CULTURAL STRATEGIES TO IMPROVE ZOYSIAGRASS ACCEPTABILITY AND PERFORMANCE IN THE TRANSITION ZONE

by

ROSS BRAUN

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Major Professor
Jack Fry

Abstract

Zoysiagrass (*Zoysia* spp.) is more heat and drought resistant and requires fewer cultural inputs than cool-season (C3) turfgrasses; however, its widespread use may be limited by an extended period of winter dormancy, the disease *Rhizoctonia* large patch (*Rhizoctonia solani* Kühn AG-2-2 LP), and lack of cold hardiness. Objectives of these 2012-2014 field studies were to evaluate: 1) turfgrass colorants and overseeding for color enhancement; 2) three colorant application volumes on color persistence; 3) colorants applied at two volumes, once or sequentially, on buffalograss (*Buchloë dactyloides*) and zoysiagrass; 4) the impact of nitrogen source and application timing on large patch severity; and 5) winter hardiness and turf quality of new experimental lines. The colorants Ultradwarf Super and Green Lawnger provided acceptable lawn-height 'Chisholm' zoysiagrass color for 7 to 9 and 19 to 24 weeks after treatment (WAT), respectively. Chisholm receiving a sequential application of either product in mid-winter (14 WAT) maintained an acceptable color level after that point until mid-May (28 WAT). Overseeding with annual ryegrass did not provide acceptable color for more than 4 weeks. Evaluation of the colorants Green Lawnger, Endurant, and Wintergreen Plus showed that acceptable Chisholm color at lawn-height occurred for 8 to 14 WAT at 80 gallons per acre (GPA) and 16 to 26 WAT at 240 GPA. Buffalograss at lawn-height receiving a single autumn colorant application had acceptable color for 8 to 12 WAT at 100 GPA or 8 to 14 WAT at 160 GPA. 'Meyer' zoysiagrass maintained at a 0.5 inch height receiving a single autumn colorant application had acceptable color for 8 to 18 WAT at 100 GPA or 14 to 18 WAT at 160 GPA. No differences in large patch occurred between spring and fall applications of ammonium sulfate and calcium nitrate, nor between those treatments and summer-applied urea. Applying fertilizer in spring when soils reached 21 ºC increased green cover on some rating dates compared to applications in fall when soil temperatures fell to 21 ºC but differences were minimal. Out of 985 experimental zoysiagrass lines planted in the field, about 25 were identified for further evaluation for cold hardiness, large patch resistance, and turf quality.

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Dedication

I dedicate this work to Peter & Myrtle Braun and Charles & Ruth Schlieve who taught me the best inspiration is not to outdo others, but outdo ourselves.

Chapter 1 - Evaluation of Colorants on Dormant 'Chisholm' Zoysiagrass

This chapter has been prepared using style guidelines for the journal *Applied Turfgrass Science*

ABSTRACT

Zoysiagrass is a warm-season turfgrass that requires less water and fewer cultural inputs than cool-season grasses. Nevertheless, some homeowners may not use zoysiagrass because they find its brown color during dormancy between October and May to be objectionable. A field study was conducted in Manhattan, KS and Haysville, KS from October 2012 to May 2013 on dormant 'Chisholm' zoysiagrass to evaluate two colorants, applied once in autumn or sequentially in autumn and mid-winter, and annual ryegrass overseeding, for their potential to enhance color. Visual turf color was rated on a 1 to 9 scale where 1 = straw brown; 6 = acceptable green color for a home lawn, and 9 = dark green. The colorant Green Lawnger applied once in autumn provided acceptable color until early April, and adding a sequential mid-winter application provided the best turf color throughout the study. A single autumn application of Ultradwarf Super provided an acceptable zoysiagrass color rating until mid-December, and turf receiving a sequential mid-winter application returned to an acceptable color level until mid-May. Annual ryegrass overseeding provided acceptable color for four weeks in Manhattan, but not in Haysville. Enhancing the appearance of dormant zoysiagrass with colorants may make this water-conserving species more attractive to homeowners and commercial turf managers in the transition zone.

INTRODUCTION

Water is a limited resource and its use to irrigate landscapes is under increasing scrutiny. In some cases, incentives are provided to replace turfgrass with other landscape plants that require less irrigation. In general, cool-season (C3) turfgrasses have higher water requirements when compared with warm-season (C4) species, but will provide green color late into the fall and early in the spring. In contrast, warm-season grasses begin to turn brown at the onset of dormancy following the first autumn frost.

Zoysia japonica (Steud.), a warm-season turfgrass, is the most widely used *Zoysia* species in the United States (Christians, 2007). It is uniquely adapted to the transition zone due to relatively good cold hardiness of cultivars within this species and low water and cultural requirements compared to cool-season grasses (Fry et al., 2008). Much of the popularity of zoysiagrass in the transition zone is due to the cultivar 'Meyer', which was released in 1952. Since then, Meyer has been the predominant cultivar used in the transition zone due to its excellent cold tolerance (Patton and Reicher, 2007; Fry et. al., 2008). Researchers at Kansas State have worked with those at Texas A&M AgriLife Research since 2004 to develop and evaluate zoysiagrasses with higher quality than Meyer for adaptation in the transition zone. Through this collaboration, 'Chisholm' zoysiagrass (*Z. japonica*), breeding code DALZ 0102, was released in 2011 (Chandra et al., 2014). Chisholm is a suitable turfgrass for residential and commercial lawns, parks, and golf courses in the transition zone.

In Kansas, Chisholm zoysiagrass usually takes on a straw-brown color of dormancy in October and greens up in mid- to late April (Okeyo et al, 2011). The five to six months of straw-brown dormant color can be unappealing to homeowners, especially when cool-season grasses, which retain color longer in autumn and green up sooner in spring, are grown in the same vicinity.

Use of turf colorants has become popular on golf course fairways and putting greens in the South to provide green color during winter dormancy. Evaluation of twelve colorants applied at 80 gallons per acre (GPA) on 'Diamond' zoysiagrass [*Zoysia matrella* (L.) Merr] in North Carolina demonstrated that Green Lawnger was one of only two products that provided acceptable color 8 WAT, when colorants were applied at a rate of 160 GPA, Green Lawnger and Match Play 'Ultradwarf Super' provided acceptable color and quality (Briscoe et al., 2010). These findings lead us to examine the two previously mentioned colorants on lawn height zoysiagrass in the transition zone. The use of turf colorants could provide another option for homeowners wanting to extend color from late autumn through early spring while benefitting from the reduced water and maintenance requirements afforded by zoysiagrass.

Winter overseeding is another solution for enhancing color of dormant warm-season lawns in the southern United States. However, overseeding procedures can be costly, disruptive to the existing turfgrass stand, delay spring green-up, and extend water usage through winter. A wide variety of cool-season turfgrasses have proven to be successful in winter overseeding (Hurley et al., 1989). Annual ryegrass (*Lolium multiflorum* Lam.) is one species commonly used in the South to overseed home lawns (Trenholm and Unruh, 2010).

The objective of this experiment was to determine if turfgrass colorants or overseeding could be used to enhance the color of lawn height Chisholm zoysiagrass between October and May in the transition zone.

MATERIALS AND METHODS

Study Sites

This experiment was conducted at the Rocky Ford Turfgrass Research Center in Manhattan, Kansas and the John C. Pair Research Center in Haysville, Kansas. Turf was Chisholm zoysiagrass maintained at a 3-inch height. Soil at Rocky Ford was a Chase silty clay loam and turf received 1 lb. of nitrogen (N) per 1,000 sq. ft. annually. At the Pair Center, soil was a Canadian-Waldeck fine sandy loam and turf received 1 lb. of N per 1,000 sq. ft. annually.

Plots measuring 5 ft. x 5 ft. and were arranged in a randomized complete-block design with four replications. The seven treatments included: 1) untreated; 2) overseeding with annual ryegrass; 3) Green Lawnger (Becker Underwood, Ames, IA) applied once in autumn; 4) Green Lawnger applied in autumn and mid-winter; 5) Match Play 'Ultradwarf Super' (Pioneer Athletics, Cleveland, OH) applied once in autumn; 6) Match Play 'Ultradwarf Super' applied in autumn and mid-winter; and 7) tall fescue (*Festuca arundinacea* Schreb.).

Overseeding Procedure

Plots to be overseeded with annual ryegrass were vertically mowed with a Billy Goat® Power Rake/Overseeder (Billy Goat Industries, Inc., Lee's Summit, MO) in two directions with 1.5 inch knife spacing on a no. 4 setting, resulting in a ½ inch soil cutting depth. After raking plant material that had been removed from the study area, plots were seeded in two directions with annual ryegrass at 10 lbs/1000 sq. ft. on 28 Sept. 2012 in Manhattan and 11 Oct. 2012 in Haysville using a hand-held shaker bottle. Overseeded plots were watered by hand 1 to 2 times daily the first week after seeding, and as needed thereafter, and a late-fall application of 0.5 lb. of N per 1000 sq. ft. from urea was applied with a shaker bottle in two directions on 31 Oct. 2012 in Manhattan.

Colorant Application

Colorants were applied using a three-nozzle, CO_2-pressurized sprayer with 8004VS nozzles calibrated to deliver 131 gallons per acre of spray solution at 30 psi. Turf colorants were applied at the same rate/dilution of 1:6 (colorant:water) in two perpendicular directions to provide uniform coverage for a total rate of 262 GPA. The first colorant application was applied to predominantly dormant zoysiagrass on 20 Oct. 2012 in Manhattan (5 to 10% green color remaining based on visual evaluation) and 31 Oct. 2012 in Haysville (<5% green color remaining based on visual evaluation). On 23 Jan. 2013 in Manhattan and 5 Feb. 2013 in Haysville, 14 weeks after the initial treatment (WAT), a sequential application of Green Lawnger and Ultradwarf Super was made to designated treatments (Figures 1-1 and 1-2).

Data Collection and Analysis

At both sites, weekly turf color was rated visually on a 1 to 9 scale where 1 = straw brown; 6 = acceptable green color for a home lawn, and 9 = dark green. Turf quality was rated once a month on a 1 to 9 scale where 1 = poorest color, uniformity, and density; 6 = acceptable quality; and 9 = optimum color, uniformity, and density (Morris and Shearman, 1999).

A digital photograph was taken with a Nikon D5000 digital camera (Nikon Inc., Tokyo, Japan) of each plot at Rocky Ford on 7 Nov. and 11 Dec. 2013 and 10 Jan., 13 Feb., 14 March, 25 April, 20 May, 7 June 2014 using a lighted camera box (20 in. x 24 in. x 22 in.). The camera was adjusted to the following manual settings: f-stop of 5.6, 1/125 sec exposure time, and 800 ISO-speed. Images were analyzed with SigmaScan Pro 5.0 (ver. 5.0, SPSS Science Marketing Dept., Chicago, IL) using the “Turf Analysis” macro for batch analysis (Karcher and Richardson, 2005). The macro threshold settings were adjusted to hue = 50 to 107 and saturation = 0 to 100. These threshold settings allowed for estimation of pixels (expressed as percentages) that represented green turf color relative to non-green (dormant) turf. After images were analyzed, a dark green color index value (on a zero to one scale) was calculated for each image using the following equation: DGCI value = [(Hue - 60)/60 + (1 - Saturation) + (1 - Brightness)]/3 (Karcher and Richardson, 2003).

Starting 28 March 2013, weekly soil temperatures at a 1.25 inch depth within each plot were monitored between 1200 and 1400 central daylight time on cloudless days with a digital T-bar thermometer (Argus Realcold Pty Ltd, Coopers Plains, Australia) at the Rocky Ford Turfgrass Research Center.

Residual normality was tested with the *w* statistic of the Shapiro-Wilk test using the UNIVARIATE procedure of Statistical Analysis System (SAS Institute Inc., Cary, NC) (Shapiro and Wilk, 1965). Data were subjected to analysis of variance (ANOVA) using the GLM procedure of SAS 9.2. Treatment differences were separated using Fisher's protected least significant difference test ($P \leq 0.05$). A Homogeneity of Variance Test for location by treatment effect was significant for the study sites, therefore results will be presented separately for each site

RESULTS AND DISCUSSION

Turf Color

Green Lawnger application resulted in higher turf visual color ratings than application of Ultradwarf Super or annual ryegrass overseeding in Manhattan and Haysville (Tables 1-1 and 1-2). In Manhattan, a single application of Green Lawnger on 20 October resulted in acceptable color (i.e., a rating $\geq$ 6) for 24 weeks (until 4 April) (Table 1-1). Zoysiagrass receiving a sequential mid-winter Green Lawnger application on 23 Jan. 2013 maintained acceptable color throughout the duration of the experiment. Three weeks prior to colorant application, tall fescue had superior color compared to zoysiagrass. After application, color of tall fescue and Green Lawnger-treated zoysiagrass were similar until 13 Dec. 2012 (8 WAT). Thereafter, starting 20 Dec. 2012, the color of zoysiagrass receiving one or two applications of Green Lawnger was superior in color compared to that of tall fescue for 15 weeks until 12 April 2013 when tall fescue again had acceptable color.

Zoysiagrass treated with Ultradwarf Super in Manhattan had acceptable color for 9 WAT (20 Dec. 2012) (Table 1-1). A sequential mid-winter Ultradwarf Super application on 23 January resulted in acceptable zoysiagrass color through the remainder of the experiment. When tall fescue was actively growing in autumn, its color was generally superior to zoysiagrass treated with Ultradwarf Super. Beginning at 12 WAT (15 Jan. 2013) the color of zoysiagrass treated with a single application Ultradwarf Super was superior compared to that of tall fescue, and this continued for 11 weeks until the 28 March 2013 rating when tall fescue had resumed active growth. Zoysiagrass receiving a sequential mid-winter application of Ultradwarf Super on 23 January had superior color than tall fescue from 15 January until 12 April 2013 (13 weeks) (Figures 1-1 and 1-2).

In Haysville, application of Green Lawnger on 31 October resulted in acceptable zoysiagrass color for 19 WAT (until 20 March) (Table 1-2). A sequential mid-winter Green Lawnger application on 5 February maintained acceptable zoysiagrass color through the experiment (Figure 1-3). Tall fescue color was lower than that of zoysiagrass treated with a single application of Green Lawnger until 22 WAT (4 April 2013). Zoysiagrass receiving the sequential mid-winter application of Green Lawnger on 5 February had superior color ratings than tall fescue until 25 WAT (25 April 2013).

Zoysiagrass treated with a single application of Ultradwarf Super in Haysville had acceptable color for 7 WAT (21 Dec. 2013) (Table 1-2). Turf receiving a sequential mid-winter application of Ultradwarf Super on 5 February had acceptable green color throughout the experiment. Color of zoysiagrass treated with Ultradwarf Super was not significantly different than that of tall fescue until 18 Jan. 2013. Beginning on 18 Jan. 2013, the single application of Ultradwarf Super provided superior color compared to tall fescue for 9 weeks until 20 March 2013. Similar to results from Manhattan, zoysiagrass receiving a sequential mid-winter application of Ultradwarf Super on 5 Feb. had better color than tall fescue for total of 13 weeks (from 18 Jan. until 16 April 2013).

Visual color ratings of zoysiagrass treated with either colorant declined over time. Turf treated with Green Lawnger maintained an acceptable level of color for 105 days longer than Ultradwarf Super in Manhattan and 84 days longer in Haysville.

Zoysiagrass overseeded with annual ryegrass in Manhattan had acceptable color for 4 weeks; however, color of overseeded turf was higher than untreated turf for 10 weeks (10 Oct. 2012 until 20 Dec. 2013) (Table 1-1). Zoysiagrass overseeded with annual ryegrass in Haysville never had acceptable color, although its color was superior compared to that of untreated turf for 3 weeks (31 Oct. 2012 until 14 Nov. 2012) (Table 1-2). Preparation of the seedbed for overseeding resulted in a decline in turf quality in overseeded plots compared to untreated plots throughout the duration of this experiment. In southern China, researchers found the light green color and fine leaf texture of annual ryegrass that was overseeded into 'Lanyin III' zoysiagrass *(Z. japonica*) at 1.5 inch mowing height resulted in unacceptable uniformity during winter (Zhang et al., 2008). Average quality of overseeded plots for the duration of the current study was 1.9, whereas that of untreated plots was 3.8 (data not shown). At Manhattan and Haysville, both colorants provided superior quality compared to overseeded or untreated turf throughout the study.

Dark Green Color Index

Green Lawnger provided a darker green, and longer duration of acceptable color compared to Ultradwarf Super, which was lighter green. (Figure 1-3). These differences in green color were clearly visible from the dark green color index (DGCI) results of monthly digital photographs under a light box at Manhattan. Dark green color index is calculated from digital photographs under a constant light source, and image-analysis software has proven to be useful in determining a consistent measure of green color (Briscoe et al., 2010; Karcher and Richardson, 2003). Green Lawnger consistently had a significantly higher value of DGCI than Ultradwarf Super throughout the study (Appendix Table A-1). Preference for color obviously varies from person to person. Some homeowners may prefer a lighter green than darker green color.

Temperatures

In addition to enhancing color, turf colorants may result in earlier spring green-up by influencing soil surface temperatures (Whitlark, 2012). Liu et al. (2007) found that dormant colorant-treated 'Tifeagle' bermudagrass [*Cynodon dactylon* (L.) Pers. X *C. transvaalensis* Burtt-Davy] putting greens had higher canopy and soil temperatures than untreated turf, and earlier spring green up than untreated turf in South Carolina. Soil under buffalograss [*Buchloe dactyloides* (Nutt.) Engelm] treated in December with Lesco Green in Nebraska was warmer, and turf initiated spring green up about two weeks earlier than untreated turf (Shearman et al., 2005). However, in the current study, no differences occurred in soil temperatures or spring green up between colorant-treated zoysiagrass and untreated turf in this experiment. Colorants likely had less of an impact on soil temperatures due to the dense turf canopy of Chisholm and higher mowing height (Appendix Table A-2).

Conclusion

Turfgrass colorants provide homeowners and commercial lawn care operators with an option for providing green turf color during zoysiagrass dormancy. The costs of these colorant products on average at the time of this study are from $50 to 60 per gallon, or less if bought bulk. At these prices, the resulting costs would range from $17 per 1,000 sq. ft. when applied at a low rate of 80 GPA to $55 per 1,000 sq. ft. when applied at the rate used in this study of 262 GPA. The potential for enhancing dormant turf color may make homeowners more amenable to planting zoysiagrass, which will ultimately reduce water useage and requirements for other cultural inputs.

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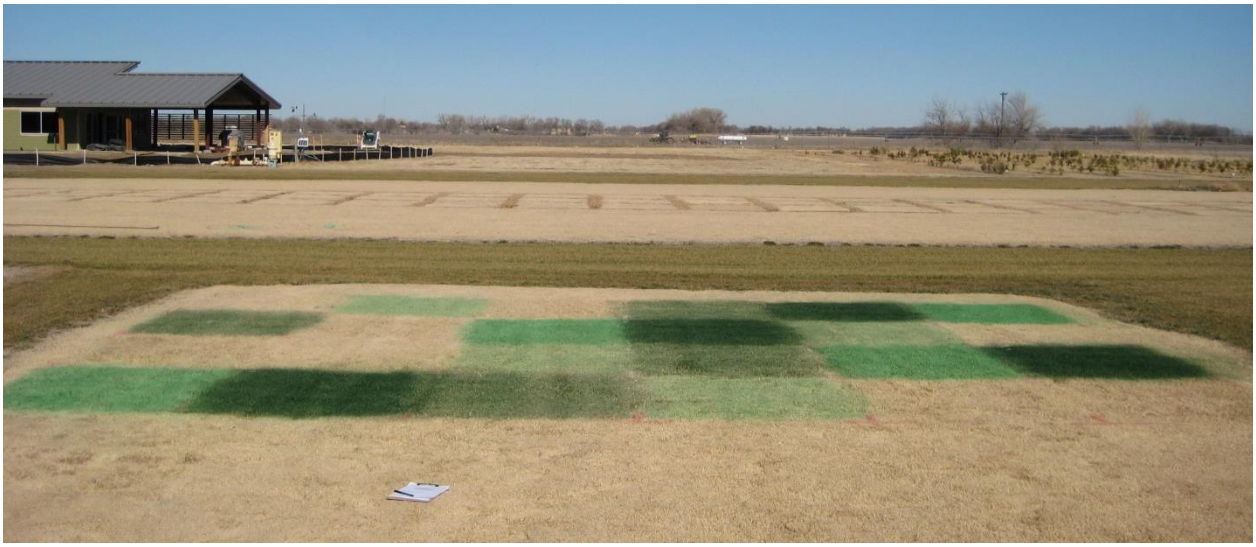

Figure 1-1. Study area after the second application of Ultradwarf Super and Green Lawnger at the John C. Pair Research Center in Haysville, Kan. on 5 Feb. 2013. Front row, from left to right: Ultradwarf Super (2 applications – 31 Oct. 31, 2012 and 5 Feb., 2013), Green Lawnger (2 applications – 31 Oct. 2012 and 5 Feb. 2013), Green Lawnger (1 application – 31 Oct. 2012), Ultradwarf Super (1 application – 31 Oct. 2012), untreated, and overseeded with annual ryegrass on 11 Oct. 2012.

Figure 1-2. Differences in Chisholm zoysiagrass appearance after receiving a sequential mid-winter application on 5 Feb. 2013 since the first autumn application on 31 Oct. 31, 2012 of Green Lawnger (left) and Ultradwarf Super (right) at Haysville, KS.

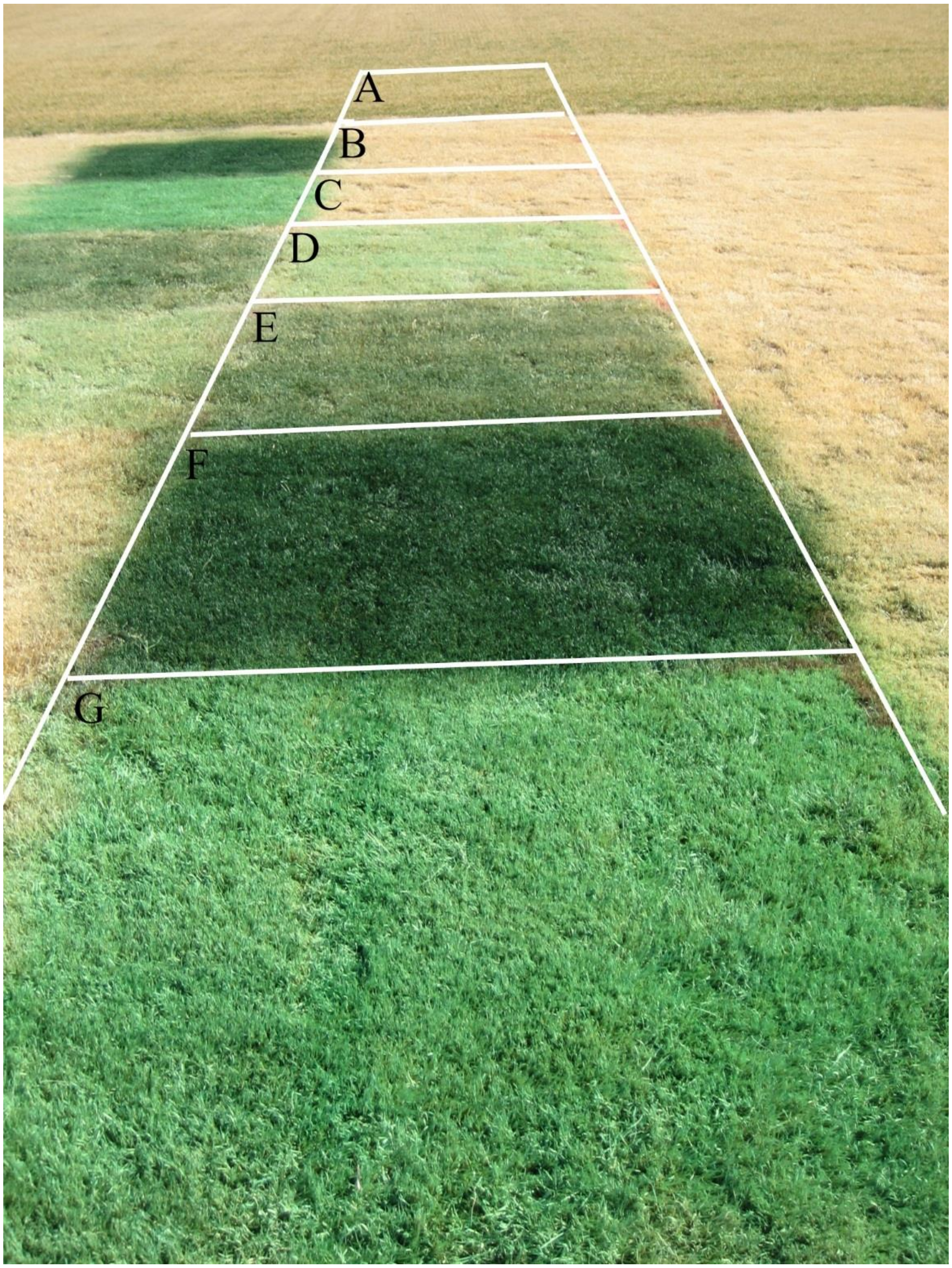

Figure 1-3. Appearance of Chisholm zoysiagrass treated with colorants on 5 Feb. 2013 at John C Pair Research Center in Haysville, KS. A) tall fescue; B) annual ryegrass overseed on 11 Oct. 2012; C) untreated; D) Ultradwarf Super applied once on 31 Oct. 2012; E) Green Lawnger applied once on 31 Oct. 2012; F) Green Lawnger applied on 31 Oct. 2012 and 5 Feb. 2013; G) Ultradwarf Super applied on 31 Oct. 2012 and 5 Feb. 2013.

Table 1-1. Effect of colorants and annual ryegrass overseeding on color of 'Chisholm' zoysiagrass at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2012-2013.

		Turf color†																					
		28 Sept.	4 Oct	10 Oct.	20 Oct.	1 Nov.	15 Nov.	29 Nov.	13 Dec.	20 Dec.	15 Jan.	25 Jan.	6 Feb.	13 Feb.	7 March	14 March	28 March	4 April	12 April	25 April	3 May	18 May	28 May
Treatment	Application Date‡	-3 WAT§	-2 WAT	-1 WAT	0 WAT	2 WAT	4 WAT	6 WAT	8 WAT	9 WAT	12 WAT	14 WAT	16 WAT	17 WAT	20 WAT	21 WAT	23 WAT	24 WAT	25 WAT	27 WAT	28 WAT	30 WAT	32 WAT
Green Lawnger																							
	20 Oct.	5.3 b¶	4.8 b	4 c	9.0 a	8.5 a	8.0 a	8 a	7.8 a	7.3 a	6.8 a	6.3 b	6 b	6 b	6.0 b	6 b	6 b	6.0 b	5.5 c	4.5 d	4.5 c	5.5 b	6.8 bc
	20 Oct. + 23 Jan.	5.0 b	4.5 b	4 c	9.0 a	8.3 a	8.0 a	8 a	7.5 ab	7.3 a	7 a	8.8 a	8.8 a	8 a	7.8 a	7.8 a	7 a	7.0 a	7 a	7 b	6.8 b	6 b	7 b
Ultradwarf Super																							
	20 Oct.	5.3 b	4.8 b	4 c	7.0 b	7 b	6.5 b	5.8 b	6 c	6.0 b	5.8 b	5 c	4.8 c	4.5 c	4.3 c	4.3 c	4.3 c	4.0 d	3 d	3 e	3.0 d	5.3 b	7 b
	20 Oct. + 23 Jan.	5.5 b	5 b	4 c	7.0 b	7 b	6.5 b	5.5 b	5.5 c	5.3 c	5.5 b	8.3 a	8.3 a	7.8 a	7.5 a	7.5 a	6.8 a	6.8 a	6.3 b	6.3 c	6.3 b	6 b	6.5 bc
Annual ryegrass overseeding	28 Sept.	5.0 b	4.8 b	5.8 b	5.8 c	6.8 b	6.3 b	3 c	2.5 d	2.0 d	1 d	1.0 e	1 e	1 e	1.0 e	1 e	1 d	1.5 e	1.5 e	1.5 f	2.0 e	4 c	6 c
Tall fescue		8.8 a	8.8 a	8.8 a	8.8 a	8.3 a	8.3 a	7.8 a	7 b	6.5 b	4.5 c	3.3 d	2.5 d	2.5 d	2.0 d	3 d	4 c	5.3 c	7 a	8 a	8.3 a	9 a	9 a
Untreated		5.3 b	4.8 b	4 c	2.3 d	1.8 c	1.0 c	1 d	1 e	1.0 e	1 d	1.0 e	1 e	1 e	1.0 e	1 e	1 d	1.0 f	1 e	1 f	1.0 f	3.5 c	6.3 bc

† Turf color was rated on a 1 to 9 scale where 1 = straw brown; 6 = acceptable green color (light green); and 9 = dark green.

‡Annual ryegrass overseeding was performed 3 weeks prior to first colorant application on 28 Sept. 2012. Colorants were applied at a dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8004VS nozzles at 131 gallons per acre of spray solution in two perpendicular directions for total rate of 262 GPA. The first colorant application was 20 Oct. 2012 and fourteen weeks after the initial application a sequential mid-winter application on the required treatments was applied on 23 Jan. 2013.

§ Weeks After Treatment (weeks after 1st colorant application).

¶ Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

Table 1-2. Effect of colorants and annual ryegrass overseeding on color of ‘Chisholm’ zoysiagrass at the John C. Pair Research Center, Haysville, KS in 2012-2013.

		Turf color†																
		11 Oct.	18 Oct.	31 Oct.	14 Nov.	29 Nov.	21 Dec.	9 Jan.	18 Jan.	5 Feb.	21 Feb.	14 March	20 March	4 April	16 April	25 April	16 May	23 May
Treatment	Application Date‡	-3 WAT§	-2 WAT	0 WAT	2 WAT	4 WAT	7 WAT	10 WAT	11 WAT	14 WAT	16 WAT	19 WAT	20 WAT	22WAT	24 WAT	25 WAT	28 WAT	29 WAT
Green Lawnger																		
	31 Oct.	5.0 b¶	4.3 b	9.0 a	8.3 a	8.5 a	8.5 a	7.8 a	8 a	7.0 c	7.5 b	6.5 b	5.8 c	5.3 c	5.3 c	5.5 c	5.8 bc	6.8 bc
	31 Oct. + 5 Feb.	4.8 b	3.8 b	9.0 a	8.3 a	8.5 a	8.8 a	7.8 a	7.75 a	9.0 a	9 a	9 a	8.5 a	8 a	7.5 a	7 a	7.0 a	7 b
Ultradwarf Super																		
	31 Oct.	4.5 b	4.3 b	8.0 b	7 b	6.5 b	6.8 b	5.8 b	5.3 b	5.3 d	5.3 d	5.3 c	4.3 d	4 e	3.8 d	4.3 d	5.3 c	6.3 cd
	31 Oct. + 5 Feb.	5.0 b	4.5 b	7.8 b	7.3 b	7.0 b	7.0 b	5.8 b	5.3 b	8.0 b	7 c	7 b	7.0 b	6.5 b	6.0 b	6 bc	6.0 b	7 b
Annual ryegrass overseeding	11 Oct.	5.3 b	4 b	2.0 c	2 c	1.8 c	1.0 c	1 c	1 d	1.0 f	1 f	1 e	1.0 e	1 e	2.0 e	2.8 e	4.5 d	5.8 d
Tall fescue		8.5 a	8.3 a	8.0 b	7.3 b	7.8 b	6.8 b	5.8 b	3.8 c	3.5 e	3 e	3 d	4.3 d	5.5 c	6.0 b	6.5 ab	7.3 a	8.3 a
Untreated		5.0 b	3.8 b	1.0 d	1.3 d	1.3 c	1.0 c	1 c	1 d	1.0 f	1 f	1 e	1.0 e	1 e	1.8 e	3.3 e	5.8 bc	6.5 bc

† Turf color was rated on a 1 to 9 scale where 1 = straw brown; 6 = acceptable green color (light green); and 9 = dark green.

‡ Annual ryegrass overseeding was performed 3 weeks prior to first colorant application on 11 Oct. 2012. Colorants were applied at a dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8004VS nozzles at 131 gallons per acre of spray solution in two perpendicular directions for a total rate of 262 GPA. The first colorant application was applied on 31 Oct. 2012 and fourteen weeks after the initial application a sequential mid-winter application on the required treatments was applied on 5 Feb. 2013.

§ Weeks After Treatment (weeks after 1st colorant application).

¶ Means in a column followed by the same letter are not significantly different according Fisher’s protected least significant difference test ($P \leq 0.05$).

Chapter 2 - Evaluation of Colorants and Application Volumes on Dormant ‘Chisholm’ Zoysiagrass

This chapter has been prepared using style guidelines for the journal *Applied Turfgrass Science*

ABSTRACT

Zoysiagrass is a warm-season turfgrass that requires less water and fewer cultural inputs than cool-season grasses, but its widespread use by homeowners may be limited because of its brown color during winter dormancy in the transition zone. Turf colorants are an option for improving zoysiagrass color during dormancy. The objective was to evaluate colorants applied in autumn at three application volumes on persistence of color through the dormancy period. Field studies were conducted in Manhattan and Haysville, KS from October 2013 to May 2014 on dormant 'Chisholm' zoysiagrass. The colorants Green Lawnger, Endurant, and Wintergreen Plus were applied in October in solutions with water at 80, 160, or 240 gallons per acre (GPA) at a 1:6 dilution (colorant:water). Intensity and duration of acceptable color (i.e., a rating $\geq$ 6) of each colorant product increased with application volume. In general, applications at 80 GPA provided acceptable color for 8 to 14 WAT; 160 GPA provided acceptable color for 10 to 20 WAT; and 240 GPA provided acceptable color for 16 to 26 WAT. Compared to tall fescue (cool-season grass), zoysiagrass treated with colorants had significantly higher color between 8 and 24 WAT at 80 GPA; 6 to 26 WAT at 160 GPA; and 4 to 26 WAT at 240 GPA. Green Lawnger and Endurant applications resulted in a darker green color, whereas Winter Green Plus resulted in a blue-green color. Turfgrass colorants increased canopy temperature by up to 12ºF, but not soil temperature. Intensity and duration of acceptable color can be enhanced by increasing application volume of colorants.

INTRODUCTION

The transition zone of turfgrass adaptation, a loosely defined area in the central US which includes Kansas, experiences wide ranges of temperature extremes and makes turfgrass management difficult. Water is a limited resource and its use to irrigate landscapes is under increasing scrutiny. Warm-season (C4) turfgrasses are more heat and drought resistant than cool-season grasses (C3), which results in water savings (Fry and Huang, 2004). Warm-season turfgrass also require fewer pesticide and fertilizer inputs compared to cool-season turfgrasses (Fry and Huang, 2004). One perceived benefit of cool-season turfgrasses is that they remain green late into autumn and also green up early in the spring. In contrast, warm-season grasses turn brown following the first autumn frost and remain so until mid to late spring. Some homeowners in the transition zone may avoid use of warm-season grasses because they object to their color during dormancy.

Zoysiagrasses (*Zoysia* spp.) are warm-season turfgrasses native to Asia, which were introduced into the United States in 1895 (Engelke and Anderson, 2003; Madison, 1971). Zoysiagrass has attained its popularity due to its excellent resistance to heat, drought, and wear, and relatively low requirements for water and other cultural inputs required by cool-season grasses (Beard, 1973; Fry and Huang, 2004; Fry et al. 2008). *Zoysia japonica* (Steud.) is the most widely used of *Zoysia* species in the United States (Christians, 2007), and it is uniquely adapted to the transition zone due to relatively good cold hardiness of cultivars within this species. Much of the popularity of zoysiagrass in the transition zone is due to the cultivar 'Meyer', which was released in 1952. Since then, it has been the predominant cultivar used in the transition zone due to its excellent cold tolerance (Patton and Reicher, 2007; Fry et. al., 2008).

Researchers at Kansas State have worked with those at Texas A&M AgriLife Research since 2004 to develop and evaluate zoysiagrasses with higher quality than Meyer for adaptation in the transition zone. Through this collaboration, 'Chisholm' zoysiagrass (*Z. japonica*), breeding code DALZ 0102, was released in 2011 (Chandra et al., 2014). Chisholm is a suitable turfgrass for residential and commercial lawns, parks, and golf courses in the transition zone. Chisholm has a coarser texture than Meyer, and equivalent to slightly inferior freezing tolerance than Meyer (NTEP, 2007). However, Chisholm has been shown to be superior to Meyer in establishment rate, and recuperative ability (NTEP, 2007; Okeyo et al., 2011b).

In Kansas, Chisholm usually takes on a straw-brown color of dormancy in October and begins to green up in mid- to late April (Okeyo et al, 2011a). The dormancy period can be unappealing to homeowners, especially when cool-season grasses, which retain color longer in autumn and green up sooner in spring, are grown in the same vicinity.

Turf colorants are an option for improving zoysiagrass color during dormancy. The use of turf colorants has become popular on golf course fairways and putting greens in the South to provide green color during winter dormancy (Long, 2006). The turf colorants Titan Green Turf, Green Lawnger, and Regreen provided acceptable color on a 'TifEagle' bermudagrass [*Cynodon dactylon* (L.) Pers. X *C. transvaalensis* Burtt-Davy] putting green during the winter in South Carolina (Liu, 2007). Evaluation of turf colorants on 'Diamond' zoysiagrass [*Zoysia matrella* (L.) Merr.] and 'Miniverde' bermudagrass [*Cynodon dactylon* (L.) Pers. X *C. transvaalensis* Burtt-Davy] putting greens demonstrated that the colorants Wintergreen Plus and Turf in a Bottle applied once in autumn, effectively enhanced color during winter dormancy on both grasses (Briscoe et al., 2010). Colorants which provided acceptable green color and the highest color ratings on dormant Diamond zoysiagrass were (in no particular order) Mtp Turfgreen, Titan Green Turf, Green Lawnger, Match Play 'Ultradwarf Super', and Wintergreen Plus (Briscoe et al., 2010).

In Chapter 1, there were differences in intensity and duration of acceptable color between the colorants Green Lawnger and Match Play 'Ultradwarf Super' applied at 262 gallons per acre (GPA). Green Lawnger provided the highest color ratings throughout the study, and a single autumn application provided acceptable color until early April (19 to 24 weeks after treatment) (WAT). However, a single autumn application of Ultradwarf Super only provided an acceptable zoysiagrass color until mid-December (7 to 9 WAT). Zoysiagrass receiving a sequential mid-winter application of either colorant in mid-winter (14 WAT) maintained an acceptable color level after that point until mid-May (28 WAT). Results from Chapter 1 led to experimental questions about influence of application volume on color intensity and duration of acceptable color. For example, a lower colorant application volume of Green Lawnger could provide acceptable winter color at a lower cost.

Colorant application rate has been shown to affect turf color and color duration. In North Carolina, intensity of turf color increased 1 to 44% on bermudagrass and 11 to 15% on zoysiagrass, both at putting green height, when application volumes were raised from 80 to 160

GPA (Briscoe et al., 2010). However, information is lacking on products and application volumes on zoysiagrass at higher mowing heights. Therefore, the objective was to determine effects of colorants and application volumes on color of Chisholm zoysiagrass at lawn height in the transition zone.

MATERIALS AND METHODS

Study Sites

This experiment was conducted at the Rocky Ford Turfgrass Research Center in Manhattan, Kansas and the John C. Pair Research Center in Haysville, Kansas. Turf was 'Chisholm' zoysiagrass maintained at a 2.5-inch height. Soil at Rocky Ford was a Chase silty clay loam and turf received 1 lb. of nitrogen (N) per 1,000 sq. ft. annually. At the Pair Center, soil was a Canadian-Waldeck fine sandy loam and turf received 1 lb. of N per 1,000 sq. ft. annually.

Plots measuring 5 ft. x 8 ft. were arranged in a randomized complete-block design with three replicates. Treatments were: 1) untreated; 2) Green Lawnger (Becker Underwood, Ames, IA) applied at a spray volume of 80 gallons per acre (GPA); 3) Endurant (Geoponics Corp, Naples, FL) applied at 80 GPA; 4) Wintergreen Plus (Precision Laboratories, Inc., Waukegan, IL) applied at 80 GPA; 5) Green Lawnger applied at 160 GPA; 6) Endurant applied at 160 GPA; 7) Wintergreen Plus applied at 160 GPA; 8) Green Lawnger applied at 240 GPA; 9) Endurant applied at 240 GPA; 10) Wintergreen Plus applied at 240 GPA; and 11) tall fescue (*Festuca arundinacea* Schreb.).

Colorant Application

Colorants were applied using a one-nozzle, three gallon SHURflo ProPack™ model SRS 600 (SHURflo, Cypress, CA) rechargeable electric backpack sprayer with an adjustable cone nozzle calibrated to deliver 0.29 gallons per minute. Turf colorants were applied at a dilution of 1:6 (colorant:water) to Chisholm zoysiagrass with 15 to 20% green color remaining on 11 Oct. 2013 at Manhattan and on 24 Oct. 2013 to Chisholm with 10 to 15% green color remaining at Haysville.

Data Collection and Analysis

Visual turf color was rated every other week at Manhattan and monthly at Haysville on a 1 to 9 scale where 1 = straw brown; 6 = acceptable green color for a home lawn, and 9 = dark green (Morris and Shearman, 1999).

Digital photographs were taken with a Nikon D5000 digital camera (Nikon Inc., Tokyo, Japan) of each plot and three replications of tall fescue at Manhattan on 19 Oct., 14 Nov., and 6 Dec. 2013 and 20 Jan., 17 Feb., 26 March, 15 April, 15 May 2014 using a lighted camera box (20 in. x 24 in. x 22 in.). The camera was adjusted to the following manual settings: f-stop of 5.6, 1/125 sec exposure time, and 800 ISO-speed. Images were analyzed with SigmaScan Pro 5.0 (ver. 5.0, SPSS Science Marketing Dept., Chicago, IL) using the "Turf Analysis" macro for batch analysis (Karcher and Richardson, 2005). The macro threshold settings were adjusted to hue = 50 to 107 and saturation = 0 to 100. These threshold settings allowed for estimation of pixels (expressed as percentages) that represented green turf color relative to non-green (dormant) turf. After images were analyzed, a dark green color index (DGCI) value (on a zero to one scale) was calculated for each image using the following equation: DGCI value = [(Hue - 60)/60 + (1 - Saturation) + (1 - Brightness)]/3 (Karcher and Richardson, 2003).

Starting 11 March 2014, then every other week, soil temperatures at both sites at a 2 inch depth were measured and averaged from three measurements within each plot between 1300 and 1500 central daylight time on cloudless days using a digital T-bar thermometer (Argus Realcold Pty Ltd, Coopers Plains, Australia). In addition, starting 11 March 2014, canopy temperatures at both sites were measured and averaged from three measurements per plot between 1300 and 1500 central daylight time on cloudless days using a handheld infrared thermometer at a 4 ft. height above the canopy (Model 100.3ZL, Everest Interscience, Tucson, Arizona).

Residual normality was tested with the *w* statistic of the Shapiro-Wilk test using the UNIVARIATE procedure of Statistical Analysis System (SAS Institute Inc., Cary, NC) (Shapiro and Wilk, 1965). Data were subjected to a two-fold nested analysis of variance (ANOVA) using the GLIMMIX procedure of SAS 9.2. Factors were application volume nested within colorant, and colorant. Treatment differences were separated using Fisher's protected least significant difference test ($P \leq 0.05$). A Homogeneity of Variance Test for location by treatment effect was significant for the study sites, therefore results will be presented separately for each site.

RESULTS AND DISCUSSION

Turf Color

The effect of spray volume nested within colorants was significant (Appendix Tables B-1 and B-2). Therefore, discussion will focus on the effect of spray volume on turf color within each colorant treatment. In general, duration of acceptable zoysiagrass color at each research location increased with increasing application volume, and color at each application volume decreased over time.

At 4 WAT at both sites, a 12 to 21% increase in turf color intensity occurred when application volume was raised from 80 to 160 GPA, 3 to 18% increase in turf color intensity occurred at 240 GPA vs. 160 GPA, and 18 to 30% increase in turf color intensity occurred at 240 GPA, relative to the 80 GPA volume. (Tables 2-2 and 2-1). Similar results were reported previously. Five weeks after application of the colorants Green Lawnger, Turf in a Bottle, and Ultradwarf Super at 160 GPA on Diamond zoysiagrass putting greens in Raleigh NC, turf color was 11 to 15% greater in intensity than turf treated at 80 GPA (Briscoe et al., 2010).

In Manhattan, Green Lawnger applied at 240 GPA had superior color than that receiving 160 GPA from 10 to 28 WAT (Table 2-1). Application at 160 GPA resulted in superior color compared to turf receiving 80 GPA at 4 and 8 WAT. Green Lawnger applied at 240 GPA had better color than that treated at 80 GPA for all but the first rating date. Acceptable color (i.e., a rating $\geq$ 6) was provided for 10 to 14 WAT for both the 80 and 160 GPA volumes, and 24 to 26 WAT at 240 GPA.

Zoysiagrass color following application of Green Lawnger at 240 GPA in Haysville was higher to that treated at 160 GPA on all dates except 8, 12, and 28 to 30 WAT. (Table 2-2). Green Lawnger applied at 160 GPA provided superior color than turf receiving 80 GPA at all but 20, 24, and 28 to 30 WAT. Application at 240 GPA led to higher ratings than turf treated at 80 GPA on all dates except 28 and 30 WAT. In general, Green Lawnger provided acceptable turf color for 8 to 12 WAT at 80 GPA, 12 to 16 WAT at 160 GPA, and 20 to 24 WAT at 240 GPA.

Endurant applied in Manhattan at 240 GPA had superior color compared to that treated at 160 GPA at 0, 24, and 28 WAT (Table 2-1). Application at 160 GPA resulted in superior zoysiagrass color compared to turf receiving 80 GPA from 4 to 24 WAT. Zoysiagrass treated at 240 GPA had better color than that receiving 80 GPA for all dates but 30 and 32 WAT.

Endurant provided acceptable turf color for 10 to 14 WAT at 80 GPA, 16 to 20 WAT at 160 GPA, and 20 to 22 WAT at 240 GPA.

In Haysville, Endurant applied at 240 GPA provided zoysiagrass with superior color compared to that receiving 160 GPA at 0, 4, 8, and 16 WAT (Table 2-2). Application at 160 GPA resulted in superior color than turf treated at 80 GPA at 0, 4, 12, 16, 20 WAT. Endurant applied at 240 GPA had superior color than that treated at 80 GPA for all dates but 28 and 30 WAT. Acceptable color was provided for 8 to 12 WAT for the 80 GPA volume, 12 to 16 WAT at 160 GPA, and 16 to 20 WAT at 240 GPA.

Chisholm treated with Wintergreen Plus at 240 GPA in Manhattan was superior in color than that treated at 160 GPA from 14 to 20 WAT (Table 2-1). Application at 160 and 240 GPA provided superior turf color to that treated at 80 GPA at all dates but 30 and 32 WAT. Wintergreen Plus provided acceptable color for 10 to 14 WAT at 80 GPA, 16 to 20 WAT at 160 GPA, and 20 to 22 WAT at 240 GPA.

In Haysville, zoysiagrass treated with Wintergreen Plus at 240 GPA had superior color to that treated with 160 GPA at 12 and 20 WAT (Table 2-2). Application at 160 and 240 GPA volumes resulted in superior color to 80 GPA at all dates except 28 and 30 WAT. Acceptable color was provided for 8 to 12 WAT at the 80 GPA volume, 16 to 20 WAT at 160 GPA, and 20 to 24 WAT at 240 GPA.

All colorant-treated zoysiagrass had superior color to that of untreated zoysiagrass for all dates but 30 and 32 WAT (Figure 2-1 and Table 2-1) in Manhattan. In Haysville, all colorant-treated zoysiagrass had superior color compared to untreated zoysiagrass for all dates except 24, 28, and 30 WAT (Table 2-2).

In Manhattan, tall fescue had below-acceptable color for 18 weeks. Green Lawnger and Endurant applied at 80 GPA had better color compared to tall fescue from 8 to 24 WAT. Wintergreen Plus applied at 80 GPA resulted in zoysiagrass with better color than tall fescue from 10 to 24 WAT. Green Lawnger applied at 160 GPA had better color compared to tall fescue from 6 to 24 WAT. Endurant and Wintergreen Plus colorants both applied at the 160 GPA volume resulted in better color to tall fescue from 6 to 26 WAT. All three colorants applied at 240 GPA resulted in zoysiagrass with better color to that of tall fescue from 4 to 26 WAT.

At Haysville, tall fescue was below acceptable color for 16 weeks (Figure 2-3). All three colorants applied at 80 GPA, and Green Lawnger and Endurant at 160 GPA, had better color compared to tall fescue from 8 to 24 WAT. All three colorants applied at the 240 GPA, and Wintergreen Plus at 160 GPA, provided higher color than tall fescue from 4 to 24 WAT.

Dark Green Color Index

There were differences in type of green color among Green Lawnger, Endurant, and Wintergreen Plus at each application volume. Green Lawnger and Endurant provided a dark green color compared to Wintergreen Plus's blue-green color, but still had a similar duration of acceptable color. These differences in green color were clearly visible in the dark green color index (DGCI) results from monthly digital photographs taken under a light box at Manhattan (Figure 2-2 & Appendix Table B-3). Dark green color index is calculated from digital photographs under a constant light source, and image-analysis software has proven to be useful in determining a consistent measure of green color (Briscoe et al., 2010; Karcher and Richardson, 2003).

However, the blue-green color of Wintergreen Plus consistently provided higher DGCI value at each application volume compared to Green Lawnger and Endurant (Appendix Table B-3). All three colorants, regardless of application volume, had significantly higher DGCI values than untreated zoysiagrass from 0 to 27 WAT. All colorants at each application volume provided higher DGCI values than tall fescue from 8 to 24 WAT, which mirrored the visual turf color ratings. Preference for color obviously varies from person to person. Some homeowners may prefer a dark-green color more than a blue-green color.

Temperatures

The application volume nested within colorant effect was not significant for canopy temperature at either site; however, the main effect of colorant was significant. (Appendix Tables B-4 and B-5). In Manhattan, Green Lawnger and Endurant applications resulted in significantly higher canopy temperature than untreated zoysiagrass on five of five dates, and Wintergreen Plus had higher canopy temperature than untreated turf on three of the five dates (Table 2-3). Canopy temperature of colorant-treated zoysiagrass was 12ºF higher than untreated turf on 26 March 2014.

In Haysville, colorant application resulted in higher canopy temperatures on two of four dates (Table 2-4). The largest canopy temperature difference (5.4ºF) occurred between Green Lawnger-treated and untreated zoysiagrass on 13 March 2014.

Neither the effect of application volume nested within colorant, nor the main effect of colorant were significant for soil temperature at either site (Appendix Tables B-4, B-5, B-6, and B-7). The higher mowing height and dense canopy of the Chisholm zoysiagrass in this study may have prevented a colorant influence on soil temperatures.

Colorants applied to Ultradwarf bermudagrass putting greens in Paradise Valley, AZ increased canopy temperatures when compared to untreated turf (Whitlark, 2012; Whitlark and Umeda, 2012). In South Carolina, colorant-treated TifEagle bermudagrass putting greens had higher canopy and soil temperatures than untreated turf, and spring green up also occurred sooner on colorant-treated turf (Liu et al., 2007). Buffalograss [*Buchloe dactyloides* (Nutt.) Engelm] treated in December with Lesco Green had in higher soil temperatures, which resulted in green up two weeks earlier than untreated turf in Nebraska (Shearman et al., 2005). In the current study, colorants influenced canopy, but not soil temperatures. However, no differences occurred in spring green-up between colorant-treated and untreated zoysiagrass (data not shown).

Conclusion

Intensity and duration of acceptable color of colorants was improved by increasing application volume. While the differences in intensity and duration of acceptable color of all colorants between application volumes of 240 GPA and 80 GPA were definitive, those between 240 GPA and 160 GPA were less pronounced. The average costs of the colorants presently range products from $50 to 60 per gallon, or less if bought bulk. At these prices, the resulting costs per 1,000 sq. ft. would be about $17 at 80 GPA, $34 at 160 GPA, and $51 at 240 GPA. Colorants increased canopy, but not soil temperature, and no obvious increase in spring green up was observed.

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Figure 2-1. Study area after application on Chisholm zoysiagrass at the Rocky Ford Turfgrass Research Center, Manhattan KS on 11 October 2013. A) Green Lawnger at 160 GPA, B) Untreated, C) Endurant at 240 GPA, D) Wintergreen Plus at 240 GPA, E) Wintergreen Plus at 80 GPA, F) Wintergreen Plus at 160 GPA, G) Endurant at 160 GPA, H) Endurant at 80 GPA, I) Green Lawnger at 80 GPA, J) Green Lawnger at 240 GPA.

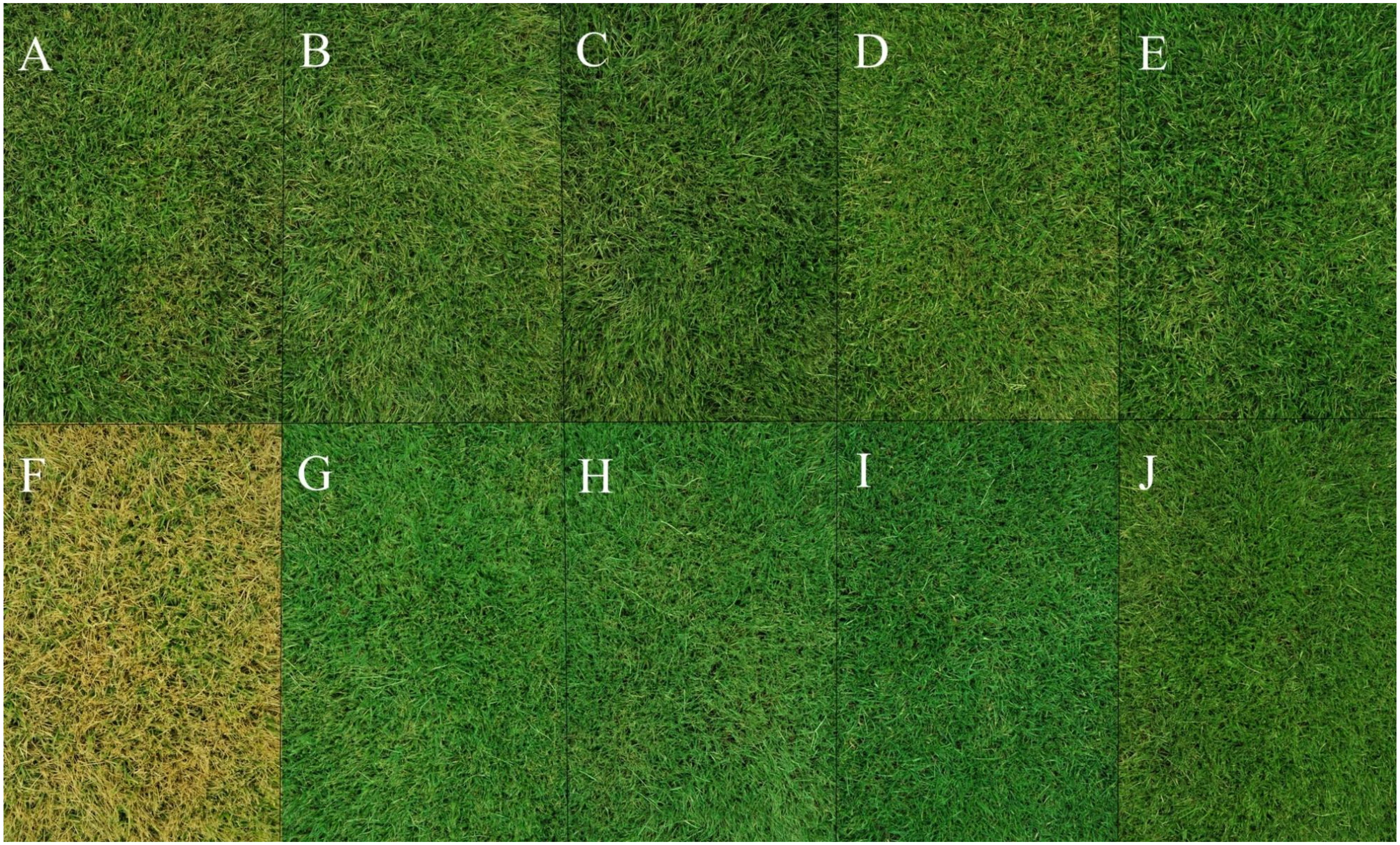

Figure 2-2. Digital photos under light box taken on 19 October 2013, eight days after first colorant application on Chisholm zoysiagrass at the Rocky Ford Turfgrass Research Center. A) Green Lawnger at 80 GPA, B) Green Lawnger at 160 GPA, C) Green Lawnger at 240 GPA, D) Endurant at 80 GPA, E) Endurant at 160 GPA, F) Untreated, G) Wintergreen Plus at 80 GPA, H) Wintergreen Plus at 160 GPA, I) Wintergreen Plus at 240 GPA, J) Endurant at 240 GPA.

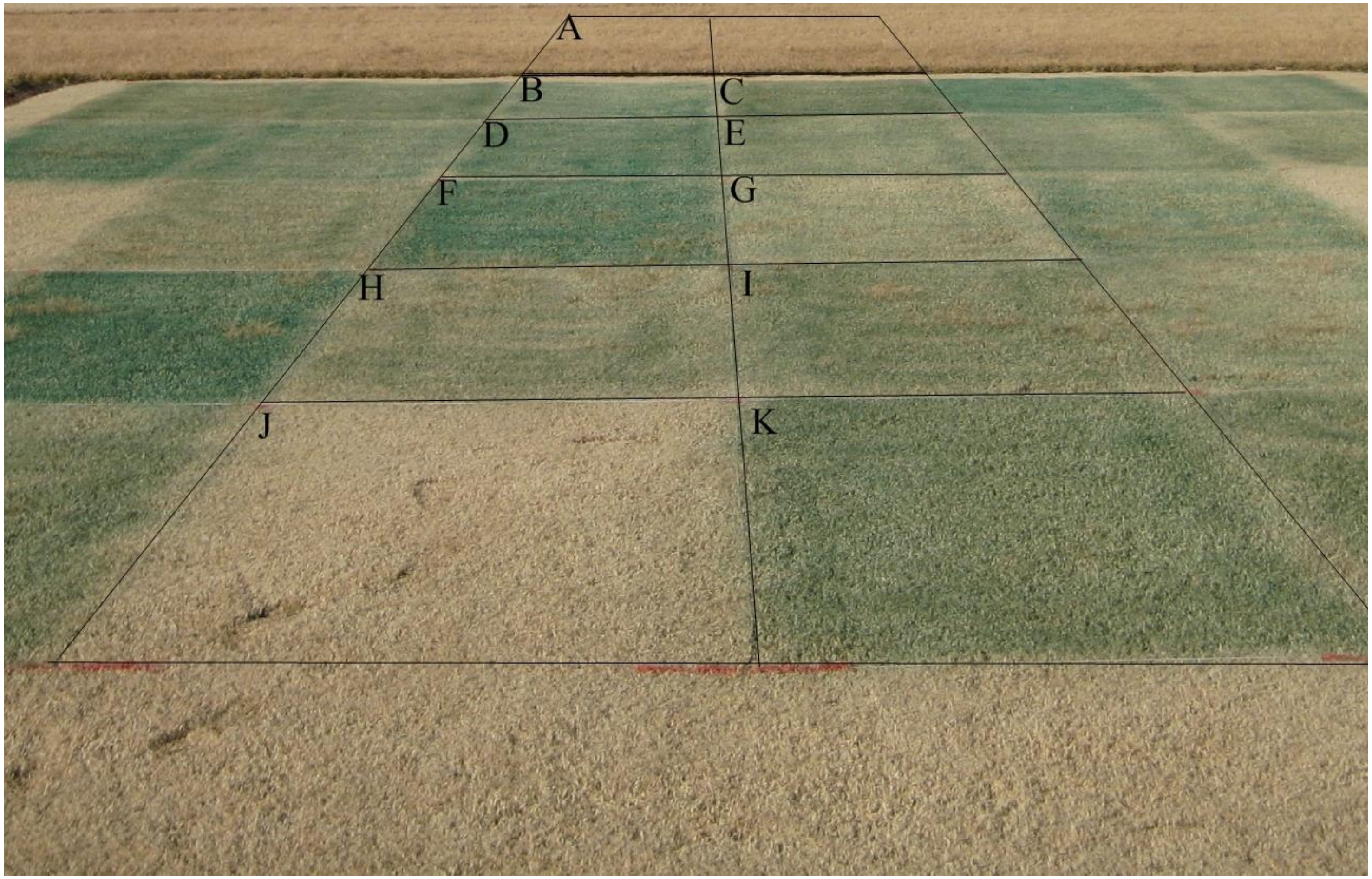

Figure 2-3. Study area on 18 Feb. 2014 (16 WAT) on Chisholm zoysiagrass at the John C Pair Research Center, Haysville, KS: A) Tall fescue; B) Wintergreen Plus at 80 GPA; C) Green Lawnger at 240 GPA; D) Wintergreen Plus at 160 GPA; E) Endurant at 160 GPA; F) Wintergreen Plus at 240 GPA; G) Endurant at 80 GPA; H) Green Lawnger at 80 GPA; I) Green Lawnger at 160 GPA; J) Untreated; and K) Endurant at 240 GPA.

Table 2-1. Effect of colorant and application volume on color of 'Chisholm' zoysiagrass at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2013-2014.

	Turf color†														
	11 Oct.	23 Oct.	6 Nov.	20 Nov.	6 Dec.	18 Dec.	15 Jan.	25 Jan.	24 Feb.	11 March	26 March	9 April	25 April	8 May‡	21 May‡
Treatment§	0 WAT¶	2 WAT	4 WAT	6 WAT	8 WAT	10 WAT	14 WAT	16 WAT	20 WAT	22 WAT	24 WAT	26 WAT	28 WAT	30 WAT	32 WAT
Green Lawnger															
80 GPA	8.7 ab#	7.3 cd	7.3 de	7.0 d	7.0 de	6.7 cd	5.3 cd	5.0 d	4.3 e	4.3 cd	3.7 de	3.0 ef	3.0 cd	3.3	5.3
160 GPA	9.0 a	8.7 ab	8.3 abc	8.3 bc	8.3 abc	7.0 bc	5.3 cd	4.7 d	4.7 de	4.3 cd	3.7 de	3.3 def	3.3 cd	3.3	5.3
240 GPA	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	8.0 a	7.7 a	7.0 ab	7.0 a	6.7 a	6.0 a	5.7 ab	5.0 b	4.7	4.7
Endurant															
80 GPA	8.0 c	7.0 d	7.0 ef	7.0 d	6.3 ef	6.0 d	5.0 d	4.3 d	4.3 e	4.0 d	3.3 e	3.3 def	3.0 cd	3.3	4.3
160 GPA	8.3 bc	8.3 ab	8.0 bcd	8.3 bc	8.0 bc	7.7 ab	6.0 bc	6.0 c	5.7 bc	5.3 b	4.3 cd	4.3 cd	3.7 c	4.3	4.7
240 GPA	9.0 a	9.0 a	8.7 ab	8.7 ab	8.7 ab	8.3 a	6.3 b	6.3 bc	6.0 bc	5.7 b	5.3 ab	5.0 bc	5.0 b	4.3	5.0
Wintergreen Plus															
80 GPA	7.3 d	7.0 d	6.3 f	6.3 e	6.0 fg	6.0 d	4.7 d	4.7 d	3.0 f	3.0 e	3.0 e	2.3 f	2.3 d	3.0	4.7
160 GPA	8.7 ab	8.0 bc	8.0 bcd	8.0 c	7.7 cd	7.7 ab	6.3 b	6.0 c	5.3 cd	5.0 bc	5.0 bc	4.0 cde	4.0 bc	3.7	5.3
240 GPA	9.0 a	8.7 ab	8.7 ab	8.7 ab	8.0 bc	7.7 ab	7.7 a	7.7 a	6.3 ab	5.0 bc	4.7 bc	4.0 cde	4.0 bc	4.0	5.3
Tall Fescue	9.0 a	8.7 ab	7.7 cde	7.0 d	5.5 g	2.0 e	1.0 e	1.0 e	1.0 g	1.0 f	3.0 e	6.7 a	8.7 a	9.0	9.0
Untreated	3.0 e	2.3 e	1.0 g	1.0 f	1.0 h	1.0 f	1.0 e	1.0 e	1.0 g	1.0 f	1.0 f	1.0 g	1.0 e	1.3	4.0

† Turf color was rated on a 1 to 9 scale where 1 = straw brown; 6 = acceptable green color (light green); and 9 = dark green.

‡ No significant difference ($P \geq 0.05$) for date.

§ Colorants were applied on 11 Oct. 2013 at a dilution of 1:6 (colorant:water) using a one-nozzle, 3 gallon SHURflo ProPack™ model SRS 600 rechargeable electric backpack sprayer with an adjustable cone nozzle calibrated to deliver 0.29 gallons per minute.

¶ Weeks After Treatment (weeks after 1st colorant application)

Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

Table 2-2. Effect of colorant and application volume on color of 'Chisholm' zoysiagrass at the John C. Pair Research Center, Haysville, KS in 2013-2014.

	Turf color†									
	24 Oct.	21 Nov.	17 Dec.	17 Jan.	18 Feb.	13 March	8 April	22 April	6 May‡	20 May‡
Treatment§	0 WAT¶	4 WAT	8 WAT	12 WAT	16 WAT	20 WAT	24 WAT	26 WAT	28 WAT	30 WAT
Green Lawnger										
80 GPA	6.7 cd#	6.7 ef	6.7 c	3.7 de	3.0 cd	3.0 ef	2.3 def	2.7 e	4.7	6.0
160 GPA	8.0 b	8.0 bc	8.0 ab	6.3 bc	4.7 b	4.0 cde	3.7 cd	4.3 cd	5.3	6.3
240 GPA	9.0 a	9.0 a	8.7 a	7.3 ab	6.3 a	6.0 ab	5.7 ab	5.7 b	6.0	6.0
Endurant										
80 GPA	6.3 d	6.3 f	6.0 c	3.3 e	2.7 d	2.3 f	2.0 ef	2.3 e	4.0	6.3
160 GPA	7.7 b	7.3 cde	7.0 bc	6.0 c	4.7 b	3.7 de	3.0 cde	3.3 de	4.7	6.0
240 GPA	9.0 a	9.0 a	8.7 a	6.7 bc	6.0 a	4.7 cd	4.3 bc	4.3 cd	4.7	6.0
Wintergreen Plus										
80 GPA	7.0 c	7.0 def	6.3 c	4.7 d	3.7 c	3.3 ef	2.7 de	2.3 e	5.0	6.3
160 GPA	9.0 a	8.7 ab	8.3 a	6.7 bc	6.0 a	5.0 bc	4.3 bc	4.0 cd	5.3	6.0
240 GPA	9.0 a	9.0 a	9.0 a	8.0 a	6.7 a	6.3 a	5.7 ab	4.7 bc	5.7	6.0
Tall Fescue	9.0 a	7.7 cd	3.3 d	1.0 f	1.0 e	1.0 g	6.7 a	8.3 a	9.0	9.0
Untreated	1.0 e	1.0 g	1.0 e	1.0 f	1.0 e	1.0 g	1.0 f	1.0 f	2.3	6.0

† Turf color was rated on a 1 to 9 scale where 1 = straw brown; 6 = acceptable green color (light green); and 9 = dark green.

‡ No significant difference ($P \geq 0.05$) for date.

§ Colorants were applied on 24 Oct. 2013 at a dilution of 1:6 (colorant:water) using a one-nozzle, 3 gallon SHURflo ProPack™ model SRS 600 rechargeable electric backpack sprayer with an adjustable cone nozzle calibrated to deliver 0.29 gallons per minute.

¶ Weeks After Treatment (weeks after 1st colorant application)

Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

Table 2-3. Effect of colorant on canopy temperature (°F) of 'Chisholm' zoysiagrass at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2014.

	Canopy temperature (°F)[†]				
Treatment[‡]	11 March	26 March	11 April	25 April	9 May
Green Lawnger	73.4 a[§]	83.5 b	100.4 a	94.5 ab	104.0 b
Endurant	73.8 a	88.0 a	101.8 a	95.9 a	107.9 a
Wintergreen Plus	72.2 b	82.6 b	97.6 b	92.7 bc	100.5 c
Untreated	69.3 c	75.9 c	93.2 c	90.9 c	97.8 c

[†] Canopy temperature was measured and averaged from three measurements within each plot using a handheld infrared thermometer.
[‡] Colorants were applied on 11 Oct. 2013 at a dilution of 1:6 (colorant:water) using a one-nozzle, 3 gallon SHURflo ProPack™ model SRS 600 rechargeable electric backpack sprayer with an adjustable cone nozzle calibrated to deliver 0.29 gallons per minute.
[§] Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

Table 2-4. Effect of colorant on canopy temperature (°F) of ‘Chisholm’ zoysiagrass at the John C. Pair Research Center, Haysville, KS in 2014.

	Canopy temperature (°F)[†]			
Treatment[‡]	13 March	8 April	22 April[§]	6 May[§]
Green Lawnger	69.8 a[¶]	71.5 a	92.1	92.6
Endurant	69.6 a	69.3 ab	92.0	93.5
Wintergreen Plus	67.6 b	69.1 ab	90.7	92.5
Untreated	64.9 c	64.2 b	86.2	88.1

[†] Canopy temperature was measured and averaged from three measurements within each plot using a handheld infrared thermometer.
[‡] Colorants were applied on 24 Oct. 2013 at a dilution of 1:6 (colorant:water) using a one-nozzle, 3 gallon SHURflo ProPack™ model SRS 600 rechargeable electric backpack sprayer with an adjustable cone nozzle calibrated to deliver 0.29 gallons per minute.
[§] No significant difference ($P \geq 0.05$) for date.
[¶] Means in a column followed by the same letter are not significantly different according Fisher’s protected least significant difference test ($P \leq 0.05$).

Chapter 3 - Evaluation of Turfgrass Colorants and Application Number and Volume on Buffalograss and Zoysiagrass

This chapter has been prepared using style guidelines for the journal *Applied Turfgrass Science*

ABSTRACT

Warm-season (C4) turfgrasses are more heat and drought resistant and require fewer pesticide and fertilizer inputs than cool-season (C3) turfgrasses. However, in the transition zone, cool-season grasses provide a longer duration of green color compared to warm-season grasses. Among the characteristics of interest to warm-season turfgrass managers are extended fall color and early spring green-up. The objective was to evaluate the color and persistence of colorants applied at two volumes, once or sequentially, on buffalograss maintained at 2.5 inches and zoysiagrass maintained at 0.5 inches. Multiple field studies were conducted in Manhattan, KS and Haysville, KS from October 2013 to May 2014 on dormant 'Sharpshooter' and 'Cody' buffalograss and 'Meyer' zoysiagrass. The colorants Green Lawnger, Endurant, and Wintergreen Plus were applied at 100 and 160 gallons per acre (GPA) in autumn or autumn plus mid-winter. In general, buffalograss receiving a single autumn colorant application had acceptable color (i.e., a visual rating ≥ 6) for 8 to 12 WAT at 100 GPA or 8 to 14 WAT at 160 GPA. Zoysiagrass receiving a single autumn colorant application had acceptable color for 8 to 18 WAT at 100 GPA or 14 to 18 WAT at 160 GPA. Applying a sequential mid-winter colorant application at either 100 or 160 GPA in mid-winter resulted in acceptable color from that point until spring green up. Winter color of buffalograss and zoysiagrass can be enhanced by colorant application, and a longer period of acceptable color can be achieved by applying at a higher volume or by including a sequential mid-winter treatment.

INTRODUCTION

The transition zone of turfgrass adaption, a loosely-defined area in the central US which includes Kansas, experiences wide ranges of temperature extremes and makes turfgrass management difficult. Water is a limited resource and its use for irrigation is under increasing scrutiny. Warm-season (C4) turfgrasses are more heat and drought resistant than cool-season (C3) grasses, which results in water savings (Fry and Huang, 2004). Warm-season turfgrass also require fewer pesticide and fertilizer inputs compared to cool-season turfgrasses (Fry and Huang, 2004). However, cool-season turfgrasses remain green late into the autumn and also green up earlier in the spring. In contrast, warm-season grasses turn brown following the first autumn frost and remain dormant until mid to late spring. Some turf managers in the transition zone avoid use of warm-season grasses because customers object to the brown color during dormancy.

The warm-season grasses buffalograss [*Buchloe dactyloides* (Nutt.) Engelm] and Japanese Lawngrass (*Zoysia japonica* Steud.), generically referred to as zoysiagrass (Japanese Lawngrass will be referred to as zoysiagrass herein), are adapted to the transition zone because of their excellent cold tolerance (Beard, 1973). Buffalograss is native to the Great Plains of North America, from Mexico to Canada (Beetle, 1950, Gould, 1979, Hitchcock, 1951, Reeder, 1971). Buffalograss is well adapted for use in lawns, golf course roughs, parks, cemeteries, athletic fields, roadsides and other low maintenance areas in the transition zone due to its low requirements for irrigation, mowing, fertilizer, and pesticides (Beard, 1973; Shearman et al., 2005), and its ability to tolerate a wide range of soil types (Dudeck and Young, 1968; Elder, 1954; Savage and Jacobson 1935).

Zoysiagrasses (*Zoysia* spp.) are warm-season turfgrasses native to Asia, which were introduced into the United States in 1895 (Engelke and Anderson, 2003; Madison, 1971). Zoysiagrass has attained its popularity due to its excellent tolerance to cold, heat, drought, and wear, and its relatively low requirements for water and other cultural inputs required by cool-season grasses (Beard, 1973; Fry and Huang, 2004; Fry et al. 2008). *Zoysia japonica* (Steud.) is the most widely used of *Zoysia* species in the United States (Christians, 2007), and it is uniquely adapted to the transition zone due to relatively good cold hardiness of cultivars within this species. Much of the popularity of zoysiagrass in the transition zone is due to the cultivar 'Meyer', which was released in 1952. Since then, it has been the predominant cultivar used in the transition zone due to its excellent cold tolerance (Patton and Reicher, 2007; Fry et. al., 2008).

Among the characteristics of interest to buffalograss and zoysiagrass managers are extended fall color and early spring green-up (Fry and Huang, 2004). During winter dormancy, a dormant brown color gradually occurs following the first autumn frost, and once spring soil temperatures rise above 50°F color slowly returns (Beard, 1973). Buffalograss has a light tan to straw-brown color when dormant and an intermediate-to-fair spring green up rate (Beard, 1973). In Kansas, buffalograss generally enters dormancy in early-to-mid October and greens up in early May. As a result of its extended winter dormancy in northern climates, its acceptance as a turfgrass species has been limited (Riordan, 1991).

In Kansas, Meyer zoysiagrass usually takes on a straw-brown color of dormancy in October and begins to green up in mid- to late April (Okeyo et al, 2011). The dormancy period for buffalograss and zoysiagrass can be unappealing to turfgrass managers and golfers, especially when cool-season grasses retain color longer in autumn and green up sooner in spring are grown in the same vicinity.

Turf colorants are an option for improving buffalograss and zoysiagrass color during dormancy. The use of turf colorants has become popular on golf course fairways and putting greens in the South to provide green color during winter dormancy (Long, 2006). Colorants have been effective in providing green color and enhancing turf quality on dormant buffalograss. Buffalograss treated with the turf colorant LESCO Green had higher visual color and quality ratings than untreated, dormant turf in Nebraska (Shearman et al., 2005). Ratings for colorant-treated turfs declined with time, but were always better than untreated turf, and were similar to semi-dormant Kentucky bluegrass (*Poa pratensis* L.) in early April.

The turf colorants Titan Green Turf, Green Lawnger, and Regreen provided acceptable color on a ‘TifEagle’ bermudagrass [*Cynodon dactylon* (L.) Pers. X *C. transvaalensis* Burtt-Davy] putting green during the winter in South Carolina (Liu, 2007). Evaluation of turf colorants on ‘Diamond’ zoysiagrass [*Zoysia matrella* (L.) Merr.] and ‘Miniverde’ bermudagrass [*Cynodon dactylon* (L.) Pers. X *C. transvaalensis* Burtt-Davy] at putting green height demonstrated that the colorants Wintergreen Plus and Turf in a Bottle, applied once in autumn, effectively enhanced color during winter dormancy on both grasses in Raleigh, NC (Briscoe et al., 2010). Colorants which provided acceptable green color and the highest color ratings on dormant Diamond zoysiagrass were (in no particular order) Mtp Turfgreen, Titan Green Turf, Green Lawnger, Match Play 'Ultradwarf Super', and Wintergreen Plus (Briscoe et al., 2010).

Colorants enhanced color on dormant 'Chisholm' zoysiagrass *(Z. japonica*) at lawn-height at Manhattan and Haysville, KS during 2012 to 2013 (Chapter 1). However, in that experiment, only one application volume of 262 gallons per acre (GPA) was evaluated using Green Lawnger and Match Play 'Ultradwarf Super' on lawn-height Chisholm zoysiagrass. Green Lawnger provided the highest color ratings throughout the study, and a single autumn application provided acceptable color until early April (19 to 24 WAT). However, a single autumn application of Ultradwarf Super only provided acceptable zoysiagrass color until mid-December (7 to 9 WAT). Zoysiagrass receiving a second application in mid-winter (14 WAT) of either colorant had acceptable color level until mid-May (28 WAT). These results led to additional questions: 1) How does buffalograss respond to colorant application? 2) Would zoysiagrass at a mowing height used on golf course fairways and tees respond similarly to what was observed with Chisholm? and 3) Would other colorants and application volumes be as effective as what was observed with Green Lawnger in Chapter 1? Colorant application volume has been shown to affect turf color intensity and longevity. Visual turf color intensity at putting green height increased 1 to 44% on bermudagrass and increased 11 to 15% on zoysiagrass when application volumes for three colorant products were raised from 80 to 160 GPA in Raleigh, NC (Briscoe et al., 2010).

Although colorants are used routinely on golf courses in the South, information is lacking on how they can be most effectively used in the transition zone. Therefore, the objective was to determine effects of colorants, application volumes, and one vs. two colorant applications on turf color and soil and canopy temperatures of buffalograss maintained under lawn/golf course rough conditions, and zoysiagrass under golf course fairway/tee conditions.

MATERIALS AND METHODS

Study Sites

The buffalograss colorant experiment was conducted at the Rocky Ford Turfgrass Research Center in Manhattan, Kansas and the John C. Pair Research Center in Haysville, Kansas. Turf was 'Sharpshooter' buffalograss in Manhattan and 'Cody' buffalograss in

Haysville. Soil at Manhattan was a Chase silty clay loam and that at Haysville was a Canadian-Waldeck fine sandy loam. Turf at each site was maintained at a height of 2.5 inches, which would be common for home lawns and golf course roughs, and received an annual June application of 1 lb. of N per 1,000 sq. ft.

The zoysiagrass colorant experiment was conducted at the Rocky Ford Turfgrass Research Center and the Colbert Hills Golf Course in Manhattan, Kansas. The soil type at Rocky Ford was the same as for the buffalograss experiment. At Colbert Hills, soil was a Clime-Sogn complex. Turf at both sites was 'Meyer' zoysiagrass maintained at a 0.5 inch height and 1 to 2 lb. of nitrogen (N) per 1000 sq. ft. per year were applied between June and August.

Plots at each site measured 5 ft. x 5 ft. and were arranged in a randomized complete-block design with four replicates. Treatments were: 1) untreated; 2) Green Lawnger (Becker Underwood, Ames, IA) applied at a spray volume of 100 gallons per acre (GPA) once in autumn; 3) Green Lawnger applied at 100 GPA in autumn and mid-winter 4) Green Lawnger applied at 160 GPA once in autumn; 5) Green Lawnger applied at 160 GPA in autumn and mid-winter; 6) Endurant (Geoponics Corp, Naples, FL) applied at 100 GPA once in autumn; 7) Endurant applied at 100 GPA in autumn and mid-winter; 8) Endurant applied at 160 GPA once in autumn; 9) Endurant applied at 160 GPA in autumn and mid-winter; 10) Wintergreen Plus (Precision Laboratories, Inc., Waukegan, IL) applied at 100 GPA once in autumn; 11) Wintergreen Plus applied at 100 GPA in autumn and mid-winter; 12) Wintergreen Plus applied at 160 GPA once in autumn; and 13) Wintergreen Plus applied at 160 GPA in autumn and mid-winter.

Colorant Application

Colorants were applied using a three-nozzle, CO_2-pressurized sprayer with 8002VS nozzles calibrated to deliver 0.40 gallons per minute at 20 psi. Colorants were applied at a dilution of 1:6 (colorant: water) and two passes were made in perpendicular directions on each plot, with one half of the total volume applied in each direction.

Sharpshooter buffalograss with 10 to 15% green canopy color remaining received its first colorant application on 10 Oct. 2013 at the Rocky Ford Turfgrass Research Center. Cody buffalograss with 5 to 10% green canopy color remaining was treated on 24 Oct. 2013 at the John C Pair Research Center. Sixteen weeks after the first colorant application (WAT) on buffalograss, treatments receiving a sequential mid-winter application were treated on 25 Jan.

2014 at the Rocky Ford Turfgrass Research Center and 18 Feb. 2014 at the John C Pair Research Center.

Meyer zoysiagrass with 15 to 20% green canopy color remaining was treated with colorants on 17 Oct. 2013 at the Rocky Ford Turfgrass Research Center. At Colbert Hills, Meyer with 15 to 20% green canopy color remaining was treated on 26 Oct. 2013. Eighteen weeks after the first colorant application (WAT), treatments receiving a sequential mid-winter application were treated on 18 Feb. 2014 at Rocky Ford Turfgrass Research Center and on 24 Feb. 2014 at the Colbert Hills Golf Course.

Data Collection and Analysis

At Rocky Ford and at Colbert Hills, visual turf color was rated every other week on a 1 to 9 scale where 1 = straw brown; 6 = acceptable green color for a lawn/golf course, and 9 = dark green (Morris and Shearman, 1999). Color was rated monthly at the Pair Center.

A digital photograph was taken with a Nikon D5000 digital camera (Nikon Inc., Tokyo, Japan) of each plot on zoysiagrass and buffalograss at the Rocky Ford Turfgrass Research Center on 19 Oct., 14 Nov., and 6 Dec. 2013 and 20 Jan., 17 Feb., 26 March, 15 April, 15 May 2014 using a lighted camera box (20 in. x 24 in. x 22 in.) The camera was adjusted to the following manual settings: f-stop of 5.6, 1/125 sec exposure time, and 800 ISO-speed. Images were analyzed with SigmaScan Pro 5.0 (ver. 5.0, SPSS Science Marketing Dept., Chicago, IL) using the “Turf Analysis” macro for batch analysis (Karcher and Richardson, 2005). The macro threshold settings were adjusted to hue = 50 to 107 and saturation = 0 to 100. These threshold settings allowed for estimation of pixels (expressed as percentages) that represented green turf color relative to non-green (dormant) turf. After images were analyzed, a dark green color index (DGCI) value (on a zero to one scale) was calculated for each image using the following equation: DGCI value = $[(\text{Hue} - 60)/60 + (1 - \text{Saturation}) + (1 - \text{Brightness})]/3$ (Karcher and Richardson, 2003).

Starting 11 March 2014, then every other week, soil temperatures at all four sites at a 2 inch depth were measured and averaged from three measurements within each plot between 1300 and 1500 central daylight time on cloudless days using a digital T-bar thermometer (Argus Realcold Property Ltd., Coopers Plains, Australia). In addition, starting 11 March 2014, canopy temperatures at all four sites were measured and averaged from three measurements within each plot between 1300 and 1500 central daylight time on cloudless days using a handheld infrared thermometer at a 4 ft. height above the canopy (Model 100.3ZL, Everest Interscience, Tucson, Arizona).

Residual normality was tested with the *w* statistic of the Shapiro-Wilk test using the UNIVARIATE procedure of Statistical Analysis System (SAS Institute Inc., Cary, NC) (Shapiro and Wilk, 1965). Data were subjected to a three-fold nested analysis of variance (ANOVA) using the GLIMMIX procedure of SAS 9.2. Factors were application timing nested within application volume nested within colorant, application volume nested within colorant, and colorant. Treatment differences were separated using Fisher's protected least significant difference test ($P \leq 0.05$). A Homogeneity of Variance Test for location by treatment effect was significant for corresponding study sites associated with either buffalograss or zoysiagrass, therefore results will be presented separately for each site.

RESULTS AND DISCUSSION

Turf Color

At all four sites, the effect of application timing nested within application volume nested within colorant was not significant until the second application timing was implemented (Appendix Tables C-1, C-2, C-3, and C-4). Therefore, only the effect of application volume nested within colorant will be discussed until the sequential mid-winter application timing was implemented at 16 WAT on buffalograss or 18 WAT on zoysiagrass. Following 16 WAT on buffalograss and 18 WAT on zoysiagrass, a significant effect of application timing nested within application volume nested within colorant occurred and will be discussed.

Buffalograss

Colorants provided acceptable color of dormant buffalograss immediately after application. When colorants, regardless of brand, were applied once in autumn acceptable color (i.e., a rating ≥ 6) occurred for 8 to 12 WAT at 100 GPA and 8 to 14 WAT at 160 GPA (Tables 3-1 and 3-2). Across both experimental sites, buffalograss treated at 160 GPA had superior turf color than that receiving 100 GPA on 6 of 18 dates for Green Lawnger, 11 of 18 dates for Endurant, and 7 of 18 dates for Wintergreen Plus.

Buffalograss receiving a sequential mid-winter colorant application at 16 WAT (25 January 2014) at Manhattan and on 18 Feb. 2014 at Haysville had acceptable color for the remaining 14 to 16 weeks through spring green-up, regardless of application volume, with one exception (Tables 3-1 and 3-2). Turf treated with Green Lawnger at 100 GPA in Haysville had unacceptable color at 20 and 24 WAT (Figure 3-3) (Table 3-2). Across both experimental sites, buffalograss receiving a sequential colorant application at 160 GPA had superior color compared to that receiving 100 GPA on 8 of 10 dates for Green Lawnger, and 3 of 10 dates for Endurant and Wintergreen Plus.

In Nebraska, researchers applied the colorant LESCO Green at the label rate and twice the label rate on buffalograss maintained at a 2.5 inch height in December, and observed higher visual color ratings compared to that of untreated buffalograss (Shearman et al., 2005). In the same experiment applying LESCO Green at twice the label rate on buffalograss resulted in significantly higher turf color to applying at the labeled rate.

Zoysiagrass

In general, zoysiagrass treated with one autumn colorant application had acceptable color for 8 to 18 WAT at 100 GPA and 14 to 18 WAT at 160 GPA (Tables 3-3 and 3-4). Across both experimental sites, zoysiagrass treated at 160 GPA had superior turf color than that receiving 100 GPA on 8 of 16 dates for Green Lawnger, 6 of 16 dates for Endurant, and 1 of 16 dates for Wintergreen Plus.

Zoysiagrass receiving the sequential mid-winter application 18 WAT had acceptable color for the remaining 10 to 12 weeks through spring green-up (Figure 2-4) (Tables 3-3 and 3-4). Across both experimental sites, zoysiagrass receiving a sequential colorant application at 160 GPA had superior turf color to that receiving 100 GPA on 1 of 8 dates for Green Lawnger and Wintergreen Plus, and 2 of 8 dates for Endurant.

Five weeks after application on a Diamond zoysiagrass putting green in North Carolina, the colorants Green Lawnger, Turf in a Bottle, and Ultradwarf Super applied at a 160 GPA had a higher turf color intensity of 11 to 15% compared to the lower application at 80 GPA. (Briscoe et al., 2010). Similar increases in turf color intensity occurred on both grass species as application volumes were raised from 100 to 160 GPA. At both sites, colorants applied at 160 GPA increased buffalograss color intensity 8 to 17% compared to the lower application at a rate of 100

GPA at 4 WAT, and 11 to 35% at 8 to 12 WAT (Tables 3-1 and 3-2). On zoysiagrass, colorants applied at 160 GPA increased zoysiagrass color intensity 2 to 9% relative to 100 GPA at 4 WAT and 4 to 19% at 8 to 12 WAT (Tables 3-3 and 3-4).

Dark Green Color Index

There were differences in type of green color among colorant products. Green Lawnger and Endurant provided a dark green color compared to Wintergreen Plus's blue-green color, but Wintergreen Plus still had a similar duration of acceptable color. These differences in green color were clearly visible in the monthly digital photographs under a light box on buffalograss and zoysiagrass at the Rocky Ford Turfgrass Research Center (Figures 3-1 and 3-2). Dark green color index values calculated from the monthly digital photographs mirrored the visual turf color ratings on buffalograss and zoysiagrass (Appendix Tables C-5 and C-6). Within each colorant product, applications at 160 GPA provided significantly higher DGCI values compared to 100 GPA on treatments receiving single or sequential applications.

Temperatures

At all sites, the effect of application timing nested within application volume nested within colorant was significant for some dates on which soil and canopy temperatures were measured on both buffalograss and zoysiagrass (Appendix Tables C-7, C-8, C-9, and C-10).

Colorants, and particularly Green Lawnger and Endurant, consistently increased spring canopy temperatures (Tables 3-5 to 3-8), but not soil temperatures (Appendix Tables C-11, C-12, C-13, and C-14) of buffalograss and zoysiagrass. Relative to untreated turf, canopy temperature on colorant-treated turf was up to 9.8ºF higher on buffalograss (8 April in Haysville) and up to 14.5ºF higher on zoysiagrass (11 March at Colbert Hills) (Tables 3-5 to 3-8). Highest numerical canopy temperatures were always observed on turf that received a sequential mid-winter application.

The turf colorant LESCO Green applied in December at both label and twice-label rate on buffalograss in Nebraska resulted in spring soil temperatures differences of 8.4ºF at a 2 inch depth compared to untreated buffalograss (Shearman et al., 2005). Liu et al. (2007) also found canopy and soil temperatures at a 3 inch depth on TifEagle bermudagrass greens in South Carolina increased after colorant application. Theoretically, a warmer canopy temperature could stimulate earlier spring growth. Such growth is difficult to quantify in this experiment due to the presence of the colorant. However, green leaves were observed emerging from colorant-treated turf two weeks earlier than in untreated turf.

Conclusion

Color of buffalograss at lawn/golf course-rough height and zoysiagrass at fairway/tee height was enhanced by using turf colorants. Green Lawnger, Endurant, or Wintergreen Plus applied at a rate of 160 GPA once in autumn provided 0 to 6 additional weeks of acceptable color than the lower volume of 100 GPA, with Green Lawnger and Wintergreen Plus displaying the most distinctive variation between application volumes. Following an average of 5.5 weeks of color that was below acceptable, a sequential mid-winter application of colorants at the same volume resulted in acceptable color for remaining 10 to 16 weeks until 100% spring green up. Therefore, acceptable green color of buffalograss and zoysiagrass during winter dormancy could be achieved by applying colorants at a low volume with a sequential mid-winter application. Spring canopy temperatures were up to 14.5ºF higher on colorant-treated turf, which could enhance spring green up.

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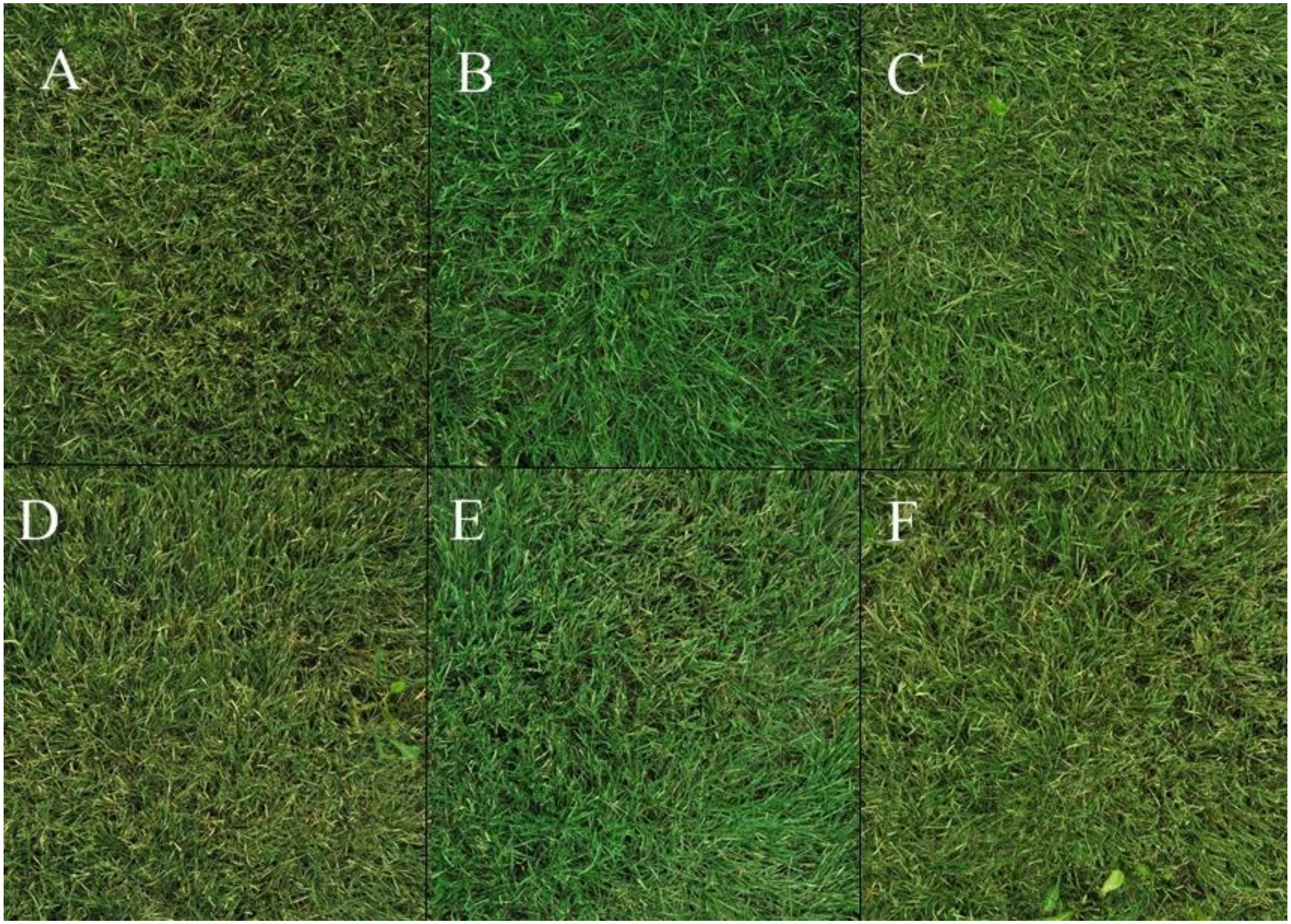

Figure 3-1. Digital photos under light box taken on 19 October 2013, nine days after first colorant application on Sharpshooter buffalograss at the Rocky Ford Research Center: A) Green Lawnger at 160 GPA; B) Wintergreen Plus at 160 GPA; C) Endurant at 160 GPA; D) Green Lawnger at 100 GPA; E) Wintergreen Plus at 100 GPA; and F) Endurant at 100 GPA.

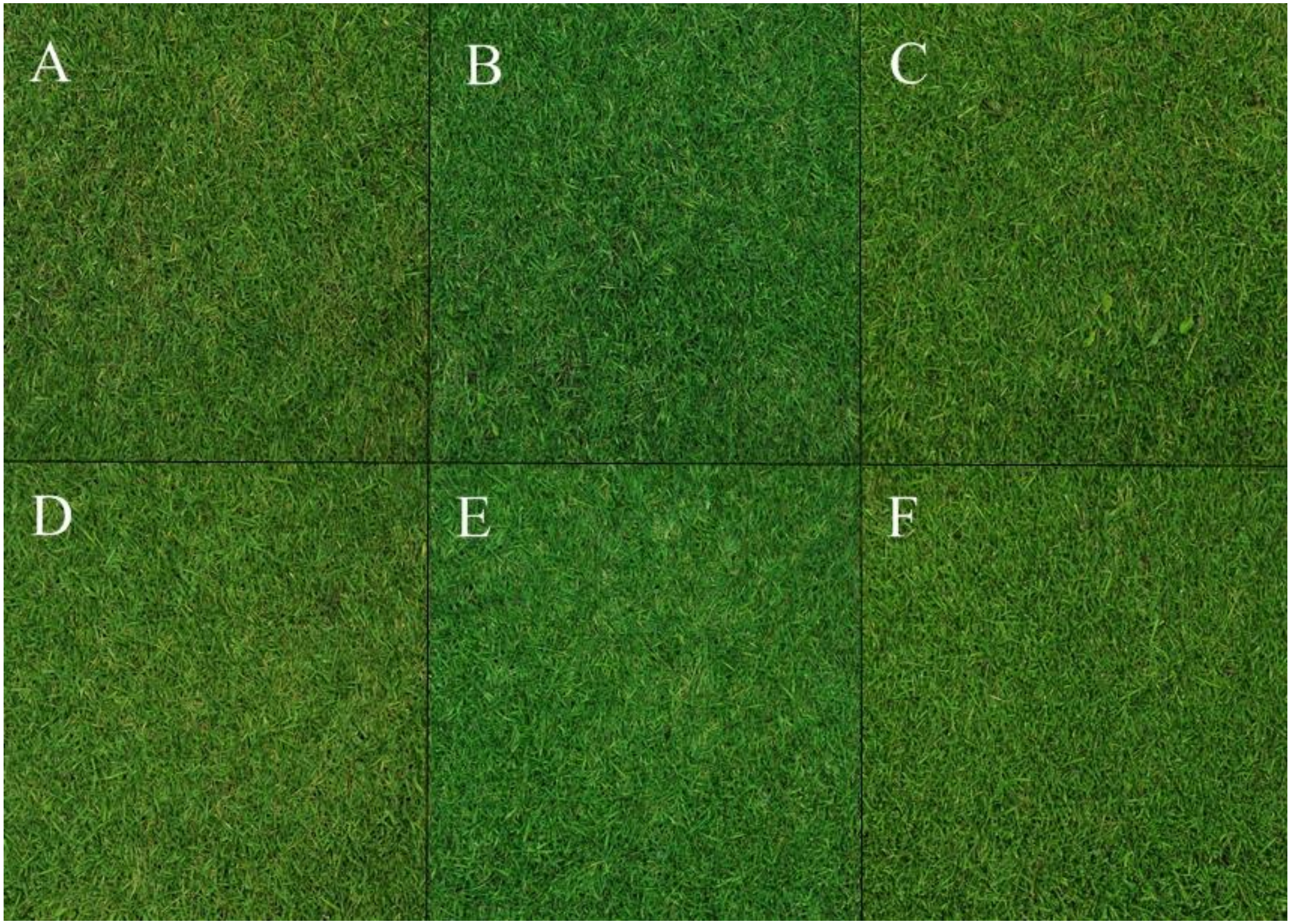

Figure 3-2. Digital photos under light box taken on 19 October 2013, two days after first colorant application on Meyer zoysiagrass at the Rocky Ford Research Center: A) Green Lawnger at 160 GPA; B) Wintergreen Plus at 160 GPA; C) Endurant at 160 GPA; D) Green Lawnger at 100 GPA; E) Wintergreen Plus at 100 GPA; and F) Endurant at 100 GPA.

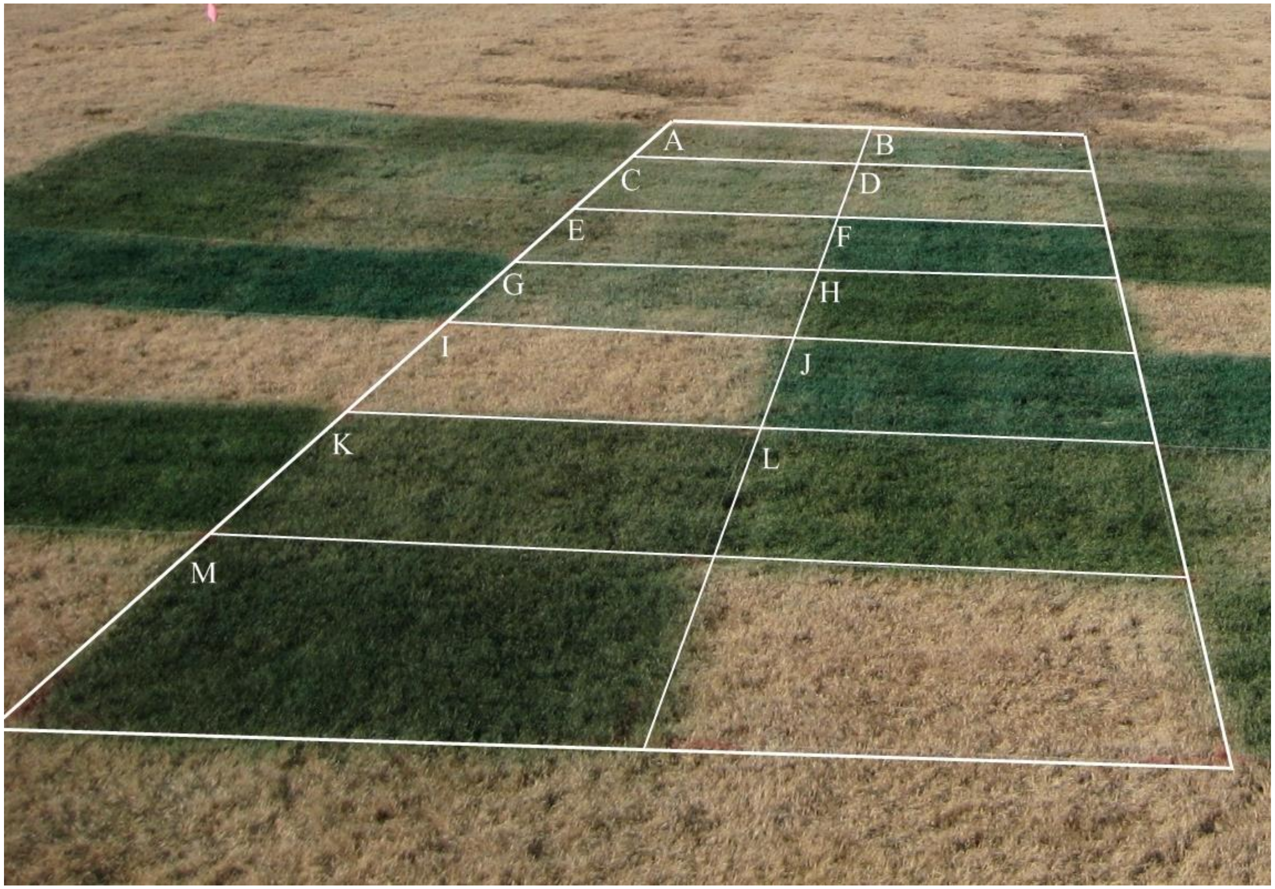

Figure 3-3. Study area four weeks after the 2nd application timing treatments on Sharpshooter buffalograss at the Rocky Ford Research Center on 21 Feb. 2014 (20 WAT). White box: A) Green Lawnger (100 GPA – 1 application); B) Wintergreen Plus (160 GPA – 1 application); C) Endurant (160 GPA – 1 application); D) Endurant (100 GPA – 1 application); E) Green Lawnger (160 – 1 application); F) Wintergreen Plus (160 GPA – 2 applications); G) Wintergreen Plus (100 GPA – 1 application); H) Endurant (160 GPA – 2 applications); I) Untreated; J) Wintergreen Plus (100 GPA – 2 applications); K) Green Lawnger (100 GPA – 2 applications); L) Endurant (100 GPA – 2 applications); M) Green Lawnger (160 GPA – 2 applications).

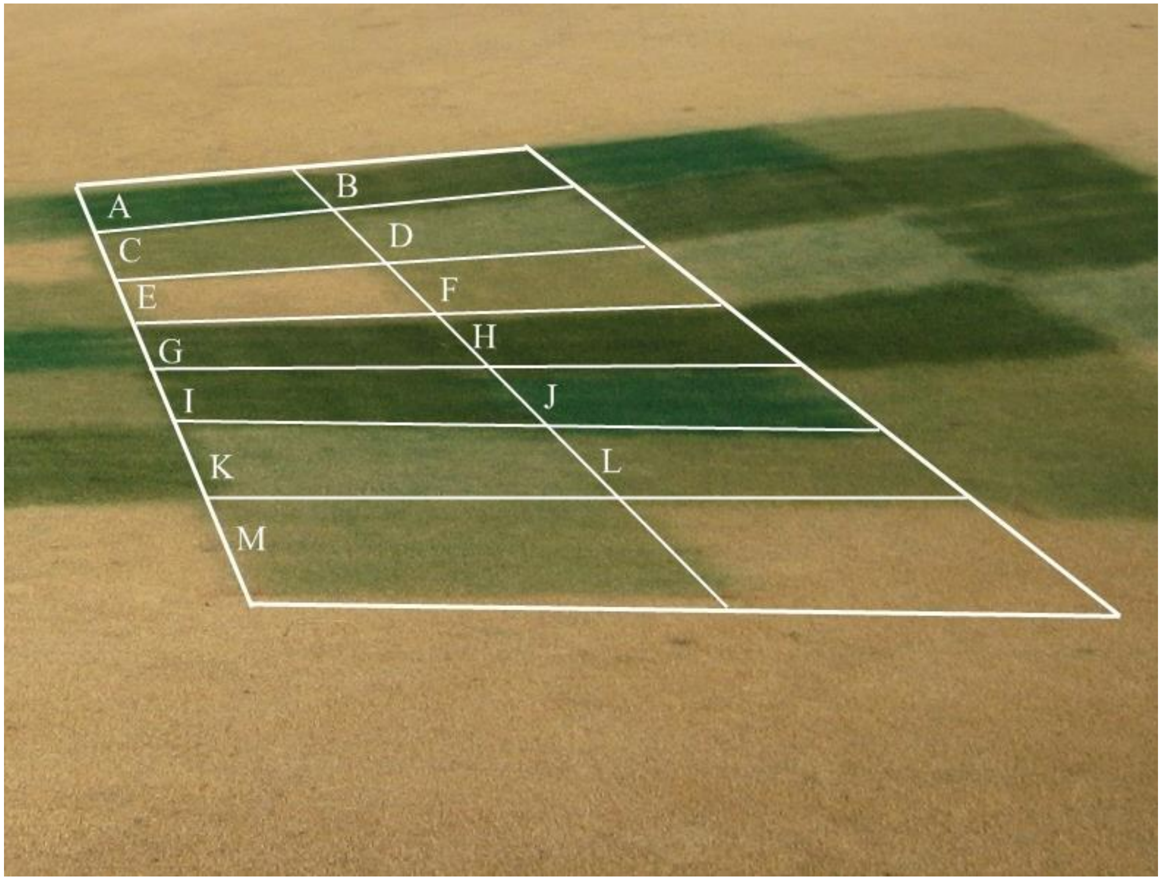

Figure 3-4. Study area after the 2nd application timing treatments on Meyer zoysiagrass at the Colbert Hills Golf Course on 24 Feb. 2014 (18 WAT). White box: A) Wintergreen Plus (100 GPA – 2 applications); B) Green Lawnger (100 GPA – 2 applications); C) Endurant (160 GPA – 1 application); D) Wintergreen Plus (100 GPA – 1 application); E) Untreated; F) Green Lawnger (100 GPA – 1 application); G) Green Lawnger (160 GPA – 2 applications); H) Endurant (160 GPA – 2 applications); I) Endurant (100 GPA – 2 applications); J) Wintergreen Plus (160 GPA – 2 applications); K) Wintergreen Plus (160 GPA – 1 application); L) Green Lawnger (160 GPA – 1 application); M) Endurant (100 GPA – 1 application).

Table 3-1. Effect of colorant, application volume, and application timing on color of ‘Sharpshooter’ buffalograss at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2013-2014.

		Turf color[†]															
		10 Oct.	23 Oct.	6 Nov.	20 Nov.	6 Dec.	18 Dec.	5 Jan.	15 Jan.	27 Jan.	24 Feb.	11 March	26 March	9 April	25 April	8 May	21 May
Treatment	Application Date[‡]	0 WAT[§]	2 WAI	4 WAT	6 WAI	8 WAT	10 WAT	12 WAT	14 WAI	16 WAT	20 WAT	22 WAI	24 WAT	26 WAI	28 WAT	30 WAT	32 WAT
Green Lawnger																	
100 GPA	10 Oct.	8.5 a[¶]	8.1 b	7.6 bc	7.4 bc	6.9 c	6.4 cd	5.1 b	4.3 b	3.3 e[††]	2.3 e	2.3 e	2.3 d	2.3 cd	2.8 c	5.8 ef	6.0 c
	10 Oct. + 25 Jan.	--[#]	--	--	--	--	--	--	--	7.5 b	6.8 d	6.8 d	6.8 c	6.5 b	6.0 b	7.5 bc	6.8 ab
160 GPA	10 Oct.	8.6 a	8.8 a	8.3 ab	8.0 ab	7.8 ab	7.5 ab	6.3 a	5.3 a	4.0 de	2.5 e	2.5 e	2.3 d	2.0 d	3.0 c	6.3 de	6.0 c
	10 Oct. + 25 Jan.	--	--	--	---	--	--	--	--	9.0 a	8.8 a	8.8 a	8.8 a	8.0 a	7.8 a	8.8 a	7.0 a
Endurant																	
100 GPA	10 Oct.	8.8 a	8.1 a	7.6 bc	7.3 c	7.0 bc	6.1 d	5.0 b	4.1 b	3.5 de	2.5 e	2.3 e	2.3 d	2.0 d	2.3 cd	6.3 de	6.5 abc
	10 Oct. + 25 Jan.	--	--	--	--	--	--	--	--	8.5 a	7.5 cd	7.5 cd	7.5 bc	7.3 ab	6.8 ab	8.0 ab	6.8 ab
160 GPA	10 Oct.	8.9 a	8.8 a	8.6 a	8.5 a	8.5 a	6.9 bc	6.3 a	5.5 a	4.0 de	3.0 e	3.0 e	3.0 d	3.0 c	2.8 c	6.3 de	6.3 bc
	10 Oct. + 25 Jan.	--	--	--	--	--	--	--	--	9.0 a	9.0 a	9.0 a	9.0 a	7.8 a	7.0 ab	8.0 ab	6.5 abc
Wintergreen Plus																	
100 GPA	10 Oct.	7.8 b	7.4 c	7.3 c	7.1 c	6.8 c	5.8 d	4.5 b	4.0 b	4.3 cd	2.8 e	2.5 e	2.5 d	2.3 cd	3.0 c	5.8 ef	6.5 abc
	10 Oct. + 25 Jan.	--	--	--	---	--	--	--	--	8.3 ab	7.8 bc	7.8 bc	7.5 bc	6.5 b	6.0 b	7.0 cd	6.8 ab
160 GPA	10 Oct.	8.9 a	8.8 a	8.6 a	8.5 a	8.1 a	7.6 a	6.3 a	5.5 a	5.0 c	3.0 e	3.0 e	3.0 d	3.0 c	2.5 cd	6.0 ef	6.5 abc
	10 Oct. + 25 Jan.	--	--	--	---	--	--	--	--	9.0 a	8.5 ab	8.5 ab	8.3 ab	7.5 a	6.5 b	7.3 bc	7.0 a
Untreated		2.0 c	1.3 d	1.0 d	1.0 d	1.0 d	1.0 e	1.0 c	1.0 c	1.0 f	1.0 f	1.0 f	1.0 e	1.0 e	1.5 d	5.3 f	6.0 c

[†] Turf color was rated on a 1 to 9 scale where 1 = straw brown; 6 = acceptable green color (light green); and 9 = dark green.

[‡] Colorants were applied at a dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8002VS nozzles at 20 psi.

[§] Weeks After Treatment (weeks after 1st colorant application)

[¶] Means in a column followed by the same letter are not significantly different according Fisher’s protected least significant difference test ($P \leq 0.05$).

[#] No significant difference ($P \geq 0.05$) for application timing for date. Therefore, application volume means are based upon n = 8 for 100 and 160 GPA for the 10 Oct. application until the 27 Jan. rating date.

[††] Means for application timing effect on colorant and application volume based upon n = 4 from 27 Jan. to 8 May.

Table 3-2. Effect of colorant, application volume, and application timing on color of 'Cody' buffalograss at the John C. Pair Research Center, Haysville, KS in 2013-2014.

		Turf color[†]									
		24 Oct.	20 Nov.	17 Dec.	17 Jan.	18 Feb.	13 March	8 April	22 April	6 May	20 May
Treatment	Application Date[‡]	0 WAT[§]	4 WAT	8 WAT	12 WAT	16 WAT	20 WAT	24 WAT	26 WAT	28 WAT	30 WAT
Green Lawnger											
100 GPA	24 Oct.	7.6 b[§]	7.3 b	7.0 b	3.5 bc	3.5 cd[††]	2.3 d	2.0 ef	2.3 ef	4.8 de	6.5 cde
	24 Oct. + 18 Feb.	--[#]	--	--	--	8.3 ab	5.3 b	5.3 d	5.3 c	6.0 bc	7.5 ab
160 GPA	24 Oct.	9.0 a	8.8 a	7.9 a	4.8 a	4.3 c	2.8 cd	2.3 ef	2.3 ef	5.0 de	6.8 cd
	24 Oct. + 18 Feb.	--	--	--	--	8.8 ab	8.5 a	7.8 ab	7.3 a	7.5 a	8.0 a
Endurant											
100 GPA	24 Oct.	7.9 b	7.4 b	6.4 c	2.9 c	2.8 d	2.3 d	1.5 fg	1.5 fg	4.5 e	6.3 de
	24 Oct. + 18 Feb.	--	--	--	--	8.8 ab	7.8 a	7.0 bc	6.5 ab	6.8 ab	7.8 a
160 GPA	24 Oct.	8.9 a	8.9 a	8.3 a	4.5 a	3.8 c	3.5 c	2.5 e	3.3 d	5.5 cd	6.5 cde
	24 Oct. + 18 Feb.	--	--	--	--	9.0 a	8.8 a	8.5 a	7.3 a	7.5 a	8.0 a
Wintergreen Plus											
100 GPA	24 Oct.	7.5 b	7.1 b	6.9 bc	4.1 ab	4.0 c	2.8 cd	1.5 fg	2.0 ef	5.0 de	7.0 bc
	24 Oct. + 18 Feb.	--	--	--	--	8.0 b	6.3 b	6.3 c	5.3 c	7.5 a	8.0 a
160 GPA	24 Oct.	8.5 a	8.4 a	7.9 a	4.8 a	3.8 c	3.5 c	2.3 ef	2.5 de	4.5 e	6.5 cde
	24 Oct. + 18 Feb.	--	--	--	--	9.0 a	8.3 a	7.3 b	6.0 bc	6.5 b	7.5 ab
Untreated		1.3 c	1.0 c	1.0 d	1.0 d	1.0 e	1.0 e	1.0 g	1.0 g	3.3 f	6.0 e

[†] Turf color was rated on a 1 to 9 scale where 1 = straw brown; 6 = acceptable green color (light green); and 9 = dark green.

[‡] Colorants were applied at a dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8002VS nozzles at 20 psi.

[§] Weeks After Treatment (weeks after 1st colorant application)

[¶] Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

[#] No significant difference ($P \geq 0.05$) for application timing for date. Therefore, application volume means are based upon $n = 8$ for 100 and 160 GPA for the 24 Oct. application until the 18 Feb. rating date.

[††] Means for application timing effect on colorant and application volume based upon $n = 4$ from 18 Feb. to 20 May.

Table 3-3. Effect of colorant, application volume, and application timing on color of 'Meyer' zoysiagrass at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2013-2014.

		Turf color†												
		17 Oct.‡	31 Oct.	13 Nov.	11 Dec.	10 Jan.	25 Jan.	21 Feb.	3 March	17 March	3 April	16 April	1 May	15 May‡
Treatment	Application Date§	0 WAT¶	2 WAT	4 WAT	8 WAT	12 WAT	14 WAT	18 WAT	20 WAT	22 WAT	24 WAT	26 WAT	28 WAT	30 WAT
Green Lawnger														
100 GPA	17 Oct.	9.0	8.9 a	8.6 a#	7.1 b	5.9 b	5.8 bc	4.5 c‡‡	4.0 d	3.0 fg	2.5 fg	3.5 e	7.3 c	9.0
	17 Oct. + 18 Feb.	--††	--	--	--	--	--	9.0 a	9.0 a	8.5 ab	8.0 b	8.3 a	9.0 a	9.0
160 GPA	17 Oct.	8.8	9.0 a	8.8 a	7.8 a	7.0 a	6.4 a	5.3 b	5.0 c	3.3 efg	3.0 efg	4.8 d	6.8 c	8.8
	17 Oct. + 18 Feb.	--	--	--	--	--	--	9.0 a	9.0 a	8.5 ab	8.0 b	8.0 ab	9.0 a	8.5
Endurant														
100 GPA	17 Oct.	8.5	8.4 b	8.0 b	6.3 c	5.4 c	5.4 c	3.8 d	3.0 e	2.5 g	2.3 g	3.5 e	6.8 c	8.8
	17 Oct. + 18 Feb.	--	--	--	--	--	---	8.8 a	8.3 ab	8.0 bc	7.3 bc	7.3 c	8.8 a	9.0
160 GPA	17 Oct.	8.9	9.0 a	8.8 a	7.5 ab	6.6 a	6.2 ab	4.3 cd	4.0 d	3.5 def	3.3 ef	4.8 d	7.5 bc	8.8
	17 Oct. + 18 Feb.	--	--	--	--	--	---	9.0 a	9.0 a	9.0 a	9.0 a	8.0 ab	8.8 a	9.0
Wintergreen Plus														
100 GPA	17 Oct.	8.9	8.8 ab	8.6 a	7.5 ab	5.8 bc	5.8 bc	5.5 b	4.5 cd	4.0 de	3.8 de	5.0 d	7.0 c	8.5
	17 Oct. + 18 Feb.	--	--	--	--	--	--	8.5 a	7.8 b	7.3 c	7.0 c	7.5 bc	8.5 ab	9.0
160 GPA	17 Oct.	8.9	8.9 a	9.0 a	7.8 a	6.6 a	6.3 a	5.3 b	4.8 cd	4.3 d	4.3 d	4.8 d	7.3 c	8.8
	17 Oct. + 18 Feb.	--	--	--	--	--	--	9.0 a	9.0 a	8.8 ab	7.8 bc	8.0 ab	9.0 a	9.0
Untreated		5.0	1.8 c	1.0 c	1.0 d	1.0 d	1.0 d	1.0 e	1.0 f	1.0 h	1.0 h	1.0 f	5.3 d	8.0

† Turf color was rated on a 1 to 9 scale where 1 = straw brown; 6 = acceptable green color (light green); and 9 = dark green.

‡ No significant difference ($P \geq 0.05$) for date.

§ Colorants were applied at a dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8002VS nozzles at 20 psi.

¶ Weeks After Treatment (weeks after 1st colorant application)

Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

†† No significant difference ($P \geq 0.05$) for application timing for date. . Therefore, application volume means are based upon $n = 8$ for 100 and 160 GPA for the 17 Oct. application until the 21 Feb. rating date.

‡‡ Means for application timing effect on colorant and application volume based upon $n = 4$ from 21 Feb. to 1 May.

Table 3-4. Effect of colorant, application volume, and application timing on color of 'Meyer' zoysiagrass at the Colbert Hills Golf Course, Manhattan, KS in 2013-2014.

		Turf color[†]											
		26 Oct.	6 Nov.[‡]	20 Nov.[‡]	18 Dec.	15 Jan.	30 Jan.	24-Feb	12 March	26 March	9 April	25 April	8 May[‡]
Treatment	Application Date[§]	0 WAT[¶]	2 WAT	4 WAT	8 WAT	12 WAT	14 WAT	18 WAT	20 WAT	22 WAT	24 WAT	26 WAT	28 WAT
Green Lawnger													
100 GPA	26 Oct.	8.3 b[#]	7.8	8.1	7.0 b	6.0 c	5.3 c	4.5 d[‡‡]	3.5 e	2.8 c	2.5 d	6.3 e	8.8
	26 Oct. + 24 Feb.	--[††]	--	--	--	--	--	8.3 b	8.0 c	7.5 b	7.5 c	8.0 bc	8.5
160 GPA	26 Oct.	9.0 a	8.5	8.5	8.0 a	7.3 a	6.8 a	5.5 c	4.0 de	3.5 c	3.0 d	6.5 de	8.8
	26 Oct. + 24 Feb.	--	--	--	--	--	--	8.8 ab	8.8 ab	8.8 a	8.5 ab	8.8 ab	9.0
Endurant													
100 GPA	26 Oct.	8.8 ab	8.8	8.1	7.1 b	6.3 bc	6.1 ab	5.5 c	4.0 de	3.0 c	3.0 d	7.3 cd	9.0
	26 Oct. + 24 Feb.	--	--	--	--	--	--	9.0 a	9.0 a	8.8 a	8.5 ab	8.5 ab	8.8
160 GPA	26 Oct.	9.0 a	8.9	8.5	8.0 a	6.9 ab	6.6 a	5.5 c	4.3 d	3.5 c	3.0 d	7.0 de	8.5
	26 Oct. + 24 Feb.	--	--	--	--	--	--	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	9.0
Wintergreen Plus													
100 GPA	26 Oct.	8.4 b	8.0	7.9	7.1 b	6.3 bc	5.6 bc	4.3 d	3.5 e	2.8 c	2.8 d	7.0 de	8.8
	26 Oct. + 24 Feb.	--	--	--	--	--	--	8.3 b	8.3 bc	8.3 ab	7.8 bc	8.5 ab	8.8
160 GPA	26 Oct.	8.4 b	8.6	8.6	7.8 ab	6.6 abc	6.3 ab	4.8 d	3.8 de	3.5 c	3.0 d	7.0 de	8.0
	26 Oct. + 24 Feb.	--	--	--	--	--	--	8.5 ab	8.8 ab	8.8 a	8.5 ab	8.5 ab	9.0
Untreated		4.5 c	3.0	1.0	1.0 c	1.0 d	1.0 d	1.0 e	1.0 f	1.0 d	1.0 e	4.5 f	8.0

[†] Turf color was rated on a 1 to 9 scale where 1 = straw brown; 6 = acceptable green color (light green); and 9 = dark green.

[‡] No significant difference ($P \geq 0.05$) for date.

[§] Colorants were applied at a dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8002VS nozzles at 20 psi.

[¶] Weeks After Treatment (weeks after 1st colorant application)

[#] Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

[††] No significant difference ($P \geq 0.05$) for application timing for date. Therefore, application volume means are based upon $n = 8$ for 100 and 160 GPA for the 26 Oct. application until the 24 Feb. rating date.

[‡‡] Means for application timing effect on colorant and application volume based upon $n = 4$ from 24 Feb. to 8 May.

Table 3-5. Effect of colorant, application volume, and number of applications on canopy temperature (°F) of 'Sharpshooter' buffalograss at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2014.

		Canopy temperature (°F)[†]				
Treatment	Application Date[‡]	11 March	26 March	11 April	25 April	9 May[§]
Green Lawnger						
100 GPA	10 Oct.	69.3 b[¶]	65.4 d	87.9 def	86.1 fg	81.6
	10 Oct. + 25 Jan.	71.7 ab	70.3 abc	92.9 a	89.3 abc	81.3
160 GPA	10 Oct.	71.6 ab	67.4 bcd	87.4 ef	86.8 efg	79.9
	10 Oct. + 25 Jan.	74.2 a	71.4 ab	91.2 abc	90.9 ab	82.5
Endurant						
100 GPA	10 Oct.	71.7 ab	69.1 abcd	88.3 def	87.1 def	80.2
	10 Oct. + 25 Jan.	73.3 a	70.1 abc	88.4 cdef	88.9 bcd	82.2
160 GPA	10 Oct.	71.8 ab	67.6 bcd	87.5 def	88.6 cde	80.0
	10 Oct. + 25 Jan.	74.7 a	72.8 a	91.5 ab	91.0 a	83.4
Wintergreen Plus						
100 GPA	10 Oct.	69.1 b	66.5 cd	86.5 f	87.9 cdef	81.9
	10 Oct. + 25 Jan.	74.6 a	68.0 bcd	90.1 bcde	89.2 abc	82.9
160 GPA	10 Oct.	68.9 b	67.3 bcd	87.0 f	86.0 fg	81.9
	10 Oct. + 25 Jan.	71.7 ab	69.4 abcd	90.4 abcd	89.6 abc	83.5
Untreated		68.7 b	65.8 d	85.8 f	85.0 g	79.3

[†] Canopy temperature was measured and averaged from three measurements within each plot using a handheld infrared thermometer.

[‡] Colorants were applied at a dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8002VS nozzles at 20 psi.

[§] No significant differences ($P \geq 0.05$) for date.

[¶] Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

Table 3-6. Effect of colorant, application volume, and number of applications on canopy temperature (°F) of 'Cody' buffalograss at the John C. Pair Research Center, Haysville, KS in 2014.

		Canopy temperature (°F)[†]			
Treatment	Application Date[‡]	13 March	8 April	22 April	6 May
Green Lawnger					
100 GPA	24 Oct.	58.2 ef[§]	66.7 c	78.7 e	86.3 cde
	24 Oct. + 18 Feb.	61.0 abc	71.6 b	82.5 abc	92.0 a
160 GPA	24 Oct.	59.0 cdef	67.0 c	79.7 cde	88.7 bcd
	24 Oct. + 18 Feb.	62.8 a	74.4 a	83.6 ab	87.9 bcd
Endurant					
100 GPA	24 Oct.	60.9 abcd	66.6 c	79.4 de	85.9 de
	24 Oct. + 18 Feb.	61.3 ab	72.5 ab	84.8 ab	89.2 abc
160 GPA	24 Oct.	60.1 bcde	67.0 c	78.9 e	86.9 bcde
	24 Oct. + 18 Feb.	62.5 a	74.6 a	85.2 a	88.6 bcd
Wintergreen Plus					
100 GPA	24 Oct.	58.6 def	67.0 c	79.3 de	84.2 e
	24 Oct. + 18 Feb.	61.0 abc	72.2 ab	82.6 abc	86.1 de
160 GPA	24 Oct.	59.5 bcdef	66.2 c	79.3 de	85.9 de
	24 Oct. + 18 Feb.	60.0 bcde	71.3 b	81.9 bcd	89.6 ab
Untreated		57.6 f	64.8 c	78.8 e	84.3 e

[†] Canopy temperature was measured and averaged from three measurements within each plot using a handheld infrared thermometer.

[‡] Colorants were applied at a dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8002VS nozzles at 20 psi.

[§] Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

Table 3-7. Effect of colorant, application volume, and number of applications on canopy temperature (°F) of 'Meyer' zoysiagrass at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2014.

		Canopy temperature (°F)[†]				
Treatment	Application Date[‡]	11 March	26 March[§]	11 April	25 April	9 May[§]
Green Lawnger						
100 GPA	17 Oct.	71.7 def[¶]	77.4	89.4 bcde	86.0 bcd	85.5
	17 Oct. + 18 Feb.	76.0 ab	78.6	95.1 a	88.2 a	85.8
160 GPA	17 Oct.	71.8 def	75.8	88.4 cde	85.4 bcde	85.9
	17 Oct. + 18 Feb.	75.0 abc	77.5	95.1 a	88.3 a	86.9
Endurant						
100 GPA	17 Oct.	71.4 ef	77.1	92.8 abc	86.6 abc	85.9
	17 Oct. + 18 Feb.	74.8 abc	79.7	92.5 abc	86.7 abc	86.6
160 GPA	17 Oct.	72.2 de	79.2	91.4 abcd	85.7 bcd	85.5
	17 Oct. + 18 Feb.	76.3 a	76.3	93.2 ab	86.9 abc	85.9
Wintergreen Plus						
100 GPA	17 Oct.	72.0 def	72.0	86.8 e	85.1 cde	85.3
	17 Oct. + 18 Feb.	73.7 bcde	75.3	91.5 abcd	84.3 de	85.4
160 GPA	17 Oct.	72.6 cde	73.8	90.0 bcde	86.8 abc	85.2
	17 Oct. + 18 Feb.	74.2 abcd	76.5	92.0 abc	87.2 ab	86.0
Untreated		69.6 f	70.4	87.3 de	83.7 e	84.3

[†] Canopy temperature was measured and averaged from three measurements within each plot using a handheld infrared thermometer.

[‡] Colorants were applied at a dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8002VS nozzles at 20 psi.

[§] No significant differences ($P \geq 0.05$) for date.

[¶] Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

Table 3-8. Effect of colorant, application volume, and number of applications on canopy temperature (°F) of 'Meyer' zoysiagrass at the Colbert Hills Golf Course, Manhattan, KS in 2014.

		Canopy temperature (°F)[†]				
Treatment	Application Date[‡]	11 March	26 March	11 April	25 April	9 May[§]
Green Lawnger						
100 GPA	26 Oct.	70.8 bcd[§]	60.4 fg	92.9 bcd	73.9 de	87.1
	26 Oct. + 24 Feb.	74.8 b	68.9 a	97.5 ab	77.5 abc	87.6
160 GPA	26 Oct.	73.5 bc	64.5 bcde	91.6 cd	78.9 ab	87.5
	26 Oct. + 24 Feb.	80.7 a	68.9 a	99.4 a	74.5 cde	87.5
Endurant						
100 GPA	26 Oct.	74.5 b	61.0 efg	90.8 cd	77.4 abcd	86.7
	26 Oct. + 24 Feb.	79.9 a	67.8 ab	95.5 abc	80.2 a	88.1
160 GPA	26 Oct.	74.8 b	63.1 cdef	91.9 cd	74.6 cde	86.4
	26 Oct. + 24 Feb.	79.9 a	65.3 abcd	95.3 abcd	76.6 bcd	87.7
Wintergreen Plus						
100 GPA	26 Oct.	68.6 cd	61.6 def	92.4 cd	74.7 cde	86.1
	26 Oct. + 24 Feb.	72.4 bc	65.7 abc	93.0 bcd	75.8 bcde	86.8
160 GPA	26 Oct.	70.5 bcd	61.8 def	90.7 de	74.9 cde	85.8
	26 Oct. + 24 Feb.	73.9 b	67.7 ab	93.5 bcd	77.6 abc	87.0
Untreated		66.2 d	57.3 g	86.1 e	73.0 e	86.1

[†] Canopy temperature was measured and averaged from three measurements within each plot using a handheld infrared thermometer.

[‡] Colorants were applied at a dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8002VS nozzles at 20 psi.

[§] No significant differences ($P \geq 0.05$) for date.

[¶] Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

Chapter 4 - Evaluation of the Influence of Nitrogen Source and Application Timing on Large Patch Development on Zoysiagrass

ABSTRACT

Rhizoctonia large patch (*Rhizoctonia solani* Kühn Anastomosis Group (AG)-2-2 LP) affects zoysiagrass throughout the transition zone and can be extremely damaging. Turfgrass managers have associated severe large patch outbreaks with excessive nitrogen (N) application. More information is needed on the influence of nitrogen source and application timing on large patch severity. A two-year field study was conducted in Manhattan, KS from April 2013 to October 2014 on 'Meyer' zoysiagrass to investigate the impact of N sources; (urea, ammonium sulfate, calcium nitrate) and timings (spring when 5-cm soil temperatures reached 15.5°C, spring when 5- cm soil temperatures reached 21°C, or fall when 5 cm soil temperatures declined to 21°C). Summer-applied urea was used as a standard comparison. All treatments were applied to provide a total N level rate of 73.2 kg/ha/yr. Percent green cover was recorded using digital image analysis. Zoysiagrass fertilized with ammonium sulfate, calcium nitrate, or urea did not consistently differ in green cover percentage. There were several rating dates when turf treated with ammonium sulfate and/or summer-applied urea had statistically higher green cover percentage than zoysiagrass fertilized with calcium nitrate, but the difference was minimal. In 2013 and 2014, applications at the Spring 21ºC timing led to higher green cover vs. the Fall 21ºC timing on some rating dates. At one date in 2014, the Spring 15.5ºC timing also had higher green cover compared to the Fall 21ºC timing. Therefore, N source and fertility timing over a longer period duration should be further examined.

INTRODUCTION

Zoysiagrass is relatively free of major disease problems (Beard, 1973). However, the fungal disease *Rhizoctonia* large patch (*Rhizoctonia solani* Kühn Anastomosis Group (AG)-2-2 LP) affects zoysiagrass throughout the transition zone and can be extremely damaging (Green et al., 1993). Large patch symptoms occur during cool and wet conditions in the spring and fall when temperatures range from 15°C to 25°C within the thatch and soil (Green et al., 1993; Smiley et al., 2005). These temperatures are in contrast to brown patch of cool-season turfgrasses, caused by different *R. solani* AG's, which occurs during hot summer conditions (night temperatures > 20°C) (Smiley et al., 2005). Poorly drained and compacted soils, resulting in prolonged soil and leaf wetness, have been associated with severe large patch symptoms (Green et al., 1993; Smiley et al., 2005). The fungal pathogen resides in the soil, in thatch, under leaf sheaths, in stolons and rhizomes, and overwinters as dormant mycelium and sclerotia, causing infections on the stolons or basal leaf sheaths and resulting in basal rot (Burpee and Martin, 1992, Ogoshi, 1987). During infection, symptoms of matted tan patches may be up to several meters in diameter with an orange margin (Green et al., 1993; Smiley et al., 2005). Water-soaked, reddish brown or black lesions usually appear on the lower sheath tissue, and tip dieback may occur as the result of sheath infection. It has been suggested that growth of the fungus is hindered when thatch and soil temperatures exceed 30°C during summer months, which also favor zoysiagrass root and shoot growth (Green et al., 1993). During the summer, turf in patches often exhibits full turf recovery; however, due to a thinner canopy, weeds may encroach.

Currently, large patch is managed primarily by fungicide application during fall and/or spring. However, cultural practices can also influence the disease. Zoysiagrass maintained at lower mowing heights was more susceptible to severe large patch symptoms in Kansas (Green et al., 1994). In the same study, neither nitrogen source (urea, urea formaldehyde, poultry litter, sewage sludge, and bovine waste) nor application rate (N at 74 and 148 kg/ha/year, applied in summer) affected large patch severity (Green et al., 1994). Summer cultivation practices (core-aerification, verticutting, and sand topdressing) also had no effect on large patch in Kansas (Obasa et al., 2013).

The amount and source of nitrogen (N) can influence disease incidence for several turfgrass diseases (Davidson and Goss, 1972; Dernoeden, 1987; Dernoeden et al., 1991; Smiley et al., 2005; Smith 1956). More specifically, turfgrass managers have associated severe large patch outbreaks with excessive nitrogen applications (Green et al., 1993). Likewise, cool-season turfgrass susceptibility to brown patch can be affected by source, rate, and timing of nitrogen applications (Burpee, 1994; Fidanza and Dernoeden 1996a, 1996b, 1996c; Smiley et al., 2005). In a multi-year, multi-site study, Obasa et al. (2013) observed spring and fall N fertility on zoysiagrass was associated with lower percentages of non-green (diseased) turf in two of three locations in several seasons. Spring and fall N was never associated with higher large patch severity. These findings contradicted their hypothesis that N at these timings may encourage large patch.

Kaminski and Dernoeden (2005) reviewed effects of various nitrogen sources on several turfgrass diseases. Briefly, the root diseases spring dead spot (*Ophiophaerella korrae* Walker and Smith), summer patch (*Magnaporthe poae* Landschoot and Jackson), and take-all (*Gaeumannomyces graminis* (Sacc.) Arx & Olivier var. avenae (E.M. Turner) Dennis) exhibited reduced severity following application of ammonium-based nitrogen fertilizers, which may have been due, in part, to a reduction in soil pH (Davidson and Goss, 1972; Dernoeden, 1987; Dernoeden et al., 1991; Smiley et al., 2005; Smith 1956). The severity of take-all in creeping bentgrass (*Agrostis stolonifera* L.) was further reduced from applications of manganese (Mn) with ammonium sulfate [$(NH_4)_2SO_4$] (Hill et al. 1999). Ammonium sulfate applications resulted in the fastest recovery from dead spot (*Ophiosphaerella agrostis* Dernoeden, M.P.S. Câmara N.R. O’Neill van Berkum et M.E. Palm) in creeping bentgrass along with no reoccurrence following the second year of the study (Kaminski and Dernoeden, 2005). Ammonium sulfate was found to be the most the effective nitrogen source in reducing yellow patch (*Rhizoctonia cerealis* van der Hoeven) severity in creeping bentgrass (Kaminski and Dernoeden, 2005).

Past research has revealed an increase in severity of several turfgrass patch diseases when turf is fertilized with alkaline-reacting NO_3-based N sources. For example, calcium nitrate and sodium nitrate made summer patch severity worse in Kentucky bluegrass (Hill et al., 2001; Smiley et al., 2005; Thompson et al., 1995). Similarly, increased soil pH was associated with increased severity of Microdochium patch (*Microdochium nivale* (Fr.) Samuels and Hallet) on annual bluegrass (*Poa annua* L.) in England (Smith, 1958).

More information is needed on the impact of nitrogen sources on large patch of zoysiagrass, particularly effects of ammonium-based fertilizers, urea, and calcium nitrate. Also, information is lacking on the impact of N fertilizer application timing on large patch on zoysiagrass. Therefore, the objective was to investigate the impact of N source and timing of spring and fall nitrogen fertilizer applications on large patch severity on zoysiagrass.

MATERIALS AND METHODS

Turf Stand and Pathogen Inoculation.

This field experiment was conducted at the Rocky Ford Turfgrass Research Center in Manhattan, Kansas in 2013 and 2014. Parallel studies were conducted at the University of Missouri, under the direction of Dr. G. L. Miller, and will not be discussed here. The experimental turf plots were established 'Meyer' zoysiagrass *(Z. japonica*) stands maintained at 1.3 cm. The zoysiagrass was inoculated with an isolate of *R. solani* AG2-2 LP. The pathogen was initially isolated from infected zoysiagrass by surface sterilizing leaf sheath sections in 10% bleach, blotting dry, and plating on ¼ strength PDA amended with antibiotics (chloramphenicol at 10 mg/l and streptomycin at 10 mg/liter). The cultures were maintained by periodically transferring to new media. Inoculum for field studies was prepared as previously described (Green et al., 1993; Obasa et al., 2012; Obasa et al., 2013). In 900 ml glass jars, 150 g of oats were combined with 150 ml distilled water and autoclaved twice for 30 minutes, then inoculated with several plugs of from the edge of actively growing cultures. The oats were incubated for two to three weeks, with shaking every few days, then used to inoculate field plots.

For each inoculation site, 8 to 10 g of infested oat kernels were placed in a furrow slice made with a knife between the turf and thatch layer. The study site was initially inoculated on 19 Sept. 2011, at 1.2 to 1.5 m spacings. On 25 Sept. 2013, the center of each plot (described below) was re-inoculated. Plots were irrigated daily for several weeks after inoculation and each spring in April and May to promote the establishment of disease. Soil temperatures at 5-cm depth in the morning and afternoon were taken daily during the spring and fall using digital T-bar thermometer (Argus Realcold Property Ltd., Coopers Plains, Australia) at $\geq$ 5 measurements within the study to determine daily average soil temperature.

Fertility Source and Timing

Plots at each site measured 1.2 m x 2.4 m and were arranged in a randomized complete-block design with four replications. The three nitrogen sources used were urea, (46-0-0; Thrive

Branded Fertilizer, Mears Fertilizer Inc., El Dorado, KS), ammonium sulfate ($(NH_4)_2SO_4$; 21-0-0+24(S); Zippsol, Martin Operating Partnership, Kilgore, TX), and calcium nitrate ($Ca(NO_3)_2$; 15.5-0-0; Yara Liva Calcinit, Yara North American Inc., Tampa, FL). Timing treatments included: Spring 15.5°C (Sp15.5); Spring 21°C (Sp21); and Fall 21°C (F21). All three sources were applied for all three timings, and a standard (summer fertilized) control was included.

Applications at spring 15.5°C, spring 21°C, and fall 21°C were applied at the rate of 36.6 kg nitrogen (N)/ha. Spring 15.5°C treatment applications were applied on 13 May 2013 and 23 April 2014 to respective plots when five day average soil temperatures at a 5 cm depth were at 15.5°C. Spring 21°C treatment applications were applied on 20 May 2013 and 26 May 2014 when five day average soil temperatures at a 5-cm depth were at 21°C. Similarly, fall 21°C treatment applications were applied on 23. Sept. 2013 when five day average soil temperature were at 21°C. On 1 June, 3 July, and 12 Aug. 2013, all treatments received summer applications of each respective nitrogen source at a rate of 12.2 kg N/ha and standard plots received urea at 24.4 kg N/ha. Summer applications in 2014 were applied on 1 June and 8 July when the study was terminated. The total annual nitrogen load per treatment was 73.2 kg N/ha.

Data Collection and Analysis

Patch symptoms within each plot were photographed weekly during disease activity using the automatic settings of a Nikon D70's digital camera (Nikon Inc., Tokyo, Japan) at 1.13 m above the canopy in 2013 and 1.8 m above the canopy in 2014. Prior to being photographed, plots were mowed and debris removed with a leaf blower. Images were analyzed with SigmaScan Pro 5.0 (ver. 5.0, SPSS Science Marketing Dept., Chicago, IL) using the "Turf Analysis" macro for batch analysis (Karcher and Richardson, 2005). The macro threshold settings were adjusted to hue = 50 to 107 and saturation = 0 to 100. The threshold settings accounted for estimation of pixels (expressed as percentages) that represented healthy (green) turf relative to non-green turf (Figure 4-1).

Residual normality was tested with the *w* statistic of the Shapiro-Wilk test using the UNIVARIATE procedure of Statistical Analysis System (SAS Institute Inc., Cary, NC) (Shapiro and Wilk, 1965). Data were subjected to a two-fold nested analysis of variance (ANOVA) using the PROC MIXED procedure of SAS 9.2 (SAS Institute, Inc., Cary, NC). Factors were timing nested within N source and N source; all factors were fixed. Other factors analyzed were N source CONTRAST statements and timing CONTRAST statements. Treatment differences were separated using Fisher's protected least significant difference test ($P \leq 0.05$). One plot for treatment ammonium sulfate (Fall 21ºC) and calcium nitrate (Spring 15.5ºC) was excluded because of a common bermudagrass (*Cynodon dactylon* var. *dactylon*) infestation within the plot.

RESULTS

2013

In spring 2013, large patch symptoms first developed in mid-May and disease was active for several weeks, with the lowest percent green cover on June 7 and June 12 (Table 4-1). The zoysiagrass began to recover by late June, with percent green cover > 95% for all treatments (Table 4-1).

In 2013, the main effect of N source was not significant for all eleven rating dates, nor was the effect of timing nested within N source (Table 4-2). When comparing specific N source treatments using contrast statements plots treated with calcium nitrate had significantly higher green cover compared to the standard treatment on two dates (20 May and 24 Oct) (Tables 4-2 and 4-3). In addition, plots treated with ammonium sulfate had higher green cover than urea on 7 June 2013 (Tables 4-2 and 4-3). When comparing application timings with contrast statements, on two rating dates (7 June and 24 Oct.) the Spring 21ºC timing had significantly higher percentage of green cover than the Fall 21ºC timing (Tables 4-2 and 4-4).

2014

In 2014, large patch symptoms first developed in early May, peaked in late May with percent green cover as low as 20%, and persisted until mid-June (Table 4-5). When compared to 2013, visible large patch symptoms were more severe in 2014, with much lower percent green cover. The zoysiagrass turf began to recover by mid-June, with percent green cover > 95% by June 26 (Table 4-5).

In 2014, testing across all N sources, the main effect of N source was significant for three rating dates, and effect of timing nested within N source was significant for one rating date (Table 4-6). On two of the three dates on which source was significant, the standard (summer urea) treatment exhibited the highest green cover percentage (Tables 4-6 and 4-7). On 15 May, ammonium sulfate was significantly higher in green cover than calcium nitrate and urea, but not the standard treatment. On 22 May, ammonium sulfate had higher green cover than calcium nitrate, but not statistically different than urea or standard treatments. On 12 June, there was a significant effect of timing nested with N source (Table 4-6). On that date, the ammonium sulfate (Spring 21ºC) and standard treatment had significantly higher green cover than calcium nitrate -(Spring 15.5ºC), calcium nitrate-(Fall 21ºC), and urea-(Spring 21ºC) treatments (Table 4-5).

When comparing among sources via contrast statements, on five rating dates, plots treated with ammonium sulfate had a higher green cover percentage vs. those treated with calcium nitrate (Tables 4-6 and 4-7). Calcium nitrate led to significantly lower green cover percentage when compared to standard (summer urea) treatments on 22 May and 12 June (Tables 4-6 and 4-7). On 8 May, 15 May, and 22 May, ammonium sulfate led to higher green cover percentage than urea (Tables 4-6 and 4-7). When comparing fertilization timing treatments via contrast statements, zoysiagrass treated at Spring 21ºC was significantly higher in green color percentage than that treated at Fall 21ºC on three dates (22 May, 12 June, 19 June) (Tables 4-6 and 4-8). Turf fertilized at Spring 15.5ºC had significantly higher green cover percentage vs. turf fertilized at Fall 21ºC on 19 June (Tables 4-6 and 4-8).

DISCUSSION

Green et al. (1994) observed nitrogen source, applied in summer, had no influence on large patch severity. In this study, no nitrogen source stood out noticeably above another. Neither ammonium sulfate, calcium nitrate, nor urea consistently resulted in higher zoysiagrass green cover percentage over one another or the standard treatment. Although there were a few dates on which ammonium sulfate or the standard treatment resulted in statistically higher green cover percentage, the difference was minimal. As large patch symptoms progressed into early summer 2014, the calcium nitrate-fertilized turf had the most rating dates with statistically lower zoysiagrass green cover percentage than ammonium sulfate and standard treatment in 2014. Past research found calcium nitrate and sodium nitrate exacerbated summer patch symptoms in Kentucky bluegrass (Hill et al., 2001; Smiley et al., 2005; Thompson et al., 1995). However, there was not enough evidence to conclude calcium nitrate increased large patch severity in this study.

Obasa et al. (2013) found that spring and fall N applications of urea on zoysiagrass was not associated with higher large patch severity compared to summer fertilized treatments. On two dates in 2013 and three dates in 2014, the Spring 21ºC timing provided statistically higher green cover percentage when compared to the Fall 21ºC timing, although differences were minimal. On 19 June 2014, the Spring 15.5ºC timing had statically higher green cover percentage vs. the Fall 21ºC timing, although the difference was minimal. There were no dates in either year which had a significance for the timing contrast of Spring 15.5ºC vs. Spring 21ºC.

There were more dates with statistical differences among nitrogen source and timing effects during the second year of the study (2014). One possible explanation is that the N source and/or timing could have a more pronounced effect on large patch over a longer duration of use. In addition, the higher disease pressure in 2014 could have led to more striking differences among treatments. While there were occurrences of statistical N source differences in 2014, the practical differences were minor. Fertility timing between Spring 21ºC vs. Fall 21ºC provided statistical differences in each year, but again the percentage difference was minimal. *Rhizoctonia* large patch continues to be primary pest problem in zoysiagrass in the transition zone. N source and fertility timing over a longer period duration should be further examined.

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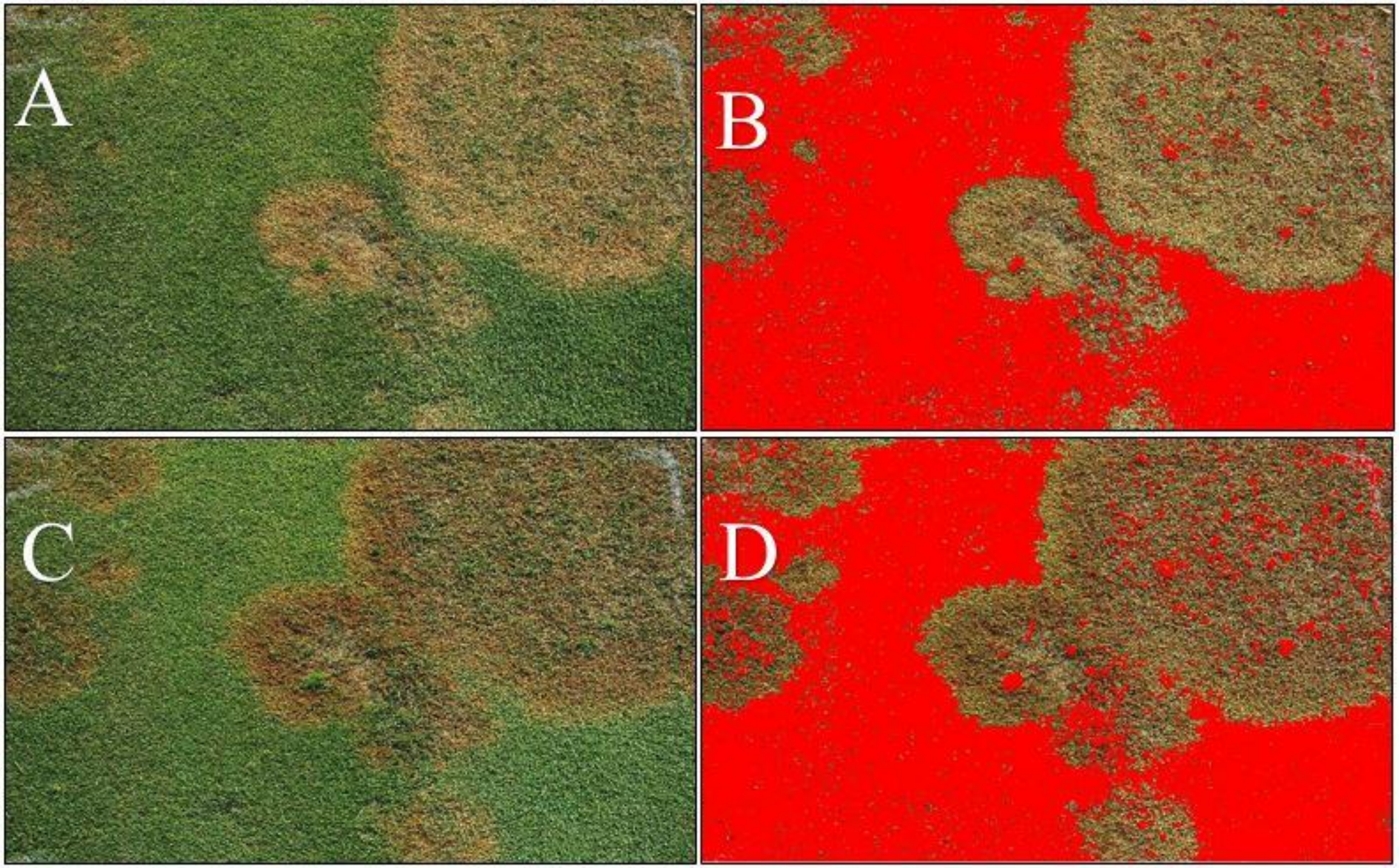

Figure 4-1. Digital images of the same plot at separate weeks in 2014 analyzed with SigmaScan Pro 5.0 using the "Turf Analysis" macro threshold settings were to hue = 50 to 107 and saturation = 0 to 100. This allowed for estimation of pixels (red overlay) that represented healthy (green) turf relative to non-green turf. A) 22 May 2014: original image, B) 22 May 2014: SigmaScan analysis, C) 25 May 2014: original image D) 25 May 2014: SigmaScan analysis.

Table 4-1. Effect of nitrogen source and timing of fertilization on green cover percentage in large patch-infested zoysiagrass at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2013.

Treatment‡	Application Date‡	Green Cover Percentage†										
		20 May§	31 May§	7 June§	12 June§	18 June§	27 June§	26 July§	21 Aug.§	20 Sept.§	8 Oct.§	24 Oct.§
$Ca(NO_3)_2$ (Spring 15.5ºC)	13 May	87.2	84.3	77.0	70.4	83.0	97.0	98.8	97.8	99.0	93.2	92.8
$Ca(NO_3)_2$ (Spring 21ºC)	20 May	85.0	82.8	78.5	77.8	88.0	96.7	98.8	97.7	98.6	95.5	93.6
$Ca(NO_3)_2$ (Fall 21ºC)	23 September	87.5	88.3	75.4	76.2	91.2	97.4	99.0	97.9	98.7	91.4	90.3
$(NH_4)_2SO_4$(Spring 15.5ºC)	13 May	85.8	83.6	77.4	77.2	88.1	97.0	98.4	97.5	98.1	91.2	88.8
$(NH_4)_2SO_4$ (Spring 21ºC)	20 May	85.1	88.8	87.2	86.2	94.2	98.5	99.1	97.1	98.9	96.9	96.5
$(NH_4)_2SO_4$ (Fall 21ºC)	23 September	82.0	81.7	79.0	74.1	86.1	95.4	99.0	97.5	98.8	95.0	92.5
Urea (Spring 15.5ºC)	13 May	88.5	88.3	76.4	80.0	89.1	97.0	98.3	97.8	98.2	92.6	92.2
Urea (Spring 21ºC)	20 May	82.4	83.6	77.9	74.9	90.8	97.3	98.3	97.6	98.2	93.4	91.4
Urea (Fall 21ºC)	23 September	81.7	75.0	69.4	70.7	87.8	96.9	98.4	97.4	97.9	88.2	86.2
Standard		75.3	77.3	81.1	79.9	89.8	95.4	97.9	97.6	98.2	90.0	85.1

† Rating dates in 2013, which plots were photographed with a Nikon D70 digital camera at 1.13 m above the canopy. Images were analyzed with SigmaScan Pro 5.0 for percentage of healthy (green) turf relative to non-green turf.

‡ Respected $Ca(NO_3)_2$ (15.5-0-0) $(NH_4)_2SO_4$ (21-0-0+24(S) and Urea (46-0-0) treatments were applied at a rate of 36.6 kg N/ha on 13 May, 20 May, and 23 September. On 1 June, 3 July, and 12 Aug. all treatments received summer applications of respected nitrogen source at a rate of 12.2 kg N/ha and standard plots received urea at 24.4 kg N/ha.

§ No significant differences ($P \geq 0.05$) for date.

¶ Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

Table 4-2. Nested analysis of variance for parameters evaluated on Meyer zoysiagrass at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2013.

Parameter	Source of variation	Date[†]										
		20 May	31 May	7 June	12 June	18 June	27 June	26 July	21 Aug.	20 Sept.	8 Oct.	24 Oct.
Green Cover Percentage	S[‡]	NS[#]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	T(S)[§]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Contrasts[¶]											
	$Ca(NO_3)_2$ v. $(NH_4)_2SO_4$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	$Ca(NO_3)_2$ v. Urea	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	$Ca(NO_3)_2$ v. Standard	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	*
	$(NH_4)_2SO_4$ v. Urea	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS
	$(NH_4)_2SO_4$ v. Standard	n/a[††]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Urea v. Standard	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Fall 21°C v. Spring 15.5°C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Fall 21°C v. Spring 21°C	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	*
	Spring 15.5°C v. Spring 21°C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[†] Rating dates in 2013, which plots were photographed with a Nikon D70 digital camera at 1.13 m above the canopy. Images were analyzed with SigmaScan Pro 5.0 for estimation of pixels that represented healthy (green) turf relative to non-green turf.
[‡] Nitrogen source (S).
[§] Effect of application timing (T) nested within nitrogen source T(S).
[¶] Contrasts among N source treatment means and among application timing treatment means.
[#] Not significant (NS).
[††] Contrast was inestimable in SAS, not available (n/a) due to one $(NH_4)_2SO_4$ (Fall 21ºC) plot excluded because of a common bermudagrass infestation within the plot.
*, **, and *** are significant at the 0.05, 0.01, and 0.001 probability level, respectively.

Table 4-3. Effect of nitrogen source on green cover percentage in large patch-infested zoysiagrass at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2013.

N Source‡	Green Cover Percentage†										
	20 May	31 May§	7 June§	12 June§	18 June§	27 June§	26 July§	21 Aug.§	20 Sept.§	8 Oct.§	24 Oct.§
$Ca(NO_3)_2$	86.6	85.1	76.9	74.8	87.4	97.0	98.9	97.8	98.8	93.4	92.2
$(NH_4)_2SO_4$	84.3	84.7	81.2	79.2	89.5	97.0	98.8	97.4	98.6	94.4	92.6
Urea	84.2	82.3	74.6	75.2	89.2	97.1	98.3	97.6	98.1	91.4	89.9
Standard	75.3	77.3	81.1	79.9	89.8	95.4	97.9	97.6	98.2	90.0	85.1

† Rating dates in 2013, which plots were photographed with a Nikon D70 digital camera at 1.13 m above the canopy. Images were analyzed with sigmascan Pro 5.0 for percentage of healthy (green) turf relative to non-green turf.

‡ $Ca(NO_3)_2$ (15.5-0-0) $(NH_4)_2SO_4$ (21-0-0+24(S) and Urea (46-0-0) sources were applied at a rate of 36.6 kg N/ha on 13 May, 20 May, and 23 September. On 1 June, 3 July, and 12 Aug. All three N sources received summer applications of respected nitrogen source at a rate of 12.2 kg N/ha and standard plots received urea at 24.4 kg N/ha.

§ No significant differences ($P > 0.05$) for date.

¶ Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P < 0.05$).

Table 4-4. Effect of timing of fertilization on green cover percentage in large patch-infested zoysiagrass at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2013.

		Green Cover Percentage†										
Timing‡	Application Date	20 May§	31 May§	7 June§	12 June§	18 June§	27 June§	26 July§	21 Aug.§	20 Sept.§	8 Oct.§	24 Oct.§
Spring 15.5ºC	13 May	87.2	85.4	76.9	75.9	86.7	97.0	98.5	97.7	98.4	92.3	91.3
Spring 21ºC	20 May	84.2	85.1	81.2	79.6	91.0	97.5	98.7	97.5	98.6	95.3	93.8
Fall 21ºC	23 Sept.	83.7	81.7	74.6	73.7	88.4	96.5	98.8	97.6	98.5	91.6	89.6

† Rating dates in 2013, which plots were photographed with a Nikon D70 digital camera at 1.13 m above the canopy. Images were analyzed with SigmaScan Pro 5.0 for percentage of healthy (green) turf relative to non-green turf.

‡ Spring and fall timings were applied at a rate of 36.6 kg N/ha when five day average soil temperatures at a 5 cm depth were at the respected target temperature. On 1 June, 3 July, and 12 Aug. all treatments received summer applications of respected nitrogen source at a rate of 12.2 kg N/ha.

§ No significant differences ($P \geq 0.05$) for date.

¶ Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

Table 4-5. Effect of nitrogen source and timing of fertilization on green cover percentage in large patch-infested zoysiagrass at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2014.

Treatment	Application Date‡	Green Cover Percentage†								
		1 May§	8 May§	15 May§	22 May§	29 May§	5 June§	12 June	19 June§	26 June§
$Ca(NO_3)_2$ (Spring 15.5ºC)	23 April	55.8	73.0	57.9	30.2	25.1	79.3	90.7 bc¶	93.5	96.4
$Ca(NO_3)_2$ (Spring 21ºC)	26 May	64.1	81.3	78.5	35.6	32.7	78.1	93.0 ab	94.6	98.5
$Ca(NO_3)_2$ (Fall 21ºC)	--	66.3	77.4	61.6	24.5	19.9	71.4	86.5 c	90.6	97.5
$(NH_4)_2SO_4$(Spring 15.5ºC)	23 April	40.8	79.8	82.7	35.7	30.6	80.2	92.8 ab	95.6	98.8
$(NH_4)_2SO_4$ (Spring 21ºC)	26 May	61.8	81.0	90.7	57.4	55.6	85.1	95.4 a	96.6	99.1
$(NH_4)_2SO_4$ (Fall 21ºC)	--	52.5	77.6	72.7	38.0	34.4	81.1	93.2 ab	90.2	98.3
Urea (Spring 15.5ºC)	23 April	72.0	77.2	78.4	40.1	38.2	78.9	93.9 ab	94.5	98.4
Urea (Spring 21ºC)	26 May	58.1	61.6	56.5	31.0	32.6	79.0	90.7 bc	93.3	97.7
Urea (Fall 21ºC)	--	36.4	62.1	64.5	28.6	34.4	85.0	91.2 ab	93.9	98.0
Standard		39.4	78.5	68.7	47.0	40.0	82.9	95.2 a	95.1	97.9

† Rating dates in 2014, which plots were photographed with a Nikon D70 digital camera at 1.8 m above the canopy. Images were analyzed with SigmaScan Pro 5.0 for percentage of healthy (green) turf relative to non-green turf.

‡ Respected $Ca(NO_3)_2$ (15.5-0-0) $(NH_4)_2SO_4$ (21-0-0+24(S) and Urea (46-0-0) treatments were applied at a rate of 36.6 kg N/ha on 23 April and 26 May. On 1 June and 8 July all treatments received summer applications of respected nitrogen source at a rate of 12.2 kg N/ha and standard plots received urea at 24.4 kg N/ha. N/A: The study was terminated prior to fall 2014 applications.

§ No significant differences ($P \geq 0.05$) for date.

¶ Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

Table 4-6. Nested analysis of variance for parameters evaluated on Meyer zoysiagrass at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2014.

Parameter	Source of variation	Date[†]								
		1 May	8 May	15 May	22 May	29 May	5 June	12 June	19 June	26 June
Green Cover Percentage	S[‡]	NS[#]	NS	*	*	NS	NS	**	NS	NS
	T(S)[§]	NS	NS	NS	NS	NS	NS	*	NS	NS
	Contrasts[¶]									
	$Ca(NO_3)_2$ v. $(NH_4)_2SO_4$	NS	NS	*	*	*	NS	**	NS	*
	$Ca(NO_3)_2$ v. Urea	NS	NS	NS	NS	NS	NS	NS	NS	NS
	$Ca(NO_3)_2$ v. Standard	*	NS	NS	*	NS	NS	**	NS	NS
	$(NH_4)_2SO_4$ v. Urea	NS	*	*	*	NS	NS	NS	NS	NS
	$(NH_4)_2SO_4$ v. Standard	n/a[††]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Urea v. Standard	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Fall 21°C v. Spring 15.5°C	NS	NS	NS	NS	NS	NS	NS	*	NS
	Fall 21°C v. Spring 21°C	NS	NS	NS	*	NS	NS	*	*	NS
	Spring 15.5°C v. Spring 21°C	NS	NS	NS	NS	NS	NS	NS	NS	NS

[†] Rating dates in 2014, which plots were photographed with a Nikon D70 digital camera at 1.8 m above the canopy. Images were analyzed with SigmaScan Pro 5.0 for estimation of pixels that represented healthy (green) turf relative to non-green turf.
[‡] Nitrogen source (S).
[§] Effect of application timing (T) nested within nitrogen source T(S).
[¶] Contrasts among N source treatment means and among application timing treatment means.
[#] Not significant (NS).
[††] Contrast was inestimable in SAS, not available (n/a) due to one $(NH_4)_2SO_4$ (Fall 21ºC) plot excluded because of a common bermudagrass infestation within the plot.
*, **, and *** are significant at the 0.05, 0.01, and 0.001 probability level, respectively.

Table 4-7. Effect of nitrogen source on green cover percentage in large patch-infested zoysiagrass at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2014.

N Source‡	Green Cover Percentage†								
	1 May§	8 May§	15 May	22 May	29 May§	5 June§	12 June	19 June§	26 June§
$Ca(NO_3)_2$	61.8	77.2	66.0 b¶	30.1 b¶	25.9	76.3	90.1 b#	92.9	97.5
$(NH_4)_2SO_4$	51.7	79.4	82.0 a	43.7 a	40.2	82.1	93.8 a	94.2	98.7
Urea	55.5	67.0	66.5 b	33.2 ab	35.1	81.0	92.0 ab	93.9	98.0
Standard	39.4	78.5	68.7 ab	47.0 a	40.0	82.9	95.2 a	95.1	97.9

† Rating dates in 2014, which plots were photographed with a Nikon D70 digital camera at 1.8 above the canopy. Images were analyzed with SigmaScan Pro 5.0 for percentage of healthy (green) turf relative to non-green turf.
‡ $Ca(NO_3)_2$ (15.5-0-0) $(NH_4)_2SO_4$ (21-0-0+24(S) and Urea (46-0-0) sources were applied at a rate of 36.6 kg N/ha on 23 April and 26 May. On 1 June and 8 July all three N sources received summer applications of respected nitrogen source at a rate of 12.2 kg N/ha and standard plots received urea at 24.4 kg N/ha.
§ No significant differences ($P \geq 0.05$) for date.
¶ Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).
# Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.01$).

Table 4-8. Effect of timing of fertilization on green cover percentage in large-patch infested zoysiagrass at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2014

		Green Cover Percentage†								
Timing‡	Application Date	1 May§	8 May§	15 May§	22 May§	29 May§	5 June§	12 June§	19 June§	26 June§
Spring 15.5ºC	23 April	56.2	76.6	73.0	35.3	31.3	79.5	92.5	94.5	97.8
Spring 21ºC	26 May	61.3	74.6	75.2	41.3	40.3	80.7	93.0	94.8	98.5
Fall 21ºC	--	51.7	72.4	66.3	30.4	29.6	79.2	90.3	91.6	97.9

† Rating dates in 2014, which plots were photographed with a Nikon D70 digital camera at 1.8 m above the canopy. Images were analyzed with SigmaScan Pro 5.0 for percentage of healthy (green) turf relative to non-green turf.

‡ Spring and fall timings were applied at a rate of 36.6 kg N/ha when five day average soil temperatures at a 5 cm depth were at the respected target temperature. On 1 June and 8 July all treatments received summer applications of respected nitrogen source at a rate of 12.2 kg N/ha.

§ No significant differences ($P \geq 0.05$) for date.

¶ Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

Chapter 5 - Evaluation of New Zoysiagrass Experimental Lines for Winter Hardiness and Turf Quality in the Transition Zone

ABSTRACT

A three-phase, six-year plan was developed through collaboration among Texas A&M AgriLife Research, Dallas, TX, Kansas State University, Manhattan, KS, and Purdue University, West Lafayette, IN to develop and evaluate new zoysiagrass lines with quality and hardiness equivalent or better than 'Meyer' zoysiagrass, but with improved resistance to the fungal disease *Rhizoctonia* large patch (*Rhizoctonia solani* Kühn Anastomosis Group (AG)-2-2 LP). Phase II (year 2-3) began in 2012 and was focused on field testing non-replicated spaced plant nurseries at Dallas, TX, Manhattan, KS, and West Lafayette, IN. A total of 881 zoysia progeny originating from parental crosses at Texas A&M were planted in 2012, and an additional 104 progeny were planted in 2013. Starting in 2013, in order to identify those progeny best adapted to the Kansas site, grasses were rated visually on ten occasions each year. Ratings were done following National Turfgrass Evaluation Program (NTEP) guidelines. These ratings occurred throughout the year to evaluate winter survival and turf quality characteristics, including density, texture, color, coverage, quality, and texture. Evaluation revealed the top performing families and individuals. A projected twenty-two of the original 985 progeny will be returned to Texas A&M AgriLife Research – Dallas for propagation in 2014. Beginning in 2015, grasses will be evaluated further for quality characteristics and large patch resistance under golf course maintenance conditions at several locations in the transition zone.

INTRODUCTION

The transition zone of turfgrass adaption is a loosely-defined area in the central US, which includes Kansas. This region experiences wide ranges of temperature extremes and makes turfgrass management difficult. The traits of warm-season (C4) turfgrasses, such as zoysiagrass (*Zoysia* spp.) are attractive to transition zone turfgrass managers desiring to conserve water and reduce expenses associated with fertilizer and pesticide inputs.

Zoysiagrasses are warm-season turfgrasses native to Asia, which were introduced into the United States in 1895 (Engelke and Anderson, 2003; Madison, 1971). Zoysiagrass has attained its popularity due to its excellent cold, heat, drought, and wear, as well as its relatively low requirements for water and other cultural inputs required by cool-season grasses (Beard, 1973; Fry and Huang, 2004; Fry et al. 2008). Zoysiagrass is relatively free of major disease problems (Beard, 1973); however, the fungal disease *Rhizoctonia* large patch caused by *Rhizoctonia solani* Kühn [anastomosis Group (AG)-2-2 LP] affects zoysiagrass throughout the transition zone and can be extremely damaging (Green et al., 1993).

Zoysia japonica (Steud.) is the most widely used *Zoysia* species in the United States (Christians, 2007), and it is uniquely adapted to the transition zone because of good cold hardiness of cultivars within this species. The popularity of zoysiagrass in the transition zone is due in large part to 'Meyer', which was released in 1952. Since then, it has been the predominant cultivar used in the transition zone due to its excellent cold tolerance (Patton and Reicher, 2007; Fry et. al., 2008). Researchers at Texas A&M AgriLife Research, Dallas TX and Kansas State University, Manhattan, KS have worked together since 2004 to develop and evaluate zoysiagrasses with higher quality than Meyer for adaptation in the transition zone. From this work, a number of advanced lines resulting primarily from paired crosses between *Z. matrella* and *Z. japonica* have demonstrated a level of hardiness equivalent to Meyer (Okeyo et al., 2011). Collaboration between universities has been ongoing to evaluate new potential zoysiagrass lines that have equivalent or higher quality and cold hardiness compared to Meyer, and improved resistance to *Rhizoctonia* large patch disease, which continues to be the primary disease problem on Meyer.

Currently large patch is managed by fungicide applications, with most zoysiagrass fairway managers making one to two fungicide applications annually at costs up to $350/Acre to limit damage from large patch (Tisserat et al., 1994). Assuming a golf course with 30 acres applied fungicide on all fairway areas in the spring and fall, it would need to budget $21,000 annually to treat this disease alone. Incorporating large patch resistance (LPR), along with cold hardiness and improved quality, into new transition zone zoysiagrasses would reduce fungicide requirements, increase sustainability, and reduce maintenance costs.

A three-phase, six-year plan has been developed by the collaboration among Texas A&M AgriLife Research, Dallas, TX, Kansas State University, Manhattan, KS, and Purdue University, West Lafayette, IN. Phase I (year 1) was conducted at Texas A&M AgriLife Research, and involved crossing various cold-hardy zoysiagrasses with TAES 5645, a zoysiagrass which has demonstrated some resistance to large patch in growth chamber studies. The large patch resistance experimental hybrids and germplasm accessions were crossed with cold hardy zoysiagrass parental lines (Meyer and Meyer derivatives). Zoysia progeny developed in 'Phase I' were distributed to Dallas, Manhattan, and West Lafayette in 2012 for field testing.

Phase II (year 2-3) began in 2012 focusing on field testing in the form of non-replicated spaced plant nurseries comprised of the newly generated progeny population that was conducted simultaneously by researchers at the aforementioned universities. The objective of Phase II field testing was selection of experimental lines that have comparable/superior cold tolerance to Meyer as well as improved turfgrass quality. In autumn of 2014 (year 3), a projected twenty-two progeny will be selected from each site and sent to Texas A&M for propagation.

Phase III (year 4-6) will begin in 2015 with the selected 66 progeny planted in the form of replicated field trials in 6 ft. x 6 ft. plots where extensive evaluation will be performed in the field at Manhattan, West Lafayette, and multiple locations in the transition zone. *Rhizoctonia solani* (AG 2-2 LP) will be inoculated on one-half of each plot at the Manhattan and West Lafayette sites, and the other half will be treated with a fungicide to evaluate for visible symptoms of large patch incidence as a result of inoculation.

The objective was to oversee Phase II of this project at the Manhattan, Kansas location for evaluation and selection of twenty-two progeny for future extensive evaluation.

MATERIALS AND METHODS

In 2012, the Rocky Ford site had an established creeping bentgrass (*Agrostis stolonifera* L.) growing in the proposed planting site; therefore, glyphosate was applied to the cool-season turf two weeks in advance of plugging. On 14 June 2012, 881 zoysia progeny from Texas A&M were hand plugged, one plug at center of 1.5 ft. x 1.5 ft. plots at a 1 ft. spacing (Table 5-1; Figure 5-1). On 25 July 2013, an additional 104 zoysia progeny were sent from Texas A&M and plugged, one plug at the center of 3 ft. x 3 ft. plots at a 1 ft. spacing. Plugs were irrigated after planting to minimize stress (Figure 5-2). Soil at Rocky Ford was a Chase silt clay loam. Turf was maintained at a 2.5 inch height and received 2 lb. of nitrogen (N) per 1000 sq. ft. per year.

In order to identify those progeny best adapted to the Kansas site, grasses were rated visually on ten occasions each year. Ratings were done following National Turfgrass Evaluation Program (NTEP) guidelines (Morris and Shearman, 1999). Color was rated on a 1 to 9 scale (1 = straw brown, 9 = dark green). Spring color was an average of two ratings, the first when Meyer zoysiagrass was at 50% green color in the spring and the second when Meyer had 100% green color. Summer color was rated in July. Fall color was an average of two ratings, the first when Meyer zoysiagrass first began to lose green color, and the second when Meyer had at least 75% brown color. Spring and late summer coverage were rated visually on a 0 to 100% scale. Early and late summer quality were rated on a 1 to 9 scale (1 = poorest color, density, texture, and uniformity, and 9 = optimum quality). Texture was rated in summer on a 1 to 9 scale (1 = coarsest texture and 9 = finest texture).

RESULTS AND DISCUSSION

2013

In 2013, a total of 573 progeny of the initial 881 (including 14 checks) survived after planting in 2012 (Table 5-2). The fourteen checks included were the uncrossed parent lines (5645, 5311-26, 5313-34, 5723-47, and 5728-26) and nine standard zoysiagrass cultivars of *Z. japonica, Z. matrella* (L.) Merr., *Z. pacifica* (Gaud.) Hotta & Kuroti., and *Z. pauciflora* Mez. The summer of 2012 was extremely hot with 18 days recorded at or above 100ºF from 14 June to 31 August, and some of the zoysiagrasses were lost during the establishment period. Cold winter temperatures also caused loss of some less hardy progeny. From 1 November 2012 to 30 April

2013, there were a total of 117 days recorded with minimum temperatures below 32 ºF (9 days of low temperatures at or below 10 ºF) and the lowest temperature of 1.6 ºF was recorded on 1 February 2013. Data were compiled for progeny performance within families (crosses) and for individual progeny for each rating in 2013 (Tables 5-2 and 5-3).

2014

In 2014, a total of 541 progeny of the 573 (including checks) from 2013 survived the 2013-2014 winter (Table 5-4). Similarly, only 38 of the additional 104 progeny planted in summer 2013 survived the 2013-2014 winter. Between 1 November 2013 and 30 April 2014, there was total of 119 days recorded of minimum temperatures below 32ºF (36 days of low temperatures at or below at 10ºF) and the lowest temperature recorded was at -8.3 ºF on 6 January 2014 (Figure 5-3). Data were compiled for progeny performance within families (crosses) and highest individual progeny for ratings until July 2014 (Tables 5-4 and 5-5).

Over both years, the top performing family lines which had more frequent higher averages across all ratings were 6097, 6099, 6100, 6101, 6102, 6109, 6119, and 6121. Currently, 38 individual zoysiagrass progeny in the family crosses listed above and others are under examination to select the proposed 22 progeny for future evaluation. These grasses will be harvested in August 2014, and sent to Texas A&M AgriLife Research-Dallas for propagation.

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Figure 5-1. Planting the initial 881 zoysiagrass progeny at the Rocky Ford Turfgrass Research Center in Manhattan, KS on 14 June 2012. Each progeny resulted from the cross of a cold-hardy zoysiagrass with a clone (TAES 5645) which has demonstrated some resistance to large patch at Texas A&M AgriLife Research in Dallas, TX.

Figure 5-2. Irrigating the zoysiagrass progeny space planting in Manhattan, KS on 21 August 2013.

Figure 5-3. Zoysiagrass progeny plots exhibiting winter injury during spring green up on 12 May 2014.

Table 5-1. Zoysiagrass progeny coded family (crosses) at the Rocky Ford Turfgrass Research Center in Manhattan, KS in 2013. For confidentiality, only species, and not cultivar names, are provided.

	Zoysiagrass Progeny Coded Family Cross	
Coded Family #	Female x Male	Preliminary Total #
6095	[(*Z. matrella* (L.) Merr. x *Z. matrella*) x *Z. japonica*] x *Z. japonica*	40
6096	(*Z. matrella* x *Z. japonica*) x *Z. japonica*	66
6097	(*Z. matrella* x *Z. japonica*) x *Z. japonica*	38
6099	*Z. japonica* x *Z. japonica*	152
6100	[(*Z. japonica* x *Z. pacifica* (Gaud.) Hotta & Kuroti) x *Z. japonica*] x *Z. japonica*	77
6101	(*Z. japonica* x *Z. matrella*) x *Z. japonica*	52
6102	*Z. japonica* x *Z. japonica*	115
6104	*Z. japonica* x *Z. japonica*	56
6105	(*Z. matrella* x *Z. japonica*) x *Z. japonica*	5
6106	[(*Z. matrella* x *Z. matrella)* x *Z. japonica*] x Z. *japonica*	5
6109	(*Z. japonica* x *Z. matrella*) x *Z. japonica*	32
6110	(*Z. matrella* x *Z. japonica*) x *Z. japonica*	51
6118	(*Z. japonica* x *Z. matrella*) x *Z. japonica*	30
6119	*Z. japonica* x [(*Z. matrella x Z. matrella*) x *Z. japonica*]	71
6120	(*Z. matrella* x *Z. japonica*) x *Z. japonica*	24
6121	(*Z. matrella* x *Z. japonica*) x *Z. japonica*	46
6126	(*Z. matrella* x *Z. japonica*) x *Z. japonica*	40
6220	(*Z. japonica* x *Z. japonica*) x *Z. japonica*	15
6221	*Z. japonica* x (*Z. japonica* x *Z. japonica*)	25
6222	(*Z. japonica* x *Z. matrella*) x *Z. japonica*	15
6263	(*Z. pauciflora* Mez. x *Z. matrella*) x *Z. japonica*	10
6315	(*Z. minima* (Colenso) Zotov *x Z. matrella*) x *Z. japonica*	6

Table 5-2. Zoysiagrass progeny family (crosses) means at the Rocky Ford Turfgrass Research Center in Manhattan, KS in 2013.†

Coded Family (TAES#)	Survival (%) 2013‡	Spring Color§	Spring Coverage¶	Early Summer Quality#	Summer Texture††	Summer Color§	Late Summer Coverage¶	Late Summer Quality#	Fall Color§
6095	68% (40)	3.2	10.0	1.6	4.4	6.8	40.7	4.2	6.5
6096	64% (66)	2.9	9.6	1.7	5.7	5.8	39.8	4.3	6.2
6097	74% (38)	3.7	12.8	2.1	4.6	6.3	46.8	4.7	6.3
6099	80% (152)	4.2	15.5	2.4	4.8	6.3	52.9	5.1	6.2
6100	69% (77)	3.5	10.3	1.9	4.9	6.5	46.9	4.9	6.7
6101	77% (52)	3.3	11.5	2.0	5.7	6.2	46.0	4.6	6.4
6102	63% (115)	3.8	14.3	2.4	4.8	6.4	50.7	4.9	6.3
6104	84% (56)	3.2	12.6	2.1	3.6	6.4	47.6	5.0	6.1
6105	60% (5)	2.7	4.0	1.0	4.7	6.7	40.0	4.3	6.0
6106	20% (5)	3.0	20.0	3.0	4.0	6.0	55.0	4.0	5.0
6109	69% (32)	4.0	14.0	2.6	5.3	6.6	49.6	5.3	6.2
6110	16% (51)	2.0	5.7	1.1	4.5	5.8	27.9	4.0	7.2
6118	33% (30)	2.5	7.6	1.3	5.4	6.2	33.0	4.3	6.6
6119	54% (71)	4.4	15.1	2.4	5.2	6.4	47.6	4.4	6.0
6120	63% (24)	2.8	9.3	1.8	4.9	6.8	34.7	4.0	5.8
6121	65% (46)	3.5	13.2	2.3	6.4	6.1	43.0	4.0	5.6
6126	75% (7)	3.3	10.0	1.6	6.0	6.0	23.3	3.0	7.5

† Only the 881 zoysiagrass progeny which were planted on 14 June 2012 were evaluated in 2013; the additional 104 progeny were not planted until 25 July 2013 and evaluation began in 2014.

‡ Survival is a percentage of the initial number planted, which is indicated in parentheses.

§ Color was rated on a 1 to 9 scale, on which 1 = straw brown and 9 = dark green. Spring color is an average of ratings on 11 and 28 May. Summer color was rated on 16 July. Fall color is an average of ratings on 2 and 15 October.

¶ Coverage was rated on 0 to 100% scale. Spring coverage was rated on 31 May, and late summer coverage was rated on 21 August.

Quality was rated on a 1 to 9 scale, on which 1 = poorest color, density, texture, and uniformity, and 9 = optimum quality. Early summer quality was rated on 11 June and late summer quality was rated on 21 August.

†† Texture was rated on a 1 to 9 scale on which 1 = coarsest, and 9 = finest. Summer texture was rated on 16 July.

Table 5-3. Highest rated individual zoysiagrass progeny entries at the Rocky Ford Turfgrass Research Center in Manhattan, KS in 2013.†

Individual Entry #								
Spring Color‡	Spring Coverage§	Early Summer Quality¶	Summer Texture#	Summer Color‡		Late Summer Coverage§	Late Summer Quality¶	Fall Color‡
6097-10	6097-10	6097-10	6096-23	6095-2	6102-10	6097-10	6097-10	6095-21
6098-8	6099-1	6099-27	6096-26	6095-4	6102-17	6099-3	6099-3	6096-27
6099-27	6099-21	6099-31	6096-32	6095-5	6102-63	6099-22	6099-8	6099-10
6099-29	6099-22	6099-132	6100-44	6095-21	6102-81	6099-27	6099-31	6099-15
6099-31	6099-27	6099-133	6101-3	6095-37	6102-82	6099-31	6099-34	6099-37
6099-45	6099-31	6101-7	6101-5	6096-56	6102-83	6100-10	6099-55	6099-43
6099-47	6099-29	6102-2	6101-49	6097-1	6102-85	6101-7	6099-58	6099-67
6099-56	6102-33	6102-8	6119-14	6097-7	6102-87	6102-33	6099-83	6099-75
6099-70	6102-37	6102-33	6121-10	6097-28	6102-109	6102-37	6099-113	6099-95
6099-140	6102-46	6102-37	6121-25	6097-33	6104-4	6109-2	6099-129	6099-124
6100-5	6102-108	6102-46	6121-27	6097-34	6104-19	6109-4	6099-141	6100-24
6101-7		6109-2		6099-10	6104-27		6100-13	6100-26
6100-29		6109-4		6099-18	6104-36		6100-60	6100-36
6102-46		6121-39		6099-24	6104-38		6102-24	6100-50
6102-82		6199-39		6099-73	6104-49		6102-62	6100-76
6109-2				6099-84	6104-51		6102-109	6101-47
6109-4				6099-101	6109-6		6104-4	6102-18
6119-21				6099-103	6109-16		6104-21	6109-20
6119-26				6099-113	6109-25		6106-5	6110-42
				6099-129	6118-5		6109-4	6126-1
				6099-147	6119-7		6109-31	
				6100-28	6119-14		6119-14	
				6100-29	6119-15		6119-42	
				6100-40	6119-18		6119-56	
				6100-47	6119-26			
				6100-54	6119-56			
				6100-62	6119-63			
				6100-65	6119-66			
				6100-73	6120-8			
				6100-76	6120-20			
				6101-3	6120-21			
				6101-27	6121-7			
				6101-51	6121-9			
					6121-31			

† Only the 881 zoysiagrass progeny which were planted on 14 June 2012 were evaluated in 2013; the additional 104 progeny were not planted until 25 July 2013 and evaluation began in 2014.
‡ Color was rated on a 1 to 9 scale, on which 1 = straw brown and 9 = dark green. Spring color is an average of ratings on 11 and 28 May. Summer color was rated on 16 July. Fall color is an average of ratings on 2 and 15 October.
§ Coverage was rated on 0 to 100% scale. Spring coverage was rated on 31 May, and late summer coverage was rated on 21 August
¶ Quality was rated on a 1 to 9 scale, on which 1 = poorest color, density, texture, and uniformity, and 9 = optimum quality. Early summer quality was rated on 11 June and late summer quality was rated on 21 August.
# Texture was rated on a 1 to 9 scale on which 1 = coarsest, and 9 = finest. Summer texture was rated on 16 July.

Table 5-4. Zoysiagrass progeny family (crosses) means at the Rocky Ford Turfgrass Research Center in Manhattan, KS in 2014.†

Coded Family (TAES #)	Survival (%) 2014‡	Spring Color§	Spring Coverage¶	Early Summer Quality#	Summer Texture††	Summer Color§
6095	65% (40)	2.8	23.6	4.4	4.7	5.4
6096	60% (66)	2.3	17.4	4.0	5.9	5.2
6097	73% (38)	2.9	24.7	3.8	4.8	5.7
6099	77% (152)	3.4	33.3	4.3	4.9	5.4
6100	68% (77)	3.5	34.4	4.4	5.1	5.6
6101	73% (52)	2.9	26.9	4.8	5.8	5.6
6102	60% (115)	3.1	28.9	4.3	4.8	5.6
6104	74% (56)	2.5	20.1	3.9	3.8	5.1
6105	60% (5)	2.3	25.0	4.0	5.7	5.3
6106	20% (5)	2.0	10.0	4.0	4.0	7.0
6109	65% (32)	2.8	27.1	4.2	5.9	5.5
6110	9% (51)	1.3	5.0	3.4	4.4	5.4
6118	30% (30)	1.9	16.1	3.6	5.6	5.4
6119	46% (71)	2.9	27.3	4.1	5.2	5.2
6120	54% (24)	2.0	15.8	4.2	5.6	5.1
6121	65% (46)	2.3	18.3	3.9	6.5	6.4
6126	61% (40)	1.8	7.2	3.3	5.5	5.3
6220	40% (15)	2.0	11.3	4.8	3.9	5.8
6221	28% (25)	1.3	8.1	3.8	4.0	4.1
6222	33% (15)	1.2	9.3	2.4	5.6	5.5
6263	30% (10)	1.1	10.0	2.0	5.0	5.5
6315	17% (6)	1.1	5.0	2.0	6.0	6.0

† 881 zoysiagrass progeny which were planted on 14 June 2012 were evaluated in 2013; the additional 104 progeny were not planted until 25 July 2013 and evaluation began in 2014.
‡ Survival is a percentage of the initial number planted, which is indicated in parentheses.
§ Color was rated on a 1 to 9 scale, on which 1 = straw brown and 9 = dark green. Spring color is an average of ratings on 2 and 21 May. Summer color was rated on 10 July.
¶ Coverage was rated on 0 to 100% scale. Spring coverage was rated on 28 May.
# Quality was rated on a 1 to 9 scale, on which 1 = poorest color, density, texture, and uniformity, and 9 = optimum quality. Early summer quality was rated on 12 June.
†† Texture was rated on a 1 to 9 scale on which 1 = coarsest, and 9 = finest. Summer texture was rated on 10 July

Table 5-5. Highest rated individual zoysiagrass progeny entries at the Rocky Ford Turfgrass Research Center in Manhattan, KS in 2014. Progeny in bold were among those selected for further evaluation and will be harvested in August and sent to Dallas for propagation†.

Individual Entry #				
Spring Color‡	Spring Coverage§	Early Summer Quality¶	Summer Texture#	Summer Color‡
6095-2	6096-36	6096-30	6096-27	6096-34
6099-10	6099-25	6097-19	6096-28	6097-19
6099-25	6099-27	6099-37	6099-99	6099-78
6099-34	**6099-77**	6099-91	**6101-3**	6101-1
6099-38	6099-151	6100-7	6101-5	6101-9
6099-41	**6100-3**	6100-61	6101-33	6101-10
6099-43	6100-5	**6101-3**	6101-52	6101-29
6099-69	6100-7	**6101-26**	6102-18	6102-2
6099-77	6100-61	**6101-32**	6118-15	6102-26
6099-84	**6101-26**	6102-20	**6119-14**	6102-80
6099-107	6102-5	6104-19	6121-3	6109-16
6099-140	6102-62	6118-5	6121-4	6121-9
6099-151	6102-108	**6119-14**	6121-9	6121-23
6100-3	6104-17	**6120-8**	6121-23	6121-26
6100-5	**6119-14**	6121-21	6121-25	6121-27
6100-7			6121-29	
6100-13			6121-31	
6100-23				
6100-61				
6100-76				
6101-26				
6101-32				
6102-5				
6102-47				
6102-62				
6104-17				
6109-8				
6109-18				
6119-14				
6119-21				
6119-58				

† 881 zoysiagrass progeny which were planted on 14 June 2012 were evaluated in 2013; the additional 104 progeny were not planted until 25 July 2013 and evaluation began in 2014.
‡ Color was rated on a 1 to 9 scale, on which 1 = straw brown and 9 = dark green. Spring color is an average of ratings on 2 and 21 May. Summer color was rated on 10 July.
§ Coverage was rated on 0 to 100% scale. Spring coverage was rated on 28 May.
¶ Quality was rated on a 1 to 9 scale, on which 1 = poorest color, density, texture, and uniformity, and 9 = optimum quality. Early summer quality was rated on 12 June.
†† Texture was rated on a 1 to 9 scale on which 1 = coarsest, and 9 = finest. Summer texture was rated on 10 July.

Appendix A - Additional Tables for Chapter 1

Table A-1. Effect of annual ryegrass overseed, colorant and number of applications on Dark Green Color Index of 'Chisholm' zoysiagrass at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2012-2013.

		Dark green color index†							
Treatment	Application Date‡	7 Nov.	11 Dec.	10 Jan.	13 Feb.	14 March	25 April	20 May	7 June
Green Lawnger									
	20 Oct.	0.517 a§	0.636 a	0.615 a	0.623 c	0.484 c	0.449 c	0.428 b	0.481 a
	20 Oct. + 23 Jan.	0.531 a	0.651 a	0.621 a	0.766 a	0.629 a	0.556 a	0.464 a	0.478 a
Ultradwarf Super									
	20 Oct.	0.384 b	0.482 b	0.475 b	0.491 d	0.380 d	0.381 d	0.389 c	0.468 ab
	20 Oct. + 23 Jan.	0.383 b	0.493 b	0.485 b	0.660 b	0.538 b	0.500 b	0.451 a	0.487 a
Annual Ryegrass Overseed	28 Sept.	0.338 c	0.343 c	0.309 c	0.339 e	0.264 e	0.307 e	0.365 d	0.446 c
Untreated		0.249 d	0.279 d	0.313 c	0.324 e	0.255 e	0.279 f	0.356 d	0.458 bc

† Digital photograph taken of each plot under lighted camera box with a Nikon D5000 camera. Images were analyzed with SigmaScan Pro 5.0 using the "Turf Analysis" macro for batch analysis, then calculated to obtain the dark green color index value on a 0 to 1.0 scale.

‡ Annual ryegrass overseeding was performed 3 weeks prior to first colorant application on 11 Oct. 2012. Colorants were applied at dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8004VS nozzles at 131 gallons per acre of spray solution in two perpendicular directions for a total rate of 262 GPA. The first colorant application was applied on 31 Oct. 2012 and fourteen weeks after initial application received a sequential application on the required treatments was applied on 5 Feb. 2013.

§ Weeks After Treatment (weeks after 1st colorant application)

¶ Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

Table A-2**.** Effect of annual ryegrass overseed, colorant and number of applications on soil temperature (°F) of 'Chisholm' zoysiagrass at Rocky Ford Turfgrass Research Center, Manhattan, KS in 2013.

		Soil temperature (°F)[†]									
Treatment	Application Date[‡]	28 March[§]	4 April[§]	12 April[§]	20 April[§]	25 April[§]	5 May[§]	11 May[§]	18 May[§]	28 May[§]	7 June[§]
Green Lawnger											
	20 Oct.	45.7	50.1	47.7	49.0	52.4	50.8	60.7	68.8	72.4	71.8
	20 Oct. + 23 Jan.	48.0	52.9	50.0	51.4	56.5	53.4	65.3	70.8	75.5	75.9
Ultradwarf Super											
	20 Oct.	46.0	50.2	48.3	49.0	52.8	51.1	60.5	68.2	72.1	71.9
	20 Oct. + 23 Jan.	45.9	50.0	48.3	48.8	52.6	51.0	60.2	68.1	71.7	72.2
Annual Ryegrass Overseed	28 Sept.	46.4	50.3	48.3	49.0	53.0	51.2	60.9	68.9	72.4	72.1
Untreated		46.1	50.4	48.5	49.4	53.9	52.3	61.5	69.0	72.4	72.5
Tall Fescue		48.5	50.5	49.5	50.8	55.2	55.8	66.5	72.5	77.8	75.7

[†] Soil temperature at a 1.25 inch depth was measured and averaged from three measurements within each plot using digital T-bar thermometer.

[‡]Annual ryegrass overseeding was performed 3 weeks prior to first colorant application on 28 Sept. 2012. Colorants at dilution of 1:6 (colorant:water) were applied using a three-nozzle, CO_2-pressurized sprayer with 8004VS nozzles at 131 gallons per acre of spray solution in two perpendicular directions for a total rate of 262 GPA. The first colorant application was applied 20 Oct. 2012 and fourteen weeks after initial application received a sequential application on the required treatments was applied on 23 Jan. 2013.

[§] No significant differences ($P \geq 0.05$) for date.

Table A-3. Effect of annual ryegrass overseed, colorant and number of applications on quality of 'Chisholm' zoysiagrass at the John C Pair Research Center, Haysville, KS in 2012-2013.

		Turf quality[†]							
		31 Oct.	29 Nov.	21 Dec.	9 Jan.	5 Feb.	20 March	16 April	16 May
Treatment	Application Date[‡]	0 WAT[§]	4 WAT	7 WAT	10 WAT	14 WAT	20 WAT	24 WAT	28 WAT
Green Lawnger									
	31 Oct.	5.0 bc[¶]	8.0 a	8.3 a	7.8 a	7.5 b	7.5 a	6.3 ab	7.3 ab
	31 Oct. + 5 Feb.	5.3 bc	8.0 a	8.0 ab	7.8 a	8.5 a	8.5 a	7.3 a	7.3 ab
Ultradwarf Super									
	31 Oct.	5.3 bc	7.5 a	7.5 ab	6.8 a	6.5 c	5.8 b	5.3 b	6.3 bc
	31 Oct. + 5 Feb.	6.0 b	7.3 a	7.3 b	6.5 a	8.0 ab	7.5 a	6.5 a	7.3 ab
Annual Ryegrass Overseed	11 Oct.	3.0 d	1.5 c	1.3 d	1.3 c	1.0 e	1.8 d	2.0 d	5.3 c
Untreated		4.8 c	4.0 b	4.0 c	3.8 b	3.3 d	3.0 c	3.5 c	6.3 bc
Tall Fescue		8.5 a	7.3a	7.3 b	6.5 a	6.5 c	6.3 b	6.3 ab	7.5 a

[†] Turf quality was rated on a 1 to 9 scale where 1 = poorest color, uniformity, and density; 6 = acceptable quality, and 9 = optimum color, uniformity, and density.

[‡]Annual ryegrass overseeding was performed 3 weeks prior to first colorant application on 11 Oct. 2012. Colorants were applied at dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8004VS nozzles at 131 gallons per acre of spray solution in two perpendicular directions for a total rate of 262 GPA. The first colorant application was applied on 31 Oct. 2012 and fourteen weeks after initial application received a sequential application on the required treatments was applied on 5 Feb. 2013.

[§] Weeks After Treatment (weeks after 1st colorant application)

[¶] Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

Appendix B - Additional Tables for Chapter 2

Table B-1. Analysis of variance for visual turf color and dark green color index evaluated on colorant treated Chisholm zoysiagrass at the Rocky Ford Turfgrass Research Center, Manhattan, KS between October 2013 to May 2014.

		Weeks after treatment (WAT)†														
Parameter	Source of variation	0	2	4	6	8	10	14	16	20	22	24	26	28	30	32
Turf color	C‡	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
	V(C)§	***	***	***	***	***	***	***	***	***	***	***	***	***	NS¶	NS
Dark green	C	***	n/a#	***	n/a	***	n/a	***	***	***	n/a	***	n/a	***	***	n/a
color index	V(C)	***	n/a	***	n/a	***	n/a	***	**	***	n/a	***	n/a	***	NS	n/a

† Colorants were applied on 11 Oct. 2013 (0 WAT) at a dilution of 1:6 (colorant:water) using a one-nozzle, 3 gallon SHURflo ProPack™ model SRS 600 rechargeable electric backpack sprayer with an adjustable cone nozzle calibrated to deliver 0.29 gallons per minute.

‡ Colorant product (C).

§ Effect of application volume (V) nested within colorant product V(C).

¶ Not significant (NS).

Not applicable (n/a).

*, **, and *** are significant at the 0.05, 0.01, and 0.001 probability level, respectively.

Table B-2. Analysis of variance for visual turf color evaluated on colorant treated Chisholm zoysiagrass at the John C Pair Research Center, Haysville, KS between October 2013 to May 2014.

		Weeks after treatment (WAT)†									
Parameter	Source of variation	0	4	8	12	16	20	24	26	28	30
Turf color	C‡	***	***	***	***	***	***	***	***	***	***
	V(C)§	***	***	***	***	***	***	***	***	NS¶	NS

† Colorants were applied on 24 Oct. 2013 (0 WAT) at a dilution of 1:6 (colorant:water) using a one-nozzle, 3 gallon SHURflo ProPack™ model SRS 600 rechargeable electric backpack sprayer with an adjustable cone nozzle calibrated to deliver 0.29 gallons per minute.

‡ Colorant product (C).

§ Effect of application volume (V) nested within colorant product V(C).

¶ Not significant (NS).

*, **, and *** are significant at the 0.05, 0.01, and 0.001 probability level, respectively.

Table B-3. Effect of colorant and application volume on Dark Green Color Index of 'Chisholm' zoysiagrass at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2013-2014.

	Dark green color index†							
Treatment§	19 Oct.	6 Nov.	6 Dec.	20 Jan.	17 Feb.	26 March	15 April	15 May‡
Green Lawnger								
80 GPA	0.490 cde¶	0.440 de	0.516 c	0.421e	0.428 d	0.416 d	0.412 e	0.368
160 GPA	0.483 de	0.442 cde	0.512 c	0.423 e	0.423 d	0.416 d	0.418 e	0.392
240 GPA	0.506 c	0.465 bc	0.539 b	0.447 cd	0.448 bc	0.440 bc	0.447 cd	0.386
Endurant								
80 GPA	0.469 e	0.417 e	0.511 c	0.431de	0.434 cd	0.425 cd	0.440 cd	0.383
160 GPA	0.503 cd	0.460 cd	0.536 b	0.464 bc	0.459 bc	0.451 b	0.472 b	0.410
240 GPA	0.500 cd	0.454 cd	0.556 b	0.459 bc	0.461 bc	0.458 b	0.469 b	0.423
Wintergreen Plus								
80 GPA	0.534 b	0.488 b	0.549 b	0.478 b	0.476 b	0.448 bc	0.460 bc	0.400
160 GPA	0.550 b	0.533 a	0.607 a	0.528 a	0.523 a	0.500 a	0.510 a	0.428
240 GPA	0.581 a	0.542 a	0.621 a	0.531 a	0.523 a	0.510 a	0.502 a	0.430
Tall fescue	0.530 b	0.421 e	0.415 d	0.285 f	0.240 e	0.340 e	0.429 de	0.385
Untreated	0.302 f	0.230 f	0.253 e	0.226 g	0.223 e	0.236 f	0.237 f	0.308

† Digital photograph taken of each plot under lighted camera box with a Nikon D5000 camera. Images were analyzed with SigmaScan Pro 5.0 using the "Turf Analysis" macro for batch analysis, then calculated to obtain the dark green color index value on a 0 to 1.0 scale.

§ Colorants were applied on 11 Oct. 2013 at a dilution of 1:6 (colorant:water) using a one-nozzle, 3 gallon SHURflo ProPack™ model SRS 600 rechargeable electric backpack sprayer with an adjustable cone nozzle calibrated to deliver 0.29 gallons per minute.

‡ No significant difference ($P \geq 0.05$) for date.

¶ Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

Table B-4. Analysis of variance for canopy and soil temperature evaluated on colorant treated Chisholm zoysiagrass at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2014.

		Date†						
Parameter	Source of variation	11 March	26 March	9 April	11 April	25 April	6 May	9 May
Canopy temperature	C‡	***	**	n/a#	***	**	n/a	***
	V(C)§	NS¶	NS	n/a	NS	NS	n/a	NS
Soil temperature	C	NS	NS	NS	n/a	NS	NS	n/a
	V(C)	NS	NS	NS	n/a	NS	NS	n/a

† Colorants were applied on 11 Oct. 2013 (0 WAT) at a dilution of 1:6 (colorant:water) using a one-nozzle, 3 gallon SHURflo ProPack™ model SRS 600 rechargeable electric backpack sprayer with an adjustable cone nozzle calibrated to deliver 0.29 gallons per minute.

‡ Colorant product (C).

§ Effect of application volume (V) nested within colorant product V(C).

¶ Not significant (NS).

Not applicable (n/a).

*, **, and *** are significant at the 0.05, 0.01, and 0.001 probability level, respectively.

Table B-5. Analysis of variance for canopy and soil temperature evaluated on colorant treated Chisholm zoysiagrass at the John C Pair Research Center, Haysville, KS in 2014.

Parameter	Source of variation	Date†			
		13 March	8 April	22 April	6 May
Canopy temperature	C‡	**	*	NS	NS
	V(C)§	NS¶	NS	NS	NS
Soil temperature	C	NS	NS	NS	NS
	V(C)	NS	NS	NS	NS

† Colorants were applied on 24 Oct. 2013 (0 WAT) at a dilution of 1:6 (colorant:water) using a one-nozzle, 3 gallon SHURflo ProPack™ model SRS 600 rechargeable electric backpack sprayer with an adjustable cone nozzle calibrated to deliver 0.29 gallons per minute.

‡ Colorant product (C).

§ Effect of application volume (V) nested within colorant product V(C).

¶ Not significant (NS).

*, **, and *** are significant at the 0.05, 0.01, and 0.001 probability level, respectively.

Table B-6. Effect of colorant and application volume on soil temperature (°F) of 'Chisholm' zoysiagrass at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2014.

	Soil temperature (°F) †				
Treatment‡	11 March§	26 March§	9 April§	25 April§	6 May§
Green Lawnger					
80 GPA	45.1	43.0	49.5	57.4	65.2
160 GPA	45.1	42.9	49.3	57.6	66.3
240 GPA	45.1	43.0	49.5	57.7	65.8
Endurant					
80 GPA	44.9	42.8	49.7	57.5	65.9
160 GPA	44.9	42.9	49.5	57.5	66.1
240 GPA	44.5	42.8	49.1	57.4	65.7
Wintergreen Plus					
80 GPA	44.7	43.1	49.2	57.5	65.6
160 GPA	45.1	42.9	49.6	57.9	66.1
240 GPA	45.1	42.8	49.2	57.3	65.7
Untreated	45.0	42.8	49.6	57.7	66.2

† Soil temperature at a 5 cm depth was measured and averaged from three measurements within each plot using digital T-bar thermometer.

‡ Colorants were applied on 11 Oct. 2013 at a dilution of 1:6 (colorant:water) using a one-nozzle, 3 gallon SHURflo ProPack™ model SRS 600 rechargeable electric backpack sprayer with an adjustable cone nozzle calibrated to deliver 0.29 gallons per minute.

§ No significant difference ($P \geq 0.05$) for date.

¶ Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

Table B-7. Effect of colorant and application volume on soil temperature (°F) of 'Chisholm' zoysiagrass at the John C. Pair Research Center, Haysville, KS in 2014.

	Soil temperature (°F)[†]			
Treatment[‡]	13 March[§]	8 April[§]	22 April[§]	6 May[§]
Green Lawnger				
80 GPA	39.6	48.7	55.3	63.3
160 GPA	39.7	48.8	55.4	62.7
240 GPA	39.6	48.7	55.6	62.8
Endurant				
80 GPA	39.6	48.6	55.4	63.2
160 GPA	39.7	48.7	55.4	63.1
240 GPA	39.6	48.7	55.6	63.0
Wintergreen Plus				
80 GPA	39.5	48.8	55.5	63.0
160 GPA	39.8	48.9	55.4	63.0
240 GPA	39.6	48.8	55.3	63.2
Untreated	39.6	48.8	55.4	63.1

[†] Soil temperature at a 5 cm depth was measured and averaged from three measurements within each plot using digital T-bar thermometer.

[‡] Colorants were applied on 24 Oct. 2013 at a dilution of 1:6 (colorant:water) using a one-nozzle, 3 gallon SHURflo ProPack™ model SRS 600 rechargeable electric backpack sprayer with an adjustable cone nozzle calibrated to deliver 0.29 gallons per minute.

[§] No significant difference ($P \geq 0.05$) for date.

[¶] Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

Appendix C - Additional Tables for Chapter 3

Table C-1. Analysis of variance for visual turf color and dark green color index evaluated on colorant treated Sharpshooter buffalograss at the Rocky Ford Turfgrass Research Center, Manhattan, KS between October 2013 to May 2014.

		Weeks after treatment (WAT)†															
Parameter	Source of variation	0	2	4	6	8	10	12	14	16	20	22	24	26	28	30	32
Turf color	C‡	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	NS
	V(C)§	**	***	***	***	***	***	***	***	***	***	***	***	**	NS	NS	NS
	T[V(C)]¶	NS#	NS	NS	*	NS	NS	NS	NS	***	***	***	***	***	***	***	*
Dark green	C	***	n/a††	***	n/a	***	n/a	***	n/a	***	***	n/a	n/a	***	n/a	***	n/a
color index	V(C)	***	n/a	***	n/a	***	n/a	***	n/a	***	***	n/a	n/a	***	n/a	**	n/a
	T[V(C)]	NS	n/a	NS	n/a	NS	n/a	**	n/a	***	***	n/a	n/a	***	n/a	***	n/a

†Colorants were applied at a dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8002VS nozzles at 20 psi calibrated to deliver spray solution at half of the total gallons per acre application volume of in two directions on 10 Oct. 2013 (0 WAT) and 2nd application were applied to respected treatments on 25 Jan. 2014 (16 WAT).

‡ Colorant product (C).

§ Effect of application volume (V) nested within colorant product V(C).

¶ Effect of application timing (T) nested within [volume(colorant)], T[V(C)].

Not significant (NS).

†† Not applicable (n/a).

*, **, and *** are significant at the 0.05, 0.01, and 0.001 probability level, respectively.

Table C-2. Analysis of variance for visual turf color evaluated on colorant treated Cody buffalograss at the John C Pair Research Center, Haysville, KS between October 2013 to May 2014.

		Weeks after treatment (WAT)†									
Parameter	Source of variation	0	4	8	12	16	20	24	26	28	30
Turf color	C‡	***	***	***	***	***	***	***	***	***	***
	V(C)§	***	***	***	***	*	***	***	***	***	NS
	T[V(C)]¶	NS#	NS	NS	NS	***	***	***	***	***	***

† Colorants were applied at a dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8002VS nozzles at 20 psi calibrated to deliver spray solution at half of the total gallons per acre application volume of in two directions on 24 Oct. 2013 (0 WAT) and 2nd application were applied to respected treatments on 18 Feb. 2014 (16 WAT).

‡ Colorant product (C).

§ Effect of application volume (V) nested within colorant product V(C).

¶ Effect of application timing (T) nested within [volume(colorant)], T[V(C)].

Not significant (NS).

*, **, and *** are significant at the 0.05, 0.01, and 0.001 probability level, respectively.

Table C-3. Analysis of variance for visual turf color and dark green color index evaluated on colorant treated Meyer zoysiagrass at the Rocky Ford Turfgrass Research Center, Manhattan, KS between October 2013 to May 2014.

Parameter	Source of variation	Weeks after treatment (WAT)†													
		0	2	4	8	12	14	16	18	20	22	24	26	28	30
Turf color	C‡	***	***	***	***	***	***	n/a††	***	***	***	***	***	***	**
	V(C)§	NS#	*	*	***	***	***	n/a	NS	***	***	***	***	NS	NS
	T[V(C)]¶	NS	NS	NS	NS	NS	NS	n/a	***	***	***	***	***	***	NS
Dark green	C	***	n/a	***	***	***	n/a	***	n/a	***	n/a	n/a	***	n/a	***
color index	V(C)	**	n/a	***	***	***	n/a	**	n/a	***	n/a	n/a	***	n/a	NS
	T[V(C)]	NS	n/a	NS	NS	NS	n/a	NS	n/a	***	n/a	n/a	***	n/a	***

†Colorants were applied at a dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8002VS nozzles at 20 psi calibrated to deliver spray solution at half of the total gallons per acre application volume of in two directions on 17 Oct. 2013 (0 WAT) and 2nd application were applied to respected treatments on 18 Feb. 2014 (18 WAT).

‡ Colorant product (C).

§ Effect of application volume (V) nested within colorant product V(C).

¶ Effect of application timing (T) nested within [volume(colorant)], T[V(C)].

Not significant (NS).

†† Not applicable (n/a).

*, **, and *** are significant at the 0.05, 0.01, and 0.001 probability level, respectively.

Table C-4. Analysis of variance for visual turf color evaluated on colorant treated Meyer zoysiagrass at the Colbert Hills Golf Course, Manhattan, KS between October 2013 to May 2014.

		Weeks after treatment (WAT)†											
Parameter	Source of variation	0	2	4	8	12	14	18	20	22	24	26	28
Turf color	C‡	***	***	***	***	***	***	***	***	***	***	***	*
	V(C)§	*	NS	NS	**	**	***	*	*	**	*	NS	NS
	T[V(C)]¶	NS#	NS	NS	NS	NS	NS	***	***	***	***	***	NS

†Colorants were applied at a dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8002VS nozzles at 20 psi calibrated to deliver spray solution at half of the total gallons per acre application volume of in two directions on 26 Oct. 2013 (0 WAT) and 2nd application were applied to respected treatments on 24 Feb. 2014 (18 WAT).

‡ Colorant product (C).

§ Effect of application volume (V) nested within colorant product V(C).

¶ Effect of application timing (T) nested within [volume(colorant)], T[V(C)].

Not significant (NS).

*, **, and *** are significant at the 0.05, 0.01, and 0.001 probability level, respectively.

Table C-5. Effect of colorant, application volume, and application timing on Dark Green Color Index of 'Sharpshooter' buffalograss at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2013-2014.

		Dark green color index†							
Treatment	Application Date‡	19 Oct.	14 Nov.	6 Dec.	20 Jan.	17 Feb.	26 March	15 April	15 May
Green Lawnger									
100 GPA	10 Oct.	0.503 d§	0.485 d	0.502 d	0.444 f#	0.411 j	0.398 g	0.386 g	0.394 fg
	10 Oct. + 25 Jan.	--¶	--	--	0.452 ef	0.527 ef	0.490 e	0.457 e	0.421 de
160 GPA	10 Oct.	0.523 c	0.509 c	0.521 c	0.468 de	0.433 hi	0.410 g	0.398 g	0.402 f
	10 Oct. + 25 Jan.	--	--	--	0.469 de	0.571 c	0.525 cd	0.494 cd	0.445 bc
Endurant									
100 GPA	10 Oct.	0.488 e	0.466 e	0.483 e	0.445 f	0.421 ij	0.414 g	0.397 g	0.407 ef
	10 Oct. + 25 Jan.	--	--	--	0.432 f	0.515 f	0.504 de	0.484 d	0.440 bc
160 GPA	10 Oct.	0.511 d	0.497 d	0.520 cd	0.478 d	0.448 h	0.438 f	0.425 f	0.409 ef
	10 Oct. + 25 Jan.	--	--	--	0.469 de	0.541 de	0.529 c	0.515 c	0.446 bc
Wintergreen Plus									
100 GPA	10 Oct.	0.585 b	0.574 b	0.590 b	0.522 c	0.472 g	0.451 f	0.410 fg	0.409 ef
	10 Oct. + 25 Jan.	--	--	--	0.537 bc	0.644 b	0.588 b	0.543 b	0.455 ab
160 GPA	10 Oct.	0.629 a	0.619 a	0.651 a	0.600 a	0.550 cd	0.522 cd	0.479 de	0.430 cd
	10 Oct. + 25 Jan.	--	--	--	0.558 b	0.670 a	0.621 a	0.582 a	0.464 a
Untreated		0.330 f	0.296 f	0.291 f	0.273 g	0.264 k	0.278 h	0.297 h	0.379 g

† Digital photograph taken of each plot under lighted camera box with a Nikon D5000 camera. Images were analyzed with SigmaScan Pro 5.0 using the "Turf Analysis" macro for batch analysis, then calculated to obtain the dark green color index value on a 0 to 1.0 scale.

‡ Colorants were applied at a dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8002VS nozzles at 20 psi.

§ Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

¶ No significant difference ($P \geq 0.05$) for application timing for date. Therefore, application volume means are based upon $n = 8$ for 100 and 160 GPA for the 10 Oct. application until the 20 Jan. rating date.

Means for application timing effect on colorant and application volume; ($n = 4$)

Table C-6. Effect of colorant, application volume, and application timing on Dark Green Color Index of 'Meyer' zoysiagrass at Rocky Ford Turfgrass Research Center, Manhattan, KS in 2013-2014.

		Dark green color index[†]							
Treatment	Application Date[‡]	19 Oct.	14 Nov.	6 Dec.	20 Jan.	17 Feb.	26 March	15 April	15 May
Green Lawnger									
100 GPA	17 Oct.	0.475 cd[§]	0.392 d	0.402 de	0.349 e	0.350 d	0.349 g[#]	0.361 g	0.403 ef
	17 Oct. + 18 Feb.	--[¶]	--	--	--	--	0.472 cd	0.460 d	0.418 bcd
160 GPA	17 Oct.	0.485 c	0.413 c	0.413 cd	0.363 cd	0.362 bc	0.368 f	0.381 f	0.410 cde
	17 Oct. + 18 Feb.	--	--	--	--	--	0.482 bc	0.470 d	0.423 b
Endurant									
100 GPA	17 Oct.	0.463 e	0.394 d	0.396 e	0.352 de	0.354 cd	0.374 f	0.383 ef	0.410 de
	17 Oct. + 18 Feb.	--	--	--	--	--	0.471 cd	0.465 d	0.423 b
160 GPA	17 Oct.	0.474 d	0.407 c	0.419 c	0.370 c	0.370 b	0.387 e	0.395 e	0.410 de
	17 Oct. + 18 Feb.	--	--	--	--	--	0.493 b	0.486 c	0.421 b
Wintergreen Plus									
100 GPA	17 Oct.	0.556 b	0.501 b	0.521 b	0.469 b	0.464 a	0.465 d	0.464 d	0.420 bc
	17 Oct. + 18 Feb.	--	--	--	--	--	0.602 a	0.562 b	0.436 a
160 GPA	17 Oct.	0.570 a	0.520 a	0.547 a	0.485 a	0.471 a	0.477 cd	0.460 d	0.419 bcd
	17 Oct. + 18 Feb.	--	--	--	--	--	0.612 a	0.580 a	0.438 a
Untreated		0.360 f	0.242 e	0.223 f	0.204 f	0.211 e	0.230 h	0.264 h	0.394 f

[†] Digital photograph taken of each plot under lighted camera box with a Nikon D5000 camera. Images were analyzed with SigmaScan Pro 5.0 using the "Turf Analysis" macro for batch analysis, then calculated to obtain the dark green color index value on a 0 to 1.0 scale.

[‡] Colorants were applied at a dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8002VS nozzles at 20 psi.

[§] Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

[¶] No significant difference ($P \geq 0.05$) for application timing for date. Therefore, application volume means are based upon $n = 8$ for 100 and 160 GPA for the 17 Oct. application until the 26 March rating date.

[#] Means for application timing effect on colorant and application volume; ($n = 4$)

Table C-7. Analysis of variance for canopy and soil temperature evaluated on colorant treated Sharpshooter buffalograss at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2014.

		Date†						
Parameter	Source of variation	11 March	26 March	9 April	11 April	25 April	6 May	9 May
Canopy temperature	C‡	*	NS	n/a††	**	***	n/a	NS
	V(C)§	NS#	NS	n/a	NS	*	n/a	NS
	T[V(C)]¶	**	*	n/a	***	***	n/a	NS
Soil temperature	C	NS	**	NS	n/a	NS	NS	n/a
	V(C)	NS	NS	NS	n/a	NS	NS	n/a
	T[V(C)]	NS	NS	NS	n/a	NS	*	n/a

†Colorants were applied at a dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8002VS nozzles at 20 psi calibrated to deliver spray solution at half of the total gallons per acre application volume of in two directions on 10 Oct. 2013 (0 WAT) and 2nd application were applied to respected treatments on 25 Jan. 2014 (16 WAT).

‡ Colorant product (C).

§ Effect of application volume (V) nested within colorant product V(C).

¶ Effect of application timing (T) nested within [volume(colorant)], T[V(C)].

\# Not significant (NS).

†† Not applicable (n/a).

*, **, and *** are significant at the 0.05, 0.01, and 0.001 probability level, respectively.

Table C-8. Analysis of variance for canopy and soil temperature evaluated on colorant treated Sharpshooter buffalograss at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2014.

Parameter	Source of variation	Date[†]			
		13 March	8 April	22 April	6 May
Canopy temperature	C[‡]	**	***	*	***
	V(C)[§]	NS[#]	NS	NS	NS
	T[V(C)][¶]	**	***	***	***
Soil temperature	C	***	***	**	NS
	V(C)	NS	NS	*	NS
	T[V(C)]	**	NS	NS	***

[†]Colorants were applied at a dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8002VS nozzles at 20 psi calibrated to deliver spray solution at half of the total gallons per acre application volume of in two directions on 24 Oct. 2013 (0 WAT) and 2nd application were applied to respected treatments on 18 Feb. 2014 (16 WAT).

[‡] Colorant product (C).

[§] Effect of application volume (V) nested within colorant product V(C).

[¶] Effect of application timing (T) nested within [volume(colorant)], T[V(C)].

[#] Not significant (NS).

[††] Not applicable (n/a).

*, **, and *** are significant at the 0.05, 0.01, and 0.001 probability level, respectively.

Table C-9. Analysis of variance for canopy and soil temperature evaluated on colorant treated Meyer zoysiagrass at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2014.

		Date[†]						
Parameter	Source of variation	11 March	26 March	9 April	11 April	25 April	8 May	9 May
Canopy temperature	C[‡]	**	***	n/a[††]	*	***	n/a	NS
	V(C)[§]	NS[#]	NS	n/a	NS	**	n/a	NS
	T[V(C)][¶]	***	NS	n/a	**	*	n/a	NS
Soil temperature	C	NS	NS	NS	n/a	NS	NS	n/a
	V(C)	NS	NS	NS	n/a	NS	NS	n/a
	T[V(C)]	NS	*	NS	n/a	NS	NS	n/a

[†]Colorants were applied at a dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8002VS nozzles at 20 psi calibrated to deliver spray solution at half of the total gallons per acre application volume of in two directions on 17 Oct. 2013 (0 WAT) and 2[nd] application were applied to respected treatments on 18 Feb. 2014 (18 WAT).

[‡] Colorant product (C).

[§] Effect of application volume (V) nested within colorant product V(C).

[¶] Effect of application timing (T) nested within [volume(colorant)], T[V(C)].

[#] Not significant (NS).

[††] Not applicable (n/a).

*, **, and *** are significant at the 0.05, 0.01, and 0.001 probability level, respectively

Table C-10. Analysis of variance for canopy and soil temperature evaluated on colorant treated Meyer zoysiagrass at the Colbert Hills Golf Course, Manhattan, KS in 2014.

		Date[†]					
Parameter	Source of variation	11 March	26 March	9 April	11 April	25 April	9 May
Canopy temperature	C[‡]	***	***	n/a[††]	***	*	NS
	V(C)[§]	NS[#]	NS	n/a	NS	NS	NS
	T[V(C)][¶]	**	***	n/a	**	*	NS
Soil temperature	C	NS	**	NS	n/a	NS	NS
	V(C)	NS	NS	NS	n/a	NS	NS
	T[V(C)]	NS	**	NS	n/a	NS	NS

[†]Colorants were applied at a dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8002VS nozzles at 20 psi calibrated to deliver spray solution at half of the total gallons per acre application volume of in two directions on 26 Oct. 2013 (0 WAT) and 2nd application were applied to respected treatments on 24 Feb. 2014 (18 WAT).

[‡] Colorant product (C).

[§] Effect of application volume (V) nested within colorant product V(C).

[¶] Effect of application timing (T) nested within [volume(colorant)], T[V(C)].

[#] Not significant (NS).

[††] Not applicable (n/a).

*, **, and *** are significant at the 0.05, 0.01, and 0.001 probability level, respectively.

Table C-11. Effect of colorant, application volume, and number of applications on soil temperature (°F) of 'Sharpshooter' buffalograss at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2014.

		Soil temperature (°F)[†]				
Treatment	Application Date[‡]	11 March[§]	26 March[§]	9 April[§]	25 April[§]	6 May
Green Lawnger						
100 GPA	10 Oct.	47.8	45.1	58.4	65.1	73.8 c[¶]
	10 Oct. + 25 Jan.	47.9	45.3	58.4	65.8	74.6 abc
160 GPA	10 Oct.	48.0	45.2	58.1	64.7	74.0 bc
	10 Oct. + 25 Jan.	47.7	45.3	58.4	65.6	75.1 ab
Endurant						
100 GPA	10 Oct.	48.2	45.4	58.8	65.7	74.3 abc
	10 Oct. + 25 Jan.	48.3	45.4	58.8	66.0	75.4 a
160 GPA	10 Oct.	48.0	45.2	57.6	65.2	74.1 bc
	10 Oct. + 25 Jan.	47.6	45.2	58.8	65.6	75.1 ab
Wintergreen Plus						
100 GPA	10 Oct.	48.1	45.4	58.3	65.1	74.3 abc
	10 Oct. + 25 Jan.	48.0	45.3	58.8	66.1	74.0 bc
160 GPA	10 Oct.	47.8	45.2	57.6	65.2	73.9 bc
	10 Oct. + 25 Jan.	47.9	45.4	58.9	66.0	75.5 a
Untreated		48.6	45.8	58.9	65.8	74.3 abc

[†] Soil temperature at a 5 cm depth was measured and averaged from three measurements within each plot using digital T-bar thermometer.
[‡] Colorants were applied at a dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8002VS nozzles at 20 psi.
[§] No significant differences ($P \geq 0.05$) for date.
[¶] Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

Table C-12. Effect of colorant, application volume, and number of applications on soil temperature (°F) of 'Cody' buffalograss at the John C. Pair Research Center, Haysville, KS in 2014.

		Soil temperature (°F)†			
Treatment	Application Date‡	13 March	8 April§	22 April§	6 May
Green Lawnger					
100 GPA	24 Oct.	38.94 cdef¶	48.88	59.13	67.08 cd
	24 Oct. + 18 Feb.	38.74 efg	48.65	59.53	67.70 abc
160 GPA	24 Oct.	39.10 bcde	48.68	58.56	66.90 d
	24 Oct. + 18 Feb.	38.39 g	48.44	58.89	67.73 ab
Endurant					
100 GPA	24 Oct.	39.03 bcde	48.79	58.58	66.88 d
	24 Oct. + 18 Feb.	38.83 def	48.71	58.65	67.68 abc
160 GPA	24 Oct.	38.65 fg	48.64	58.80	67.25 bcd
	24 Oct. + 18 Feb.	38.83 def	48.66	58.85	67.20 bcd
Wintergreen Plus					
100 GPA	24 Oct.	39.55 a	48.99	59.51	67.13 bcd
	24 Oct. + 18 Feb.	39.11 bcd	48.86	59.66	67.93 a
160 GPA	24 Oct.	39.36 ab	48.76	59.08	66.95 d
	24 Oct. + 18 Feb.	39.20 abc	48.78	59.15	67.68 abc
Untreated		39.36 ab	49.13	59.18	67.28 bcd

† Soil temperature at a 5 cm depth was measured and averaged from three measurements within each plot using digital T-bar thermometer.
‡ Colorants were applied at a dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8002VS nozzles at 20 psi.
§ No significant differences ($P \geq 0.05$) for date.
¶ Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

Table C-13. Effect of colorant, application volume, and number of applications on soil temperature (°F) of 'Meyer' zoysiagrass at the Rocky Ford Turfgrass Research Center, Manhattan, KS in 2014.

		Soil temperature (°F)[†]				
Treatment	Application Date[‡]	11 March[§]	26 March	9 April[§]	25 April[§]	8 May[§]
Green Lawnger						
100 GPA	17 Oct.	49.90	47.99 abcd[¶]	59.25	65.28	73.91
	17 Oct. + 18 Feb.	49.95	48.14 abcd	59.33	65.08	73.91
160 GPA	17 Oct.	50.30	48.15 abcd	58.50	65.40	73.93
	17 Oct. + 18 Feb.	50.70	48.16 abcd	58.78	65.31	73.84
Endurant						
100 GPA	17 Oct.	49.95	47.83 cd	58.48	64.99	73.68
	17 Oct. + 18 Feb.	50.98	48.58 ab	59.70	65.54	74.03
160 GPA	17 Oct.	49.80	47.73 d	59.05	65.06	73.80
	17 Oct. + 18 Feb.	50.73	48.43 abc	59.63	65.60	73.93
Wintergreen Plus						
100 GPA	17 Oct.	50.35	47.85 cd	59.40	65.18	73.94
	17 Oct. + 18 Feb.	52.00	48.61 a	59.25	65.48	73.58
160 GPA	17 Oct.	50.13	47.88 cd	59.20	64.95	73.86
	17 Oct. + 18 Feb.	49.93	48.24 abcd	59.03	64.88	73.68
Untreated		50.13	47.95 bcd	58.33	64.88	73.68

[†] Soil temperature at a 5 cm depth was measured and averaged from three measurements within each plot using digital T-bar thermometer.
[‡] Colorants were applied at a dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8002VS nozzles at 20 psi.
[§] No significant differences ($P \geq 0.05$) for date.
[¶] Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).

Table C-14. Effect of colorant, application volume, and number of applications on soil temperature (°F) of 'Meyer' zoysiagrass at the Colbert Hills Golf Course, Manhattan, KS in 2014.

		Soil temperature (°F)[†]				
Treatment	Application Date[‡]	11 March[§]	26 March	9 April[§]	25 April[§]	9 May[§]
Green Lawnger						
100 GPA	26 Oct.	43.66	43.58 cd[¶]	50.28	54.55	74.08
	26 Oct. + 24 Feb.	43.84	44.11 abcd	50.64	54.85	73.39
160 GPA	26 Oct.	44.10	43.95 abcd	51.20	56.03	73.00
	26 Oct. + 24 Feb.	43.95	44.38 ab	50.73	54.31	73.18
Endurant						
100 GPA	26 Oct.	44.45	43.41 de	50.90	55.63	73.58
	26 Oct. + 24 Feb.	44.50	44.26 abc	51.58	55.84	73.51
160 GPA	26 Oct.	43.81	43.39 de	50.43	54.91	73.65
	26 Oct. + 24 Feb.	44.23	43.75 bcd	51.16	55.49	74.28
Wintergreen Plus						
100 GPA	26 Oct.	44.38	43.38 de	50.20	54.39	73.08
	26 Oct. + 24 Feb.	44.14	43.90 abcd	51.05	54.85	73.23
160 GPA	26 Oct.	43.55	43.54 cde	50.21	54.66	73.25
	26 Oct. + 24 Feb.	43.99	44.58 a	50.73	55.18	72.43
Untreated		43.18	42.79 e	49.78	54.31	73.15

[†] Soil temperature at a 5 cm depth was measured and averaged from three measurements within each plot using digital T-bar thermometer.
[‡] Colorants were applied at a dilution of 1:6 (colorant:water) using a three-nozzle, CO_2-pressurized sprayer with 8002VS nozzles at 20 psi.
[§] No significant differences ($P \geq 0.05$) for date.
[¶] Means in a column followed by the same letter are not significantly different according Fisher's protected least significant difference test ($P \leq 0.05$).