0.046
Dithiopyr	Dimension 2EW	Corteva Agriscience, LLC Indianapolis, IN, USA	0.73 fl. oz	0.011
Prodiamine	Barricade 65WG	Syngenta Crop Protection, LLC, Greensboro, NC, USA	0.05 lbs	0.033
2,4-D + quinclorac + dicamba + sulfentrazone	Q4 Plus	PBI-Gordon Corporation, Kansas City, MO, USA	2.6 fl. oz	0.015 + 0.001 + 0.018 + 0.002
Untreated control	--	--	--	

Table 4.2 Initial and sequential herbicide treatment timings and fertilizer application rate and timing information for Expt. 1 and Expt. 2 in Olathe, KS.

Herbicide application information	Expt. 1	Expt. 2
Preemergence herbicide applications	9 July 2021	7 June 2022
Postemergence herbicide application	2 August 2021	8 July 2022
Preemergence herbicide sequential applications	14 April 2022	17 April 2023
Postemergence herbicide sequential application	15 June 2022	21 May 2023
In Expt. 1 fertilizer applications included 1 lb N/1,000 ft² (16-0-8) on 30 July 2021; 1 lb N/1,000 ft² (46-0-0) on 16 August 2021; and 1.5 lb N/1,000 ft² (16-0-8) on 24 June 2022. In Expt. 2 fertilizer applications included 1.5 lb N/1,000 ft² (16-0-8) on 24 June 2022; and 1 lb N/1,000 ft² using 24-0-8 on 9 June 2023.		

Table 4.3 Analysis of variance on the effects of Treatment, Experimental run, and Treatment x Experimental run on establishment (%) of Innovation zoysiagrass at 1, 2, 3, 4, and 12 months after sprigging in Olathe, KS.

	1	2	3	4	12
Treatment	**	***	***	***	***
Expt.	ns	ns	ns	ns	ns
T x E	*	***	***	***	**

*, **, *** significant at p-value < 0.05, 0.001, and 0.0001, respectively.
ns = not significant

Table 4.4 Effect of herbicide treatment on the establishment of Innovation zoysiagrass at 1, 2, 3, 4, and 12 months after sprigging in Expt. 1 (2021-2022) and Expt. 2 (2022-2023) in Olathe, KS.

Treatment	Establishment (%) ^a				
	Months after sprigging ^b				
	1	2	3	4	12
Untreated control	17.5 a ^c	12.7 bcd	2.8 c	13.8 b	37.5 cd
Oxadiazon (granular)	16.3 a	19.4 ab	18.8 ab	20.6 b	64.4 ab
Oxadiazon (liquid)	12.5 ab	21.3 a	29.4 a	50.0 a	83.8 a
Indaziflam	6.3 b	6.5 d	8.8 bc	9.4 b	12.1 d
S-metolachlor	5.0 b	8.1 d	15.6 bc	15.6 b	47.5 bc
Simazine	6.3 b	12.1 bcd	16.9 b	12.5 b	53.1 bc
Dithiopyr	10.0 ab	10.3 cd	16.5 b	16.3 b	29.4 cd
Prodiamine	10.0 ab	7.4 d	14.4 bc	12.5 b	30.0 cd
2,4-D + quinclorac + dicamba + sulfentrazone	12.5 ab	16.3 abc	18.8 ab	19.4 b	38.1 bcd

^a Establishment was rated on a 0 to 100% scale with 0% representing no turf cover with the experimental plot and 100% representing full cover and complete establishment of the plot.

^b Sprigging was done on 9 July 2021 (Expt. 1) and 7 June 2022 (Expt. 2) at a 1:10 ratio (1 ft² of sod spread over a 10 ft² area).

^c Means followed by the same lower case letter in a column are not significantly different ($P < 0.05$). Means are averages over replication and experimental run, $n = 8$.

Figure 4.2 Indaziflam-treated experimental plot (A); and liquid oxadiazon-treated experimental plot (B) 15 months after sprigging in Expt. 1 (2021-2022) in Olathe, KS.



Table 4.5 Analysis of variance on the effects of Treatment, Experimental run, and Treatment x Experimental run on weed emergence (%), turf vigor, turf color, root length (mm) and root number of Innovation zoysiagrass at different months after sprigging in Olathe, KS.

			Weed emergence (%)					Turf vigor				Turf color				Root length (mm)		Root number	
	Num	Den				Num	Den			Num	Den			Num	Den				
	DF	DF	3	10	12	DF	DF	2	12	DF	DF	2		DF	DF	11		11	
Treatment	8	24	***	*	***	8	24	***	***	8	24	*		8	24	**		*	
Expt.	1	3	***	*	ns	1	3	ns	*	1	3	*		3	3	ns		ns	
T x E	8	24	***	**	*	8	24	***	*	8	23	*		8	22	ns		ns	

DF = Degrees of freedom

*, **, *** significant at p-value < 0.05, 0.001, and 0.0001, respectively.

ns = not significant

Table 4.6 Weed emergence within experimental plots at 3, 10, and 12 months after sprigging in Expt. 1 (2021-2022) and Expt. 2 (2022-2023) in Olathe, KS.

Treatment	Weed emergence (%) ^a					
	Expt. 1	Expt. 2	Expt. 1	Expt. 2	Expt. 1	Expt. 2
	Months after sprigging ^b					
	3		10		12	
Untreated control	58.8 a ^c	90.0 a	67.5 a	4.3 ab	61.3 ab ^d	78.8 a
Oxadiazon (granular)	7.5 c	87.5 a	47.5 ab	8.8 ab	20.0 cd	36.3 bcd
Oxadiazon (liquid)	1.3 c	15.0 cd	55.0 ab	7.5 ab	8.8 d	3.5 d
Indaziflam	5.0 c	3.0 d	6.3 b	1.3 b	4.3 d	10.0 d
S-metolachlor	2.5 c	46.3 b	22.5 ab	11.8 ab	33.8 bcd	20.0 cd
Simazine	30.0 b	86.3 a	61.3 ab	11.8 ab	51.3 abc	32.5 bcd
Dithiopyr	17.8 bc	36.3 bc	40.0 ab	19.3 a	32.5 bcd	31.3 bcd
Prodiamine	1.5 c	15.0 cd	22.5 ab	15.0 ab	37.5 bcd	36.3 bcd
2,4-D + quinclorac + dicamba + sulfentrazone	11.3 bc	82.5 a	72.5 a	12.5 ab	8.8 d	5.5 d

^a Weed emergence was rated on a 0 to 100% scale with 0% representing no weed cover within the experimental plot and 100% representing complete weed cover of the plot.

^b Sprigging was done on 9 July 2021 (Expt. 1) and 7 June 2022 (Expt. 2) at a 1:10 ratio (1 ft² of sod spread over a 10 ft² area).

^c Means followed by the same lower case letter in a column are not significantly different ($P < 0.05$). Means are averages over replication, n = 4.

^d Means followed by the same lower case letter within the two columns under the 12 month rating date are not significantly different ($P < 0.05$). Means are averages over replication and experimental run, n = 8.

Table 4.7 Weed emergence separated by broadleaf and grassy weeds within experimental plots 12 months after sprigging in Expt. 2 (2022-2023) in Olathe, KS.

Treatment	Broadleaf	Grassy
	(%) ^a	
Untreated control	8.8 bc ^b	70.0 a
Oxadiazon (granular)	15.5 abc	18.3 b
Oxadiazon (liquid)	3.3 c	5.3 b
Indaziflam	7.0 bc	3.0 b
S-metolachlor	18.8 abc	1.3 b
Simazine	8.0 bc	24.5 b
Dithiopyr	27.5 ab	3.8 b
Prodiamine	33.8 a	1.3 b
2,4-D + quinclorac + dicamba + sulfentrazone	0.5 c	5.0 b

^a Broadleaf and grassy weed emergence was rated individually on a 0 to 100% scale with 0% representing no broadleaf/grassy weed cover within the experimental plot and 100% representing complete broadleaf/grassy weed cover of the plot.

^b Means followed by the same lower case letter in a column are not significantly different ($P < 0.05$). Means are averages over replications, $n = 4$.

Table 4.8 Turf vigor of sprigs during establishment within experimental plots at 2 and 12 months after sprigging in Expt. 1 (2021-2022) and Expt. 2 (2022-2023) in Olathe, KS.

Treatment	Turf vigor ^a		
	Combined	Expt. 1	Expt. 2
	Months after sprigging ^b		
	2	12	
Untreated control	2.4 c ^c	5.3 a	2.5 c
Oxadiazon (granular)	3.8 b	7.3 a	4.0 bc
Oxadiazon (liquid)	5.8 a	7.5 a	7.8 a
Indaziflam	4.3 b	5.8 a	2.8 c
S-metolachlor	4.1 b	5.3 a	5.0 b
Simazine	3.4 bc	6.3 a	4.3 bc
Dithiopyr	3.5 b	6.5 a	3.5 bc
Prodiamine	3.9 b	6.0 a	3.0 c
2,4-D + quinclorac + dicamba + sulfentrazone	3.9 b	5.8 a	4.0 bc

^a Zoysiagrass vigor was rated on a 1 to 9 scale (1 = dead; 6 = acceptable; and 9 = maximum vigor).

^b Sprigging was done on 9 July 2021 (Expt. 1) and 7 June 2022 (Expt. 2) at a 1:10 ratio (1 ft² of sod spread over a 10 ft² area).

^c Means followed by the same lower case letter in a column are not significantly different ($P < 0.05$). For the 2 month rating date, means are averages over replication and experimental run, n = 8. For the 12 month rating date, means are averages over replication, n = 4.

Table 4.9 Turf color of sprigs in experimental plots at 2 months after sprigging in Expt. 1 (2021-2022) and Expt. 2 (2022-2023) in Olathe, KS

Treatment	Turf color ^a	
	Expt. 1	Expt. 2
Untreated control	5.8 a ^b	6.9 ab
Oxadiazon (granular)	6.3 a	7.0 a
Oxadiazon (liquid)	5.8 a	7.3 a
Indaziflam	5.5 a	6.8 ab
S-metolachlor	5.5 a	7.0 a
Simazine	5.5 a	7.3 a
Dithiopyr	5.8 a	6.0 ab
Prodiamine	5.3 a	4.8 b
2,4-D + quinclorac + dicamba + sulfentrazone	6.0 a	6.8 ab

^a Turf color was rated on a 1 to 9 scale (1 = brown/straw/dead; 9 = dark green).

^b Means followed by the same lower case letter in a column are not significantly different ($P < 0.05$). Means are averages over replication, n = 4.

Table 4.10 Effect of herbicide treatment on NDVI in Expt. 1 (2021-2022) at intervals after sprigging^a in Olathe, KS

Treatment	NDVI ^b			
	7/14/21	8/11/21	8/27/21	9/10/21
Oxadiazon (granular)	0.26 b ^c	0.33 a	0.34 ab	0.36 a
Oxadiazon (liquid)	0.27 ab	0.32 a	0.31 ab	0.35 a
Indaziflam	0.28 ab	0.29 a	0.23 b	0.25 a
S-metolachlor	0.29 a	0.29 a	0.24 ab	0.27 a
Simazine	0.27 ab	0.28 a	0.23 b	0.27 a
Dithiopyr	0.27 ab	0.31 a	0.25 ab	0.33 a
Prodiamine	0.29 a	0.30 a	0.25 ab	0.29 a
2,4-D + quinclorac + dicamba + sulfentrazone	0.28 ab	0.32 a	0.36 a	0.33 a

^a Sprigging was done on 9 July 2021 (Expt. 1) at a 1:10 ratio (1 ft² of sod spread over a 10 ft² area).

^b Normalized difference vegetation index (NDVI) measurements range from -1 to 1, with higher values indicating greater plant health.

^c Means followed by the same lower case letter in a column are not significantly different ($P < 0.05$). Means are averages over replication, n = 4.

Table 4.11 Effect of herbicide treatment on root length and total root number of new stolons in Expt. 1 (2021-2022) and Expt. 2 (2022-2023) in Olathe, KS.

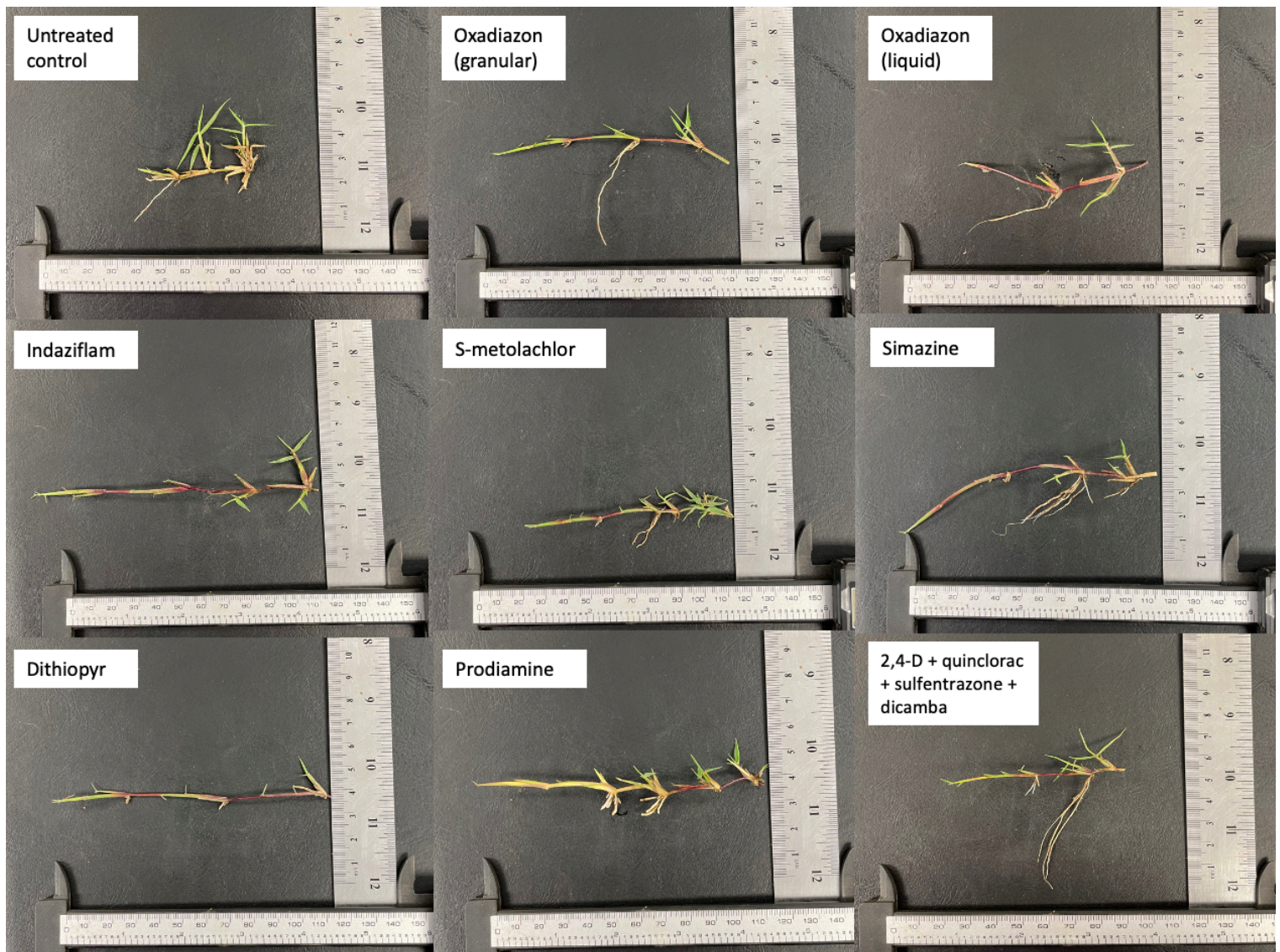
Treatment	Root length (mm) ^a	Total root number ^b
Untreated control	16.2 ab ^c	2.4 ab
Oxadiazon (granular)	25.0 a	2.6 a
Oxadiazon (liquid)	17.2 ab	2.2 ab
Indaziflam	6.0 b	1.0 b
S-metolachlor	13.6 ab	2.5 ab
Simazine	23.5 a	2.9 a
Dithiopyr	6.2 b	2.2 ab
Prodiamine	6.8 b	1.8 ab
2,4-D + quinclorac + dicamba + sulfentrazone	19.7 ab	2.7 a

^a 1 month following sequential applications of preemergence herbicide treatments (11 months after sprigging) a digital caliper was used to measure the root length by pulling up stolons from the soil.

^b Total root number was determined by counting the number of roots growing from the second to last node on new stolons.

^c Means followed by the same lower case letter in a column are not significantly different ($P < 0.05$). Means are averages over replication, and 3 stolon measurements within experimental plots $n = 12$.

Figure 4.3 Differences in root length and total number of roots on sample stolons for each herbicide treatment 1 month after sequential preemergence herbicide applications and 11 months after sprigging in Expt. 1 (2021-2022) in Olathe, KS.



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**Chapter 5 - Effectiveness of combining new herbicide containing
metcamifen with fluazifop-P-butyl for bermudagrass suppression in
zoysiagrass swards**

Abstract

The aggressive growth habit of bermudagrass makes it a desirable species for use on sports fields and recreation areas; however, because of these growth characteristics, bermudagrass is extremely difficult to control in turfgrass systems. Due to physiological similarities between bermudagrass and zoysiagrass, there are limited selective herbicides available to control bermudagrass without causing injury to zoysiagrass. Recognition, a new herbicide for the control of certain broadleaf, sedge, and grass weeds in turf, containing trifloxysulfuron-sodium and a proprietary safener (metcamifen), can be tank-mixed with Fusilade II for the control of bermudagrass in zoysiagrass turf. Minimal research has been reported on the effects of bermudagrass suppression and zoysiagrass injury when Recognition is tank-mixed with Fusilade II. Therefore, research was conducted in Olathe, KS to determine how spring-applied and fall-applied treatments affect 'Riviera' bermudagrass suppression and 'Meyer' zoysiagrass injury; and to determine if sequential applications are needed when Recognition is tank-mixed with Fusilade II at 12 fl. oz/acre or 24 fl. oz/acre. When Recognition was tank-mixed with Fusilade II at 24 fl. oz/acre and received a 4-week sequential application, bermudagrass suppression reached 95% at six weeks following initial application, and maintained acceptable suppression levels until eleven weeks following initial application. Zoysiagrass quality was unaffected and zoysiagrass phytotoxicity was negligible when Recognition was tank-mixed with Fusilade II. This research indicates that a 4-week sequential application of Recognition tank-mixed with Fusilade at 24 fl. oz/acre is necessary for > 95% bermudagrass suppression. Applying Recognition with Fusilade II significantly decreased the amount of injury incurred on Meyer zoysiagrass compared to Fusilade II applied alone.

Introduction

Bermudagrass (*Cynodon dactylon*) establishes rapidly and produces a vigorous, dense sward of turf with a deep root system (McCarty and Miller, 2002). The aggressive growth habit of bermudagrass makes it a desirable species for use on sports fields and recreation areas. However, because of these growth characteristics, bermudagrass is extremely difficult to control in turfgrass systems, ornamental beds, agronomic crops, and pastures (Brown et al., 1985; Ferrell et al., 2005; Newman et al., 2003). When bermudagrass invades a sward of desired turfgrass, the quality of the sward generally declines due to the differences in growth habit, color, and texture (Johnson and Carrow, 1995). Zoysiagrass (*Zoysia* spp. Willd) is a commonly used warm-season species in the U.S. transition zone due to its low fertility requirements, high density, shade tolerance, and slow growth rate (McCarty, 2005). However, bermudagrass is one of the most problematic weeds within zoysiagrass swards. It is often necessary to use chemical control strategies to alleviate bermudagrass encroachment within desired turfgrass swards. Because of the physiological similarities between bermudagrass and zoysiagrass, there are limited selective herbicides available to control bermudagrass without causing injury to zoysiagrass (Johnson, 1987; Johnson, 1992; Dernoeden, 1989).

Glyphosate is a non-selective herbicide that can be applied prior to replanting a desired turfgrass species. Previous studies have reported varying results of glyphosate effectiveness, with bermudagrass suppressed for several weeks before regrowth from rhizomes occurred (Boyd, 1991; Dickens et al., 1987; Johnson, 1988). Postemergence graminicides have been previously studied to evaluate selective control of bermudagrass in zoysiagrass swards. Fenoxaprop applied alone at differing rates or tank-mixed with triclopyr can effectively control common bermudagrass (Cudney et al., 1997; Dernoeden, 1989; Johnson, 1987; Johnson, 1992). Favorable

results of bermudagrass suppression have often been reported after three to four applications of fenoxaprop or fluazifop-P-butyl. However, unacceptable injury to zoysiagrass can occur after applications of fluazifop-P-butyl. In Georgia, fluazifop-P-butyl was found to control Tifway bermudagrass (>99%) after three applications, but caused excessive injury to Emerald zoysiagrass one month following application (Johnson, 1987). Similarly, in Fayetteville, AR and Auburn, AL, fluazifop-P-butyl averaged 83% bermudagrass suppression 28 days after three sequential applications, but injured Meyer and Zorro zoysiagrass (Patton et al., 2017).

Fusilade II (fluazifop-P-butyl) is a selective herbicide for the control of grass weeds that can be applied up to 6 fl oz/acre during a single application (Syngenta Professional Products, 2022). Fusilade II is an acetyl CoA carboxylase (ACCase) inhibitor and blocks the production of phospholipids that are necessary for cell growth (Senseman, 2007). ACCase inhibitors control grass weeds, however, broadleaf weeds are unaffected by an application of Fusilade II due to an insensitive ACCase enzyme (Senseman, 2007). Recognition, a new herbicide for the control of certain broadleaf, sedge, and grass weeds in turf, containing trifloxysulfuron-sodium and a proprietary safener (metcamifen; Syngenta Professional Products, 2021), entered the market in 2023. Herbicide safeners are designed to improve enzyme activity within a desired plant species for protection from herbicidal injury without causing a reduction in efficacy on the target weed species (Davies and Caseley, 1999). Recognition can be tank-mixed with Fusilade II for the control of bermudagrass in zoysiagrass turf. Because of new label guidelines, single applications of Fusilade II can be made up to 24 fl. oz/acre when tank-mixed with Recognition. However, minimal research has been reported on the effects of bermudagrass suppression and zoysiagrass injury when Recognition is tank-mixed with Fusilade II. Therefore, the objectives of this study were to: 1) determine how spring-applied and fall-applied treatments affect Riviera

bermudagrass suppression; 2) determine if sequential applications are needed when Recognition is tank-mixed with Fusilade II at 12 fl. oz/acre or 24 fl. oz/acre; and 3) investigate if Recognition tank-mixed with Fusilade II causes injury to Meyer zoysiagrass.

Materials and Methods

Two separate field studies were conducted at the Olathe Horticulture Research and Extension Center in Olathe, KS (long. 39.48° N, lat. 95.66° W) from 2022 to 2023 to determine the effects of Recognition and Fusilade II applied alone or tank-mixed at differing rates, on bermudagrass suppression and zoysiagrass phytotoxicity and turf quality. Both studies were arranged on conjoining swards of Riviera bermudagrass and Meyer zoysiagrass (Figure 5.1). Soil type was an Oska-Martin silty clay loam with a pH of 6.3. The experiment sites were maintained at a 0.75 in. height of cut mowed three times weekly with supplemental irrigation applied as needed to deliver roughly 0.50 in. of irrigation/week. No preemergence herbicides or additional nutrients were applied to the study areas during each trial. Each of the studies are detailed below.

Fall-applied bermudagrass suppression study

A field study was conducted during the late summer to early fall in 2022 and replicated throughout the same seasons in 2023. The study was arranged in a randomized complete block design with four replicates and a one-way treatment structure was used to evaluate five treatments: Recognition (1.29 oz/A); Fusilade II (12 fl oz/A); Recognition + Fusilade II (1.29 oz/A + 12 fl oz/A); Recognition + Fusilade II (1.29 oz/A + 24 fl oz/A); and an untreated control. Initial and sequential application timings for each treatment are detailed in Table 5.1. Experimental plots measured 5-ft x 10-ft, with 5-ft x 5-ft of the experimental plot nested within a bermudagrass sward and 5-ft x 5-ft of the experimental plot nested within a zoysiagrass sward (Note: across the study site, zoysiagrass and bermudagrass did not always fully fill the 5-ft x 5-ft

plot area, as one covered more area than the other, but allowed enough of each for evaluation). Herbicides were applied using a carbon dioxide (CO₂)-pressurized, handheld spray boom (R&D Sprayers, Opelousas, LA, USA) equipped with four flat-fan nozzles (8003; TeeJet Technologies, Springfield, IL, USA) on 10-inch spacing calibrated to deliver 43 gal/acre. In 2023, applications were made to the same experimental plots as the treatments in 2022.

Spring-applied bermudagrass suppression study

A field study was conducted from May through August in 2023 to evaluate single or sequential applications of Recognition applied alone or in combination with Fusilade II at two rates. The study was arranged in a randomized complete block design with three replicates and a two-way treatment structure was used to evaluate four herbicide treatments (whole plots): Recognition (1.29 oz/A); Recognition + Fusilade II (1.29 oz/A + 12 fl oz/A); Recognition + Fusilade II (1.29 oz/A + 24 fl oz/A); and untreated control. In addition, there were two application timings (subplots): single application or sequential applications (Table 5.2). Whole plots measured 5-ft x 10-ft, with 5-ft x 5-ft of the experimental plot nested within a bermudagrass sward and 5-ft x 5-ft of the experimental plot nested within a zoysiagrass sward. Subplots measured 2.5-ft x 10-ft, with 2.5-ft x 5-ft of the experimental plot in bermudagrass and 2.5-ft x 5-ft of the experimental plot in zoysiagrass (some variability in full size of each experimental plot as described above; Figure 5.2). On 26 May 2023, herbicides were applied using a carbon dioxide (CO₂)-pressurized, handheld spray boom (R&D Sprayers, Opelousas, LA, USA) equipped with four flat-fan nozzles (8003; TeeJet Technologies, Springfield, IL, USA) on 10-inch spacing calibrated to deliver 43 gal/acre to whole plots. On 23 June 2023, herbicides were applied using a single nozzle carbon dioxide (CO₂)-pressurized, handheld spray boom

(R&D Sprayers, Opelousas, LA, USA) equipped with one flat-fan nozzle (8002VS; TeeJet Technologies, Springfield, IL, USA) calibrated to deliver 43 gal/acre to subplots.

Measurements and statistical analysis

Throughout both studies, treatments were visually assessed biweekly by measuring zoysiagrass quality, zoysiagrass phytotoxicity, and bermudagrass suppression. In the Fall-applied bermudagrass suppression study, weed emergence, zoysiagrass fall color and spring greenup, and bermudagrass spring regrowth was also evaluated. Zoysiagrass quality was rated on a 1 to 9 scale (1 = dead; 6 = minimally acceptable; 9 = optimum color, density, uniformity, and texture). Zoysiagrass phytotoxicity was rated on a 0% to 100% scale (0% = no zoysiagrass phytotoxicity from herbicide treatment; 100% = complete zoysiagrass phytotoxicity from herbicide treatment). Bermudagrass suppression was rated on a 0% to 100% scale (0% = no bermudagrass suppression; 100% = complete bermudagrass suppression). Weed cover was rated on a 0 to 100% scale (0% = no weed cover within experimental plot; 100% = complete weed cover of experimental plot). Zoysiagrass fall color was rated when experimental plots entered dormancy in the fall of 2022 on a 1 to 9 scale (1 = straw brown; 9 = complete color retention). Zoysiagrass spring greenup was rated in the spring of 2023 on a 1 to 9 scale (1 = straw brown; 9 = completely green). Bermudagrass regrowth was rated in the spring of 2023 on a 1 to 9 scale (1 = no regrowth; 9 = complete regrowth). Each of the above measurements were subjected to analysis of variance (ANOVA) using the Glimmix procedure in SAS (version 9.4, SAS Institute Inc.). Experimental run was included for fall-applied study data, and data were combined when experimental run was not significant ($P \leq 0.05$). Means were separated according to Tukey's HSD test ($\alpha = .05$) when the F tests were significant ($P \leq 0.05$).

Results

Fall-applied bermudagrass suppression study

Experiment was not significant for zoysiagrass quality rated six and eight weeks following initial herbicide applications (Table 5.3); therefore, zoysiagrass quality data are presented combined across experimental run. At six weeks following initial applications, untreated zoysiagrass had an average turf quality of 7.0, whereas Fusilade II applied alone significantly reduced the quality of the sward with an average turf quality of 5.1 (Table 5.4). Zoysiagrass quality was reduced to 4.4 at eight weeks following an application of Fusilade II. Turf quality at six and eight weeks following initial application was not reduced when Recognition was applied alone or tank-mixed with Fusilade II at 12 or 24 fl. oz/acre.

Experiment was not significant for bermudagrass suppression rated six and eight weeks following initial herbicide applications (Table 5.3); therefore, bermudagrass suppression data are presented combined across experimental run. Six weeks following initial applications of treatments, Fusilade II applied alone or tank-mixed with Recognition at 12 fl. oz/acre had similar bermudagrass suppression (81% and 89% bermudagrass suppression, respectively; Table 5.5). Fusilade II applied at 24 fl. oz/acre tank-mixed with Recognition had 97% bermudagrass suppression six weeks following initial application when averaged across replications and experimental run. Eight weeks following initial application, bermudagrass suppression increased in plots receiving Fusilade II applied alone or tank-mixed with Recognition at 12 fl. oz/acre treatments (86% and 90% bermudagrass suppression, respectively). Recognition applied alone did not suppress bermudagrass at either rating date presented.

Zoysiagrass phytotoxicity was significantly higher in Fusilade II treatments compared to all other treatments (Figure 5.3; Figure 5.4). Zoysiagrass reached 60% phytotoxicity eight weeks

following an application of Fusilade II at 12 fl. oz/acre. Eleven weeks following the application of Fusilade II, zoysiagrass phytotoxicity decreased to 56% when averaged across replications and experimental run. Zoysiagrass phytotoxicity was negligible for all other treatments (< 10% zoysiagrass phytotoxicity) throughout the eleven week rating period.

In Expt. 2, differences in weed emergence within experimental plots were observed (Figure 5.5). Weeds present within experimental plots included dandelion (*Taraxacum officinale*) and common lespedeza (*Lespedeza* sp.). Untreated and Fusilade II experimental plots averaged 11% weed emergence, whereas experimental plots receiving Recognition or Recognition tank-mixed with Fusilade II had < 3% weed emergence in experimental plots. Differences in fall color when zoysiagrass began to go dormant in late October were also observed. Fusilade II applied alone significantly decreased zoysiagrass fall color compared to all other treatments (Table 5.7). Similarly, zoysiagrass spring greenup reached 6.8 on 20 April 2023 following fall applications of Recognition and Recognition tank-mixed with Fusilade II (at both rates) in Expt. 1 (Table 5.7). Although not significantly different from any other treatment, spring greenup of Fusilade II treatments at the same date reached 5.3. Bermudagrass regrowth within experimental plots on 20 April 2023 in Expt. 1 was negligible for experimental plots receiving Recognition tank-mixed with 24 fl. oz of Fusilade II (Table 5.7).

Spring-applied bermudagrass suppression study

Zoysiagrass quality data was insignificant at all rating dates throughout the summer of 2023 when experimental plots received a single or sequential application of herbicide treatments (Table 5.8). Zoysiagrass quality for all treatments averaged 6.5 to 7.2 throughout the rating period (data not shown).

Application number (single or sequential) was insignificant for bermudagrass suppression rated at intervals before 5 July 2023 (six weeks following initial application; Table 5.9). Bermudagrass suppression data are presented for dates six to thirteen weeks following initial application of herbicide treatments. A single application of Recognition tank-mixed with Fusilade II at 12 fl. oz/acre had an average of 23% bermudagrass suppression six weeks following application, but was reduced to < 5% by seven weeks following application (Table 5.10). When Recognition tank-mixed with Fusilade II at 12 fl. oz/acre had a 4-week sequential application, bermudagrass suppression reached 75% six weeks following initial application. However, bermudagrass suppression was decreased to 51% by seven weeks following initial application. A single application of Recognition tank-mixed with Fusilade II at 24 fl. oz/acre had an average of 30% bermudagrass suppression six weeks following application. When Recognition tank-mixed with Fusilade II at 24 fl. oz/acre had a 4-week sequential application, bermudagrass suppression reached 95% at six weeks following initial application, and maintained acceptable suppression levels until eleven weeks following initial application. Nine weeks following applications of Recognition tank-mixed with Fusilade II at 12 fl. oz and 24 fl. oz when a sequential application was made resulted in 25% and 86% bermudagrass suppression, respectively (Figure 5.6). No bermudagrass suppression was observed when Recognition was applied alone, regardless of single or sequential applications.

Discussion

Zoysiagrass quality was unaffected and zoysiagrass phytotoxicity was negligible when Recognition was tank-mixed with Fusilade II throughout both studies. When Fusilade II was applied at a rate of 24 fl. oz/acre with a 4-week sequential application, bermudagrass suppression reached nearly 100%. Bermudagrass suppression increased during both fall-applied experimental

runs in Recognition tank-mixed with Fusilade II at 12 fl. oz/acre experimental plots, compared to Fusilade II applied at 12 fl. oz/acre plots, likely because Recognition tank-mixed with Fusilade II at 12 fl. oz/acre received a 4-week sequential application whereas Fusilade II applied alone did not.

Although fluazifop-P-butyl (Fusilade II) applied alone can suppress bermudagrass, zoysiagrass is also injured (Johnson, 1992; McElroy and Breeden, 2006; Patton et al., 2017). Recognition applied in combination with fluazifop-P-butyl reduced zoysiagrass injury to nearly 0%. Metcamifen, a sulphonamide safener in Recognition, has been widely used in maize (Brazier-Hicks et al., 2022), and previously reported to protect rice from clodinafop-propargyl (Brazier-Hicks et al., 2020). Similar to these previous reports, metcamifen likely enhances the selectivity of fluazifop-P-butyl through the induction of cytochrome P450 (CYPs), a key detoxifying enzyme. It can be concluded from the results herein that zoysiagrass CYPs are responsible for the rapid herbicide metabolism and ultimate degradation of fluazifop-P-butyl, causing a significant reduction in zoysiagrass injury when Recognition is tank-mixed with Fusilade II.

Recognition (1.29 oz/acre) combined with Fusilade II (24 fl. oz/acre) suppressed bermudagrass within experimental plots for eleven weeks following spring-time applications, and until winter dormancy after fall applications. A 4-week sequential application was necessary for > 95% bermudagrass suppression. No supplemental nutrients were applied throughout both studies; however, adequate fertilization to zoysiagrass swards would likely help the zoysiagrass sward fill in after bermudagrass is suppressed. Future research should investigate how Recognition applied with other herbicides affects weed control and phytotoxicity of desirable warm-season turfgrasses.

Figure 5.1 Trial area for the Fall-applied and Spring-applied bermudagrass suppression studies conducted in 2022 and 2023 in Olathe, KS. Experimental plots were arranged on adjoining swards of Riviera bermudagrass and Meyer zoysiagrass.

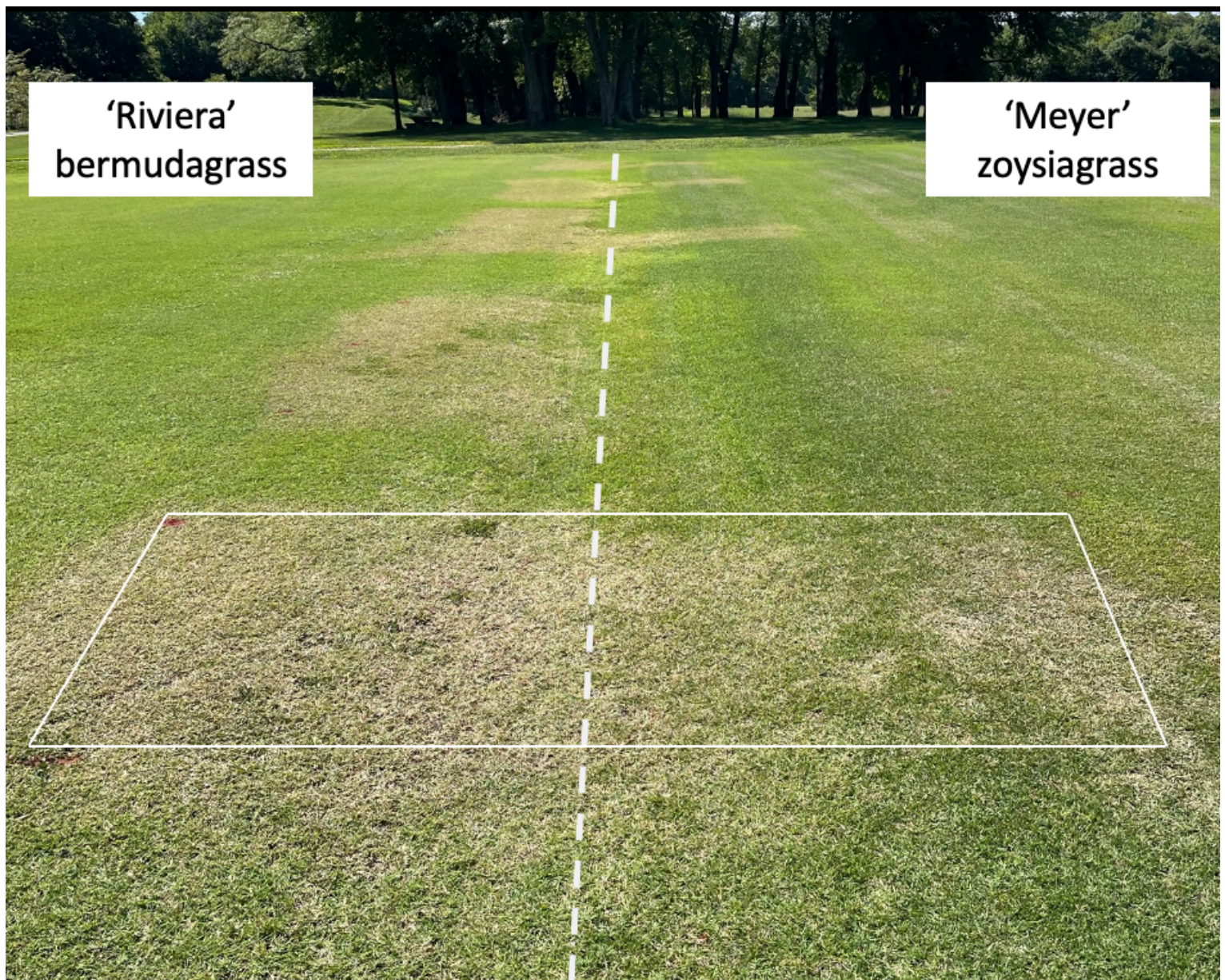


Table 5.1 Herbicide treatments and application dates for the fall-applied bermudagrass suppression study conducted in 2022 (Expt. 1) and 2023 (Expt. 2) in Olathe, KS.

Treatment (rate/acre) ^{a,b}	2022		2023	
	Initial	Sequential	Initial	Sequential
Recognition 1.29 oz	15-Aug	12-Sept	28-Jul	23-Aug
Fusilade 12 fl. oz	15-Aug	--	28-Jul	--
Recognition 1.29 oz + Fusilade II 12 fl. oz	15-Aug	12-Sept	28-Jul	23-Aug
Recognition 1.29 oz + Fusilade II 24 fl. oz	15-Aug	12-Sept	28-Jul	23-Aug
Untreated	--	--	--	--

^a Treatments were made using a CO₂-pressurized, handheld spray boom equipped with four flat-fan nozzles on 25-cm spacing calibrated to deliver 43 gal/acre.

^b 0.25% v/v nonionic surfactant was included with each treatment.

Table 5.2 Herbicide treatments and application dates for the spring-applied bermudagrass suppression study conducted in 2023 in Olathe, KS.

Treatment (rate/acre) ^a	Application number	Application timing
Recognition 1.29 oz	Single ^b	26-May
	Sequential ^c	23-Jun
Recognition 1.29 oz + Fusilade II 12 fl. oz	Single	26-May
	Sequential	23-Jun
Recognition 1.29 oz + Fusilade II 24 fl. oz	Single	26-May
	Sequential	23-Jun
Untreated	--	--

^a 0.25% v/v nonionic surfactant was included with each treatment.

^b Initial treatments were made to whole plots using a CO₂-pressurized, handheld spray boom equipped with four flat-fan nozzles on 25-cm spacing calibrated to deliver 43 gal/acre.

^c Sequential treatments were made to subplots using a CO₂-pressurized, handheld spray boom equipped with one flat-fan nozzle calibrated to deliver 43 gal/acre.

Figure 5.2 Map of treatments within one replication of the spring-applied bermudagrass suppression study conducted in 2023 in Olathe, KS.

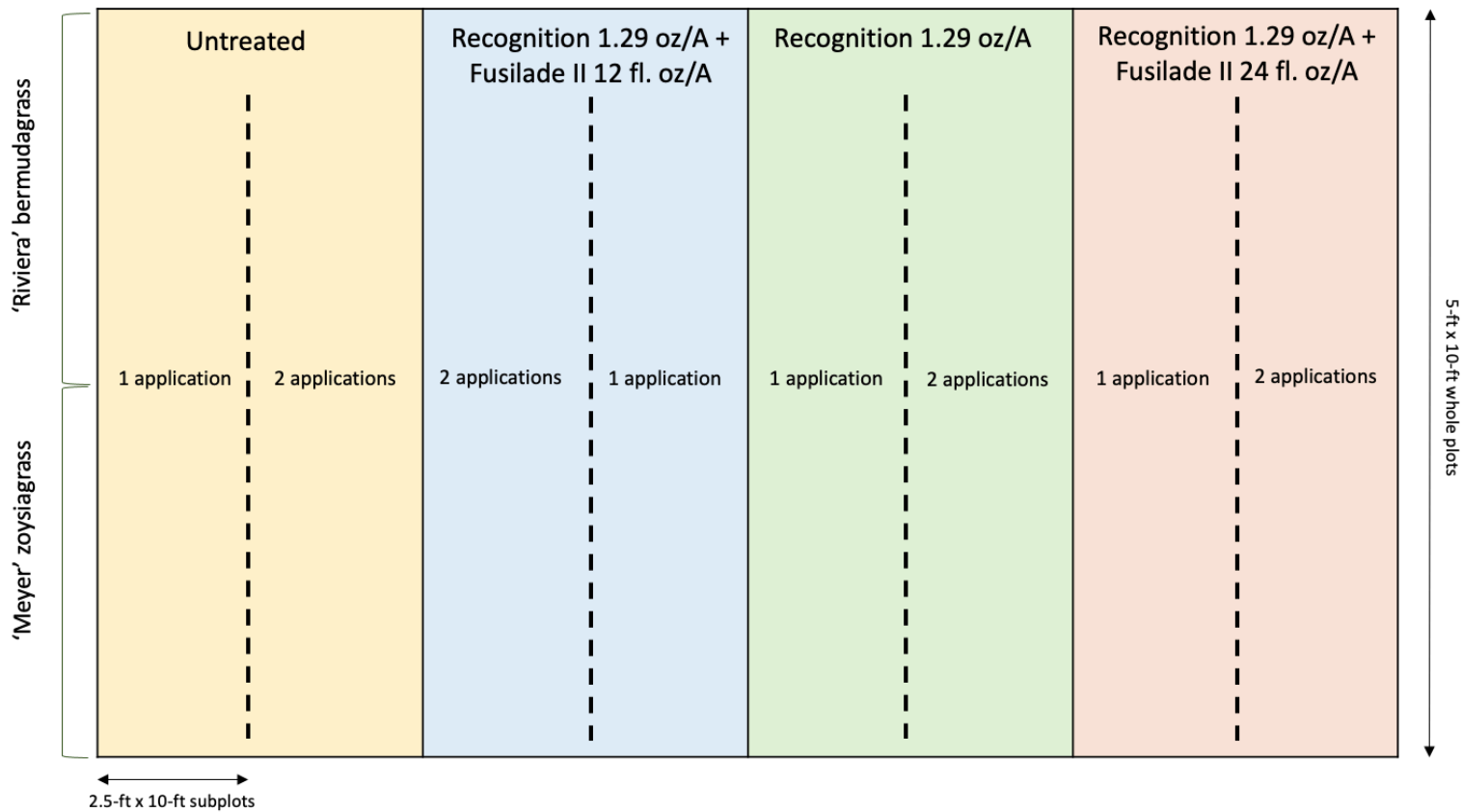


Table 5.3 Analysis of variance on the effects of Treatment, Experimental run, and Treatment x Experimental run on zoysiagrass turf quality and bermudagrass suppression at 2, 4, 6, and 8 weeks following initial applications in the fall of 2022 and 2023 in Olathe, KS.

		Turf quality				Bermudagrass suppression			
		Weeks after initial application							
	DF	2	4	6	8	2	4	6	8
Treatment	4	***	**	***	***	***	***	***	***
Expt.	1	*	*	ns	ns	***	***	ns	ns
T x E	4	***	**	ns	ns	***	***	*	ns

DF = Degrees of freedom

*, **, *** significant at p-value < 0.05, 0.001, and 0.0001, respectively.

ns = not significant

Table 5.4 Effect of herbicide treatment on zoysiagrass quality at 6 and 8 weeks following initial application of treatments in Expt. 1 (2022) and Expt. 2 (2023) when treatments were applied during the fall in Olathe, KS.

Treatment (rate/acre) ^b	Zoysiagrass quality (1-9) ^a	
	Weeks after initial application	
	6	8
Recognition 1.29 oz	6.8 a ^c	6.4 a
Fusilade 12 fl. oz	5.1 b	4.4 b
Recognition 1.29 oz + Fusilade II 12 fl. oz	6.5 a	6.3 a
Recognition 1.29 oz + Fusilade II 24 fl. oz	6.8 a	6.6 a
Untreated	7.0 a	6.8 a

^a Zoysiagrass quality was rated visually on a 1 to 9 scale (1 = dead; 6 = minimally acceptable; 9 = optimum color, density, uniformity, and texture).

^b Treatments were applied on 15 Aug. 2022 (Expt. 1) and 28 Jul. 2023 (Expt. 2). Sequential applications were made on 12 Sept. 2022 (Expt. 1) and 23 Aug. 2023 (Expt. 2) for all treatments except Fusilade II applied alone. 0.25% v/v nonionic surfactant was included with each treatment.

^c Means followed by the same lower case letter in a column are not significantly different ($P < 0.05$). Means are averages over replication and experimental run, n = 8.

Table 5.5 Effect of herbicide treatment on bermudagrass suppression at 6 and 8 weeks following initial application of treatments in Expt. 1 (2022) and Expt. 2 (2023) when treatments were applied during the fall in Olathe, KS.

Treatment (rate/acre) ^b	Bermudagrass suppression (%) ^a	
	Weeks after initial application	
	6	8
Recognition 1.29 oz	0.0 c ^c	0.0 c
Fusilade 12 fl. oz	81.0 b	86.3 b
Recognition 1.29 oz + Fusilade II 12 fl. oz	89.4 ab	90.0 ab
Recognition 1.29 oz + Fusilade II 24 fl. oz	97.0 a	97.3 a
Untreated	0.0 c	0.0 c

^a Bermudagrass suppression was rated visually on a 0 to 100% scale (0% = no bermudagrass suppression; 100% = complete bermudagrass suppression).

^b Treatments were applied on 15 Aug. 2022 (Expt. 1) and 28 Jul. 2023 (Expt. 2). Sequential applications were made on 12 Sept. 2022 (Expt. 1) and 23 Aug. 2023 (Expt. 2) for all treatments except Fusilade II applied alone. 0.25% v/v nonionic surfactant was included with each treatment.

^c Means followed by the same lower case letter in a column are not significantly different ($P < 0.05$). Means are averages over replication and experimental run, $n = 8$.

Figure 5.3 Zoysiagrass phytotoxicity (%) at intervals following herbicide applications in 2022 (Expt. 1) and 2023 (Expt. 2) in Olathe, KS. Experimental plots treated with Fusilade II (12 fl. oz/acre) significantly increased zoysiagrass phytotoxicity compared to all other treatments. Means followed by the same lower case letter are not significantly different ($P < 0.05$). Means are averages over replication and experimental run, $n = 8$.

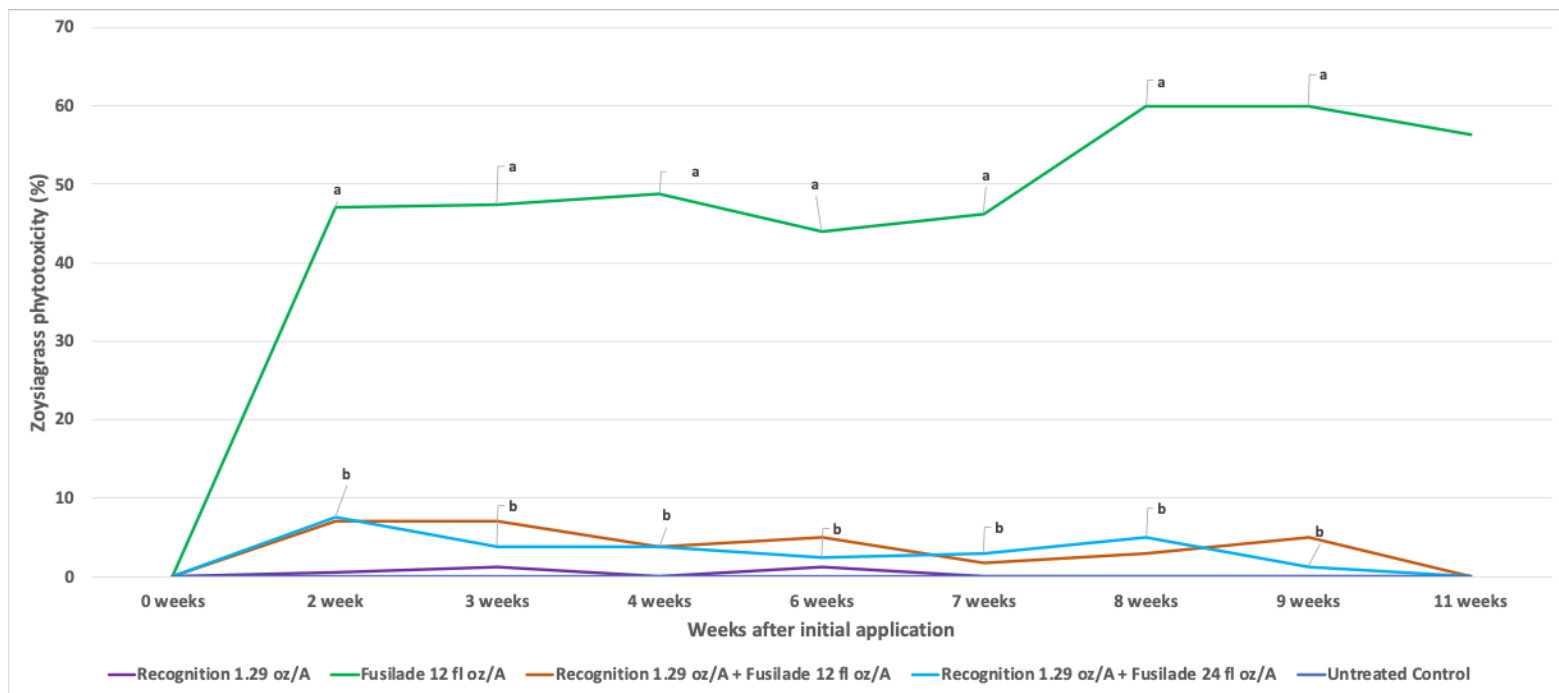


Figure 5.4 Differences in zoysiagrass phytotoxicity (bottom $\frac{3}{4}$ of experimental plot) eight weeks after initial treatment in experimental plots treated with Fusilade 12 fl. oz/acre (A); Recognition 1.29 oz/acre + Fusilade 12 fl. oz/acre (B); and Recognition 1.29 oz/acre + Fusilade 24 fl. oz/acre (C) during Expt. 1 in 2022 in Olathe, KS.

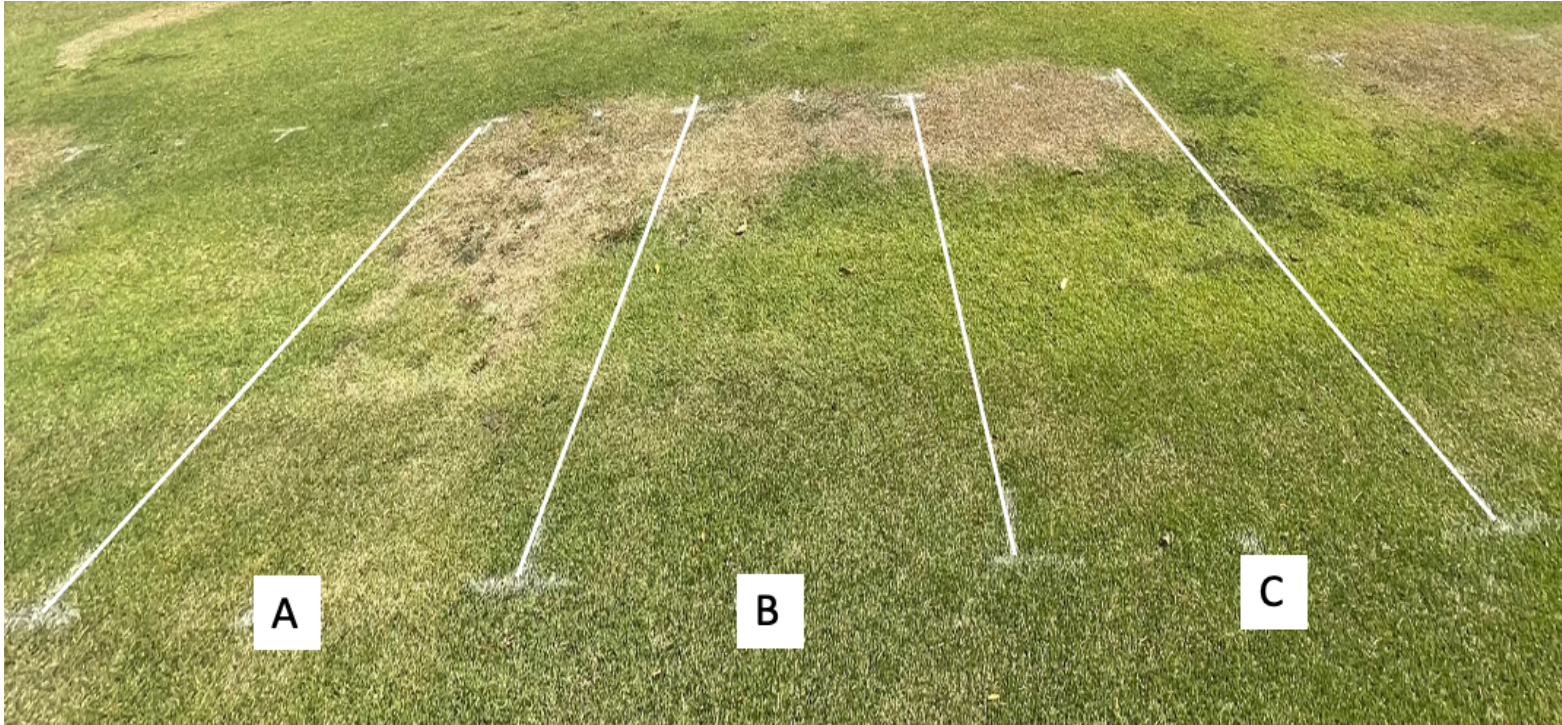


Figure 5.5 Differences in weed emergence within experimental plots treated with Fusilade at 12 fl. oz/acre (A); Recognition + Fusilade at 1.29 oz + 12 fl. oz/acre (B); and Recognition at 1.29 oz/acre (C) eleven weeks after initial herbicide applications in Expt. 2 (2023) in Olathe, KS. Bottom $\frac{3}{4}$ of experimental plot contained Meyer zoysiagrass while the top $\frac{1}{4}$ contained Riviera bermudagrass.



Table 5.6 Effect of herbicide treatment on weed emergence within experimental plots in Expt. 2 (2023) when treatments were applied during the fall in Olathe, KS.

Treatment (rate/acre) ^a	Weeds (%) ^b
Recognition 1.29 oz	0.0 b ^c
Fusilade 12 fl. oz	11.8 a
Recognition 1.29 oz + Fusilade II 12 fl. oz	3.0 ab
Recognition 1.29 oz + Fusilade II 24 fl. oz	2.5 ab
Untreated	11.3 a

^a Treatments were applied on 28 Jul. 2023, and sequential applications were made on 23 Aug. 2023 for all treatments except Fusilade II applied alone. 0.25% v/v nonionic surfactant was included with each treatment.

^b Weed emergence was rated on a 0 to 100% scale (0% = no weed emergence within experimental plot; 100% = complete weed cover of experimental plot). Weeds present within experimental plots included dandelion and common lespedeza.

^c Means followed by the same lower case letter in a column are not significantly different ($P < 0.05$). Means are averages over replication, $n = 4$.

Table 5.7 Effect of herbicide treatment on zoysiagrass fall color, spring greenup, and bermudagrass regrowth from dormancy in Expt. 1 (2022) when treatments were applied during the fall in Olathe, KS.

Treatment (rate/acre) ^d	Fall color ^a	Spring greenup ^b	Regrowth ^c
	Rating date		
	10/23/22	4/20/23	4/20/23
Recognition 1.29 oz	2.3 b ^c	6.8 a	3.3 ab
Fusilade 12 fl. oz	1.3 c	5.3 a	2.5 bc
Recognition 1.29 oz + Fusilade II 12 fl. oz	2.8 ab	6.8 a	2.7 bc
Recognition 1.29 oz + Fusilade II 24 fl. oz	3.0 a	6.8 a	1.5 c
Untreated	3.0 a	7.0 a	4.5 a

^a Zoysiagrass fall color was rated on a 1 to 9 scale (1 = straw brown; 9 = complete color retention).

^b Zoysiagrass spring greenup was rated on a 1 to 9 scale (1 = straw brown; 9 = completely green).

^c Bermudagrass regrowth from dormancy was rated on a 1 to 9 scale (1 = no regrowth; 9 = complete regrowth).

^d Treatments were applied on 15 Aug. 2022, and sequential applications were made on 12 Sept. 2022 for all treatments except Fusilade II applied alone. 0.25% v/v nonionic surfactant was included with each treatment.

^e Means followed by the same lower case letter in a column are not significantly different ($P < 0.05$). Means are averages over replication, n = 4.

Table 5.8 Analysis of variance on the effects of Treatment, application number (single or sequential), and Treatment x application number on zoysiagrass turf quality at intervals following initial applications in the spring of 2023 in Olathe, KS.

	Jun-9	Jun-16	Jun-23	Jun-30	July-5	Aug-10	Aug-23
Treatment	*	ns	ns	ns	ns	ns	ns
Application	ns	ns	ns	ns	ns	ns	ns
T x A	ns	ns	ns	ns	ns	ns	ns

*, **, *** significant at p-value < 0.05, 0.001, and 0.0001, respectively.

ns = not significant

Table 5.9 Analysis of variance on the effects of Treatment, application number (single or sequential), and Treatment x application number on bermudagrass suppression at intervals following initial applications in the spring of 2023 in Olathe, KS.

	Jun-9	Jun-16	Jun-23	Jun-30	Jul-5	Jul-14	Jul-28	Aug-10	Aug-23
Treatment	***	***	***	***	***	***	***	***	***
Application	ns	ns	ns	ns	*	*	**	*	*
T x A	ns	ns	ns	*	***	**	***	***	***

*, **, *** significant at p-value < 0.05, 0.001, and 0.0001, respectively.

ns = not significant

Table 5.10 Effect of herbicides on bermudagrass suppression following single and sequential application treatments during the Spring of 2023 in Olathe, KS.

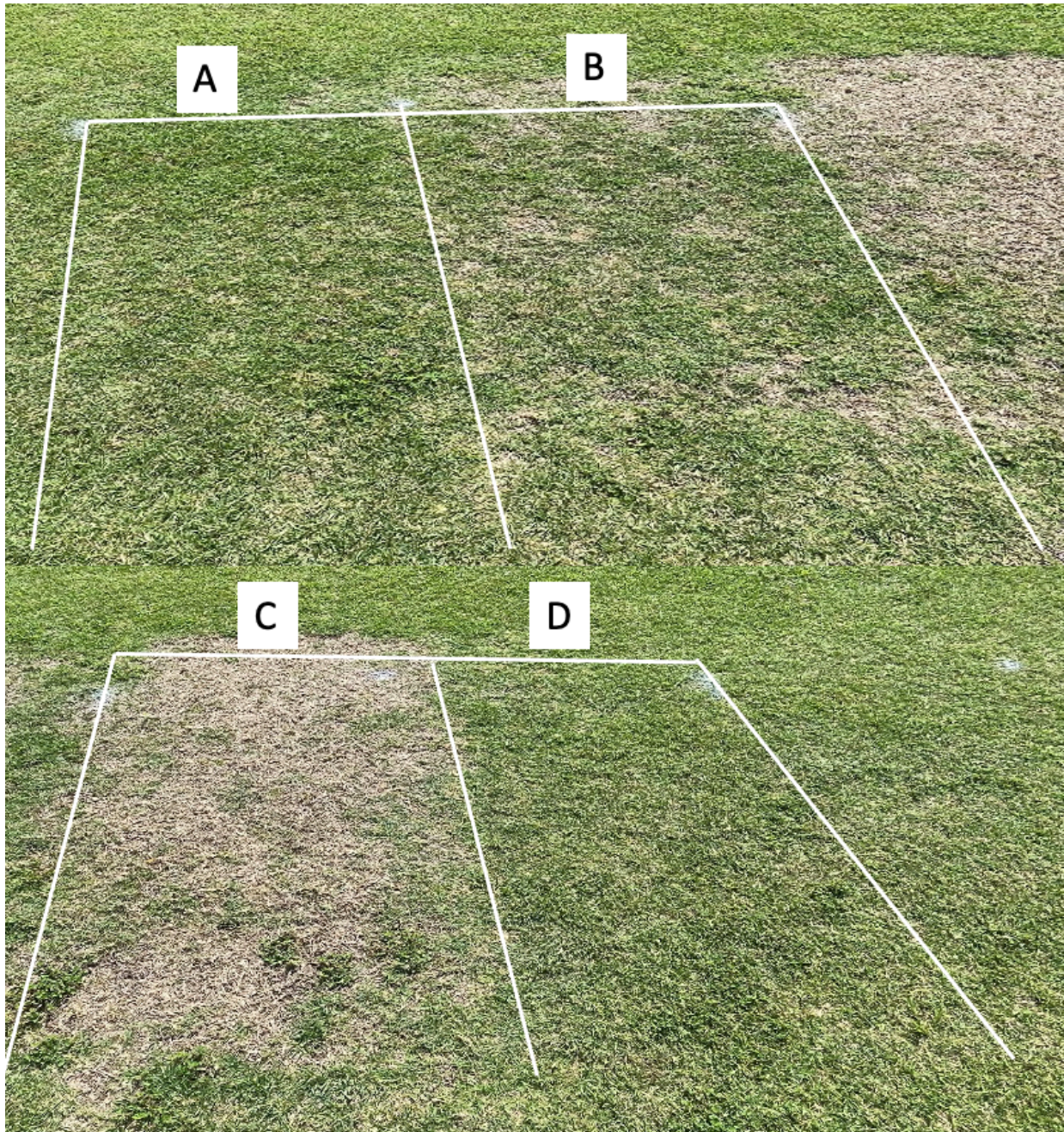
Treatment (rate/acre)	Applications ^b	Bermudagrass suppression (%) ^a				
		Weeks after initial application				
		6	7	9	11	13
Recognition 1.29 oz	Single	0.0 b ^c	0.0 c	0.0 c	0.0 b	0.0 b
	Sequential	0.0 b	0.0 c	0.0 c	0.0 b	0.0 b
Recognition 1.29 oz + Fusilade II 12 fl. oz	Single	23.3 b	4.0 c	0.0 c	0.0 b	0.0 b
	Sequential	75.0 a	51.7 b	25.0 b	6.7 b	5.0 b
Recognition 1.29 oz + Fusilade II 24 fl. oz	Single	30.0 b	5.0 c	0.0 c	0.0 b	0.0 b
	Sequential	95.0 a	93.3 a	86.7 a	36.7 a	28.3 a
Untreated	Single	0.0 b	0.0 c	0.0 c	0.0 b	0.0 b
	Sequential	0.0 b	0.0 c	0.0 c	0.0 b	0.0 b

^a Bermudagrass suppression was rated visually on a 0 to 100% scale (0% = no bermudagrass suppression; 100% = complete bermudagrass suppression).

^b Initial applications were made on 26 May 2023. Sequential applications were made on 23 June 2023; 0.25% v/v nonionic surfactant was included with each treatment.

^c Means followed by the same lower case letter in a column are not significantly different ($P < 0.05$). Means are averages over replications, $n = 3$.

Figure 5.6 Bermudagrass suppression in experimental plots treated with a single application of Recognition + Fusilade at 1.29 oz/A + 12 fl. oz/A (A); sequential applications of Recognition + Fusilade at 1.29 oz/A + 12 fl. oz/A (B); sequential applications of Recognition + Fusilade at 1.29 oz/A + 24 fl. oz/A (C); and a single application of Recognition + Fusilade at 1.29 oz/A + 24 fl. oz/A (D) nine weeks after initial application in Olathe, KS.



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Chapter 6 - Evaluation of experimental zoysiagrass genotypes for commercial potential

Abstract

‘Meyer’ zoysiagrass (*Z. japonica* Steud.) was released in 1951 and is the most widely used zoysiagrass cultivar in the transition zone due to its drought tolerance compared to Kentucky bluegrass, and improved cold hardiness compared to bermudagrass. However, Meyer is very slow to establish and has a range of pest and disease problems. Within the last two decades, zoysiagrass breeding programs in the U.S. have focused their efforts on developing progeny that exhibit finer leaf texture, enhanced rooting and drought tolerance, increased pest tolerance, and increased growth rates compared to Meyer. Therefore, the objective of this study was to evaluate a set of sixty-nine experimental zoysiagrass hybrids based on their performance from 2018 to 2020 to identify the potential for commercial release. In the summer of 2021, seventy-four zoysiagrass genotypes were planted at seven sites (Fayetteville, AR; Gainesville, FL; West Lafayette, IN; Olathe, KS; Knoxville, TN; Dallas, TX; and Blacksburg, VA). In Kansas and Texas, several entries reached > 75% establishment before winter dormancy in 2021. Five entries were in the top statistical grouping across all locations (DALZ 1702, DALZ 1808, TAES 6844-04, TAES 6940-15, and TAES 6941-36). Experimental lines in the 6782, 6783, 6785, 6787, and 6789 TAES families exhibited finer leaf texture compared to other entries. Elite experimental lines DALZ 1701, 1702, 1808, and 1818 were in the top statistical grouping for spring greenup in Indiana, Kansas, Tennessee, and Texas in the spring of 2023. Throughout the two year evaluation period in Kansas, elite experimental line DALZ 1701 was in the top statistical grouping for several data collection events including spring greenup, winter injury, and wilt. Throughout this study, several experimental entries exhibited enhanced cold tolerance, including TAES 6844-202 and 6844-150; while TAES 6941-36 performed well throughout southern study sites suggesting good drought resistance. Elite experimental lines DALZ 1701,

1702, 1808, 1818, and experimental lines 6782-75 and 6782-104 show promise within a range of environments; however, no entry had exceptional performance across all seven study sites. The results of this study suggest genotype by environment interactions continue to challenge breeding advancements of zoysiagrass varieties with a wide range of adaptation.

Introduction

Zoysiagrass (*Zoysia* spp. Willd.) is a warm-season (C₄) turfgrass that was introduced to the United States in 1892 (Patton et al., 2017) and zoysiagrass breeding is thought to have started over fifty years later in Beltsville, MD (Hanson, 1965). Within the *Zoysia* genus there are eleven species, and during the early days of zoysiagrass breeding new germplasm was created by using open pollination, irradiation, and directed crosses of the different species (Christians et al., 2017; Hanson, 1965). *Z. japonica*, *Z. matrella*, and *Z. pacifica* (formerly *Z. tenuifolia*) are the three zoysiagrass species extensively used in the United States for turfgrass systems (Chandra et al., 2017). Zoysiagrass is commonly planted on golf course fairways, tee boxes, and bunker faces in the U.S. transitional and warm climatic regions, and as of 2015 it is estimated that zoysiagrass covers 10,375 hectares throughout the U.S (Braun et al., 2022; Patton et al., 2017). ‘Meyer’ zoysiagrass (*Z. japonica* Steud.) was released in 1951 and is the most widely used zoysiagrass cultivar in the transition zone (Dunn and Diesburg, 2004). Meyer is preferred by golf course superintendents in the transition zone due to its drought tolerance compared to Kentucky bluegrass (*Poa pratensis*) in the summer months, and improved cold hardiness compared to bermudagrass (*Cynodon dactylon*) in the winter months, however Meyer is very slow to establish and has a range of pest and disease problems.

Within the last two decades, zoysiagrass breeding programs in the U.S. have focused their efforts on developing progeny that exhibit finer leaf texture, enhanced rooting and drought tolerance, increased pest tolerance, and increased growth rates (Patton et al., 2017). A collaborative effort amongst Texas A&M, Kansas State, and Purdue Universities began in 2012 to evaluate 2,858 new zoysiagrass progeny (Braun et al., 2022). Results from this ten year study resulted in the release of ‘DALZ 1701’ which has performed well across multiple states in the

transition zone and in Texas (Chandra et al., 2023). In 2017 to 2018 the breeding team at Texas A&M developed over 4,600 zoysiagrass hybrids by crossing parental lines. From these experimental hybrids, less than 2% (sixty-five genotypes) were selected for further testing. A following experiment has been underway between 2018 and 2023, sponsored by the USGA, to identify genotypes that could do well on tees, fairways, and greens. Therefore, the objective of this study was to evaluate a set of sixty-nine experimental zoysiagrass hybrids based on their superior performance from 2018 to 2020 to identify the potential for commercial release.

Materials and methods

In the summer of 2021, seventy-four zoysiagrass genotypes were planted at seven sites (Fayetteville, AR; Gainesville, FL; West Lafayette, IN; Olathe, KS; Knoxville, TN; Dallas, TX; and Blacksburg, VA). Genotypes planted in this study included sixty-five experimental lines, four elite experimental lines (DALZ 1701, 1702, 1808, and 1818) and five commercial ‘standards’ (Emerald, Innovation, Meyer, Palisades, and Zeon; Table 1). Entries were grown in 18-cell trays at the Texas A&M AgriLife Research and Extension Center in Dallas, TX and shipped to each study site. Each tray contained eighteen 3 in. x 3 in. diam. plugs, and individual plugs were divided into four 1.5 in. diam. mini-plugs. Plugs were planted on 1-ft centers with twenty-four mini plugs/5 ft. x 5 ft. experimental plot (Figure 1). Planting date and maintenance information are included in Table 2 for each study site.

Measurements and statistical analysis

Establishment was rated at each study site in 2021-2023 on a 0-100% scale in which 0% = no establishment, and 100% = complete establishment of experimental plot. Turf quality was rated during the summer of 2022 and 2023 on a 1 to 9 scale in which 1 = lowest quality; 6 = minimum acceptable quality; and 9 = maximum quality. In 2022, principal component analysis

(PCA) was performed for establishment and turf quality data for all study sites using GraphPad Prism (v.9.5., GraphPad Software) to better understand genotype by environment interaction. PCA biplots show entries that performed poorly across environments (away from the locations arrows) as well as entries that performed well across locations. Entries located intermediate of locations suggest they perform well across all locations. Leaf texture data were collected in the summer of 2022 for each study site. Leaf texture was rated on a 1 to 9 scale in which 1 = coarse; and 9 = fine. Winter injury was visually rated as desiccation injury from freezing or direct low temperatures in the spring of 2022 in Kansas and Indiana on a 0-100% scale in which 0% = no winter injury and 100% = complete winter injury. Spring greenup was rated at different intervals throughout the spring of 2023 in Florida, Indiana, Kansas, Tennessee, and Texas. Spring greenup was rated on a 1 to 9 scale in which 1 = brown/straw/dead; and 9 = dark green.

In addition to evaluations under full sun conditions, a study was conducted in Texas where all experimental lines and standard entries were planted in June 2021 as single plugs with three replications under moderate artificial shade (63% shade). Data collection for this study included turf quality, genetic color, leaf texture, and spring greenup.

In Florida, a 7-day dry down period was initiated from 1 May to 8 May 2023. During this period, there was no rainfall or supplemental irrigation. Green cover was rated on a 0 to 100% scale (0% = no green cover and 100% = complete green cover) to evaluate turf performance during the drought period, and for seven days following dry-down when irrigation was resumed.

Divot recovery was investigated in Arkansas beginning on September 1, 2023 when damage was initiated. Divots were simulated using a modified edger (5 cm x 10 cm divot size) and backfilled with topdressing sand. Recovery was monitored for each divot by collecting digital images weekly, beginning on the day of injury and continuing until full recovery (100%

cover). A total of three divots for each experimental plot were analyzed independently for turf coverage. Data are presented for divot recovery at 19 days following divot injury, as all other rating dates were insignificant.

In August of 2022 and 2023, traffic tolerance was evaluated in Tennessee. Traffic tolerance was simulated with a 4-ft wide modified Cady Traffic Simulator. One pass with the trafficker was equivalent to 57 cleat marks/ft². Five simulated traffic events were initiated starting in August and applied weekly, for a total of 30 total games each year. Lightbox pictures were taken after each ten games and analyzed using Turf Analyzer Software to evaluate green cover on a 0 to 100% scale (0 = no green cover; 100 = complete green cover).

Data were analyzed separately by location and data collection event using the GLIMMIX procedure in SAS (version 9.4, SAS Institute) with replication as a random effect. Means were separated according to Tukey's HSD test ($\alpha = .05$) when the F tests were significant ($P \leq 0.05$). Data are only presented if the entry occurred in the top statistical grouping for each rating event. In Kansas, additional data were collected on many traits that are used to characterize turfgrasses (genetic color, fall color, and wilt from drought stress) and a cumulative turf performance index (TPI) score was generated for each genotype representing the number of times the entry occurred in the top statistical grouping across all data collection events throughout 2021 to 2023.

Results and Discussion

Establishment

Establishment trends varied across sites. Following planting in Arkansas in 2021, four entries were in the top statistical grouping, whereas 42 entries were in the top statistical grouping in Kansas (Table 3). Experimental entry 6844-152 and standard entry Palisades were in the top statistical grouping for all locations except Virginia. In Kansas and Texas, several entries

reached > 75% establishment before winter dormancy in 2021. In comparison, establishment was slower in Arkansas, Florida, Indiana, and Virginia, with the highest establishment in experimental plots reaching 60%, 43%, 55%, and 46%, respectively, before winter dormancy in 2021. In 2022, establishment rates across entries were similar for study sites in Kansas, Tennessee, and Texas (Fig. 2). Many entries began to establish in Florida and Virginia; however, establishment was slow in Indiana for the majority of entries. PCA biplots show entries that performed poorly across environments (away from the locations arrows) as well as entries that performed well across locations. For establishment, all locations except Florida were generally closely correlated and many top-performing genotypes along with standard entries performed well in this cluster of environments (Fig. 3)

Turf quality

Throughout this study, many entries exhibited acceptable to superior turf quality. During the summer of 2022, 71 of 74 entries were in the top statistical grouping in Arkansas; 31 entries in Florida; 35 entries in Indiana, 61 entries in Kansas, 72 entries in Tennessee, 55 entries in Texas, and 71 entries in Virginia (Table 4). Five entries were in the top statistical grouping across all locations (DALZ 1702, DALZ 1808, 6844-04, 6940-15, and 6941-36). The average turf quality for entries in the top statistical grouping in Tennessee and Texas was 7.6 and 7.3, respectively. In the summer of 2023, several entries were in the top statistical grouping across all locations, including the five standard entries (Emerald, Innovation, Meyer, Palisades, and Zeon), three elite experimental entries (DALZ 1702, 1808, and 1818), and fifteen experimental entries. In 2023 the average turf quality across all entries in Florida was 3.2, likely due to the increased drought stress throughout the summer months at that study site. PCA biplots for turfgrass quality suggest that Texas and Florida (southern locations) were more correlated than Kansas (transition

zone location; Fig. 3). Tennessee and Arkansas were closely correlated where standard entries Meyer and Palisades performed well; whereas, in Virginia, standard entries Emerald and Zeon exhibited better turf performance. Elite experimental lines DALZ 1701 and 1818 were located intermediate of locations, suggesting these two entries performed well throughout all six study sites.

Leaf texture

Leaf texture was rated in the summer of 2022 at all seven study sites. Experimental lines in the 6782, 6783, 6785, 6787, and 6789 TAES families exhibited finer leaf texture compared to other entries (Table 5). *Z.pacifica* is in the genetic background of each of the aforementioned families and likely contributed to the finer leaf texture observed, as the primary use of *Z.pacifica* is for breeding zoysiagrass hybrids with fine leaf texture (Patton et al., 2017). DALZ 1702 was in the top statistical grouping for leaf texture in Arkansas (6.3), Indiana (6.0), and Tennessee (7.3). Several other experimental entries exhibited finer leaf texture compared to standard entries at all locations with the exception of Indiana. As stated above, entries exhibiting finer leaf texture commonly had *Z.pacifica* in the genetic background. *Z.pacifica* hybrids that survived in Kansas suggest an improvement, however, there is a cold hardiness limit of *Z. pacifica* hybrids as they did not survive in Indiana.

Winter injury

Winter injury was evaluated in Kansas and Indiana in the late spring of 2022. Although weather conditions within these two states are similar compared to the other study sites, winter injury in Indiana was more severe than Kansas for a majority of the entries in this study. In Kansas, five experimental lines had winter injury of 33% or more (Table 6). In Indiana, 21 of the 74 entries had winter injury of 50% or less. Several experimental entries had 100% winter injury,

affecting data collection for other evaluations such as turf quality, leaf texture, and spring greenup.

Spring greenup

Elite experimental lines DALZ 1701, 1702, 1808, and 1818 were in the top statistical grouping for spring greenup in Indiana, Kansas, Tennessee, and Texas in the spring of 2023 (Table 7). DALZ 1808 had a spring greenup of 8.0 in Kansas compared to Emerald zoysiagrass which had an average spring greenup of 5.0 on the same rating date. In Tennessee, Innovation and Meyer experimental plots had completely greened up from winter dormancy by the end of April (9.0), with elite experimental lines (DALZ 1701, 1702, 1808, and 1818) averaged a spring greenup between 8.0 to 8.7. However, in Indiana and Texas, the four elite experimental lines stated above had an average spring greenup of 4.3 to 5.7. Emerald and experimental entry 6785-19 had an average spring greenup rating of 7.7 when spring greenup was evaluated on 4 April 2023 in Texas.

Shade tolerance

Turf quality under 63% shade conditions ranged between 2.7 and 8.0 in Texas in 2023 and 32 of 73 entries were in the top statistical grouping (Table 8). Alternatively, 52 of 73 entries were in the top statistical grouping for turf quality evaluated under full sun conditions in Texas in 2023 (Table 4). DALZ 1808 had an average turf quality of 5.3 and was the only elite experimental line to be in the top statistical grouping. Genetic color under shade conditions ranged from 5.3 to 8.7. DALZ 1701, 1818, and 1808 had an average genetic color of 8.0, 7.7, and 7.0, respectively. Experimental line TAES 6782-104 shows promise under shade conditions because of its high turf quality (8.0), dark genetic color (8.7), fine leaf texture (7.3) and hastened spring greenup (5.3) compared to other experimental entries. TAES 6782-104 performed well

when evaluated under full sun conditions in Texas, with an average turf quality between 7.3 to 7.7 in 2022 and 2023.

Drought tolerance

Irrigation was withheld from experimental plots beginning on 1 May 2023 in Florida. On 4 May 2023, twelve entries exhibited decreased quality compared to others. The 62 entries in the top statistical grouping on this rating date ranged from 40% to 93% green cover (Table 9). On the seventh day of drought stress, there were 49 entries in the top statistical grouping ranging from 13% to 60% green cover. Standard entry Emerald, and elite experimental line DALZ 1702 showed increased drought tolerance compared to standard entries Innovation and Zeon, and elite experimental lines DALZ 1701, 1808, and 1818. Many entries had recovered with the addition of irrigation at seven days following drought stress; with 59 of the 74 entries in the top statistical grouping. At seven days post-dry down, elite experimental entries DALZ 1702, 1701, and 1808 had an average green cover of 78%, 70%, and 70%, respectively.

Divot recovery

Divots were removed from experimental plots on 1 September 2023 in Arkansas. Digital green cover index (%) ranged from 24% to 44% across experimental plots on the same day of divot initiation. Data collected on 1 September and 8 September 2023 were insignificant ($P > 0.05$). However, on 19 September 2023 most entries had significantly recovered from divot injury. Forty-four of the 74 entries had $> 70\%$ divot recovery including DALZ 1701 and DALZ 1702 (Table 10). Experimental line TAES 6844-34 had the highest recovery 18 days following divot injury with an average of 82% recovery across replications. Experimental lines TAES 6789-23 and 6844-53 were the only entries with significantly lower recovery compared to all other entries recovering 46% and 43%, respectively, 18 days following divot injury.

Traffic tolerance

Traffic was simulated in Tennessee by applying cleat marks equivalent to five games/week for six weeks. Green cover of experimental plots ranged from 84% to 99% prior to inducing traffic treatments in 2022 (Table 11). In 2022, green cover was reduced for all treatments following ten traffic events; DALZ 1701 had a 9% decrease in green cover after ten traffic events, a 16% decrease after twenty traffic events, and a 61% decrease after thirty traffic events. Although statistically insignificant ($P > 0.05$) green cover was reduced for all entries by 49% to 71% following thirty traffic events in 2022. Following ten to twenty traffic events in 2023 all entries were similar in tolerance. Green cover of Emerald zoysiagrass was reduced to 56% after twenty traffic events, whereas elite experimental lines DALZ 1701, 1702, and 1818 had 64% green cover following twenty traffic events.

Kansas TPI

Eighteen individual data collection events occurred throughout 2021 to 2023 in Kansas to evaluate establishment, turfgrass quality, genetic color, fall color retention, spring greenup, winter injury, and summer wilt. Entries had a TPI score ranging between two to seventeen (out of eighteen). Ten entries had a score of seventeen including elite experimental line DALZ 1818 and standard entry Innovation (Table 12). Elite experimental line DALZ 1701 was in the top statistical grouping for several data collection events including spring greenup, winter injury, and wilt; however, this entry was only in the top statistical grouping for turf quality one out of five times. Throughout the two year evaluation period, DALZ 1701 exhibited good quality in Arkansas, Tennessee, and Texas (Table 4), suggesting this elite experimental entry might not perform well across different environments.

Summary

Throughout this study, several experimental entries exhibited enhanced cold tolerance, including TAES 6844-202 and 6844-150, while TAES 6941-36 performed well throughout southern study sites suggesting good drought resistance. Elite experimental lines DALZ 1701, 1702, 1808, and 1818 show promise within a range of environments; however, no entry had exceptional performance across all seven study sites. The results of this study suggest that multiple experimental lines could perform well in specific regions, but not across all regions in the United States. As of February 2024, nine entries were selected for further evaluations in the southern region, which include: 6782-75, 6782-104, 6785-19, 6789-23, 6789-40, 6792-44, 6829-69, 6941-36, and 6942-22. Nine entries were also selected for further evaluations in the transition zone, which include: 6782-75, 6782-79, 6782-104, 6829-36, 6844-36, 6844-74, 6844-104, 6844-150, and 6844-202. Future research should focus on the adaptability and performance of these aforementioned entries under different maintenance regimes to better understand the genotype x environment x management interactions.

Table 6.1 Texas Agricultural Experiment Station (TAES) family lineage summary

TAES Family	Lineage
DALZ 1701	$(Zm \times Zj) \times Zj$
DALZ 1702	$(Zm \times Zj) \times Zj$
DALZ 1808	$Zj \times Zj$
DALZ 1818	$(Zp \times Zj) \times Zj$
6782	$[(Zj \times Zp)/Zj] \times Zp$
6783	$[(Zj \times Zp)/Zj] \times Zp$
6784	$[(Zj \times Zp)/Zj] \times Zp$
6785	$[(Zj \times Zp)/Zj] \times Zp$
6786	$[(Zj \times Zp)/Zj] \times Zp$
6787	$[(Zj \times Zp)/Zj] \times Zp$
6789	$[(Zj \times Zp)/Zj] \times Zp$
6791	$[(Zj \times Zp)/Zj] \times Zp$
6792	$[(Zj \times Zp)/Zj] \times Zp$
6828	$Zm \times [(Zj \times Zp)/Zj]$
6829	$[(Zj \times Zp)/Zj] \times Zm$
6830	$((Zm \times Zj) \times Zm)$
6831	$Zm \times (Zm \times Zj)$
6835	$(Zm \times Zj) \times Zm$
6836	$[(Zmin \times Zm)/Zm] \times [(Zj \times Zp)/Zj]$
6839	$Zm \times [(Zj \times Zp)/Zj]$
6840	$Zm \times [(Zj \times Zp)/Zj]$
6844	$[Zm \times Zj] \times [(Zj \times Zp)/Zj]$
6910	$Zj \times (Zj \times Zm)$
6919	$[(Zm \times Zp)/Zj] \times [Zm \times Zj]$
6923	$(Zj \times Zm) \times Zj$
6924	$(Zm \times Zj) \times (Zm \times Zj)$
6925	$(Zm \times Zj) \times (Zm \times Zj)$
6933	$(Zm \times Zj) \times (Zm \times Zj)$
6940	$(Zj \times Zm)$
6941	$(Zj \times Zm)$
6942	$(Zj \times Zp)$
Emerald	$(Zj \times Zp)$
Innovation	$(Zm \times Zj)$
Meyer	Zj
Palisades	Zj
Zeon	Zm

Zj: *Zoysia japonica*; *Zm*: *Zoysia matrella*; *Zp*: *Zoysia pacifica*;
Zmin: *Zoysia minima*; Complex crosses such as double and triple
crosses to introgress desirable traits require the use of x, /, () and [] to
indicate hybrid parentage.

Table 6.2 Site information for replicated field trials during establishment of experimental zoysiagrasses from plugs in 2021.

Site info	Fayetteville, AR	Olathe, KS	Knoxville, TN	West Lafayette, IN	Blacksburg, VA	Dallas, TX	Gainesville, FL
Planting Date	21 July	17 June	17 June	21 July	18 June	24 June	30 August
Soil Type	Captina Silt Loam	Oska-Martin Silty Clay Loam	Sequatchie Silt Loam	Silty Clay Loam	Groseclose-Urban Land Complex Loam	Silty Clay Loam	Candler Sand
Fertilizer (lbs N/ 1,000ft ²)	21 July 2.5	6 July 0.75	1x/month 1.00	21 July, 17 Aug 0.25, 1.00	18 July 1.00	22 July, 15 Sept 1.00	27 Oct 1.00
Irrigation	As needed	2x/week	2x/week	4x/week	4x/week	2x/week	4x/week
Mowing HOC	3/4"	None	7/8"	1.75"	None	1"	None

Figure 6.1 Planting of experimental zoysiagrass plugs on 17 June 2021 in Olathe, KS.



Table 6.3 Establishment of experimental zoysiagrass entries in the top statistical grouping in seven replicated field trials in 2021.

TAES entry code ^b	Establishment (%) ^a						
	AR	FL	IN	KS	TN	TX	VA
6095-101	.	38.3	.	90.0	53.0	80.0	35.0
6095-83	.	35.0	46.7	.	49.7	88.3	.
6099-145	.	36.7	45.0	85.0	60.0	76.7	.
6109-87	.	.	.	78.3	.	65.0	33.3
6782-104	.	.	.	95.0	.	.	.
6782-42	.	.	.	91.7	.	.	31.7
6782-75	.	.	.	88.3	.	.	46.7
6782-79	.	.	.	96.7	.	61.7	35.0
6784-17	.	.	.	.	.	70.0	.
6789-40	.	.	.	.	.	.	31.0
6789-52	.	36.7	.	.	56.0	71.7	.
6792-44	.	.	.	.	.	.	30.0
6828-27	.	.	.	68.3	.	.	.
6828-53	.	.	.	.	53.0	75.0	.
6828-77	.	.	.	65.0	.	.	40.0
6829-02	.	.	.	81.7	.	65.0	30.0
6829-20	.	41.7	.	68.3	46.7	61.7	30.0
6829-36	.	.	.	70.0	45.3	.	.
6829-69	.	38.3	.	93.3	.	83.3	.
6830-02	.	.	.	70.0	59.0	70.0	.
6830-11	.	.	.	73.3	46.7	.	30.0
6830-39	.	36.7	.	.	71.7	68.3	.
6830-56	.	.	.	68.3	45.0	78.3	.
6831-09	50.0 ^c	.	.	88.3	60.0	88.3	33.3
6835-33	.	.	.	.	54.0	.	30.0
6836-09	.	.	.	63.3	.	.	.
6839-08	.	.	.	85.0	50.3	75.0	33.3
6840-20	.	.	.	.	54.0	71.7	.
6844-04	.	.	.	.	47.7	.	.
6844-104	.	.	.	.	56.3	73.3	.
6844-141	.	.	.	78.3	.	61.7	.
6844-147	34.4	.	.	76.7	50.0	68.3	.
6844-150	.	.	.	78.3	.	.	33.3
6844-152	56.7	38.3	45.0	70.0	52.3	86.7	.
6844-154	.	.	.	.	61.3	65.0	.
6844-190	.	.	.	.	.	61.7	.
6844-202	.	.	.	.	.	.	30.0
6844-31	.	.	.	68.3	46.7	65.0	31.7
6844-34	.	.	45.0	91.7	64.7	85.0	33.3
6844-36	.	.	.	65.0	50.0	68.3	.
6844-42	.	.	.	100.0	45.0	75.0	38.3
6844-53	.	.	.	91.7	49.0	.	41.7
6844-74	.	.	.	80.0	.	.	30.0
6844-89	.	38.3	.	70.0	.	66.7	.
6910-172	.	36.7	.	73.3	.	81.7	31.7
6919-29	.	.	.	65.0	.	.	29.3
6923-11	45.0	43.3	46.7	.	73.3	90.0	.
6924-44	.	36.7	46.7	61.7	48.7	78.3	.
6924-47	.	.	.	78.3	.	60.0	.
6924-66	.	.	.	83.3	51.7	.	35.0
6925-53	.	.	45.0	.	47.3	61.7	30.0

(Cont.)	AR	FL	IN	KS	TN	TX	VA
6933-11	.	.	.	96.7	45.3	61.7	33.3
6940-15	.	.	.	.	48.3	70.0	.
6941-36	.	.	.	.	47.7	65.0	.
6942-22	.	35.0	.	70.0	58.3	68.3	31.7
Emerald	.	.	.	73.3	47.3	.	.
Innovation	.	.	.	88.3	.	.	.
Meyer	.	.	.	61.7	.	.	.
Palisades	60.0	41.7	55.0	65.0	77.0	86.7	.
Zeon	.	.	.	96.7	.	.	48.3
<i>Average</i>	49.2	38.1	46.9	78.7	53.5	72.4	33.8

^a Establishment was rated on a 0 to 100% scale in which 0% = no establishment; and 100% complete establishment

^b Texas Agricultural Experiment Station (TAES) entry code

^c Entries with a mean presented occurred in the top statistical grouping by individual location ($P < 0.05$). Means are averages over replication, $n = 3$

Figure 6.2 Establishment distribution of experimental entries across six replicated field studies in 2022. Shaded bars within each location indicate the average establishment across all entries. Round markers within bars indicate percent establishment for each entry.

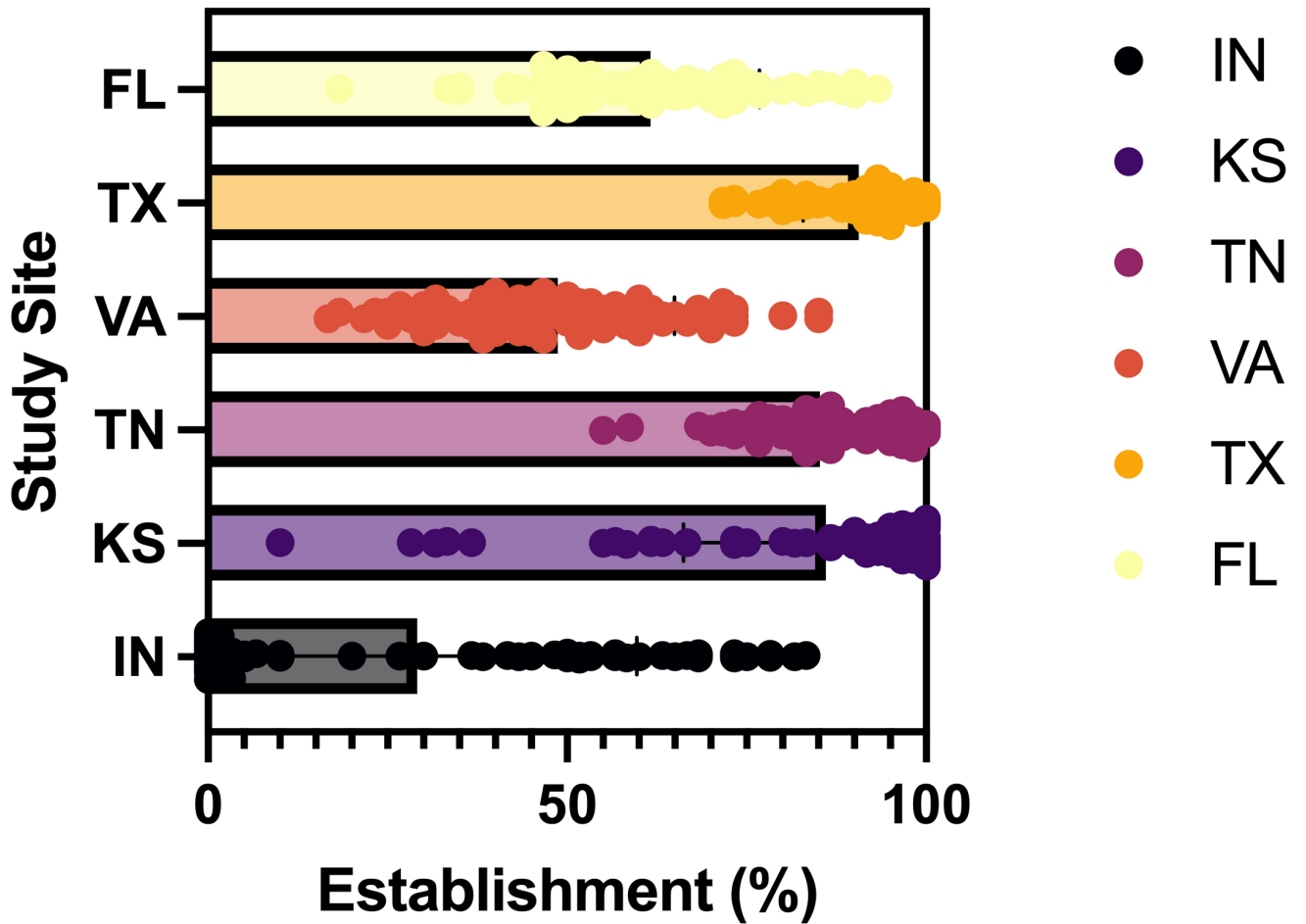


Figure 6.3 Loadings (locations) and principal component plots from the analysis of turfgrass establishment across ≥ 7 locations (a), and turfgrass quality across ≥ 6 locations (b) in 2022. The direction of the locations shows how much weight they have on each of the principal components (PC).

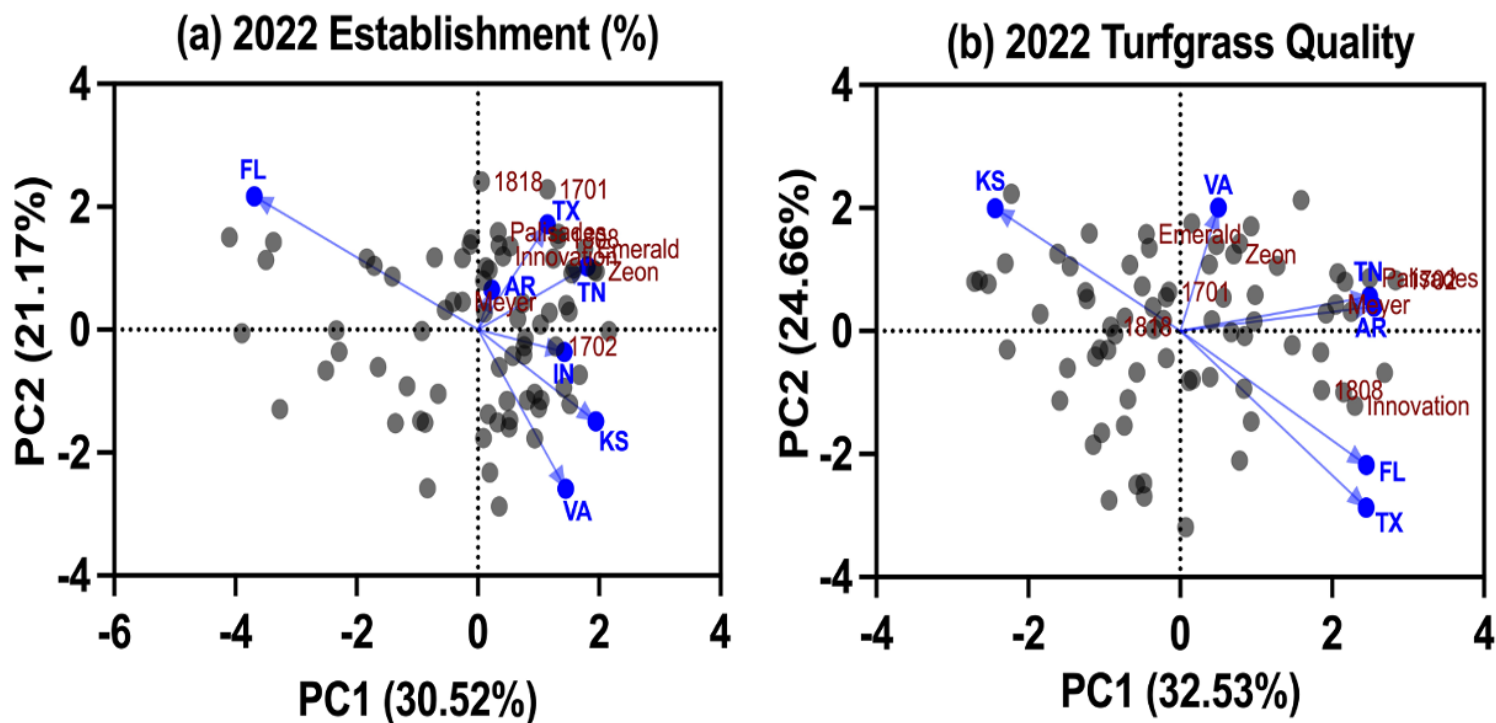


Table 6.4 Turf quality of experimental zoysiagrass entries in the top statistical grouping at seven locations during the summer of 2022 and 2023.

TAES entry code ^b	Turf quality ^a													
	2022							2023						
	AR	FL	IN	KS	TN	TX	VA	AR	FL	IN	KS	TN	TX	VA
DALZ 1702	7.0 ^c	5.7	5.7	5.7	8.3	6.3	6.0	7.0	3.3	5.0	6.0	7.0	5.7	7.7
DALZ 1701	7.0	5.3	5.7	.	7.7	8.3	5.3	7.3	3.7	5.7	.	7.3	7.0	.
DALZ 1808	7.3	4.3	6.3	6.0	7.3	7.3	6.3	6.7	4.0	6.3	6.3	6.7	5.0	8.0
DALZ 1818	7.0	.	.	6.3	7.0	6.7	6.3	7.0	2.7	3.3	6.3	7.0	6.3	7.3
6782-104	5.7	5.0	.	6.3	7.0	7.7	4.7	5.7	3.0	.	8.0	8.3	7.3	7.3
6782-120	6.3	.	.	.	7.3	7.7	4.7	6.7	3.7	.	.	7.7	7.7	.
6782-42	5.7	.	.	6.7	6.7	6.7	5.7	.	2.3	.	7.0	7.3	5.3	7.0
6782-75	6.0	5.0	.	7.0	7.3	7.0	6.0	5.7	3.3	.	7.0	7.7	7.0	7.7
6782-79	6.0	.	.	6.3	7.0	7.0	5.7	6.3	3.7	.	6.7	8.0	7.0	7.7
6783-03	7.0	.	.	.	6.7	7.0	4.3	.	3.3	.	.	7.0	6.0	.
6784-17	6.0	.	.	.	7.0	8.7	5.7	6.7	3.3	.	.	8.0	6.7	6.3
6785-19	6.0	.	.	5.0	6.7	7.3	5.7	6.7	3.3	.	.	7.0	8.0	.
6785-22	6.3	.	.	5.7	7.0	7.0	5.3	6.7	2.7	.	.	7.7	7.3	5.3
6786-02	5.7	.	.	.	7.3	8.0	.	6.3	2.3	.	.	8.0	6.3	.
6787-18	.	.	.	5.7	.	7.0	6.3	7.3	3.7	.	.	7.3	6.3	6.0
6787-20	5.7	.	.	.	.	.	5.3	6.3	3.0	.	.	8.0	.	5.3
6789-23	6.0	4.3	.	.	7.3	8.0	4.7	7.0	3.0	.	.	8.3	8.3	5.3
6789-40	6.0	5.7	.	.	7.0	7.0	5.3	6.0	4.7	.	.	7.7	6.7	7.0
6789-52	7.3	5.0	.	5.0	8.0	7.3	5.0	6.7	3.7	.	6.3	7.0	5.3	7.0
6791-06	.	.	.	.	7.3	6.7	5.0	6.7	2.7	.	.	7.3	6.0	.
6792-44	6.3	.	.	5.0	7.3	6.7	4.7	6.3	3.3	3.1	.	7.7	6.0	7.0
6828-27	6.0	.	.	7.0	7.0	.	6.0	5.0	2.3	.	8.0	8.0	5.0	8.0
6828-53	6.7	.	.	5.0	7.0	.	4.7	6.7	3.3	2.9	6.0	7.0	.	6.3
6828-56	5.7	4.3	.	5.3	7.7	.	6.0	.	3.0	.	.	7.3	.	7.3
6828-77	.	.	.	6.0	7.3	7.0	6.0	.	2.7	.	6.7	7.3	.	7.7
6829-02	6.7	5.0	.	6.3	7.7	8.3	5.0	6.3	3.0	.	7.0	7.3	.	7.0
6829-20	7.3	4.7	.	5.7	8.0	7.0	5.7	6.7	3.7	.	6.3	7.3	5.0	6.7
6829-34	6.0	5.0	.	.	7.3	7.0	5.7	7.7	4.0	.	.	7.3	6.0	8.0
6829-36	6.7	4.3	6.7	5.7	7.7	.	4.7	6.7	4.0	6.3	7.0	7.0	5.0	5.7
6829-69	6.7	6.3	.	6.0	7.0	8.3	.	5.7	4.3	.	6.3	7.7	6.7	5.3
6830-02	6.7	5.0	.	5.7	8.3	7.3	5.3	7.3	3.3	.	7.3	7.3	.	6.3
6830-11	6.0	.	6.3	5.0	7.3	.	5.3	5.3	3.7	6.0	6.7	7.7	.	7.0
6830-39	6.3	5.7	.	6.0	8.0	6.7	5.0	6.7	3.7	.	6.7	7.3	6.0	7.7
6830-56	6.7	4.3	5.3	5.3	7.7	.	4.7	5.0	3.3	5.3	5.7	7.3	.	6.7
6831-09	6.7	5.3	.	6.0	8.3	8.3	5.7	7.0	2.3	3.7	6.0	7.7	5.0	7.3
6835-33	6.7	5.0	.	5.0	7.7	.	6.3	6.7	3.3	2.9	7.0	6.3	.	7.7
6836-09	6.7	5.0	.	6.3	7.0	6.7	5.0	6.7	2.3	.	7.0	7.7	.	8.0
6839-08	6.7	.	5.3	6.0	8.0	6.7	6.3	5.7	5.0	5.7	7.7	7.7	5.0	8.0
6840-20	6.3	4.7	.	5.3	8.3	8.3	5.3	6.7	2.7	3.4	6.7	7.3	7.7	6.7
6844-04	5.7	4.3	6.0	5.3	8.0	6.3	5.0	5.7	3.3	6.0	6.3	8.3	6.0	6.7
6844-104	7.3	.	6.3	5.7	8.0	8.3	6.0	7.0	3.0	7.0	7.7	7.7	5.7	7.3
6844-128	6.3	4.3	5.7	.	7.3	6.3	5.0	6.0	2.7	6.3	.	7.0	5.0	7.0
6844-141	6.3	.	6.0	6.0	8.0	.	.	5.7	2.3	6.0	6.7	7.7	.	.
6844-147	7.0	.	4.3	5.7	7.7	7.3	5.3	7.0	2.3	5.0	7.0	7.0	5.0	6.7
6844-150	6.7	.	.	7.0	7.3	.	5.7	5.7	3.3	4.7	7.3	7.3	5.0	8.0
6844-152	7.3	.	6.7	5.7	8.3	.	4.7	6.0	3.3	5.0	6.7	6.7	.	7.7
6844-154	6.3	4.3	5.7	.	7.7	8.0	5.0	7.0	3.3	5.7	.	7.0	5.0	5.3
6844-190	6.0	.	6.0	5.0	7.3	6.7	4.7	5.0	4.0	6.0	.	7.0	.	6.0
6844-202	6.0	4.7	6.3	6.0	7.3	7.7	6.3	6.0	2.0	6.0	7.7	7.7	5.7	7.7

(Cont.)	2022							2023						
	AR	FL	IN	KS	TN	TX	VA	AR	FL	IN	KS	TN	TX	VA
6844-31	7.0	.	5.3	6.3	7.7	7.3	5.7	6.7	2.7	5.3	6.3	7.7	5.7	7.0
6844-34	7.0	.	6.0	6.0	8.3	6.7	6.0	5.7	3.0	6.3	6.7	7.0	5.0	7.3
6844-36	6.7	.	6.3	6.0	7.7	8.3	5.7	7.3	3.0	5.7	7.7	7.3	5.3	7.7
6844-42	6.7	.	4.7	6.0	7.7	7.3	5.3	6.7	3.0	5.0	6.0	7.0	.	6.3
6844-53	5.7	.	.	6.0	7.7	6.7	6.0	5.7	3.0	3.9	6.7	8.0	6.3	8.0
6844-74	6.3	.	5.7	6.3	7.3	8.3	5.0	5.7	3.0	6.7	6.0	8.7	6.3	7.3
6844-89	6.0	.	6.0	6.0	7.7	.	4.7	.	2.7	5.3	6.7	7.3	.	7.0
6844-91	5.7	.	6.7	.	7.3	.	5.7	5.0	3.0	4.7	.	7.7	.	6.0
6910-157	7.0	.	.	5.3	7.0	7.0	6.0	6.3	3.3	3.4	.	6.3	6.0	7.3
6910-172	7.7	4.3	5.7	5.3	7.7	8.3	6.3	7.0	2.7	4.7	5.7	.	6.7	8.0
6919-29	5.7	.	6.0	5.0	7.3	.	5.3	5.7	2.7	5.3	.	7.7	.	6.7
6923-11	6.7	5.3	5.7	5.3	8.7	7.0	5.7	6.7	2.7	6.0	6.3	6.7	5.3	7.7
6924-44	6.3	.	6.0	5.7	8.3	.	5.0	6.0	2.3	5.7	7.0	7.3	.	6.0
6924-47	6.3	.	6.0	6.0	7.7	.	6.0	.	2.7	4.3	6.3	6.7	5.0	7.7
6924-66	5.7	.	4.7	5.7	7.3	.	5.7	5.7	3.0	4.3	6.3	7.7	.	6.7
6925-53	6.7	.	5.3	5.3	7.7	6.7	6.0	6.3	2.7	4.0	7.3	7.0	.	7.7
6933-11	5.7	.	.	7.3	7.3	7.7	6.0	5.3	2.7	.	7.7	8.3	.	7.3
6940-15	7.0	4.7	6.0	5.0	9.0	7.3	5.3	6.3	4.0	6.0	.	6.7	5.3	7.0
6941-36	7.0	5.3	5.7	5.3	7.7	7.7	5.3	7.3	4.3	5.7	.	6.7	7.3	7.3
6942-22	7.0	4.7	.	5.3	8.7	7.0	5.7	7.0	4.0	4.9	.	7.0	7.0	7.3
Emerald	7.0	5.0	.	6.0	8.0	7.3	6.0	7.3	3.7	3.7	6.7	7.0	7.3	7.0
Innovation	6.7	.	6.0	6.0	7.0	.	5.0	6.0	3.0	6.7	7.0	7.0	6.0	8.0
Meyer	7.0	.	6.0	6.0	7.0	.	5.7	5.7	2.0	5.3	7.3	7.3	5.3	7.3
Palisades	7.3	.	5.7	5.7	8.0	7.7	5.0	7.0	3.3	5.3	6.3	6.3	7.3	7.3
Zeon	7.0	.	.	6.0	8.3	6.3	6.7	7.0	4.0	2.9	5.7	7.3	5.3	7.3
Average	6.5	4.9	5.8	5.8	7.6	7.3	5.5	6.4	3.2	5.1	6.7	7.4	6.1	7.0

^a Turf quality was rated visually on a 1 to 9 scale (1 = dead; 6 = minimally acceptable; 9 = optimum color, density, uniformity, and texture).

^b Texas Agricultural Experiment Station (TAES) entry code

^c Entries with a mean presented occurred in the top statistical grouping by individual location ($P < 0.05$). Means are averages over replications, $n = 3$

Table 6.5 Leaf texture of experimental zoysiagrass entries in the top statistical grouping at seven locations during the summer of 2022.

TAES entry code ^b	Leaf texture ^a						
	AR	IN	FL	KS	TN	TX	VA
DALZ 1702	6.3 ^c	6.0	.	.	7.3	.	.
DALZ 1701	6.7	.	.	.	7.3	.	.
DALZ 1808	6.7	.	.	.	.	.	.
DALZ 1818	6.0	.	.	.	.	.	.
6782-104	6.7	.	8.0	.	9.0	9.0	.
6782-120	6.3	.	8.0	8.5	9.0	8.0	7.7
6782-42	7.0	.	8.0	.	9.0	8.0	.
6782-75	6.7	.	8.0	.	9.0	8.0	.
6782-79	6.7	.	7.3	.	8.7	8.0	.
6783-03	6.7	.	7.7	8.0	9.0	8.3	8.0
6784-17	7.0	.	7.0	8.0	8.3	8.0	7.0
6785-19	7.3	.	7.7	8.3	9.0	8.0	8.0
6785-22	6.7	.	8.0	8.0	8.7	8.0	7.0
6786-02	7.0	.	7.7	8.0	9.0	8.3	7.7
6787-18	7.3	.	8.0	8.3	9.0	8.7	6.7
6787-20	7.3	.	8.0	8.0	9.0	.	8.0
6789-23	7.7	.	7.0	7.7	9.0	8.3	7.0
6789-40	7.0	.	8.0	8.0	9.0	8.0	7.3
6789-52	8.0	.	7.3	.	8.7	8.0	.
6791-06	7.3	.	7.7	8.3	9.0	8.0	7.7
6792-44	6.7	.	7.3	8.0	9.0	8.0	6.7
6828-27	6.7	.	.	.	7.3	.	.
6828-53	6.7	.	7.0	.	8.0	.	.
6828-56	7.3	.	6.7	.	8.0	.	.
6828-77	7.0	.	.	.	7.7	.	.
6829-02	6.7	.	.	.	8.0	.	.
6829-20	7.3	.	.	6.7	7.3	.	.
6829-34	7.0	.	.	7.7	8.0	.	.
6829-36	6.3	6.7	.	6.3	7.3	.	6.7
6829-69	6.7	6.0	.	.	8.3	.	.
6830-02	7.0	.	.	.	8.0	.	.
6830-11	6.3	6.3	.	6.7	.	.	.
6830-39	7.3	.	6.7	.	8.3	8.0	.
6830-56	6.7	6.5	.	7.0	7.7	.	.
6831-09	6.3	6.9	.	6.3	8.0	.	.
6835-33	6.7	.	.	.	8.0	.	.
6836-09	7.3	.	7.0	.	8.3	.	.
6839-08	6.0	7.7	6.7	7.0	7.3	.	6.7
6840-20	6.3	.	6.7	6.7	8.0	.	.
6844-04	7.0	6.0	.	.	7.3	.	.
6844-104	6.0	6.3	.	.	8.0	.	.
6844-128	6.0	.	.	7.7	.	.	7.7
6844-141	6.7	6.0	.	6.7	7.7	.	6.7
6844-147	6.3	6.6	.	6.7	7.7	.	7.3
6844-150	7.0	7.5	6.7	.	7.7	.	.
6844-152	7.0	6.0	.	.	.	.	.
6844-154	6.7	6.1	.	8.0	7.3	.	.
6844-190	6.7	6.3	.	7.7	.	.	.
6844-202	6.3	6.7	.	6.3	7.3	.	.

(Cont.)	AR	IN	FL	KS	TN	TX	VA
6844-31	6.7	6.0	.	6.3	7.3	.	7.0
6844-34	6.3	6.0	.	7.0	.	.	6.7
6844-36	6.0	6.7	.	.	.	.	.
6844-42	6.3	7.2	.	7.0	7.3	.	6.7
6844-53	6.7	.	.	.	7.7	.	.
6844-74	6.3	7.0	.	.	7.3	.	.
6844-89	6.3	7.0	.	6.3	7.7	.	.
6844-91	6.0	.	.	6.7	7.7	.	.
6910-157	6.0	.	.	8.3	7.7	.	.
6910-172	6.0	.	.	8.0	.	.	.
6919-29	6.3	6.0	.	6.3	.	.	.
6923-11	6.7	6.7	.	6.7	.	.	.
6924-44	6.3	6.0	.	7.3	7.7	.	7.0
6924-47	6.7	6.0	.	6.3	7.3	.	.
6924-66	6.3	6.0	.	7.3	.	.	7.0
6925-53	6.7	7.0	.	.	7.7	.	.
6933-11	6.3	.	.	6.3	8.0	.	.
6940-15	6.3	.	.	6.3	.	.	7.0
6941-36	6.3	.	.	8.0	.	.	.
6942-22	6.3	.	.	6.3	7.7	.	6.7
Emerald	7.0	.	6.7	7.0	8.3	.	7.0
Innovation	6.7	6.3	.	6.7	7.7	.	.
Meyer	6.7	.	.	7.7	.	.	.
Palisades	6.3	.	.	.	.	.	.
Zeon	7.0	.	6.7	.	7.7	.	.
<i>Average</i>	6.7	6.5	7.4	7.3	8.1	8.2	7.1

^a Leaf texture was visually rated on a 1 to 9 scale in which 1 = coarse; 9 = fine.

^b Texas Agricultural Experiment Station (TAES) entry code

^c Entries with a mean presented occurred in the top statistical grouping by individual location ($P < 0.05$). Means are averages over replications, $n = 3$

Table 6.6 Winter injury of experimental zoysiagrasses during the early spring at two locations in the transition zone in 2022.

TAES entry code ^b	Winter injury (%) ^a	
	KS	IN
DALZ 1702	0.0	90.0 A ^c
DALZ 1701	1.7	70.0 A
DALZ 1808	0.0	56.7
DALZ 1818	0.0	100.0 A
6782-104	0.0	100.0 A
6782-120	61.7 A	100.0 A
6782-42	0.0	100.0 A
6782-75	0.0	100.0 A
6782-79	0.0	100.0 A
6783-03	50.0 A	100.0 A
6784-17	8.3	100.0 A
6785-19	5.7	100.0 A
6785-22	5.0	100.0 A
6786-02	50.0 A	100.0 A
6787-18	0.0	100.0 A
6787-20	33.3 A	100.0 A
6789-23	39.0 A	100.0 A
6789-40	5.0	100.0 A
6789-52	0.0	100.0 A
6791-06	5.0	100.0 A
6792-44	11.7	100.0 A
6828-27	0.0	100.0 A
6828-53	2.3	100.0 A
6828-56	10.7	100.0 A
6828-77	0.0	100.0 A
6829-02	0.0	100.0 A
6829-20	0.0	100.0 A
6829-34	3.3	100.0 A
6829-36	0.0	23.3
6829-69	0.0	100.0 A
6830-02	0.0	100.0 A
6830-11	1.7	26.7
6830-39	0.0	100.0 A
6830-56	1.7	41.7
6831-09	0.0	100.0 A
6835-33	0.0	100.0 A
6836-09	0.0	100.0 A
6839-08	0.0	88.3 A
6840-20	0.0	96.7 A
6844-04	0.0	8.3
6844-104	0.0	30.0
6844-128	1.7	13.3
6844-141	0.0	18.3
6844-147	0.0	71.7 A
6844-150	0.0	81.7 A
6844-152	0.0	26.7
6844-154	5.0	53.3
6844-190	0.0	16.7
6844-202	0.0	56.7

(Cont.)	KS	IN
6844-31	0.0	43.3
6844-34	0.0	23.3
6844-36	0.0	31.7
6844-42	0.0	91.7 A
6844-53	0.0	95.0 A
6844-74	1.7	45.0
6844-89	0.0	46.7
6844-91	3.0	5.0
6910-157	1.7	100.0 A
6910-172	0.0	86.7 A
6919-29	0.0	18.3
6923-11	13.3	40.0
6924-44	5.0	21.7
6924-47	0.0	21.7
6924-66	1.7	85.0 A
6925-53	0.0	86.7 A
6933-11	0.0	100.0 A
6940-15	4.0	53.3
6941-36	0.0	61.7 A
6942-22	0.0	98.3 A
Emerald	0.0	98.3 A
Innovati	0.0	36.7
Meyer	0.0	11.7
Palisade	0.7	86.7 A
Zeon	0.0	100.0 A
Average	4.5	73.8

^a Winter injury was visually rated on a 0 to 100% scale in which 0% = no winter injury; and 100% = complete winter injury

^b Texas Agricultural Experiment Station (TAES) entry code

^c Means followed by a capital 'A' in a column suffered significantly more winter injury ($P < 0.05$). Means are averages over replications, $n = 3$.

Table 6.7 Spring greenup of experimental zoysiagrass entries in the top statistical grouping at five locations during the spring of 2023.

TAES entry code ^b	Spring greenup ^a				
	FL	IN	KS	TN	TX
DALZ 1702	6.7 ^c	4.7	7.0	8.3	4.7
DALZ 1701	.	4.3	7.0	8.0	5.7
DALZ 1808	5.3	4.7	8.0	8.7	5.0
DALZ 1818	.	5.0	6.7	8.0	5.0
6782-104	6.0	.	7.0	.	6.7
6782-120	6.0	.	.	.	5.3
6782-42	6.3	.	7.7	.	3.7
6782-75	6.7	.	7.0	.	6.3
6782-79	6.0	.	7.7	5.3	7.0
6783-03	6.7	.	.	.	5.0
6784-17	.	.	4.7	6.0	4.7
6785-19	5.7	.	.	6.7	7.7
6785-22	6.0	.	.	6.7	7.0
6786-02	6.0	.	.	.	5.0
6787-18	5.3	.	5.3	6.0	6.0
6787-20	5.3	.	.	7.0	.
6789-23	.	.	.	7.0	6.7
6789-40	6.0	.	.	6.0	6.0
6789-52	6.7	.	6.3	5.3	4.0
6791-06	6.0	.	.	6.3	5.7
6792-44	6.3	4.5	.	7.0	6.0
6828-27	.	3.6	6.3	8.0	3.7
6828-53	.	2.6	7.7	.	.
6828-56	.	.	5.7	7.0	.
6828-77	.	.	7.3	6.0	.
6829-02	.	.	7.0	7.3	4.3
6829-20	7.3	.	6.7	6.0	4.3
6829-34	6.3	1.9	5.3	7.0	4.3
6829-36	.	6.3	7.3	8.7	3.7
6829-69	6.0	.	6.7	8.0	5.3
6830-02	6.0	.	7.3	7.0	3.7
6830-11	.	7.3	5.7	8.7	.
6830-39	6.0	.	7.7	6.0	.
6830-56	.	5.0	5.0	7.3	.
6831-09	5.3	3.7	6.3	5.3	4.0
6835-33	.	2.8	8.0	5.3	.
6836-09	.	.	7.0	7.7	5.0
6839-08	.	6.0	5.3	7.0	5.7
6840-20	.	3.3	7.7	7.3	4.7
6844-04	.	6.7	6.7	8.7	5.0
6844-104	.	5.3	7.7	8.7	4.3
6844-128	.	5.7	6.0	9.0	5.0
6844-141	.	5.0	6.0	6.3	4.0
6844-147	.	4.3	6.0	7.7	4.3
6844-150	.	6.0	7.3	8.7	3.7
6844-152	.	5.0	7.7	8.3	5.7
6844-154	.	4.7	5.0	9.0	4.7
6844-190	.	4.0	.	8.0	4.0
6844-202	.	5.7	8.0	8.3	5.3
6844-31	.	4.0	6.3	8.0	6.0

(Cont.)	FL	IN	KS	TN	TX
6844-34	.	6.0	.	7.3	4.0
6844-36	.	4.7	7.0	8.7	5.0
6844-42	.	4.7	6.3	7.0	3.7
6844-53	.	3.8	7.0	8.0	4.0
6844-74	.	6.3	5.3	9.0	5.7
6844-89	.	6.0	6.0	7.3	4.7
6844-91	.	4.3	6.0	9.0	.
6910-157	6.3	3.8	.	5.3	4.3
6910-172	.	3.7	.	7.7	5.3
6919-29	.	6.3	5.0	9.0	3.7
6923-11	.	4.7	8.0	5.3	.
6924-44	.	5.7	7.0	6.0	.
6924-47	.	4.0	6.7	8.3	4.0
6924-66	.	3.3	.	8.7	.
6925-53	.	3.7	7.7	7.7	4.0
6933-11	.	.	7.3	7.3	3.7
6940-15	.	5.3	5.3	8.3	4.7
6941-36	5.3	3.0	5.7	8.0	6.0
6942-22	7.0	6.3	6.7	5.3	5.7
Emerald	.	4.3	5.0	7.3	7.7
Innovation	.	5.7	7.0	9.0	.
Meyer	.	5.7	7.3	9.0	4.7
Palisades	.	4.7	6.7	6.7	4.7
Zeon	5.3	.	6.7	6.7	5.3
Average	6.1	4.7	6.6	7.4	5.0

^a Spring greenup was visually rated on a 1 to 9 scale in which 1 = brown/straw/dead; 9 = dark green.

^b Texas Agricultural Experiment Station (TAES) entry code

^c Entries with a mean presented occurred in the top statistical grouping by individual location ($P < 0.05$). Means are averages over replications, $n = 3$

Table 6.8 Shade tolerance^a of experimental zoysiagrasses in Dallas, TX in 2022-2023 .

TAES entry code ^b	Turf quality ^c		Genetic color ^d		Leaf texture ^e		Spring greenup ^f	
6782-104	8.0	A ^g	8.7	A	7.3	A	5.3	A
6792-44	7.7	A	8.0	A	7.0	A	5.0	A
6789-23	7.0	A	8.7	A	7.0	A	5.3	A
6785-19	7.0	A	8.7	A	7.0	A	3.3	A
6785-22	7.0	A	8.0	A	7.0	A	3.3	A
6840-20	7.0	A	7.7	A	6.0		1.7	
6829-02	6.7	A	7.7	A	6.0		3.0	
6783-03	6.7	A	8.0	A	6.7	A	2.7	
6782-120	6.3	A	8.7	A	6.7	A	6.3	A
6789-40	6.3	A	8.3	A	7.7	A	4.0	A
6784-17	6.3	A	8.0	A	7.0	A	4.0	A
6786-02	6.3	A	8.3	A	7.0	A	3.7	A
6941-36	6.3	A	7.7	A	4.0		3.0	
6844-154	6.3	A	7.0	A	5.0		2.3	
Emerald	6.0	A	8.0	A	6.0		5.0	A
6782-42	6.0	A	8.3	A	7.3	A	4.3	A
6942-22	6.0	A	7.3	A	6.0		4.0	A
6787-18	6.0	A	8.3	A	7.0	A	3.0	
6933-11	6.0	A	8.0	A	5.3		2.3	
6782-75	5.7	A	8.7	A	7.0	A	5.3	A
6844-147	5.7	A	7.3	A	5.0		1.7	
6923-11	5.7	A	7.7	A	5.0		1.3	
Palisades	5.3	A	7.7	A	3.0		2.7	
6831-09	5.3	A	7.7	A	6.0		2.3	
DALZ 1808	5.3	A	7.0	A	5.0		2.3	
6940-15	5.3	A	7.0	A	4.3		2.3	
6844-36	5.3	A	8.0	A	5.7		2.0	
6924-66	5.3	A	7.7	A	5.0		2.0	
6844-104	5.3	A	7.0	A	6.0		2.0	
6919-29	5.3	A	7.7	A	5.3		1.7	
6844-141	5.3	A	7.7	A	5.0		1.3	
6844-202	5.3	A	7.0	A	5.3		1.0	
DALZ 1701	5.0		8.0	A	4.7		3.0	
6782-79	5.0		6.7	A	6.7	A	2.3	
6839-08	5.0		7.3	A	6.0		2.0	
DALZ 1818	5.0		7.7	A	4.7		1.7	
6844-74	5.0		7.7	A	5.7		1.3	
6791-06	4.7		7.3	A	7.0	A	5.3	A
6836-09	4.7		7.7	A	6.0		2.7	
6829-34	4.7		7.3	A	5.7		2.7	
6830-02	4.7		7.0	A	6.0		2.3	
Zeon	4.7		7.0	A	6.0		2.3	
6828-27	4.7		6.7	A	5.7		2.3	
6844-128	4.7		6.7	A	4.3		2.3	
6828-56	4.7		7.0	A	6.0		1.0	
6844-190	4.7		7.0	A	5.0		1.0	
6910-172	4.7		7.0	A	4.0		1.0	
DALZ 1702	4.3		7.0	A	5.0		3.7	A
6789-52	4.3		7.3	A	6.7	A	3.0	
6829-69	4.3		7.0	A	5.7		2.7	
6829-20	4.3		7.0	A	5.3		2.3	
6830-39	4.3		6.7	A	6.0		1.3	
6844-31	4.3		7.7	A	5.3		1.0	
Innovation	4.3		7.3	A	5.7		1.0	

(Cont.)	Turf quality	Genetic color	Leaf texture	Spring greenup
6844-04	4.0	8.0 A	5.0	2.0
6925-53	4.0	7.7 A	5.3	2.0
6844-34	4.0	7.0 A	5.0	1.7
Meyer	4.0	7.0 A	4.0	1.7
6830-11	4.0	7.0 A	5.0	1.3
6829-36	4.0	6.7 A	5.7	1.3
6844-150	4.0	7.3 A	5.3	1.0
6844-42	4.0	7.0 A	5.3	1.0
6844-91	4.0	7.0 A	5.0	1.0
6844-152	3.7	6.3	5.7	1.7
6844-53	3.7	7.0 A	5.7	1.3
6828-77	3.7	6.7 A	6.0	1.3
6924-47	3.7	6.0	5.0	1.3
6828-53	3.7	7.0 A	5.7	1.0
6910-157	3.7	6.0	5.0	1.0
6844-89	3.3	7.0 A	5.7	1.3
6835-33	2.7	5.7	6.0	1.7
6830-56	2.7	5.3	5.0	1.3
6924-44	2.7	5.7	5.7	1.0

^a Shade tolerance was evaluated under 63% shade.

^b Texas Agricultural Experiment Station (TAES) entry code.

^c Turf quality visually rated on a 1-9 scale (1 = lowest quality; 6 = minimum acceptable quality; 9 = maximum quality).

^d Genetic color visually rated on a 1-9 scale (1 = brown/straw/dead; 9 = dark green)

^e Leaf texture visually rated on a 1-9 scale (1 = coarse; 9 = fine).

^f Spring greenup visually rated on a 1-9 scale (1 = brown/straw/dead; 9 = dark green)

^g Means followed by a capital 'A' in a column are not significantly different ($P < 0.05$). Means are averages over replications, $n = 3$.

Table 6.9 Drought tolerance of experimental zoysiagrasses in Florida in 2023.

TAES entry code ^c	Green cover (%) ^{a,b}							
	Drought Period				Recovery Period			
	4-May		8-May		11-May		15-May	
6829-69	93.3	A ^d	30.0	A	80.0	A	86.7	A
6942-22	86.7	A	60.0	A	85.0	A	86.7	A
6941-36	83.3	A	53.3	A	78.3	A	85.0	A
6829-34	81.7	A	33.3	A	71.7	A	81.7	A
6840-20	83.3	A	50.0	A	76.7	A	81.7	A
6789-40	85.0	A	30.0	A	71.7	A	78.3	A
DALZ 1702	93.3	A	40.0	A	66.7	A	78.3	A
6829-36	76.7	A	13.3	A	61.7	A	76.7	A
6830-02	86.7	A	18.3	A	53.3	A	76.7	A
6940-15	81.7	A	40.0	A	60.0	A	76.7	A
6782-75	63.3	A	50.0	A	68.3	A	73.3	A
6829-02	71.7	A	21.7	A	60.0	A	71.7	A
DALZ 1701	66.7	A	6.7		56.7	A	70.0	A
DALZ 1808	73.3	A	8.3		46.7	A	70.0	A
Emerald	75.0	A	46.7	A	66.7	A	70.0	A
6844-202	68.3	A	25.0	A	49.6	A	68.3	A
6844-154	60.0	A	10.0		45.0	A	66.7	A
6828-56	58.3	A	25.0	A	61.7	A	66.7	A
6787-20	68.3	A	43.3	A	60.0	A	65.0	A
6782-104	50.0	A	35.0	A	53.3	A	63.3	A
6783-03	66.7	A	43.3	A	60.0	A	63.3	A
6786-02	63.3	A	15.0	A	40.0		61.7	A
6844-104	60.0	A	15.0	A	46.7	A	61.7	A
6787-18	46.7	A	18.3	A	50.0	A	61.7	A
6784-17	56.7	A	36.7	A	55.0	A	61.7	A
6782-79	61.7	A	43.3	A	58.3	A	61.7	A
6829-20	65.0	A	50.0	A	51.7	A	61.7	A
6844-36	53.3	A	6.7		40.0		60.0	A
6789-52	76.7	A	25.0	A	46.7	A	60.0	A
6782-120	63.3	A	36.7	A	50.0	A	60.0	A
6830-39	81.7	A	5.0		20.0		58.3	A
6828-77	53.3	A	18.3	A	43.3	A	58.3	A
6789-23	58.3	A	30.0	A	51.7	A	58.3	A
6836-09	52.4	A	18.6	A	39.3		58.2	A
6910-172	55.0	A	16.7	A	46.7	A	56.7	A
Zeon	50.0	A	8.3		40.0		55.0	A
6844-152	55.0	A	15.0	A	46.7	A	55.0	A
6844-34	53.3	A	18.3	A	45.0	A	53.3	A
6828-27	51.7	A	25.0	A	40.0		53.3	A
6923-11	50.0	A	3.3		30.0		51.7	A
6844-74	48.3	A	11.7		26.7		50.0	A
6828-53	56.7	A	13.3	A	40.0		50.0	A
6830-56	63.3	A	5.0		33.3		48.3	A
6830-11	46.7	A	21.7	A	38.3		48.3	A
6844-53	51.7	A	26.7	A	35.0		48.3	A
6782-42	46.7	A	30.0	A	38.3		48.3	A
6839-08	40.0	A	5.0		26.7		46.7	A
6924-44	41.7	A	8.3		43.3	A	46.7	A
6844-91	53.3	A	13.3	A	46.7	A	46.7	A
6844-128	50.0	A	21.7	A	33.3		46.7	A

(Cont.)	4-May		8-May		11-May		15-May	
Palisades	51.7	A	23.3	A	45.0	A	46.7	A
6791-06	40.0	A	26.7	A	41.7		46.7	A
6785-22	43.3	A	30.0	A	40.0		46.7	A
DALZ 1818	46.7	A	11.7		26.7		45.0	A
6910-157	40.0	A	21.7	A	35.0		45.0	A
6831-09	53.3	A	5.0		43.3	A	43.3	A
6844-04	48.3	A	11.7		40.0		43.3	A
6844-150	36.7		5.0		20.0		41.7	A
6933-11	38.3		23.3	A	38.3		41.7	A
6844-89	51.7	A	10.0		26.7		40.0	
6844-141	36.7		5.0		23.3		38.3	
Innovation	38.3		10.0		31.7		38.3	
6792-44	31.7		13.3	A	30.0		38.3	
6844-190	33.3		15.0	A	33.3		38.3	
6785-19	40.0	A	16.7	A	33.3		38.3	
6844-147	40.0	A	18.3	A	36.7		38.3	
6844-42	36.7		1.7		26.7		36.7	
6844-31	36.7		10.0		16.7		36.7	
6919-29	36.7		11.7		26.7		36.7	
6924-47	31.7		5.0		30.0		30.0	
6925-53	20.0		3.3		15.0		26.7	
Meyer	58.3	A	13.3	A	23.3		25.0	
6835-33	43.3	A	1.7		15.0		16.7	
6924-66	6.7		1.7		6.7		8.3	

^a Experimental plots were irrigated on the morning of 1 May 2023 and then withheld for 7 days. Irrigation resumed on 8 May 2023.

^b Green cover was visually rated on a 0 to 100% scale in which 0% = no green cover; and 100% = complete green cover.

^c Texas Agricultural Experiment Station (TAES) entry code

^d Means followed by a capital 'A' in a column are not significantly different ($P < 0.05$). Means are averages over replications, $n = 3$.

Table 6.10 Divot recovery of experimental zoysiagrass in Arkansas in 2023.

TAES entry code ^c	Divot recovery (%) ^{a,b}			
	1-Sept	8-Sept	19-Sept	
6844-34	36.8	40.4	82.9	A ^d
6844-190	35.7	32.2	81.1	A
6828-53	39.3	44.1	78.9	A
6784-17	37.6	43.5	78.6	A
6919-29	43.9	48.7	78.3	A
6924-44	39.8	44.2	77.9	A
6844-89	41.5	42.8	77.4	A
6941-36	36.9	44.3	77.0	A
6844-91	32.4	39.3	76.9	A
6828-77	33.5	36.3	76.1	A
6844-147	33.3	35.5	75.8	A
6844-31	28.8	35.8	75.3	A
6829-69	29.2	36.8	75.2	A
6844-74	39.3	44.4	74.8	A
6782-75	34.0	41.7	74.8	A
6910-172	36.8	42.4	74.8	A
6783-03	38.8	46.4	74.4	A
DALZ 1818	42.8	48.2	74.2	A
6923-11	40.2	43.3	74.1	A
6844-04	36.8	41.9	73.9	A
6844-36	34.9	39.2	73.9	A
6789-52	38.6	40.4	73.9	A
DALZ 1702	39.8	40.9	73.8	A
6844-150	41.3	41.6	73.7	A
DALZ 1701	35.1	40.5	73.3	A
6910-157	36.4	41.1	73.3	A
6925-53	40.5	43.3	73.0	A
6835-33	44.1	43.2	72.8	A
6844-42	31.5	33.9	72.7	A
6829-08	36.7	36.0	72.2	A
6785-22	38.8	43.9	71.8	A
6924-66	32.7	37.3	71.6	A
Palisades	39.2	39.8	71.4	A
6844-202	37.5	37.0	71.4	A
6924-47	44.9	45.7	71.4	A
6933-11	34.9	37.6	71.3	A
6831-09	24.2	44.5	71.2	A
6828-27	43.3	45.9	70.9	A
6829-34	32.5	44.2	70.7	A
6844-104	35.0	39.4	70.7	A
6791-06	36.7	39.4	70.5	A
6844-152	38.2	43.9	70.5	A
Emerald	37.1	43.5	70.4	A
6844-141	38.6	46.3	70.3	A
Zeon	35.2	41.7	69.8	A
6830-02	42.0	47.1	69.6	A
6839-08	38.8	42.5	69.3	A
6782-79	34.7	44.8	69.2	A
Meyer	36.9	41.4	69.0	A
6829-36	39.8	44.9	68.8	A
6828-56	34.8	37.2	68.8	A

(Cont.)	1-Sept	8-Sept	19-Sept	
6786-08	41.4	43.2	68.6	A
6782-42	37.3	39.6	67.8	A
6782-120	34.4	36.0	67.7	A
6940-15	29.6	35.6	67.6	A
6844-128	35.1	37.9	67.2	A
6840-20	41.4	42.9	67.2	A
DALZ 1808	35.8	42.6	67.2	A
6829-20	40.2	41.2	66.9	A
6782-104	39.1	41.3	66.1	A
6830-11	34.8	35.3	65.0	A
6830-39	33.6	43.5	64.9	A
6792-44	40.5	40.4	64.8	A
6836-09	35.3	38.3	63.8	A
6789-40	24.5	27.5	63.4	A
6844-154	37.8	38.8	63.0	A
6830-56	39.1	35.4	62.9	A
6942-22	34.7	37.8	62.3	A
Innovation	41.1	38.1	61.7	A
6785-19	34.3	42.1	59.6	A
6787-20	27.9	35.9	58.7	A
6787-18	38.2	44.1	57.9	A
6789-23	30.1	35.8	46.9	
6844-53	28.5	27.8	43.6	

^a Standardized divots (5cm x 10cm) were cut from each plot on 1 September 2023 using a modified edger and then backfilled with topdressing sand.

^b Recovery was monitored for each divot by collecting digital images and analyzed for turf coverage.

^c Texas Agricultural Experiment Station (TAES) entry code.

^d Means followed by a capital 'A' in a column are not significantly different and occurred in the top statistical group ($P < 0.05$). Means are averages over replications, $n = 3$.

Table 6.11 Traffic tolerance of experimental zoysiagrasses after simulated traffic events in Tennessee in 2022 and 2023.

TAES entry code ^c	Green cover (%) ^a							
	0 traffic events ^b		10 traffic events		20 traffic events		30 traffic events	
	2022	2023	2022	2023	2022	2023	2022	2023
6836-09	96.5	A ^d	96.3	A	81.9	A	77.9	A
6787-20	97.1	A	96.3	A	85.2	A	77.9	A
6844-190	86.3		96.2	A	68.1	A	77.8	A
6828-53	95.2	A	96.2	A	75.4	A	77.8	A
6829-02	98.4	A	96.0	A	89.1	A	77.6	A
6923-11	92.4	A	96.0	A	72.5	A	77.6	A
6828-56	94.2	A	95.7	A	69.4	A	77.3	A
6789-40	97.0	A	95.7	A	78.2	A	77.2	A
6844-36	92.4	A	95.5	A	73.2	A	77.1	A
6785-19	96.5	A	95.5	A	81.2	A	77.1	A
6844-74	96.7	A	95.4	A	83.0	A	77.0	A
6830-39	91.1	A	95.4	A	67.9	A	77.0	A
DALZ 1702	90.7	A	95.3	A	80.3	A	76.9	A
6844-91	92.3	A	95.3	A	76.2	A	76.9	A
6910-157	96.0	A	95.2	A	78.3	A	76.8	A
6787-18	96.9	A	95.1	A	83.0	A	76.7	A
6844-141	94.1	A	95.1	A	70.2	A	76.7	A
6844-31	92.6	A	95.0	A	70.9	A	76.6	A
DALZ 1701	97.2	A	94.9	A	88.4	A	76.5	A
6844-147	96.2	A	94.9	A	69.8	A	76.5	A
6791-06	97.8	A	95.0	A	83.6	A	76.5	A
DALZ 1818	98.0	A	94.8	A	82.3	A	76.4	A
6844-34	90.1	A	94.8	A	68.9	A	76.4	A
6829-20	94.8	A	94.8	A	80.0	A	76.4	A
6828-77	95.8	A	94.7	A	82.5	A	76.3	A
6782-104	98.1	A	94.7	A	86.4	A	76.3	A
6830-02	94.3	A	94.6	A	71.5	A	76.2	A
6844-128	91.8	A	94.5	A	64.8	A	76.1	A
6830-56	94.7	A	94.6	A	80.5	A	76.1	A
Zeon	96.7	A	94.5	A	74.8	A	76.1	A
6844-202	94.6	A	94.5	A	80.4	A	76.1	A
6844-53	97.3	A	94.3	A	82.6	A	75.9	A
6786-02	97.3	A	94.3	A	81.2	A	75.9	A
6789-23	99.1	A	94.2	A	91.8	A	75.8	A
6829-69	99.0	A	94.3	A	85.8	A	75.8	A
6844-04	89.9	A	94.2	A	74.7	A	75.8	A
6829-36	95.0	A	94.2	A	57.1		75.7	A
6789-52	93.2	A	94.1	A	52.5		75.7	A
6933-11	96.8	A	94.1	A	82.3	A	75.7	A
6844-154	94.0	A	94.0	A	66.4	A	75.6	A
6924-44	92.8	A	94.0	A	47.1		75.6	A
6844-42	91.8	A	93.9	A	61.3	A	75.5	A
6829-34	97.3	A	94.0	A	84.8	A	75.5	A
6782-79	96.1	A	93.7	A	80.1	A	75.3	A
6785-22	98.0	A	93.7	A	85.6	A	75.3	A
6835-33	87.8	A	93.6	A	48.1		75.2	A
Innovation	92.1	A	93.6	A	67.3	A	75.2	A
6828-27	93.5	A	93.5	A	73.3	A	75.1	A

(Cont.)	0		0		10		10		20		20		30	
6919-29	91.6	A	93.5	A	78.2	A	75.1	A	69.0	A	62.7	A	42.9	40.7
6830-11	94.4	A	93.5	A	72.8	A	75.0	A	61.9	A	62.7	A	38.8	36.6
6941-36	98.4	A	93.1	A	93.9	A	74.7	A	89.9	A	62.3	A	52.5	50.2
6844-152	84.8		93.0	A	64.8	A	74.6	A	54.0	A	62.2	A	35.3	33.0
6840-20	93.1	A	92.9	A	61.1	A	74.5	A	48.3		62.1	A	29.4	27.2
6940-15	95.9	A	92.7	A	84.2	A	74.2	A	75.9	A	61.9	A	39.7	37.4
6925-53	93.6	A	92.3	A	80.9	A	73.9	A	71.9	A	61.6	A	36.9	34.7
6831-09	93.6	A	92.1	A	53.8		73.7	A	41.1		61.4	A	35.0	32.8
6784-17	93.1	A	92.2	A	56.7		73.7	A	44.4		61.4	A	50.8	48.6
6844-150	97.4	A	92.2	A	87.1	A	73.7	A	79.3	A	61.4	A	42.3	40.1
6844-104	94.8	A	92.1	A	75.4	A	73.7	A	63.6	A	61.3	A	38.0	35.8
6942-22	93.7	A	92.0	A	76.5	A	73.6	A	66.3	A	61.3	A	22.2	20.0
6782-42	94.7	A	91.9	A	80.1	A	73.5	A	69.8	A	61.1	A	42.6	40.4
6924-66	90.6	A	91.8	A	57.0		73.4	A	43.1		61.1	A	46.5	44.2
6782-75	97.9	A	91.8	A	83.4	A	73.3	A	72.8	A	61.0	A	41.3	39.1
6783-03	95.6	A	91.6	A	82.0	A	73.2	A	71.6	A	60.8	A	43.4	41.2
6782-120	96.9	A	91.5	A	82.1	A	73.1	A	72.7	A	60.7	A	42.4	40.2
6839-08	89.3	A	91.4	A	61.6	A	73.0	A	50.5		60.6	A	39.9	37.6
6924-47	93.2	A	91.0	A	64.8	A	72.5	A	53.0	A	60.2	A	31.5	29.2
6844-89	91.6	A	90.5	A	40.2		72.1	A	27.9		59.7	A	31.1	28.8
Meyer	95.3	A	90.4	A	78.1	A	72.0	A	67.7	A	59.6	A	45.1	42.9
DALZ 1808	96.9	A	90.4	A	79.9	A	71.9	A	69.9	A	59.6	A	34.4	32.2
6792-44	98.8	A	90.2	A	87.4	A	71.8	A	77.7	A	59.4	A	59.2	57.0
Palisades	95.7	A	89.4	A	79.1	A	71.0	A	70.7	A	58.6	A	22.5	20.3
6910-172	97.0	A	88.9	A	86.4	A	70.5	A	78.3	A	58.1	A	42.7	40.5
Emerald	95.6	A	87.5	A	71.4	A	69.1	A	59.1	A	56.7	A	28.4	26.2
<i>Average</i>	94.6		93.7		74.8		75.2		64.5		62.9		40.4	38.1

^a Turf Analyzer Software was used to evaluate green cover on a 0 to 100% scale (0% = no green cover; 100% = complete green cover).

^b Traffic events were simulated with a 4-ft wide modified Cody Traffic Simulator. One pass with the trafficker is equivalent to 57 cleat marks/ft². Five simulated traffic events were initiated in August of 2022 and 2023 and applied weekly, for a total of 30 traffic events each year.

^c Texas Agricultural Experiment Station (TAES) entry code

^d Means followed by a capital 'A' in a column are not significantly different and occurred in the top statistical group ($P < 0.05$). Means are averages over replication, $n = 3$.

Table 6.12 Turf performance index (TPI) based on observational ratings of experimental plots from 2021 to 2023 in Kansas.

TAES entry code ^a	Establishment (3 max)	Turf quality (5 max)	Genetic color (2 max)	Fall color (2 max)	Spring greenup (3 max)	Winter injury (2 max)	Wilt (1 max)	Total TPI ^b (18 max)
DALZ 1818	3	5	2	1	3	2	1	17
6782-104	3	5	2	1	3	2	1	17
6782-42	3	5	2	1	3	2	1	17
6782-75	3	5	2	1	3	2	1	17
6782-79	3	5	2	1	3	2	1	17
6830-02	3	5	2	1	3	2	1	17
6844-152	3	5	2	1	3	2	1	17
6844-53	3	5	2	1	3	2	1	17
6933-11	3	5	2	1	3	2	1	17
Innovation	3	5	2	1	3	2	1	17
DALZ 1808	3	5	1	1	3	2	1	16
6828-77	3	5	2	0	3	2	1	16
6829-02	3	5	2	0	3	2	1	16
6829-20	3	5	2	1	3	2	0	16
6830-39	2	5	2	1	3	2	1	16
6836-09	3	4	2	1	3	2	1	16
6844-104	2	5	2	1	3	2	1	16
6844-150	3	5	2	0	3	2	1	16
6844-31	3	4	2	1	3	2	1	16
6844-36	3	5	2	0	3	2	1	16
6844-42	3	5	1	1	3	2	1	16
6924-44	3	5	2	1	2	2	1	16
Meyer	3	5	2	0	3	2	1	16
Palisades	3	4	2	1	3	2	1	16
DALZ 1702	3	5	1	0	3	2	1	15
6789-52	2	5	2	1	3	2	0	15
6829-36	3	5	2	0	2	2	1	15
6829-69	3	5	1	0	3	2	1	15
6831-09	3	5	2	0	3	2	0	15
6835-33	2	5	2	0	3	2	1	15
6840-20	2	5	2	0	3	2	1	15
6844-04	2	5	2	0	3	2	1	15
6844-141	3	4	2	1	2	2	1	15
6844-147	3	4	2	0	3	2	1	15
6844-202	2	5	2	1	2	2	1	15
6924-47	3	4	2	1	2	2	1	15
6925-53	2	5	2	0	3	2	1	15
6942-22	3	4	2	1	2	2	1	15
Zeon	3	4	2	1	2	2	1	15
6828-27	3	4	2	0	2	2	1	14
6828-53	2	4	2	1	2	2	1	14
6839-08	3	4	2	1	1	2	1	14
6844-89	3	3	2	1	3	2	0	14
6923-11	2	4	2	1	2	2	1	14
Emerald	3	3	2	0	2	2	1	13
6830-11	3	2	2	1	2	2	0	12
6830-56	3	3	2	0	1	2	1	12
6844-128	2	2	2	1	2	2	1	12
6844-74	3	3	2	0	1	2	1	12
DALZ 1701	2	1	2	1	2	2	1	11
6787-18	2	2	2	2	1	1	1	11
6829-34	2	1	2	1	2	2	1	11

(Cont.)	Establishment (3 max)	Turf Quality (5 max)	Genetic color (2 max)	Fall color (2 max)	Spring greenup (3 max)	Winter injury (2 max)	Wilt (1 max)	Total TPI (18 max)
6844-34	3	4	1	0	1	1	1	11
6844-91	2	1	2	1	2	2	1	11
6910-172	3	3	2	0	1	1	1	11
6940-15	2	2	2	1	1	2	1	11
6941-36	2	1	2	1	2	2	1	11
6828-56	2	2	2	0	2	2	0	10
6844-154	2	1	2	2	1	1	1	10
6844-190	2	2	2	1	0	2	1	10
6910-157	2	2	2	2	0	1	1	10
6919-29	3	1	2	0	3	1	0	10
6924-66	3	3	2	0	0	2	0	10
6784-17	2	0	2	2	1	1	1	9
6785-22	2	1	2	2	0	1	1	9
6791-06	2	0	2	2	0	1	1	8
6792-44	1	1	2	2	0	1	1	8
6783-03	0	0	2	2	0	0	1	5
6785-19	0	1	1	2	0	1	0	5
6789-23	0	0	2	2	0	0	1	5
6789-40	0	0	2	1	0	1	1	5
6787-20	0	0	1	2	0	1	0	4
6786-02	0	0	1	2	0	0	0	3
6782-120	0	0	0	2	0	0	0	2

^a Texas Agricultural Experiment Station (TAES) entry code.

^b Turf performance index (TPI) represents the number of times an entry occurred in the top statistical grouping across data collection events. Means highlighted in green are best performers, those in yellow are moderate, those in red are poorest.

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Chapter 7 - Summary of zoysiagrass research conducted between 2020 and 2023

Aerification Effects on Thatch, Rooting, and Quality of ‘Innovation’ Zoysiagrass

This study was conducted from 2020 to 2022 to determine the influence of aerification intensities on thatch levels, rooting, and turfgrass quality of Innovation zoysiagrass. The results from this three-year study indicated that aerification decreased organic matter in the surface 1-inch compared to nonaerified turf. Nonaerified turf had an average organic matter content of 16%, whereas intensively aerified turf had an average organic matter content of 11%. Zoysiagrass that was moderately aerified significantly enhanced rooting at the 0-3, 3-6, and 6-9 cm depths below the soil surface. Under conditions evaluated throughout this three year study, turf quality was significantly reduced when zoysiagrass was intensively aerified (20% to 54% of surface area impacted) compared to nonaerified turf. This was likely due to the amount of injury which occurred from intensive aerification. However, turf color was significantly higher in intensively aerified treatments compared to nonaerified turf. Research herein suggests moderately aerifying Innovation zoysiagrass can reduce organic matter and increase rooting, while also enhancing turf quality and color compared to nonaerified turf. Intensively aerifying Innovation zoysiagrass during the summer months might impede healthy growth of the zoysiagrass sward.

Nitrogen and Mowing Height Effects on Zoysiagrass Grow-in, Thatch Accumulation, and Post-harvest Rooting

This study was conducted from 2021 to 2023 to evaluate how nitrogen rate and mowing height influence establishment rate, turf quality, thatch accumulation, and post-harvest root strength of DALZ 1808, Innovation, and Meyer zoysiagrass from sprigs. Sprigs were planted in

the summer of 2021 and two nitrogen rates (77 kg N ha⁻¹ or 175 kg N ha⁻¹) were evaluated throughout the establishment period. During the early summer of 2022, the trial was rearranged to incorporate two mowing height treatments. Twenty-four months following sprigging, sod was cut and placed into plastic frames (rooting sieves) to evaluate the amount of force needed to detach the rooting sieve from the soil at 15 d and 30 d following planting. DALZ 1808 had the fastest establishment rate regardless of nitrogen rate, reaching > 90% establishment 15 weeks following sprigging. During grow-in of sprigs in 2022, DALZ 1808 and Meyer had significantly higher turf quality compared to Innovation. Innovation mowed at 3.8 cm HOC had significantly more large patch occurrence within the experimental plots compared to all other treatments. Twenty-three months after sprigging, DALZ 1808 had numerically accumulated the least amount of thatch compared to Meyer and Innovation regardless of nitrogen rate. Two years following sprigging, a digital caliper was used to record thatch depth in mm. Innovation mowed at 3.8 cm HOC averaged a thatch depth of 17.9 mm, significantly more thatch compared to all other treatments. DALZ 1808 was the only genotype in this study that had thatch levels below 10 mm regardless of mowing height and nitrogen rate. Innovation zoysiagrass that was maintained at 1.9 cm HOC and received 77 kg N ha⁻¹ annually had a reduction in root strength compared to Meyer zoysiagrass maintained at 3.8 cm HOC and fertilized with 175 kg N ha⁻¹ annually when sieves were detached from the soil at 30 d following planting. This study indicates that recommended mowing height and annual nitrogen rate for a reduction in thatch accumulation and better turf quality and post-harvest rooting differs depending on zoysiagrass cultivar.

Identifying Herbicides for Use during ‘Innovation’ Zoysiagrass Establishment from Sprigs

A field study was conducted in 2021 and replicated in 2022 to evaluate how commonly used preemergence herbicides affect the weed encroachment, establishment, and rooting of Innovation zoysiagrass when applied immediately following sprigging. At four months following sprigging, the liquid formulation of oxadiazon was the only treatment to reach 50% cover; all other treatments were significantly lower. One year after sprigging, many treatments had hindered establishment of the zoysiagrass sprigs; indaziflam-treated plots averaged 12% establishment at 12 months following sprigging, while liquid oxadiazon-treated plots averaged almost 84% establishment. In Expt. 1, many of the treatments reduced weed pressure within experimental plots compared to the untreated control. Liquid oxadiazon-, s-metolachlor-, prodiamine-, and indaziflam-treated plots had < 5% weed pressure at three months following sprigging. Prodiamine-treated plots had significantly reduced the amount of grassy weed encroachment (1%), but did not control broadleaf weeds (33%) within experimental plots. Alternatively, simazine reduced the number of broadleaf weeds (8%), but did not control grassy weeds (24%). There was < 5% emergence of broadleaf and grassy weeds in liquid oxadiazon-, and 2,4-D + quinclorac + dicamba + sulfentrazone-treated plots. The root length of granular oxadiazon-, and simazine-treated stolons was 25.0 mm, and 23.5 mm, respectively, whereas indaziflam-, dithiopyr-, and prodiamine-treated stolons had an average root length of 6.0 mm, 6.2 mm, and 6.8 mm, respectively. Overall, liquid oxadiazon applied on Innovation zoysiagrass immediately following sprigging had nearly complete establishment twelve months following sprigging. Liquid oxadiazon also decreased weed pressure within experimental plots and did not affect root length and number of roots on new stolons. This study indicates that the liquid formulation of oxadiazon has potential for use at the time of zoysiagrass sprigging without impeding establishment.

Effectiveness of Combining New herbicide Containing Metcamifen with Fluazifop-P-butyl for Bermudagrass Suppression in Zoysiagrass Swards

Two field trials were conducted in 2022 and 2023 to investigate bermudagrass suppression and zoysiagrass safety when treatments were applied in the spring and fall, and to determine if sequential applications are needed when Recognition (trifloxysulfuron-sodium + metcamifen) is tank-mixed with Fusilade II (fluazifop-P-butyl) at a high and low rate. During the fall-applied study, untreated zoysiagrass had an average turf quality of 7.0, whereas Fusilade II applied alone significantly reduced the quality of the sward with an average turf quality of 5.1 six weeks, and quality was reduced to 4.4 at eight weeks following application. Turf quality at six and eight weeks following initial application was not reduced when Recognition was applied alone or tank-mixed with Fusilade II at 12 or 24 fl. oz/acre. Fusilade II applied at 24 fl. oz/acre tank-mixed with Recognition had 97% bermudagrass suppression six weeks following initial application; however, Recognition applied alone did not suppress bermudagrass throughout the study. Zoysiagrass phytotoxicity was significantly higher in Fusilade II treatments compared to all other treatments. Zoysiagrass reached 60% phytotoxicity eight weeks following an application of Fusilade II at 12 fl. oz/acre. During the spring-applied study, when Recognition was tank-mixed with Fusilade II at 12 fl. oz/acre and received a 4-week sequential application, bermudagrass suppression reached 75% six weeks following initial application. However, bermudagrass suppression was decreased to 51% by seven weeks following initial application. When Recognition was tank-mixed with Fusilade II at 24 fl. oz/acre and received a 4-week sequential application, bermudagrass suppression reached 95% at six weeks following initial application, and maintained acceptable suppression levels until eleven weeks following initial application. Zoysiagrass quality was unaffected and zoysiagrass phytotoxicity was negligible

when Recognition was tank-mixed with Fusilade II throughout both studies. When Fusilade II was applied at a rate of 24 fl. oz/acre with a 4-week sequential application, bermudagrass suppression reached nearly 100%. These studies indicate that a 4-week sequential application of Recognition tank-mixed with Fusilade at 24 fl. oz/acre is necessary for > 95% bermudagrass suppression. Applying Recognition with Fusilade II significantly decreased the amount of injury incurred on Meyer zoysiagrass compared to Fusilade II applied alone. No supplemental nutrients were applied throughout both studies; however, adequate fertilization to zoysiagrass swards would likely help the zoysiagrass sward fill in after bermudagrass is suppressed.

Evaluation of Experimental Zoysiagrass Genotypes for Commercial Potential

In the summer of 2021, seventy-four zoysiagrass genotypes were planted at seven locations across the U.S. based on their superior performance from 2018 to 2020 to identify the potential for commercial release. In Kansas and Texas, several entries reached > 75% establishment before winter dormancy in 2021. In comparison, establishment was slower in Arkansas, Florida, Indiana, and Virginia, with the highest establishment in experimental plots reaching 60%, 43%, 55%, and 46%, respectively, before winter dormancy in 2021. During the summer of 2022, 71 of 74 entries were in the top statistical grouping in Arkansas; 31 entries in Florida; 35 entries in Indiana, 61 entries in Kansas, 72 entries in Tennessee, 55 entries in Texas, and 71 entries in Virginia. Five entries were in the top statistical grouping across all locations (DALZ 1702, DALZ 1808, TAES 6844-04, TAES 6940-15, and TAES 6941-36). Experimental lines in the 6782, 6783, 6785, 6787, and 6789 TAES families exhibited finer leaf texture compared to other entries. Elite experimental lines DALZ 1701, 1702, 1808, and 1818 were in the top statistical grouping for spring greenup in Indiana, Kansas, Tennessee, and Texas in the spring of 2023. DALZ 1808 had an average turf quality of 5.3 and was the only elite

experimental line to be in the top statistical grouping when evaluated on 63% shade conditions. Genetic color under shade conditions ranged from 5.3 to 8.7. DALZ 1701, 1818, and 1808 had an average genetic color of 8.0, 7.7, and 7.0, respectively. Experimental line TAES 6782-104 shows promise under shade conditions because of its high turf quality (8.0), dark genetic color (8.7), fine leaf texture (7.3) and hastened spring greenup (5.3) compared to other experimental entries. Under drought conditions, elite experimental line DALZ 1702 showed increased drought tolerance compared to standard entries Innovation and Zeon, and elite experimental lines DALZ 1701, 1808, and 1818. Throughout the two year evaluation period in Kansas, elite experimental line DALZ 1701 was in the top statistical grouping for several data collection events including spring greenup, winter injury, and wilt; however, this entry was only in the top statistical grouping for turf quality one out of five times. However, DALZ 1701 exhibited good quality in Arkansas, Tennessee, and Texas, suggesting this elite experimental entry might not perform well across different environments. Throughout this study, several experimental entries exhibited enhanced cold tolerance, including TAES 6844-202 and 6844-150; while TAES 6941-36 performed well throughout southern study sites suggesting good drought resistance. Elite experimental lines DALZ 1701, 1702, 1808, and 1818 show promise within a range of environments; however, no entry had exceptional performance across all seven study sites. The results of this study suggest that multiple experimental lines could perform well in specific regions, but not across all regions in the United States. As of February 2024, nine entries were selected for further evaluations in the southern region, which include: 6782-75, 6782-104, 6785-19, 6789-23, 6789-40, 6792-44, 6829-69, 6941-36, and 6942-22. Nine entries were also selected for further evaluations in the transition zone, which include: 6782-75, 6782-79, 6782-104, 6829-

36, 6844-36, 6844-74, 6844-104, 6844-150, and 6844-202. Future research should focus on the adaptability and performance of these entries under different maintenance regimes.

Conclusions

Numerous research studies have been conducted on zoysiagrass throughout the years. However, because of the recent commercialization of Innovation and the potential for future commercialization of DALZ 1808, there was a need to investigate how these cultivars are affected by cultural practices and herbicide applications. Additionally, because Recognition became commercially available in 2023, there was a need to investigate its effects on bermudagrass suppression and zoysiagrass safety when tank-mixed with Fusilade II. Lastly, zoysiagrass breeding is an ongoing process which relies on evaluations of genotypes in field settings across a range of environments. The results of the research herein will benefit turfgrass practitioners on zoysiagrass management strategies in the U.S. transition zone and beyond.

