THE EFFECT OF MANAGEMENT PRACTICES ON BUFFALOGRASS DIVOT RECOVERY AND TOLERANCE TO GOLF CART TRAFFIC

by

EVAN JAMES ALDERMAN

B.S., Iowa State University, 2014

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Horticulture and Natural Resources
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2016

Approved by:

Major Professor
Dr. Jared A. Hoyle

Copyright

ABSTRACT

Buffalograss [*Buchloe dactyloides* (Nutt.) Engelm] is a warm-season turfgrass species that is native to North America and requires minimal maintenance to survive. However, the use of buffalograss on golf courses throughout the transition zone is limited due to its appearance, growth habit, and lack of information available. Buffalograss is more drought tolerant than many other turfgrass species cultivated on golf courses, therefore, its drought resistance can lead to significant water savings. The objectives of these 2014 – 2016 field research studies were to evaluate: 1) buffalograss divot recovery as influenced by nitrogen source and application rate; 2) the influence of nitrogen application rate and simulated golf cart traffic on the wear tolerance of buffalograss; 3) the effect of simulated golf cart traffic on colorant treated buffalograss; and 4) buffalograss recovery from winter trafficking. When compared to untreated turf, divots in buffalograss treated with urea achieved 50% divot recovery 6.3 days faster when 1 lb N/1,000 ft^2 was applied, which was statistically similar to the 3 lb N/1,000 ft^2 rate. Applications of a slow-release polymer coated urea did not enhance divot recovery duration when compared to untreated turf. As nitrogen application rate increased in the presence of traffic stress, regardless of traffic rate, the green cover, quality, and color of the turf was enhanced. Percent green cover values for 0, 1, 2, and 3 lb N/1,000 ft^2 10 weeks after initiation (WAI), regardless of traffic rate, were 60.2%, 69.0%, 75.5%, and 79.1% respectively. Regardless of nitrogen application rate, buffalograss receiving 16 passes/week of traffic never provided >72% green cover, while buffalograss receiving 0 passes/week had 74% green cover prior to the onset of dormancy. Endurant Premium turfgrass colorant in the presence of wear treatments provided >50% green cover 0 – 5 weeks after treatment in 2014 and 0 – 3 weeks in 2015. In general, as traffic rate increased, turfgrass colorant longevity decreased. Overseeded perennial ryegrass hindered buffalograss recovery after winter trafficking in comparison to untreated turf and colorant applications.

Table of Contents

List of Figures

List of Tables

Acknowledgements

I would like to express my gratitude to the Department of Horticulture and Natural Resources at Kansas State University and the Kansas Turfgrass Foundation for the support in making this thesis possible.

I would especially like to thank Dr. Jared Hoyle for all the advice, patience, encouragement, time, and allowing me to pursue my passion. You have not only helped me grow professionally, but also as an individual. Without you, this dream would have never been possible, and for that, I am forever grateful for your friendship and support.

Thank you to Drs. Jack Fry and Steve Keeley for your advice and serving on my committee. Both of you have always allowed me to ask questions and run ideas past you at any time, and I am thankful for that. Steve Keeley, thank you for allowing me to TA for you during my time at K-State. You allowed me to realize my passion for teaching and assisting students.

Jake Reeves, I cannot sum up in words how truly grateful I am for your help and support towards this thesis. You helped me acclimate to Manhattan when I first arrived, and whenever I needed help with anything, you never thought twice. Thank you for always being willing to lend a helping hand and for being a great friend.

Cassandra Knutson, through our lives we have been through so many ups and downs, but no matter how chaotic things got, you have always been by my side. You have always encouraged me to pursue my dreams no matter how big, or small, they may be. Thank you for allowing me to pursue my passions and for making me a better person along the way.

I am sincerely grateful for the unending support and encouragement from my family: David and Heather Alderman, Eric Alderman, Dr. John and Anne Alderman, and James and Betty Heye.

Lastly, I would like to express my appreciation to Alan, Julie, and Allison Knutson for their support over the years. Also, thanks to Ryan Adams, Dr. Zane Raudenbush, Dr. Cole Thompson, Cliff Dipman, and fellow graduate students Ross Braun and Mingying Xiang, for their guidance, support, and friendship.

Dedication

I would like to dedicate this work to all people who are unsure which path to take in life. Sometimes you may feel like there is no hope for what is to come in your future, but with hard work and dedication, you will succeed in making your own path.

"*Excellence is an art won by training and habituation. We do not act rightly because we have virtue or excellence, but we rather have those because we have acted rightly. We are what we repeatedly do. Excellence, then, is not an act, but a habit"*

\- *Aristotle*

Chapter 1 - Review of Literature

INTRODUCTION

Turf was developed and cultivated by the modern man to enrich his environment from the standpoint of functional, recreational, and ornamental use (Beard, 1973). For more than 10 centuries, humans have utilized turfgrasses as a component in many common landscapes (Walsh et al., 1999). Today, many different turfgrass species are used in home lawns, parks, gardens, sports fields, and golf courses.

With increasing drought conditions throughout many portions of the United States, irrigation may eventually become limited for landscapes utilizing turfgrass as one of its main essential foundations. In 2005, researchers estimated that approximately 40.5 million acres of land in the continental United States contained a form of cultivated turfgrass, three times larger area than any other irrigated crop (Milesi et al., 2005). Although home lawns contribute to a significant larger portion of cultivated turf in the United States (approximately 26 million acres), publicly golf courses are most scrutinized for being the largest water consumers in the turfgrass industry (Vinlove and Torla, 2010). According to a 2009 survey, there are approximately 1.2 million acres of irrigated turfgrass on golf courses in the United States, with a total water usage estimated at 2,312,701 acre-feet/year (Throssell et al., 2009).

According to a 2006 survey in Kansas, 788,370 acres were involved in some sort of horticulture activity, of which maintained turfgrass area was approximately 764,000 acres (not including roadsides) (Kansas Department of Agriculture, 2007). The Ogallala aquifer provides up to 80% of the water used in Kansas, and years of pumping has led to a steady decline in water levels (Buchanan et al., 2001). Therefore, not only is there a need to consider water saving techniques for agricultural use, but also water saving practices for home lawns, sports fields, and golf courses.

KANSAS CLAMATIC ZONE OF ADAPTATION

Kansas lies in a climatic zone of adaptation known as the transition zone. This zone is claimed to be the most difficult zone in which to manage turf because it is often cold enough during the winter month's causing warm-season turfgrass species to suffer, and hot enough during the summer that cool-season grasses to struggle (Christians, 2011).

Tall fescue [*Lolium arundinacea* Shreb.] is currently one of the most predominantly used species in the transition zone, due to its superior heat and drought tolerance of any cool-season turfgrass species (Fry and Huang, 2004). Although tall-fescue is one of the most widely used species in the transition zone, various warm-season turfgrass species, such as bermudagrass [*Cynodon* spp.], zoysiagrass [*Zoysia* spp.], and buffalograss [*Buchloe dactyloides* (Nutt.) Engelm.] have been identified as species able to handle the colder winters in this area of the country (Fry and Huang, 2004). Examples of specific warm-season cultivars that are tolerant to winters in Kansas include: Bermudagrass – 'Latitude 36' and 'Yukon' (Thompson et al., 2014); Zoysiagrass – 'Meyer', experimental progenies KSUZ 1201 and KSUZ 0802, and 'Chisholm' (Thompson et al., 2014; Chandra et al., 2014); and Buffalograss – 'Sharps Improved II', 'Cody', and 'Prairie' (Hoyle et al., 2014). Although warm-season species use less water when compared to cool-season species, warm-season species are undesirable during the winter months due to their brown color; therefore, widespread use of warm-season species is limited in the transition zone due to this prolonged dormancy period (Keeley and Fagerness, 2001; Severmutlu et al., 2005). Furthermore, the longer growing season and green aesthetics of cool-season turf may appeal more to homeowners, landscape managers, and golf course superintendents than the warm-season species, which have a prolonged dormancy. Various cool- and warm-season turfgrass species are able to grow in the transition zone, although each species has different water requirements.

Due to recent trends for water conservation in the transition zone, the use of warm-season turfgrass species has become more acceptable. A hypothetical golf course in the Kansas City area converting tees and fairways from creeping bentgrass [*Agrostis stolonifera* L.] (cool-season) to zoysiagrass [*Zoysia japonica* Steud.] (warm-season) could reduce irrigation annually by approximately 5.8 million gal, while reducing irrigation cost by up to $28,403 (Fry et al., 2008). A shift from cool- to warm-season turfgrass species in the transition zone could be an effective strategy for reducing irrigation consumption on golf courses and home lawns.

BUFFALOGRASS

Drought Tolerance

Buffalograss is a native, drought tolerant turfgrass species that is well adapted for minimally irrigated lawns, parks, athletic fields, roadsides, and golf courses in the transition zone (Wenger, 1943; Beard, 1973; Fry, 1995; McCarty, 1995; Fry and Huang, 2004). Although turfgrass quality may be enhanced with irrigation during the growing season, buffalograss in low maintenances areas of the golf course may be maintained with no additional irrigation beyond natural precipitation (Riordan et al., 1996). To maintain an acceptable buffalograss lawn, only one to two inches of rainfall or supplemental irrigation every two to four weeks are required (Brakie, 2013).

Various morphological adaptations allow buffalograss to survive periods of drought stress. The grey-green buffalograss leaf color is due to the fine hairs that cover each leaf blade (Beard, 1973). Pubescence on the turfgrass leaf blade helps maintain a portion of the boundary layer around the leaf tissue, resulting in lower transpiration rates (Ehleringer and Mooney, 1978). The reduction in transpiration rate during periods of heat and drought stress can greatly contribute to buffalograss' low water use. Research has demonstrated that buffalograss' mean summer evapotranspiration (ET) rate is very low (0.20 inch/d – 0.27 inch/d) relative to tall fescue (0.14 inch/d – 0.50 inch/d) (Kenna and Horst, 1993). Furthermore, through pan evaporation (Ep), minimum requirements to prevent drought stress in 'Prairie' buffalograss (7% - 26% Ep) were significantly less than 'Rebel II' tall fescue (49% - 67% Ep) (Qian and Engelke, 1999). Therefore, the use of alternative, low input turfgrass species such as buffalograss could lead to a reduction of irrigation in golf course roughs.

The extensive root system also increases the ability of buffalograss to survive in drought conditions. Buffalograss contains many tough, fine roots that penetrate 4 ft to 6 ft deep into the soil profile in unmown natural areas (Brakie, 2013). Although buffalograss roots can penetrate 4 ft to 6 ft deep in natural areas, root systems in maintained turfgrass areas will be shallower due to the relationship between above the ground leaf tissue being proportionate to root system depth. Within a maintained buffalograss system, approximately 70% (by weight) of the roots were found in the top 6 inch of the soil (Weaver, 1958). Buffalograss roots are efficient in utilizing shallow soil moisture during infrequent irrigation or rainfall, but may also utilize water deeper in the soil profile in times of soil drying (Beard, 1973; Huang, 1999). In comparison to zoysiagrass under soil drying conditions, buffalograss' roots elongated more rapidly, resulting in a larger proportion of roots deeper in the soil profile (Huang, 1999). When compared to the water uptake of zoysiagrass, the higher proportion of roots deeper in the soil profile for buffalograss resulted in an increased rate of water depletion at a 15.7 inch depth (Huang, 1999). Efficiently utilizing soil moisture within the soil profile contributes to buffalograss' ability to survive limited water situations. During periods of excessive drought, buffalograss can enter summer dormancy as a drought tolerance mechanism (Christians, 2011). Once sufficient irrigation or rainfall is acquired, buffalograss will regain full growth and color relatively quick (Beard, 1973).

Buffalograss Maintenance

An acceptable stand of buffalograss requires minimal management inputs, such as water, mowing, and pest control (Beard, 1973). The preferred mowing height for buffalograss is 2 – 3 inches, although lower mowing heights will be tolerated (Christians, 2011). Data collected in 1997 from Nebraska (NE) and Kansas (KS) demonstrated that when mown at 1 inch, 'NE 91-118', '378', and 'Cody' resulted in quality ratings (1 – 9 scale) of 6.0, 6.0, and 5.9 at the NE site, respectively, and 6.2, 5.8, and 5.6 at the KS site, respectively (Frank et al., 2004). When mown at 2 – 3 inches, mowing frequency will be infrequent due to buffalograss' slow vertical shoot growth (Beard, 1973). More frequent mowing may be needed to remove the male flowers of buffalograss, which grow on an erect stem in the turfgrass canopy (Brackie, 2013).

BUFFALOGRASS NITROGEN FERTILITY

Increased buffalograss quality, color, and growth has been observed when moderate levels of N fertilizer are applied (Falkenberg 1982; Frank et al., 2004). In a three year study, Frank et al. (2004) reported that applying 2 lb N/1,000 ft^2/yr increased both the color and quality of 'Cody', 'Texoka', '378', and 'NE 91-118' buffalograss varieties when compared to a non-treated control. Furthermore, 'Cody' receiving two midsummer applications of N to total 2 lb N/1,000 ft^2 had a quality rating of 6.2 (acceptable), but a quality rating of 4.7 (below acceptable) when receiving no N (Frank et al., 2004). Applications of urea (46-0-0) up to 3 lb N/1,000 ft^2/yr on 'Cody' buffalograss resulted in 27% more turfgrass cover at season end compared to 0 lb

N/1,000 ft^2 (Frank et al., 2002). Current recommendations for buffalograss N fertilization range from 0 to 3 lb N/1,000 ft^2/yr (Beard, 1973; Riordan et al., 1996; Frank et al., 2004; Christians, 2011; Hoyle et al., 2014) Applications of nitrogen have been shown to increase buffalograss color, quality, and establishment rate, and also have the potential to increase recovery rate when injury occurs (Johnson et al., 2000).

TURFGRASS INJURY

Divot Injury

Both biotic and abiotic injury can occur to a turfgrass plant. Biotic injury such as disease outbreaks can often be avoided or cured with the use of pesticides. Abiotic injuries, that are human inflicted, occur on a daily basis and have to be constantly managed by turfgrass managers. A divot is created when a golfers' club strikes the golf ball at a downward angle removing a portion of the turf after contact with the ball (Patton et al., 2010; Trappe et al., 2011; Lee, 2012). Excessive divots in golf course roughs, tees, and fairways can be problematic due to the voids created in the turfgrass canopy (Karcher et al., 2005a). This open space in the turf may create a favorable opportunity for weed seed to germinate, and also decrease the playability and aesthetics of the playing surfaces on the golf course (Beard, 2002; Bigelow, 2006). Divot recovery is largely dependent on the amount and size of divots removed from the turfgrass, as well as turfgrass growth habit, species, and management inputs (Beard, 1973; Patton et al., 2010; Trappe et al., 2011; Lee, 2012). Divot recovery differences exist among bermudagrass (*Cynodon* spp. Rich) and zoysiagrass (*Zoysia* spp. Willd.) species (Trappe et al., 2011), and among bermudagrass [*Cynodon dactylon* (L.) Pers. *C. dactylon* × *C. transvaalensis* Burtt-Davy] (Karcher et al., 2005b), and zoysiagrass [*Zoysia japonica* Steud., *Z. matrella* (L.) Merr, and *Z. tenuifolia* Willd] cultivars (Karcher et al., 2005a). Differences within and across zoysiagrass and bermudagrass cultivars and species have been reported for divot recovery, and various management practices have been evaluated to increase divot recovery duration.

Nitrogen and Divot Recovery

Nitrogen applications have been observed to increase turf recovery rate from divot injury. Creeping bentgrass (*Agrostis palustris* Huds.) recovered from divots ten days sooner when receiving urea at 5 lb N/1,000 ft^2/yr compared to turf receiving 3 lb N/1,000 ft^2/yr (Calhoun, 1996). Due to divot injury re-occurring over time, slow release nitrogen sources have also been evaluated to enhance turfgrass divot recovery over longer periods of time. Polyon mini (41-0-0) applied to creeping bentgrass at 2 lb N/1000 ft^2 had the best divot recovery when compared to split urea (46-0-0) applications (totaling 2 lb N/1000 ft^2) and a non-treated control (Lee, 2012). Although Lee (2012) reported better performance with Polyon mini when considering divot recovery, data collected from this study was solely based on turfgrass quality (1-9 scale); specific evaluations for divot recovery were not acknowledged. Therefore, further investigation is needed to determine the influence of slow-release nitrogen products on divot recovery. Due to minimal fertility requirements and the fine textured canopy of buffalograss, recuperative potential from divot injury is of concern (Beard, 1973; Frank et al., 2004).

Traffic Injury

Traffic damage from golf carts is observed as wear, the direct physical damage to the turfgrass leaf tissue, as well as soil compaction (Beard, 1973; Kohlmeier and Eggens, 1983; Carroll and Petrovic, 1991; Carrow and Johnson, 1996; Trenholm et al., 2000; Trenholm et al., 2001; Samaranayake et al., 2008). Wear injury from golf cart tires results from the abrasion, scuffing, and/or tearing of the leaf tissue (Beard, 1973). Compaction damage from repeated golf cart trafficking affects plant growth through reducing oxygen content in the soil, and also increasing soil strength (Trenholm et al., 2000). Unacceptable canopy density, turfgrass injury, or plant death can result from wear and compaction of traffic injury if additional management strategies are not implemented (Beard, 1973; Carrow and Johnson, 1996). Thatch management, increased mowing height, and moderate levels of nitrogen fertility are cultural practices that have been observed to promote wear tolerance in various turfgrass species (Younger, 1961; Beard, 1973; Kohlmeier and Eggens, 1983; Trenholm et al., 2000).

Nitrogen and Wear Tolerance

As mowing height increases, turfgrass traffic tolerance also increases. Higher mowing heights will generally enhance wear tolerance due to the greater shoot growth and higher proportions of above the ground leaf tissue (Beard, 1973). Higher heights of cut on the golf course may hinder playability; therefore, the ability to increase turfgrass shoot density through fertilizer applications has been evaluated as a means to increase wear tolerance in turfgrasses (Kohlmeier and Eggens, 1982; Shearman, 1989; Carroll and Petrovic, 1991; Trenholm et al., 2001; Schiavon, 2014). Two hundred revolutions from a gasoline-engine-driven pneumatic wear simulator applied to greens height creeping bentgrass resulted in 6 and 17% higher percent unworn turf when receiving 4 lb N/1,000 ft^2 compared to 2 lb N/1,000 ft^2 (Carroll and Petrovic, 1991). Similarly, in 1982 (Kohlmeier and Eggens, 1982) N applications of 6 lb N/1,000 ft^2/yr on a creeping bentgrass putting green increased root production, green color, and healing potential when exposed to wear treatments compared to turf receiving no N. Under wear stress, nitrogen significantly increased turfgrass quality of two eco-types (AP-10 and AP-14) of greens height seashore paspalum [*Paspalum vaginatum* Swartz] (Trenholm et al., 2001). Seashore paspalum ecotypes AP-10 and AP-14 receiving 8 lb N/1,000 ft^2/yr received a quality score of 7.6 and 6.9, respectively, compared to a quality score of 6.7 and 4.8, respectively when receiving 4 lb N/1,000 ft^2/yr (Trenholm et al., 2001). Nitrogen applications to both cool- and warm-season turfgrass have shown an increase in wear tolerance.

Winter Traffic Tolerance

In the transition zone, golf can be played year-around as mild spells do occur during the winter months. Therefore, the stress from golf cart traffic will also occur year-around. Warm-season turfgrass species will go dormant in the transition zone which may lead to a decrease in wear tolerance. Crown and leaf tissue of warm-season turfgrass species are susceptible to injury and desiccation during the dormancy period, potentially leading to reduced turfgrass cover, winter survival, and spring recovery (Carrow and Johnson, 1996; Kauffman et al., 2009). A reduction in turfgrass cover was observed after two weeks of simulated athletic field traffic on dormant bermudagrass (Stewart et al., 2008). This reduction of turf cover also influenced spring green up, where no-traffic plots had 45% more green cover than turf receiving the heavy traffic treatment (traffic every day, unless a rain event occurred) (Stewart et al., 2008). Weight of the vehicle applying traffic stress to the dormant turf has also been observed to influence percent cover values during winter dormancy. Ten passes/week of traffic applied with a Segway X2 personal transporter for eight weeks resulted in higher than 80% dormant turf cover, while traffic applications with a Club Car (DS Electric Golf Car) at the same rate resulted in less than 70%

dormant turfgrass cover (Kauffman, 2009). Therefore, golf cart traffic will need to be closely managed on dormant turfgrass to reduce the potential for injury and reduced spring green up (Danneberger, 2012). Furthermore, the ability of a warm-season turfgrass species to withstand the wear and compaction from winter golf cart traffic, and also its ability to recover from winter trafficking, will be vital to the turfgrass' sustainability on golf courses in the transition zone.

WINTER TURFGRASS COLOR

Overseeding

Several different practices have been used in the southern portions of the United States to sustain the green color of warm-season turfgrass species during the winter months. Overseeding dormant warm-season turfgrass species with cool-season turfgrass species has long been the industry standard on bermudagrass [*Cynodon* spp.] for maintaining green color and playability during the winter dormancy period (Foy, 1998; Horgan and Yelverton, 2001; Trenholm and Unruh, 2001; Trappe et al., 2012). Although overseeding has been used for many years, various issues with this process are evident. Problems or issues that may arise when overseeding include: decrease in putting quality on golf course greens at establishment and transition (Whitlark, 2012); physical disruption of the warm-season turfgrass density and uniformity (Long, 2006); persistence of cool-season turfgrass species into the summer (Horgan and Yelverton, 2001); transition from overseeded cool-season turf to severely thin or dead warm-season turf (Long et al., 2005); and additional costs associated with mowing, fertilization, and irrigation to maintain the overseeded turf (Foy, 1998). Therefore, turfgrass colorant applications have increased in popularity for warm-season turfgrass species due to their playability, aesthetics, and affordability (Liu et al., 2007).

Turfgrass Colorants

Turfgrass colorants date back to Hollywood movie sets in the 1950's where different dyes were developed in a water-soluble acrylic latex base to paint bermudagrass green (Anonymous, 1978). Since that time, many different turfgrass colorants have become available, and have become the leading alternative in the southern portions of the United States to overseeding (Briscoe et al., 2010). Turfgrass colorant applications on golf course greens in 2009, costs ranged from \$700 - \$2,000 per acre for two applications, when compared to \$2,500 to \$5,000 per acre for overseeding (Liu et al., 2007; Briscoe et al., 2010). Therefore, this lower cost option of turfgrass colorants has led to their evaluations on different turfgrass species at varying heights of cut.

Increased visual color and quality with applications of turfgrass colorants on buffalograss have been observed. Applications of LESCO Green (LESCO, Strongsville, Ohio) turfgrass colorant increased the quality of buffalograss with ratings (1 – 9 scale) of 6.2, 6.5, and 7.0 on 15 January 2002, 28 January 2002, and 23 April 2002, respectively, when applied at 8.25 fl oz/1,000 ft^2 (Shearman et al., 2005). During this same study, differences were observed when higher application rates were applied. LESCO green applied at 8.25 fl oz/1,000 ft^2 received a color rating of 4.0 on 17 December 2015, while an application at 16.5 fl oz/1,000 ft^2 was rated 6.3 on the same date (Shearman et al., 2005). Increased longevity of green color has also been observed with higher application rates of turfgrass colorants. Green Lawnger (BASF Corp., Research Triangle Park, North Carolina), Wintergreen Plus (Precision Laboratories, Inc., Waukegan, Illinois), and Endurant (Geoponics Corp., Naples, Florida) turfgrass colorants applied to buffalograss at 100 gal/acre received higher than acceptable turfgrass color ratings 8 – 12 weeks after treatment application, while application rates of 160 gal/acre increased acceptable color for an additional week (Braun, 2014). Although higher application rates of turfgrass colorants mean increased green color intensity and longevity, it may not be cost effective for low-input golf course operations. Therefore, lower application rates need to be evaluated for these low-budget turfgrass systems. Furthermore, turfgrass colorant longevity may be decreased in the presence of golf cart traffic due to the abrasion and ripping and tearing action from a golf cart tire. Colorant longevity under these stresses will need evaluation for long-term use and acceptability on golf course fairways that experience winter play from golfers.

REFERENCES

Anonymous. 1987. Paints & colorants. SportsTurf. 3(12):14-16, 18-19.

Beard, J.B. 1973. Turfgrass: science and culture. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Beard, J.B. 2002. Turf management for golf courses. 2nd Ed. A publication of the United States Golf Association. Ann Arbor Press, Chelsea, Michigan.

Bigelow, C.A., B.T. Bunnell, J.E. Kaminski III, and G. Hardebeck. 2006 Creeping bentgrass divot recovery as affected by various plant growth regulators. In: C05 Turfgrass Science abstracts online. ASA, CSSA, & SSSA International Annual Meeting, Indianapolis, IN. https://scisoc.confex.com/crops/2006am/techprogram/P26786.HTM.

Brakie, M.R. 2013. Plant guide for buffalograss [*Bouletoua dactyloides* (Nutt.) J.T. Columbus]. USDA-NRCS, East Texas Plant Materials Center. Nacogdoches, TX.

Braun, R. 2014. Cultural strategies to improve zoysiagrass acceptability and performance in the transition zone. M.S. Thesis. Kansas State Univ., Manhattan, KS.

Briscoe, K., G. Miller, and S. Brinton. 2010. Evaluation of green turf colorants as an alternative to overseeding on putting greens. Online. Applied Turfgrass Science doi:10.1094/ATS-2010-0326-02-RS.

Buchanan, R.C., B.B. Wilson, R.R. Buddemeier, and J.J. Butler Jr. 2001. The high plains aquifer (Revised 2009). Kansas Geological Survey Public Information Circular, 18, Sept. 2001.

Calhoun, R.N. 1996. Effect of three plant growth regulators and two nitrogen regimes on growth and performance of creeping bentgrass (*Agrostis palustris* Huds.). Master’s thesis, Michigan State Univ., East Lansing.

Carroll, M.J. and A.M. Petrovic. 1991. Wear tolerance of Kentucky bluegrass and creeping bentgrass following nitrogen and potassium application. HortScience 26(7):851-853.

Carrow, R.N. and B.J. Johnson. 1996. Turfgrass wear stress: effects of golf car and tire design. HortScience 31(6):968-971.

Chandra, A., J.D. Fry, M.C. Engelke, A.D. Genovesi, B.G. Wherley, J.A. Reinert, S.P. Metz, Q. Zhang, and D. Okeyo. 2014. Registration of ‘Chisholm’ zoysiagrass. Journal of Plant Registrations 9:21-26 (2015).

Christians, N.E. 2011. Fundamentals of turfgrass management. 4th ed. John Wiley & Sons, Inc., Hoboken, New Jersey.

Danneberger, K. 2012. Watch for wear injury. Golfdom 68(12):p.17.

Ehleringer J.R. and H.A. Mooney. 1978. Leaf hairs: effects on physiological activity and adaptive value to a desert shrub. Oecologia (Berl.) 37:183-200.

Falkenberg, D.F. 1982. Buffalograss, blue grama, and fairway wheatgrass for dryland turf. M.S. Thesis. Colorado State Univ., Fort Collins, Colorado.

Foy, J.H. 1998. The pros and cons of fairway overseeding. USGA Green Section Record, September/October 1998.

Frank, K.W., R.E. Gaussoin, J.D. Fry, M.D. Frost, and J.H. Baird. 2002. Nitrogen, phosphorus, and potassium effects on seeded buffalograss establishment. HortScience 37(2):371-373.

Frank, K.W., R.E. Gaussoin, T.P. Riordan, R.C. Shearman, J.D. Fry, E.D. Miltner, and P.G. Johnson. 2004. Nitrogen rate and mowing height effects on turf-type buffalograss. Crop Sci.44:1615-1621.

Fry, J.D. 1995. Establishing buffalograss. Golf Course Management. 63(4): 58-62.

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

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

Huang, Bingru. 1999. Water relations and root activities of *Buchloe dactyloides* and *Zoysia japonica* in response to localized soil drying. Plant and Soil 208:179-186.

Horgan, B.P and F.H. Yelverton. 2001. Removal of perennial ryegrass from overseeded bermudagrass using cultural methods. Crop Sci. 41:118-126.

Hoyle, J., S. Keeley, and M. Fagerness. 2014. Buffalograss lawns (MF658). Kansas State University Agricultural Experiment Station and Cooperative Extension Service, Kansas State University, Manhattan, KS, 66506.

Johnson, P.G., T.P. Riordan, and J. Johnson-Cicalese. 2000. Low-mowing tolerance in buffalograss. Crop Sci. 40:1339-1343.

Kansas Department of Agriculture. 2007. Horticulture release: 2006 Kansas horticultural survey. Kansas Agricultural Statistics, Topeka, KS 66601.

Karcher D.E., M.D. Richardson, J.W. Landreth, and J.H McCalla, Jr. 2005a. Recovery of zoysiagrass varieties from divot injury. Online. Applied Turfgrass Science doi:10.1094/ATS-2005-0728-01-RS.

Karcher D.E., M.D. Richardson, J.W. Landreth, and J.H McCalla, Jr. 2005b. Recovery of bermudagrass varieties from divot injury. Online. Applied Turfgrass Science doi:10.1094/ATS-2005-0117-01-RS.

Kauffman, A., J. Sorochan, D. Karcher, and T. Samples. 2009. Segway and golf car wear on dormant bermudagrass fairways. Arkansas Turfgrass Report 2008, Ark. Ag. Exp. Stn. Res. Ser. 568:40-44.

Keeley, S.J. and M.J. Fagerness. 2001. Bermudagrass lawns (MF1112). Kansas State University Agricultural Experiment Station and Cooperative Extension Service, Kansas State University, Manhattan, KS, 66506.

Kenna, M.P. and G.L. Horst. 1993. Turfgrass water conservation and quality. p. 99-113. In: R.E. Carrow, N.E. Christians, and R.C. Shearman (ed.) International turfgrass society research journal 7. Intertec Publishing Corp., Overland Park, Kansas.

Kohlmeier, G.P. and J.L. Eggens. 1983. The influence of wear and nitrogen on creeping bentgrass growth. Can. J. Plant Sci. 63:189-193

Lee, S. 2012. Evaluating various nitrogen sources for divot recovery on creeping bentgrass. Asian J. Turfgrass Sci. 26(2):135-139.

Liu, H., B.L. McCarty, C.M. Baldwin, W.G. Sarvis, and S.H. Long. 2007. Painting dormant bermudagrass putting greens. Golf Course Management. 75(11):86-91.

Long, S.H. 2006. Thatch control, winter painting, and plant growth regulator management on golf course putting greens. M.S. thesis. Clemson Univ., Clemson, South Carolina.

Long, S.H., H. Liu, L.B. McCarty, and J.A. Thackston. 2005. If it’s winter, it must be time to put on a coat (of green paint). Online. Turgrass Trends. December 2005.

McCarty, L.B. 1995. Buffalograss, description and use. University of Florida Cooperative Extension Service. p. 1-4.

Milesi C., C.D. Elvidge, J.B. Dietz, B.T. Tuttle, R.R. Nemani, and S.W. Running. 2005. A strategy for mapping and modeling the ecological effects of US lawns. In: 3rd international symposium for remote sensing and data fusion over urban areas (URBAN 2005), 5th international symposium for remote sensing of urban area (URS 2005), Tempe, AZ., March 14-16 2005.

Patton, A.J., J. Trappe, D. Karcher, and M. Richardson. 2010. Golf club selection and golfer influence divot size in bermudagrass fairways. Arkansas Turfgrass Report 2009, Ark. Ag. Exp. Stn. Res. Ser. 579:165-168.

Qian, Y.L. and M.C. Engelke. 1999. Performance of five turfgrasses under linear gradient irrigation. HortScience. 34(5):893-896.

Riordan, T.P, F.P. Baxendale, R.E. Gaussoin, and J.E. Watkins. 1996. Buffalograss: an alternative native grass for turf (revised October 1998) (G96-1297). Historical Materials from University of Nebraska-Lincoln Extension. Paper 1048. http://digitalcommons.unl.edu/extensionhist/1048.

Samaranayake H., T.J. Lawson, and J.A. Murphy. 2008. Traffic stress effects on bentgrass putting green and fairway turf. Crop Sci. 48:1193-1202.

Schiavon, M. 2014. Response of seeded and vegetative buffalograss [*Buchloe dactyloides* (Nutt.)] cultivars to nitrogen fertilization and simulated traffic. In: C05 Turfgrass Science abstracts online. ASA, CSSA, & SSSA International Annual Meeting, Long Beach, CA.

Severmutlu, S., T.P. Riordan, R.C. Shearman, R.E. Gaussoin, and L.E. Moser. 2005. Overseeding buffalograss turf with fine-leaved fescues. Crop Sci. 45:704-711.

Shearman, R. 1989. Cultural practice interactions on golf course turfgrass. USGA Research Reports. pp. 23-24.

Shearman, R.C., L.A. Wit, S. Severmutlu, H. Budak, and R.E. Gaussoin. 2005. Colorant effects on dormant buffalograss turf performance. HortTechnology 15:244-246.

Stewart, B, C.J. Nettles Jr., G. Munshaw, H. Philley, and W. Wells. 2008. Traffic-ability of dormant bermudagrass. In: C05 Turfgrass Science abstracts online. ASA, CSSA, & SSSA International Annual Meeting, Houston, TX.

Thompson, C., J. Fry, J. Hoyle, and J. Griffin. 2014. Winter survival of 2013 national turfgrass evaluation program zoysiagrass and bermudagrass entries at Kansas locations (SRP1107). 2014 Turfgrass Research Report. Kansas State University Agricultural Experiment Station and Cooperative Extension Service, Kansas State University, Manhattan, KS, 66506.

Throssell, C.S., G.T. Lyman, M.E. Johnson, and G.A. Stacey. 2009. Golf course environmental profile measures water use, source, cost, quality, and management and conservation strategies. Online. Applied Turfgrass Science doi:10.1094/ATS-2009-0129-01-RS.

Trappe, J.M., D.E. Karcher, M.D. Richardson, and A.J. Patton. 2011. Bermudagrass and zoysiagrass cultivar selection: part 2, divot recovery. Online. Applied Turfgrass Science doi:10.1094/ATS-2011-0630-02-RS.

Trenholm, L.E., R.N. Carrow, and R.R. Duncan. 2000. Mechanisms of wear tolerance in seashore paspalum and bermudagrass. Crop Sci. 40:1350-1357.

Trenholm L.E., R.N. Carrow, and R.R. Duncan. 2001. Wear tolerance, growth, and quality of seashore paspalum in response to nitrogen and potassium. HortScience 36(4):780-783.

Vinlove, F.K. and R.F. Torla. 2010. Comparative estimations of U.S. home lawn area. Applied Turfgrass Science doi:10.1300/J099v01n01_07.

Walsh, B., S.S. Ikeda, and G.J. Boland. 1999. Biology and management of dollar spot (Sclerotinia homoeocarpa); an important disease of turfgrass. Hort. Sci. 34:13-21.

Weaver, J.E. 1985. Summary and interpretation of underground development of natural grassland communities. Ecological Monographs 28(1):55-78.

Wenger, L.E. 1943. Buffalo grass. Agricultural Experiment Station. Kansas State College of Agriculture and Applied Science. Manhattan, KS. Bulletin 321.

Whitlark, B. 2012. Ultradwarf bermudagrass tinting study: how do different paints and pigments affect the surface temperature of greens? USGA Green Section Record 50:1-2.

Chapter 2 - Buffalograss Divot Recovery as Affected by Nitrogen Source and Rate

This chapter has been prepared using style guidelines for the journal of *Crop, Forage, and Turfgrass Management*

ABSTRACT

Divots result when a golfer's club impacts the surface and removes turf. No research has been conducted to explore the influence of nitrogen fertility on divot recovery in buffalograss [*Buchloe dactyloides* (Nutt.) Engelm]. The objective of this study was to determine if nitrogen source and rate influence divot recovery in buffalograss. Research trials were initiated in 2014 at the Rocky Ford Research Center (RF) in Manhattan, KS and Council Grove Country Club (CG) in Council Grove, KS. Three divots were created per plot using a modified edger. Urea (46-0-0) served as the quick-release source of N and polymer coated urea (PCU) (43-0-0) was the controlled release source; each was applied to provide 0, 1, 2, and 3 lb N/1,000 ft^2. Buffalograss treated with urea to provide 1 lb N/1,000 ft^2 achieved 50% divot recovery 6.3 days faster than untreated turf; however, the 3 lb N/1,000 ft^2 rate did not enhance buffalograss divot recovery in comparison. Polymer coated urea applications did not improve divot recovery rates compared to the 0 lb N treatment. Good divot recovery is possible in buffalograss with a soluble N source, and N fertility levels as low as 1 lb N/1,000 ft^2/yr.

INTRODUCTION

With increasing drought conditions and decreasing water supplies, drought tolerant turfgrass species are being explored for use on golf courses. With over 1.2 million acres of irrigated turfgrass in the United States, water conservation has become an issue throughout the turfgrass industry (Throssell et al., 2009). In recent years, the conversion from cool- to warm-season turfgrass species has become more acceptable in the transition zone. Golf courses in the Kansas City area converting tees and fairways from creeping bentgrass [*Agrostis stolonifera* L.] to zoysiagrass [*Zoysia japonica* Steud.] could reduce irrigation annually by 5,767,570 gal while reducing irrigation costs by up to $28,403 (Fry et al., 2008). In Kansas, the Ogallala aquifer provides up to 80% of the water used, although years of pumping has led to a steady decline in water levels (Buchanan et al., 2001). The use of drought tolerant turfgrass species would help conserve water supplies.

Buffalograss [*Buchloe dactyloides* (Nutt.) Engelm] is a native, drought tolerant, warm-season turfgrass species used for lawns, parks, athletic fields, roadsides, and golf courses in the Great Plains (Wenger, 1943; Beard, 1973; Fry, 1995; McCarty, 1995; Fry and Huang, 2004). Qian and Engelke (1999) demonstrated through pan evaporation (Ep) that minimum requirements to prevent drought stress in ‘Prairie’ buffalograss were 7% to 26% Ep, compared to 49% to 67% Ep for ‘Rebel II’ tall fescue [*Lolium arundinacea* Schreb.]. Turfgrass breeders have developed buffalograss cultivars that survive drought with limited irrigation (Beard, 1973; Riordan et al., 1996). Turf-type buffalograss seeded cultivars such as ‘Cody’, ‘Rutgers’, ‘Bison’, and ‘Texoka’ have shown increased drought resistance in comparison to the other seeded cultivars in the 1991 and 1996 national buffalograss tests (Morris, 1996; Morris, 2001). Utilization of buffalograss on golf courses could lead to reduced water consumption while maintaining a reasonably dense playing surface.

Previous research has demonstrated that buffalograss can be maintained as an acceptable fairway turf with proper management practices. Data collected in 1997 from Nebraska (NE) and Kansas (KS) demonstrated that when mown at 1 in, ‘NE 91-118’, ‘378’, and ‘Cody’ resulted in quality ratings of 6.0, 6.0, and 5.9 at the NE site respectively, and 6.2, 5.8, and 5.6 at the KS site, respectively (Frank et al., 2004).

Buffalograss responds to N fertility, and studies in Nebraska and Colorado have shown increased buffalograss quality, color, and growth with increasing N (Falkenberg 1982; Frank et al., 2004). In Nebraska, Frank et al. (2004) reported that applications of 2 lb N/1,000 ft^2 improved color and quality of ‘Cody’, ‘Texoka’, ‘378’, and ‘NE 91-118’ buffalograss when compared to untreated turf. Furthermore, ‘Cody’ receiving two midsummer applications of N to total 2 lb N/1,000 ft^2 had a quality rating of 6.2 (acceptable), but a quality rating of 4.7 (below acceptable) when receiving no N (Frank et al., 2004). Current nitrogen recommendations for buffalograss range from 0 to 2 lb N/1,000 ft^2/yr (Beard, 1973; Christians, 2011; Frank et al., 2004; Riordan et al., 1998). These recommendations were made based on the health and appearance of buffalograss without regard to maximizing potential recovery if injured by golf course play.

Divots produced by golfers’ clubs when striking the ball frequently damage golf course turf. Divots are problematic because they create a void in the turf in which weed seed may germinate, and also decrease the playability and aesthetics of golf course roughs, tees, and fairways (Beard, 2002). Researchers indicated that divot recovery differences existed among different bermudagrass [*Cynodon dactylon* (L.) Pers. *C. dactylon* × *C. transvaalensis* Burtt-Davy] (Karcher et al., 2005a) and zoysiagrass [*Zoysia japonica* Steud., *Z. matrella* (L.) Merr, and *Z. tenuifolia* Willd] cultivars (Karcher et al., 2005b).

Nitrogen fertility has been shown to maximize divot recovery. Divots taken from creeping bentgrass (*Agrostis palustris* Huds.) receiving 5 lb N/1,000 ft^2/yr healed ten days faster than divots on turf receiving 3 lb N/1,000 ft^2/yr (Calhoun, 1996). Lee (2012) reported that polyon mini (41-0-0) applied at 2 lb N/1000 ft^2 to creeping bentgrass (*Agrostis stolonifera* L.) had the best performance when considering divot recovery when compared to split applications of urea (46-0-0) and a no nitrogen treatment. Recuperative potential from divot injury is affected by the size of the divot and the growth habit of the turf species (Beard, 1973; Lee, 2012). Bermudagrass, zoysiagrass, and creeping bentgrass are generally classified as having good to excellent recuperative potentials, making them great choices for playing surfaces on golf courses which may encounter divot injury (Beard, 1973; Karcher et al., 2005).

Although acceptable buffalograss quality and playability can be achieved on golf course fairways with minimal inputs, divot recovery is of concern due to low fertility requirements (Frank et al., 2004). Research is needed to evaluate buffalograss fertility management to maximize divot recovery. The objective of this study was to determine the influence of N source and rate on ‘Cody’ buffalograss fairway divot recovery.

MATERIALS AND METHODS

Buffalograss Divot Recovery Field Trials

Field studies were initiated 1 July 2014 and 1 August 2014 at the Rocky Ford Turfgrass Research Center (RF) in Manhattan, KS and 3 July 2014 at Council Grove Country Club (CG) in Council Grove, Kansas. Soil at RF was a Chase silty clay loam (fine, montmorrillonitic, mesic Aquertic Argiudolls) with a pH of 6.8 and 2.7% organic matter. Soil at CG was a Labette- (fine, mixed, superactive, mesic Udic Argiustolls) Dwight (fine, smectitic, mesic Typic Natrustolls) complex with a pH of 6.1 and 3% organic matter. Mowing was conducted twice weekly at 0.625 inch and 1.00 inch at RF and CG, respectively. After study initiation, irrigation was only applied to prevent drought stress and to water in fertilizers after application (0.5 inch of irrigation applied after N applications). To prevent drought stress, approximately 1.5 inch of supplemental irrigation was applied at each site over the experimental periods. At trial initiation, oxadiazon 3-[2,4-dichloro-5-(1-methyloxy)phenyl]-5-(1,1-dimethylethyl)-1,3,4-oxadiazol-2(3H)-one was applied at 2 lb product/1,000 ft^2 to prevent summer annual weed encroachment. Three weeks prior to trial initiation at RF, thiencarbazone-methyl + idosulfuron-methyl-sodium + dicamba was applied at 0.085 oz of product/1,000 ft^2 on 17 June 2014 to remove existing broadleaf and grassy weeds.

Nitrogen Treatment Application and Divot Installation

Field studies were a randomized complete block designs, with a 2 × 4 factorial treatment structure and four replications. Main effects consisted of N sources (2) and rates (4). Nitrogen sources were a quick release urea fertilizer (46-0-0) and a 120-day controlled release polymer-coated urea (PCU) (43-0-0). Nitrogen rates were 0, 1, 2, and 3 lb N/1,000 ft^2. Nitrogen from urea was applied in two equal applications; one at study initiation and the other 28 days after initiation (DAI). All N from PCU was applied at trial initiation. Fertilizers were applied in at least two directions in each plot using a shaker jar.

Prior to treatment application, divots were created using a custom built edger (Fry et al., 2008). The divot simulator was a modified lawn edger with a 140 cc gasoline engine (model no 25B-554M711; Troy Built, Valley City, Ohio). The standard edging blade was replaced with 13, 7.25 inch carbide tip circular saw blades (0.079 inch thick) (67-757P; Black+Decker, New Britain, Connecticut) spaced with 0.079 inch thick washers. Three standardized 5.5 × 2.13 × 0.13 (L × W × D) inch divots (subsamples) were installed in each plot. Experimental plots were 5 ft × 7 ft with divots centered on two foot intervals within each plot. Divots were backfilled with mixed pink sand based on Williams et al. (2011). Due to the pink color of the sand fading over time in the first two studies, divots in the second RF study location were backfilled using store-bought pink sand (Pink Flamingo Play Sand, Crayola, Eaton, Pennsylvania).

Data Collection

Divot recovery was determined by visual analysis and digital image analysis (DIA). Digital images were collected weekly using a Nikon D5000 digital camera (Nikon Inc., Tokyo, Japan) with a custom-built camera light box (20 × 24 × 22 inch). DIA was completed using SigmaScan Pro (v. 5.0, 1998; Systat Software, Inc., San Jose, CA) based on the methods of Karcher et al., 2005, Richardson et al., 2001, and Williams et al., 2011. All images were analyzed using three different methods to determine divot recovery. Divot recovery was measured using the methods of Williams et al. 2011 for an enhanced method of tracking divot recovery in turfgrass using pink sand. Due to the pink color of the sand used in this study, all images were analyzed twice using different hue settings within the DIA software (0 – 20 hue, 200 – 255 hue; 0 – 100 saturation) in order to pick up the whole divot. Output values from each hue setting were summed to achieve total percent divot cover for each individual divot. DIA using this method proved to be unsuccessful. Through DIA, it was observed that the intended pink sand color was not achieved, and the pink color of the sand faded over time. In order to mimic low maintenance golf course practices, and also to avoid altering the established divots, the divots were not repeatedly backfilled on a weekly basis. The second method for divot analysis was conducted using the methods of Karcher et al. (2005), where percent green cover (45 – 107 hue; 0 – 100 saturation) was used to determine divot recovery. Percent divot recovery was calculated using Equation 1:

$$\%recovery = \frac{(\%cover_{(x)} - \%cover_{(0)})}{(100\% - \%cover_{(o)})}$$

where %cover$_{(x)}$ was the percent turf cover on the day the image was taken and %cover$_{(o)}$ was the percent turf cover on the day divot was installed (Karcher et al., 2005). The third method for analysis was a combination of the first two methods where output values from each hue setting were summed to achieve total percent divot cover for each individual divot. Divot percent cover values were subtracted by 100% to get a value for calculated percent turf cover in each image. Percent recovery was then determined using Equation 1. DIA for divot recovery also proved to be unsuccessful when determining green turf cover around the divot. In order for the standard method of divot recovery analysis through DIA to be accurate, it is required that the surrounding turf needs to be 100% dense and 100% green in color (Williams et al., 2011). DIA using the standard method of divot analysis was ineffective based on buffalograss' open, fine-textured canopy and its grey-green color (Beard, 1973). Therefore, visual analysis of the divots best estimated actual divot recovery in this study.

Divot recovery as influenced by N rate and source was analyzed using Proc Mixed in SAS (SAS Institute Inc., 2012, Cary, North Carolina). Data for analysis were combined across all three locations. Divot recovery for each N rate and source was regressed against days after injury (DAI) using SigmaPlot (v. 11.0, 2008; Systat Software, Inc., San Jose, CA). The three-parameter sigmoid regression model was effective at estimating divot recovery as influenced by N source and rate. Differences in divot recovery were determined using the following sigmoid regression model shown in Equation 2:

$$y = \frac{a}{1+e^{(-(\frac{x-R_{50}}{b}))}}$$

where, y is percent divot recovery on rating date x (DAI), R_{50} is DAI to reach 50% divot recovery, a is the maximum divot recovery (upper limit), and b is the slope at R_{50}. Additionally, weekly visual ratings consisted of turfgrass color and quality according to the National Turfgrass Evaluation Program (Morris and Shearman). Turfgrass color was rated on a 1 to 9 scale, where, 1 = straw brown, 6 = acceptable color, and 9 = dark green color. Turfgrass quality was rated on a 1 to 9 scale, where, 1 = poor, 6 = acceptable, and 9 = best.

RESULTS AND DISCUSSION

Nitrogen Effects on Buffalograss Divot Recovery

A significant N source (F = 12.00, P = 0.0010) main effect as well as an N source by rate (F = 4.59, P = 0.0061) interaction were observed for divot recovery (Table 2-1). No significant treatment-by-location interaction (F = 0.94, P = 0.4797) occurred; therefore, data were pooled across locations. The three-parameter sigmoid regression model described the data well with R^2 values ranging from 0.83 to 0.90 (Table 2-2). Differences in divot recovery duration were observed from the regression model as R_{50}, with lower values corresponding with quicker divot recovery (Table 2-2). Buffalograss color and quality were enhanced with the application of the nitrogen treatments when compared to the control treatment. A significant main effect of N rate (F = 7.96, P = 0.0002) was observed for visual color ratings of the buffalograss (Appendix Table A-1); statistical significance for the main effect of N source (F = 1.70, P = 0.1981) and the interaction of the main effects (F = 0.62, P = 0.6049) was not observed. For buffalograss quality observations, statistical significance was not detected for the main effect of N rate (F = 1.85, P =0.1489) or the interaction of the main effects (F = 0.65, P = 0.5863), although, statistical significance was observed for N source (F = 3.86, P = 0.0541) (Appendix Table A-2).

For all treatments, divot recovery increased over time (Figure 2-1). Untreated turf reached 50% divot recovery in 23.8 days. Fourteen DAI, divot recovery in turf treated with 1 lb N/1,000 ft^2 from urea and PCU was 39.2% and 19.1%, respectively. Urea fertilizers cause rapid plant growth shortly after the N is applied to the turf, but have a relatively short residual response (Beard, 1973). Divot recovery of buffalograss treated with PCU at 1, 2, and 3 lb N/1,000 ft^2 reached 50% divot recovery in 26.7, 23.1, and 22.2 days, respectively, which were not different than untreated turf. Slow release N fertilizers, such as PCU, give a delayed response from the plant, but have longer residual effects. A PCU (43-0-0) formulated for longer-term N release applied to ‘Tifway’ hybrid bermudagrass resulted in a very poor 0-30 day turf quality response (14% of quality ratings > than urea response), but a very good 61-95 day quality response (71% of quality ratings > than urea response) (Carrow, 1997). Conversely, Lee (2012) evaluated various N sources for divot recovery in creeping bentgrass and reported that N release speed did not influence divot recovery. However, data in that study were based solely on turfgrass quality (1-9 scale); percent divot recovery was not evaluated.

Divots occur routinely throughout the growing season on golf courses. With PCU's having greater long-term effects than short-term, divots made 28 DAI may have recovered at a different rate than divots made at initiation due to the longer duration release pattern. Polymer coated urea can be formulated with various release patterns based on the coating thickness. Researchers in 1992 described that coated urea with thinner coatings had higher initial quality ratings compared to urea with a thicker coating (Peacock and DiPaola, 1992). In our study, a 120-day controlled release PCU was used as the slow release source. In comparison to the quick release urea, initial rapid growth was not achieved with the slow release N source, consequently, divot recovery rate was not increased with PCU. Using a controlled release PCU with a quicker release pattern may enhance divot recovery better than a longer duration release pattern.

Buffalograss treated with urea (1, 2, or 3 lb N/1,000 ft^2) reached 50% divot recovery faster than untreated turf (23.8 days). Fifty percent divot recovery was achieved with the quick release N source in 17.5, 20.9 and 18.6 days for 1, 2 and 3 lb N/1,000 ft^2, respectively. The quick release treatment of 1 lb N/1,000 ft^2 was just as effective as the higher rates in this study, achieving 50% divot recovery 6.3 days faster than the untreated turf. In low input turfgrass management systems, past research has shown that buffalograss responds positively to applications of urea. Frank et al. (2002) demonstrated that rates of urea (46-0-0) up to 3 lb N/1,000 ft^2 resulted in 27% more buffalograss cover at season end compared to 0 lb N/1,000 ft^2. In the present study we observed that applying urea at rates up to 3 lb N/1,000 ft^2 enhanced buffalograss' recuperative abilities in comparison to untreated turf, however the 1 lb N/1,000 ft^2 rate was adequate for optimal divot recovery. Frank et al. (2004) observed that buffalograss cover was enhanced with rates up to 3 lb N/1,000 ft^2, but they did not evaluate divot recovery. Failing to apply nitrogen to buffalograss tees and fairways can prolong divot recovery in comparison to applying a quick release source of N. Recommendations for buffalograss N fertilization range from 0 to 2 lb N/1,000 ft^2/yr (Beard, 1973; Christians, 2011; Frank et al., 2004; Riordan et al., 1998). The fertilization regime for divot recovery of 1 lb N/1,000 ft^2, using a quick release source, fits into the pre-established range for buffalograss N fertility. Therefore, applying nitrogen for increased color and quality will also increase the recuperative potential of buffalograss from divot injury.

CONCLUSIONS

Buffalograss' low water requirement and its ability to be maintained at fairway mowing heights make it very valuable in low input turfgrass management systems. From the data collected in this study, applying a quick release N fertilizer at rates as low as 1 lb N/1,000 ft^2 will result in a shorter duration to reach 50% divot recovery compared to buffalograss receiving no N. Applying 1lb N/1,000 ft^2 as urea, led to 50% divot recovery 6.3 days faster than turf receiving 0 lb N/1,000 ft^2. This study has shown that under limited irrigation situations and with minimal fertilization, buffalograss exhibits improved divot recovery and, thus, playability in low input turfgrass management systems.

REFERENCES

Beard, J.B. 1973. Turfgrass: science and culture. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Beard, J.B. 2002. Turf management for golf courses. 2nd Ed. A publication of the United States Golf Association. Ann Arbor Press, Chelsea, Michigan.

Buchanan, R.C., B.B. Wilson, R.R. Buddemeier, and J.J. Butler Jr. 2001. The high plains aquifer (Revised 2009). Kansas Geological Survey Public Information Circular, 18, Sept. 2001.

Calhoun, R.N. 1996. Effect of three plant growth regulators and two nitrogen regimes on growth and performance of creeping bentgrass (*Agrostis palustris* Huds.). Master's thesis, Michigan State Univ., East Lansing.

Carrow, R.N. 1997. Turfgrass response to slow-release nitrogen fertilizers. Agron. J. 89:491-496.

Christians, N.E. 2011. Fundamentals of turfgrass management. 4th ed. John Wiley & Sons, Inc., Hoboken, New Jersey.

Falkenberg, D.F. 1982. Buffalograss, blue grama, and fairway wheatgrass for dryland turf. M.S. Thesis. Colorado State Univ., Fort Collins, Colorado.

Frank, K.W., R.E. Gaussoin, J.D. Fry, M.D. Frost, and J.H. Baird. 2002. Nitrogen, phosphorus, and potassium effects on seeded buffalograss establishment. HortScience 37(2):371-373.

Frank, K.W., R.E. Gaussoin, T.P. Riordan, R.C. Shearman, J.D. Fry, E.D. Miltner, and P.G. Johnson. 2004. Nitrogen rate and mowing height effects on turf-type buffalograss. Crop Sci.44:1615-1621.

Fry, J.D. 1995. Establishing buffalograss. Golf Course Management. 63(4): 58-62.

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

Fry, J.D., M. Kennelly, and R. St. John. 2008. Zoysiagrass: economic and environmental sense in the transition zone. GCM May 2008, 127 – 132.

Fry, L.R., M.D. Richardson, and D.E. Karcher. 2008. An improved method for simulating divot injury on turfgrass. Crop Sci. 48:2459-2462.

Karcher, D.E., M.D. Richardson, J.W. Landreth, J.H. McCalla, Jr. 2005. Recovery of bermudagrass varieties from divot injury. Applied Turfgrass Science. doi: 10.1094/ATS-2005-0117-01-RS.

Karcher, D.E., M.D. Richardson, J.W. Landreth, and J.H. McCalla, Jr. 2005. Recovery of zoysiagrass varieties from divot injury. Applied Turfgrass Science. doi: 10.1094/ATS-2005-0728-01-RS.

Karcher, D.E. and M.D. Richardson. 2005. Batch analysis of digital images to evaluate turfgrass characteristics. Crop Sci. 45:1536-1539.

Lee, S. 2012. Evaluating various nitrogen sources for divot recovery on creeping bentgrass. Asian J. Turfgrass Sci. 26(2):135-139.

McCarty, L.B. 1995. Buffalograss, description and use. University of Florida Cooperative Extension Service. p. 1-4.

Morris, K.N. 1996. National Buffalograss Test-1991. NTEP Final Report.

Morris, K.N. 2001. National Buffalograss Test-1996. NTEP Final Report.

Morris, K.N. and R.C. Shearman. 2014. NTEP turfgrass evaluation guidelines. National Turfgrass Evaluation Program. http://www.ntep.org/cooperator.htm (accessed 21 Jun. 2014).

Peacock, C.H. and J.M. DiPaola. 1992. Bermudagrass response to reactive layer coated fertilizers. Agron. J. 84:946-950.

Qian, Y.L. and M.C. Engelke. 1999. Performance of five turfgrasses under linear gradient irrigation. HortScience. 34(5):893-896.

Richardson, M.D., D.E. Karcher, and L.C. Purcell. 2001. Quantifying turfgrass cover using digital image analysis. Crop Sci. 41:1884-1888.

Riordan, T.P, F.P. Baxendale, R.E. Gaussoin, and J.E. Watkins. 1996. G96-1297 Buffalograss: an alternative native grass for turf (revised October 1998). Historical Materials from University of Nebraska-Lincoln Extension. Paper 1048. http://digitalcommons.unl.edu/extensionhist/1048.

Throssell, C.S., G.T. Lyman, M.E. Johnson, and G.A. Stacey. 2009. Golf course environmental profile measures water use, source, cost, quality, and management and conservation strategies. Online. Applied Turfgrass Science doi:10.1094/ATS-2009-0129-01-RS.

Wenger, L.E. 1943. Buffalo grass. Agricultural Experiment Station. Kansas State College of Agriculture and Applied Science. Manhattan, KS. Bulletin 321.

Williams, B.T., J.K Kruse, J. B. Unruh, and J.B. Sartain. 2011. An enhanced method of tracking divot recovery in turfgrass. Crop Sci. 51:2194-2198.

Table 2-1. ANOVA for divot recovery across all study locations.

Effect†	F Value	Pr > F‡
Source	12.00	0.0010
Fertilizer Rate	1.91	0.1392
Source × Rate	4.59	0.0061

‡Effects were determined to be statistically significant when $P \leq 0.05$.

Table 2-2 Parameter estimates (± standard errors) from fitting Equation 2 to data for urea and PCU rates % recovery across all locations.

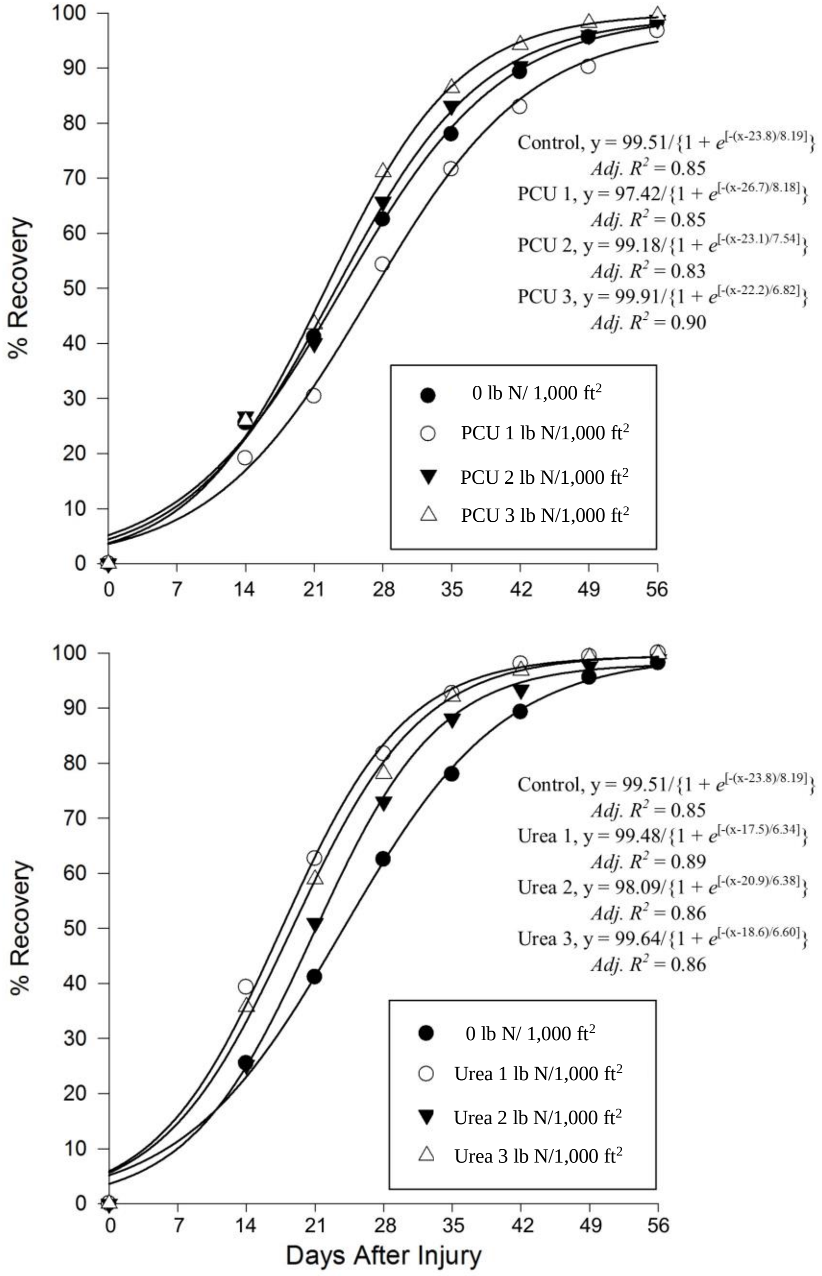
Source†	Rate (lb N/1,000 ft^2)	*a*‡	*b*	R_{50}	*Adj* R^2
--§	0	99.51 ± 3.12	1.17 ± 0.12	23.8 ± 1.0	0.85
PCU	1	97.42 ± 4.96	1.17 ± 0.18	26.7 ± 1.5	0.85
PCU	2	99.18 ± 4.41	1.08 ± 0.18	23.1 ± 1.3	0.83
PCU	3	99.91 ± 2.89	0.97 ± 0.12	22.2 ± 1.0	0.90
Urea	1	99.48 ± 2.42	0.91 ± 0.12	17.5 ± 1.0	0.89
Urea	2	98.09 ± 3.15	0.91 ± 0.14	20.9 ± 1.0	0.86
Urea	3	99.64 ± 3.01	0.94 ± 0.14	18.6 ± 1.0	0.86

†Sigmoid regression model defined by equation 2.

‡Abbreviations: *a,* maximum recovery; *b*, slope; R_{50}, days after injury to achieve 50% recovery; *Adj*, adjusted; PCU, polymer coated urea.

§ During this field study two untreated plots (Slow 0 lb N/1,000 ft^2 and Quick 0 lb N/1,000 ft^2) were used to attain a 2 × 4 complete randomized factorial design. For the purpose of nonlinear regression analysis data from the two control treatments were combined and treated as one treatment.

Figure 2-1. Three-parameter sigmoid regression model for urea and PCU nitrogen treatments as determined by Equation 2. Abbreviations: PCU, polymer coated urea; y, percent divot recovery; x, rating date (DAI); Adj., adjusted.



Chapter 3 - Evaluating the Effects of Nitrogen Rate and Simulated Golf Cart Traffic on ‘Cody’ Buffalograss Roughs

This chapter has been prepared using style guidelines for the journal of *Crop, Forage, and Turfgrass Management*

ABSTRACT

Requiring minimal management, buffalograss [*Buchloe dactyloides* (Nutt.) Engelm] is increasing in popularity for use in golf course roughs. Limited information is available when considering nitrogen and golf cart traffic in these rough areas. The objective of this study was to determine the influence of nitrogen rate and repeated simulated golf cart traffic on buffalograss. Field trials were initiated in July 2014 and 2015 at the Rocky Ford Turfgrass Research Center in Manhattan, KS on ‘Cody’ buffalograss maintained at 3 inches. Factors were four nitrogen application rates, and five traffic rates. Nitrogen (46-0-0 Urea) rates included 0, 1, 2, and 3 lb N/1,000 ft^2. Traffic treatments were applied with a custom-built golf cart traffic simulator so that 0, 2, 4, 8, or 16 passes occurred. Although no interaction was observed, main effects of traffic and nitrogen rate were significant both years of the study. As nitrogen rate increased, regardless of traffic rate, the green cover, quality, and color of buffalograss increased. Conversely as traffic rate increased, regardless of nitrogen rate, buffalograss green cover, quality, and color decreased.

INTRODUCTION

Drought conditions over the past years have increased the awareness of water consumption on golf courses. In a 2009 survey, the highest portion of irrigated acres on golf courses were roughs (34 acres) and fairways (31 acres), with rough areas accounting for approximately 42% (Throssell et al., 2009). Out of 1.5 million acres of maintained turfgrass on U.S. golf courses, with nearly 777,051 acres of rough, alternative drought tolerant turfgrass species have shown potential to reduce water usage in golf course roughs (Lyman et al., 2007).

Buffalograss [*Buchloe dactyloides* (Nutt.) Engelm] is a native drought tolerant turfgrass species that is well adapted for unirrigated lawns, parks, athletic fields, roadsides, and golf courses in the transition zone (Wenger, 1943; Beard, 1973; Fry, 1995; McCarty, 1995; Fry and Huang, 2004). Buffalograss in low maintenances golf course areas, including roughs, may be maintained with no additional irrigation beyond natural precipitation. Turfgrass quality, however, may be enhanced with irrigation during the active growing season (Riordan et al., 1996). Buffalograss' mean summer evapotranspiration (ET) rate is very low (0.20 inch/d – 0.27 inch/d) when compared to tall fescue [*Lolium arundinacea* Schreb.] ET (0.14 inch/d – 0.50 inch/d), the most predominant rough species (Kenna and Horst, 1993). When compared to tall fescue, Kenna and Horst (1993) described buffalograss' relative drought resistance as excellent. Furthermore, minimum requirements to prevent drought stress in 'Prairie' buffalograss [7% - 26% of pan evaporation (Ep)] were much less in comparison to 'Rebel II' tall fescue (49% - 67% Ep) (Qian and Engelke, 1999). Therefore, the use of alternative, low input turfgrass species such as buffalograss could lead to a significant reduction of golf course rough irrigation.

Golf course roughs are subjected to a multitude of stresses on a daily basis. Golf cart trafficking cause's significant injury to turf in roughs. Damage from golf cart traffic imposes direct physical damage to the turfgrass leaf tissue, and causes soil compaction (Beard, 1973; Kohlmeier and Eggens, 1983; Carroll and Petrovic, 1991; Carrow and Johnson, 1996; Trenholm et al., 2000; Trenholm et al., 2001; Samaranayake et al., 2008). Turfgrass wear is associated with the abrasive scuffing, or tearing action on the leaf tissue from a golf cart tire (Beard, 1973). Compaction from repeated trafficking affects the turfgrass root system by reducing soil oxygen and increasing resistance to root penetration (Trenholm et al., 2000). Due to these forms of injury, high traffic areas on golf courses often have unacceptable canopy density, turfgrass injury, and/or plant death if additional management strategies are not implemented (Beard, 1973; Carrow and Johnson, 1996). Cultural practices that have shown promote wear tolerance in turfgrass include: an acceptable thatch layer, an increased mowing height, and moderate levels of nitrogen (N) fertility (Younger, 1961; Beard, 1973; Kohlmeier and Eggens, 1983; Trenholm et al., 2000).

Increasing shoot growth and density through N fertilizer applications has increased wear resistance in high traffic areas. Percent unworn turf for creeping bentgrass [*Agrostis palustris* Huds.] with 200 revolutions from a gasoline-engine-driven pneumatic wear simulator applied at two sites averaged 75% when receiving 4 lb N/1,000 ft^2, and 64% when receiving 2 lb N/1,000 ft^2 (Carroll and Petrovic, 1991). Similarly, 6 lb N/1,000 ft^2/yr on a creeping bentgrass putting green increased root production, green color, and healing potential when exposed to wear treatments compared to 0 lb N/1,000 ft^2/yr (Kohlmeier and Eggens, 1982).

Although increased wear tolerance has been observed in cool-season turfgrass species with N applications, warm-season turfgrass species are more resistant to traffic injury regardless of N rate (Younger, 1961; Beard, 1973; Trenholm et al., 2000). Trenholm et al. (2001) reported that under traffic stress, nitrogen significantly influenced turfgrass quality of two eco-types of greens-height seashore paspalum [*Paspalum vaginatum* Swartz]. Data collected seven days after wear treatment indicated that AP-10 and AP-14 receiving 8 lb N/1,000 ft^2/yr received an average quality rating of 7.3 (6.0 = acceptable) compared to 5.8 when receiving 4 lb N/1,000 ft^2/yr (Trenholm et al., 2001).

Buffalograss evaluated in Nebraska and Kansas had higher quality, color, and growth with N applications (Frank et al., 2004). Over a three year evaluation period, urea (46-0-0) applied at 2 lb N/1,000 ft^2 increased the quality of ‘Cody’, ‘Texoka’, ‘378’, and ‘NE 91-118’ when compared to 0.5 and 1 lb N/1,000ft^2 and non-treated turf (Frank et al., 2004). Similarly, ‘NEBFG 07-01’, ‘Sundancer’, ‘NEBFG 07-4E’, and ‘UC Verde’ buffalograss mowed at 2 inches and receiving 4 lb N/1,000 ft^2 had higher turfgrass quality compared to turf recieving 2 lb N/1,000 ft^2 (Schiavon, 2014). In this same study, simulated traffic (10 soccer games/yr with the Brinkman traffic simulator) was determined to decrease turf quality and increase weed intrusion (Schiavon, 2014).

Although acceptable buffalograss rough can be achieved with minimal maintenance, buffalograss’ ability to withstand injury from golf cart traffic is of concern due to its fine-textured canopy, soft leaf blades, and slow growth characteristics (Beard, 1973; Frank et al., 2004). Limited information is available on buffalograss' abilities to withstand golf cart traffic injury; therefore, research is needed to investigate the effects of fertility management on traffic tolerance in rough height buffalograss. The objective of this study was to determine the influence of nitrogen rate and simulated golf cart traffic on the wear tolerance of 'Cody' buffalograss.

MATERIALS AND METHODS

Research Site Information

Three individual field studies were conducted at the Rocky Ford Turfgrass Center (RF) in Manhattan, KS on 1 July 2014, 7 July 2015, and 20 July 2015. Soil at RF was a Chase silty clay loam (fine, montmorrillonitic, mesic Aquertic Argiudolls) with 6.8 pH and 2.7% organic matter. This study was conducted on a mature 'Cody' buffalograss that was established in 2006. Plots were maintained at 3 inches with a rotary mower. Irrigation was only applied to prevent dormancy from drought stress and water in fertilizer treatments totaling <2 inches of supplemental irrigation throughout the study period. At trial initiation, oxadiazon 3-[2,4-dichloro-5-(1-methyloxy)phenyl]-5-(1,1-dimethylethyl)-1,3,4-oxadiazol-2(3H)-one] was applied at 2 lb product/1,000 ft^2 to prevent summer annual weed encroachment. For the trials conducted in 2015, 2,4-dichlororphenoxyacetic acid + (+)-(R)-2-(2-methyl-4-chlorophenoxy) propionic acid + 3,6-dichloro-o-anisic acid applied at 1.2 fl oz product/1,000 ft^2, flazasulfuron applied at 0.034 oz product/1,000 ft^2, mesotrione applied at 0.11 fl oz product/1,000 ft^2, and quinclorac + sulfentrazone + 2,4-D + dicamba applied at 1.8 fl oz product/1,000 ft^2 were applied prior (7 July 2015 and 20 July 2015) to trial initiation to remove existing broadleaf and grassy weeds. No other irrigation, fertilizers, and pesticides were previously applied to the study areas.

Nitrogen and Traffic Treatment Implementation

Field studies were arranged in a strip-plot design, with a 4 × 5 factorial treatment structure. Main effects were four nitrogen rates (N) and five simulated golf cart traffic rates. Whole plot size for trials 1 and 2 were 25 ft × 10 ft, with the strip plot being 5 ft × 40 ft. Due to the minimal amount of 'Cody' buffalograss area at RF, whole plot size for trial 3 was reduced to 25 ft × 5 ft, with the strip plot being 5 ft × 20 ft. Nitrogen source used was a urea fertilizer (46N-

0P-0K) applied at 0, 1, 2, and 3 lb N/1000 ft^2. The nitrogen fertilizer was applied in two half rate applications, once at trial initiation and again 8 weeks after initiation. All nitrogen treatments were applied by hand using a shaker jar, in at least two directions in each plot.

Traffic was applied twice per week during the study period, with total traffic rate values of 0, 2, 4, 8, and 16 passes/week. Two different traffic simulators were used during the 2014 and 2015 study years. Traffic simulator 1 was a custom built golf cart traffic simulator pulled behind a turf utility vehicle and consisted of two 1,000 lb traffic trailers on an axle containing five golf cart tires pulled in tandem based on the methods of Watkins et al. (2010). Traffic simulator 2 consisted of two 18 inch × 36 inch lawn rollers pulled in tandem. Both of the rollers were filled to capacity with water totaling 390 lb of water in each roller. Due to mechanical issues with traffic simulator 1 causing it to be inoperable, traffic simulator 2 was used 0 – 6 weeks after initiation (WAI) during 2014 and 7 – 8 WAI during 2015.

Data Collection

Plots were evaluated bi-weekly for the duration of the study period. Visual evaluations included color and quality. Turfgrass color was rated on a 1-9 scale, where 1 = straw brown, 6 = acceptable color, and 9 = dark green color (Morris and Shearman, 2014). Quality was rated on a 1-9 scale, where 1 = poor, 6 = acceptable quality, and 9 = optimum color, density, and uniformity (Morris and Shearman, 2014). Instrumentational evaluations of soil strength at a 0 – 4 inch depth (PSI averaged over sample depth) (FieldScout SC 900 Soil Compaction Meter, Spectrum Technologies Inc.), normalized difference vegetation index (NDVI) (0.0 – 1.0 scale with higher values corresponding to greater densities of green leaf tissue values) (FieldScout CM 1000 NDVI Meter, Spectrum Technologies, Inc.) and soil moisture (% Volumetric Water Content) (FieldScout TDR 300 Soil Moisture Meter, Spectrum Technologies, Inc.) were also conducted bi-weekly.

Digital images were collected on each rating date using a Nikon D5000 digital camera (Nikon Inc., Tokyo, Japan) and a custom built camera light box (20 inch × 24 inch × 22 inch). Digital image analysis (DIA) was conducted according to the methods of Richardson et al. (2001), and Karcher and Richardson (2005) in SigmaScan Pro 5.0 (45 – 107 hue and 0 – 100 saturation) (v. 5.0, 1998; Systat Software, Inc., San Jose, CA). The hue was reduced to compensate for the grey-green color of buffalograss (Beard, 1973) to 45-107 whereas a healthy green turf is between 57 – 107 (Williams et al., 2011). Dark green color index (DGCI) values were calculated from digital images according to Karcher and Richardson (2003) shown in Equation 1:

$$DGCI\ value = \frac{[\frac{(hue - 60)}{60} + (1 - saturation) + (1 - brightness)]}{3}$$

DGCI values range from 0 to 1, where 0 = no green color, and 1 = dark green color.

ANOVA was performed using Proc Glimmix in SAS (SAS Institute, 2008). Means were separated for each weeks after traffic initiation (WAI) using Fisher's Protected LSD procedure at $P \leq 0.05$. No significant treatment-by-trial interaction was observed for digital percent green cover ($F = 0.21$, $P = 1.00$), visual quality ($F = 1.06$, $P = 0.3690$), NDVI ($F = 0.97$, $P = 0.5206$), visual color ($F = 0.22$, $P = 1.00$), DGCI ($F = 0.33$, $P = 1.00$), compaction ($F = 0.34$, $P = 0.9999$), and soil moisture ($F = 0.18$, $P = 1.00$), therefore, data were was pooled across all experimental runs.

Digital Percent Green Cover of 'Cody' Buffalograss

Significant main effects for N application rate ($F = 98.00$, $P < 0.0001$) and simulated golf cart traffic rate ($F = 118.67$, $P < 0.0001$) were observed throughout the 14 week study period for digital percent green cover (Appendix Table B-1). No significant interaction was observed ($F = 0.47$, $P = 0.9296$).

Regardless of traffic rate applied, percent green cover of the 'Cody' buffalograss was greater with higher application rates of N. Two through 9 WAI, N applications rates of 2 and 3 lb N/1,000 ft^2 were similar, but also had higher digital percent green cover values than 0 and 1 lb N/1,000 ft^2 (Table 3-1). After trial initiation, similarities between 0 and 1 lb N/1,000 ft^2 were observed at 4 and 6 WAI. At 2 and 8 – 14 WAI, any N application rate, regardless of traffic rate, increased percent green cover values compared to no N. Ten WAI, just before the turf began entering dormancy, percent green cover values for 0, 1, 2, and 3 lb N/1,000 ft^2 were 60.2%, 69.0%, 75.5%, and 79.1% respectively.

Similar results were observed in research with creeping bentgrass. In a 1986 study of creeping bentgrass under wear stress, percent unworn turf for 4 lb N/1,000 ft^2 averaged 75% at two locations, and averaged 63.5% when 2 lb N/1,000 ft^2 was applied (Carrol and Petrovic, 1991). Percent healing potential (measure of stolon regrowth over bare ground) of ‘Penncross’ creeping bentgrass regardless of traffic rate, also increased with the application of 6 and 12 lb N/1,000 ft^2 (33-0-0) in comparison to applications of 3 lb N/1,000 ft^2 (Kohlmeier and Eggens, 1983).

Regardless of traffic rate applied, N stimulated growth to sustain or increase green cover of the buffalograss. When considering the current recommendations of nitrogen fertility for buffalograss (0 – 3 lb N/1,000 ft^2/yr), applications of N resulted in higher values of percent green cover than when N was not applied. Applications of N were also observed to increase NDVI ($F = 80.33$, $P < 0.0001$) values during the study (Appendix Tables B-2 and B-3). Overall, applications rates of 2 and 3 lb N/1,000 ft^2/yr resulted in higher percent green cover, when compared to no N.

Across all N rates, higher amounts of simulated golf cart traffic resulted in lower digital percent green ‘Cody’ buffalograss cover. Sixteen passes/week of simulated golf cart traffic resulted in the lowest digital percent green cover over the entire study (Table 3-2). Buffalograss receiving the highest level of traffic never achieved over 72% digital green cover after the initial rating. Zero passes/week of simulated traffic resulted in the highest percent of digital green cover during the study, and was similar to two passes/week between 2 - 10 WAI. No difference was observed at 2, 6, 8, and 10 WAI when comparing 0, 2, and 4 passes/week regardless of N application rate. On creeping bentgrass, Kohlmeier and Eggens (1983) observed about 54% uninjured leaves during a fall rating when receiving 0 or 3 passes/day of traffic (26 total traffic applications). Although creeping bentgrass receiving 0 and 3 passes/day of traffic were similar, turf receiving 6 passes/day resulted in 47% uninjured leaves, and was different from the low and middle level of wear applied (Kohlmeier and Eggens, 1983).

Wear damage from golf cart tires can significantly decrease the green cover of a turfgrass stand. Wear is the direct abrasion, ripping, or tearing of the leaf tissue from the crown of the turfgrass plant (Beard, 1973). In the present study, regardless of nitrogen rate applied, as traffic rate increased, the percent green cover of the ‘Cody’ buffalograss decreased. This reduction in digital percent green cover was also observed through NDVI ($F = 119.37$, $P < 0.0001$) measurements (Appendix Tables B-2 and B-4). Due to the fine texture of buffalograss, increased rates of traffic will ultimately lead to unacceptable levels of green cover.

Effect of Nitrogen and Traffic Treatments on Buffalograss Quality and Color

Factors considered in turfgrass quality, which includes color, density, uniformity, and texture can all be influenced by N and traffic. Significant N rate ($F = 33.28$, $P < 0.0001$) and traffic rate ($F = 105.99$, $P < 0.0001$) main effects for quality were observed during the study; an interaction were not observed ($F = 0.41$, $P = 0.9587$) (Appendix Table B-5).

Application rates of N up to 3 lb N/1,000 ft^2 maintained higher than acceptable quality (≥ 6 quality) from 2 - 10 WAI (Table 3-3). Generally, as N application rate increased, buffalograss quality also increased, although similarities existed between 0 lb N and 1 lb N/1,000 ft^2 on rating dates 4 and 6 WAI. With no N, regardless of traffic rate, quality ratings remained below an acceptable level for the entire experiment. In a 2004 study conducted in Kansas on various buffalograss cultivars, applications of N from urea up to 2 lb N/1,000 ft^2 increased buffalograss quality when compared to untreated turf (Frank et al., 2004). Quality ratings for ‘Cody’ buffalograss during the second year of evaluations were 4.7, 5.4, 5.7, and 6.2 for 0, 0.5, 1, and 2 lb N/1,000 ft^2 respectively (Frank et al., 2004). Furthermore, 4 lb N/1,000 ft^2 applied to various buffalograss cultivars, in the presence of athletic field traffic, provided higher quality ratings and less weed cover than when 2 lb N/1,000 ft^2 was applied (Schiavon, 2014). Similar results were observed in the current study where increased nitrogen application rates increased or sustained buffalograss quality. Turfgrass quality ratings can also be affected by the color of the turfgrass. Differences in buffalograss color were observed through the biweekly ratings of visual turfgrass color (N rate - $F = 247.63$, $P < 0.0001$) and DGCI (N rate - $F = 129.90$, $P < 0.0001$) (Appendix Tables B-6 and B-7). Similarities between turfgrass quality and color ratings were observed. Over all traffic rates, buffalograss receiving 0 lb N/1,000 ft^2 never achieved an acceptable color rating. After trial initiation, any application rate of N up to 3 lb N/1,000 ft^2 resulted in higher than acceptable visual color. Acceptable color was observed for 8 weeks during the study period when 1 lb N/1,000 ft^2 was applied, while applications of 2 and 3 lb N/1,000 ft^2 resulted in 12 weeks of acceptable buffalograss color (Table 3-5). Similar trends for nitrogen’s influence on green color were observed digitally with DGCI values (Appendix Table B-8). Nitrogen applied to buffalograss at rates up to 3 lb N/1,000 ft^2 will increase turfgrass quality and color, regardless of traffic applied.

Ripping, tearing, and abrasion associated with wear from golf cart tires can greatly decrease the density, uniformity, and texture of a turfgrass stand. Schiavon (2014) reported that buffalograss quality was negatively influenced when traffic was applied. Wear applied to AP-10 and AP-14 seashore paspalum ecotypes resulted in quality ratings lower than when wear was not applied (Trenholm et al., 2001). Furthermore, quality of creeping bentgrass at putting green height for no traffic and traffic treatments were 5.6 and 4.2, respectively (Samaranayake et al., 2008). Similar results were evident throughout the current study. Sixteen passes/week of traffic resulted in the lowest overall quality throughout the study and never reached an acceptable quality rating (Table 3-4). Quality of buffalograss receiving 8 passes/week of traffic was only acceptable for the first two weeks, and then fell below acceptable for the remainder of the study. Turf receiving no traffic resulted in higher than acceptable quality 2 – 14 WAI. Two traffic passes/week resulted in 10 weeks of acceptable quality, and 4 passes/week resulted in 8 weeks of acceptable quality. As with the main effect of N, similarities between turfgrass quality, color ($F = 103.40$, $P < 0.0001$), and DGCI ($F = 150.07$, $P < 0.0001$) ratings were observed for traffic (Appendix Tables B-6 and B-7). Applications of 16 passes/week of traffic resulted in the lowest visual color ratings when compared to all other traffic treatments (Table 3-6). Sixteen passes/week had acceptable color at only one rating date (10 WAI); two weeks after the second application of N. Higher than acceptable color was observed for no traffic for all rating periods after trial initiation. The low and moderately-low (2 and 4 passes/week) traffic treatments had acceptable color for 10 and 8 weeks of the study, respectively. Dark green color index values responded to traffic treatments similarly to the ratings of visual buffalograss color (Appendix Table B-9). Under traffic stress, discoloration or browning of the turf can often occur causing a decrease in visual quality and color. Therefore, buffalograss receiving low to moderately low levels of traffic will be able to sustain acceptable quality and color, regardless of N rate applied. Traffic will need to be managed in high traffic areas in buffalograss roughs to reduce the likeliness of decreased quality.

Influence of Simulated Golf Cart Traffic on Compaction

The main effect of traffic on compaction ($F = 8.69$, $P < 0.0001$) was significant at 2, 6, 10, 12, and 14 WAI (Appendix Table B-10). Sixteen passes/week resulted in the highest compaction values and was statistically different than all other traffic treatments on all significant dates except for 10 WAI (Table 3-7). Compaction levels for all other traffic treatments were statistically similar on all rating dates but 12 WAI. Golf cart traffic can have a considerable impact on soil compaction. When compaction has occurred, soil aeration and water movement can greatly be hindered, thus decreasing turfgrass quality and growth (Beard, 1973). These varying compaction levels likely contributed to decreases in digital percent green cover, turfgrass quality, and turfgrass color throughout the study. Compaction measurements with a penetrometer are greatly dependent on soil moisture content. Measurements taken with the FieldScout SC 900 Soil Compaction Meter should be taken after a rainfall or irrigation event because the dry soil conditions will not yield meaningful data (Product Manual, FieldScout SC 900 Soil Compaction Meter, Spectrum Technologies Inc.). Irrigating prior to measurements was not followed because the objectives were to only irrigate to prevent drought stress. Not irrigating prior to compaction measurements may have led to increased soil strength, thus, affecting measurements. High levels of soil strength and compaction may also have led to inaccurate soil moisture ratings. Although a significant main effect of N rate (F = 3.02, P = 0.0315) was observed for soil moisture content when pooled over all dates (Appendix Table B-11), no trend within nitrogen rate was evident between compaction and soil moisture ratings (Appendix Tables B-12).

CONCLUSIONS

The ability of buffalograss to survive in the transition zone with minimal fertility and irrigation makes it an option for rough areas in low-input turfgrass management systems. Regular applications of nitrogen have the ability to increase buffalograss green cover, quality, and color compared to when nitrogen is not applied in areas with and without traffic. Buffalograss can survive in areas of the rough with no- to moderately-low traffic levels with minimal adverse effects. High traffic areas in golf course roughs may require additional traffic management strategies to sustain buffalograss health and appearance.

REFERENCES

Beard, J.B. 1973. Turfgrass: science and culture. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Carroll, M.J. and A.M. Petrovic. 1991. Wear tolerance of Kentucky bluegrass and creeping bentgrass following nitrogen and potassium application. HortScience 26(7):851-853.

Carrow, R.N. and B.J. Johnson. 1996. Turfgrass wear stress: effects of golf car and tire design. HortScience 31(6):968-971.

Frank, K.W., R.E. Gaussoin, T.P. Riordan, R.C. Shearman, J.D. Fry, E.D. Miltner, and P.G. Johnson. 2004. Nitrogen rate and mowing height effects on turf-type buffalograss. Crop Sci.44:1615-1621.

Fry, J.D., M. Kennelly, and R. St. John. 2008. Zoysiagrass: economic and environmental sense in the transition zone. GCM May 2008, 127 – 132.

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

Karcher, D.E. and M.D. Richardson. 2005. Batch analysis of digital images to evaluate turfgrass characteristics. Crop Sci. 45:1536-1539.

Kenna, M.P. and G.L. Horst. 1993. Turfgrass water conservation and quality. p. 99-113. *In* R.E. Carrow, N.E. Christians, and R.C. Shearman (ed.) International turfgrass society research journal 7. Intertec Publishing Corp., Overland Park, Kansas.

Kohlmeier, G.P. and J.L. Eggens. 1983. The influence of wear and nitrogen on creeping bentgrass growth. Can. J. Plant Sci. 63:189-193

Lyman, G.T., C.S. Throssell, M.E. Johnson, G.A. Stacey, and C.D. Brown. 2007. Golf course profile describes turfgrass, landscape, and environmental stewardship features. Online. Applied Turfgrass Science doi:10.1094/ATS-2007-1107-01-RS.

Morris, K.N. and R.C. Shearman. 2014. NTEP turfgrass evaluation guidelines. National Turfgrass Evaluation Program. http://www.ntep.org/cooperator.htm (accessed 21 Jun. 2014).

Richardson, M.D., D.E. Karcher, and L.C. Purcell. 2001. Quantifying turfgrass cover using digital image analysis. Crop Sci. 41:1884-1888.

Riordan, T.P, F.P. Baxendale, R.E. Gaussoin, and J.E. Watkins. 1996. G96-1297 Buffalograss: an alternative native grass for turf (revised October 1998). Historical Materials from University of Nebraska-Lincoln Extension. Paper 1048. http://digitalcommons.unl.edu/extensionhist/1048.

Samaranayake H., T.J. Lawson, and J.A. Murphy. 2008. Traffic stress effects on bentgrass putting green and fairway turf. Crop Sci. 48:1193-1202.

Schiavon, M. 2014. Response of seeded and vegetative buffalograss [*Buchloe dactyloides* (Nutt.)] cultivar to nitrogen fertilization and simulated traffic. In: C05 Turfgrass Science abstracts online. ASA, CSSA, & SSSA International Annual Meeting, Long Beach, CA.

Throssell, C.S., G.T. Lyman, M.E. Johnson, and G.A. Stacey. 2009. Golf course environmental profile measures water use, source, cost, quality, and management and conservation strategies. Online. Applied Turfgrass Science doi:10.1094/ATS-2009-0129-01-RS.

Trenholm, L.E., R.N. Carrow, and R.R. Duncan. 2000. Mechanisms of wear tolerance in seashore paspalum and bermudagrass. Crop Sci. 40:1350-1357.

Trenholm L.E., R.N. Carrow, and R.R. Duncan. 2001. Wear tolerance, growth, and quality of seashore paspalum in response to nitrogen and potassium. HortScience 36(4):780-783.

Watkins, E., A.B. Hollman, and B.P. Horgan. 2010. Evaluation of alternative turfgrass species for low-input golf course fairways. HortScience: 45(1):113-118.

Younger, V.B. 1961. Accelerated wear tests on turfgrasses. Agron. J. 53:217-218.

Table 3-1. N rate effects on green cover of ‘Cody’ buffalograss at the Rocky Ford Turfgrass Research Center in Manhattan, KS in 2014 and 2015.

	Green Cover (%)†							
	WAI§							
Nitrogen Level (lb N‡/1000 ft^2)	0	2	4	6	8	10	12	14
0	79.5 a#	70.8 c	67.6 b	76.1 b	67.8 c	60.2 d	45.2 d	30.1 d
1	79.0 a	76.0 b	69.1 b	78.1 b	70.3 b	69.0 c	54.2 c	37.5 c
2	77.4 ab	81.9 a	75.8 a	81.8 a	74.1 a	75.5 b	61.0 b	41.2 b
3	76.1 b	82.2 a	75.5 a	82.5 a	74.2 a	79.1 a	66.0 a	47.5 a

† Percent buffalograss green cover was evaluated in SigmaScan Pro 5.0 (Hue: 45-107, Saturation 0-100) using digital images taken with a camera light box. Evaluations were on a 0-100% scale where 0% = no green cover, and 100% = complete green cover in the image. Data was pooled across all experimental runs.

‡ Nitrogen (N) (Urea 46-0-0)

§ Weeks after initiation of traffic. Urea treatments (46-0-0) were applied in split half rate applications at trial initiation, and eight weeks after. Urea treatments were applied with a shaker jar in at least two directions. Nitrogen treatment applications were watered in immediately after application with 0.25 inch of water.

Means in a column with like letters are not statistically different according to Fisher’s protected LSD test, ($P \leq 0.05$).

Table 3-2. Traffic effects on green cover of ‘Cody’ buffalograss at the Rocky Ford Turfgrass Research Center in Manhattan, KS in 2014 and 2015.

	Green Cover (%)†							
	WAI‡							
Traffic (passes/week)	0	2	4	6	8	10	12	14
0	79.2	81.4 a§	79.8 a	83.9 a	74.8 a	75.4 a	66.5 a	52.2 a
2	77.6	79.9 a	78.2 a	82.0 a	74.0 ab	75.2 a	62.8 b	45.7 b
4	78.8	79.2 a	74.3 b	82.3 a	72.7 ab	73.4 a	58.4 c	39.5 c
8	77.3	76.3 b	68.7 c	77.2 b	71.5 b	69.5 b	51.9 d	32.7 d
16	77.2	71.9 c	58.7 d	71.9 c	64.9 c	61.1 c	43.5 e	25.2 e

† Percent buffalograss green cover was evaluated in SigmaScan Pro 5.0 (Hue: 45-107, Saturation 0-100) using digital images taken with a camera light box. Evaluations were on a 0-100% scale where 0% = no green cover, and 100% = complete green cover in the image. Data was pooled across all experimental runs.

‡ Weeks after initiation of traffic. Plots designated to receive traffic treatments were trafficked twice per week with the traffic simulator at 0, 1, 2, 4, or 8 passes/day to achieve the full weekly rates. Traffic treatments were conducted for all 14 weeks of the trial period.

§ Means in a column with like letters are not statistically different according to Fisher’s protected LSD test, ($P \leq 0.05$).

Table 3-3. N rate effects on visual quality of ‘Cody’ buffalograss at the Rocky Ford Turfgrass Research Center in Manhattan, KS in 2014 and 2015.

	Visual Quality†							
	WAI§							
Nitrogen Level (lb N‡/1000 ft^2)	0	2	4	6	8	10	12	14
0	5.5	5.8 c#	5.9 c	5.9 b	5.8 c	5.7 c	5.0 d	4.3 d
1	5.5	6.2 b	6.1 bc	6.1 ab	6.2 b	6.1 b	5.5 c	5.0 c
2	5.6	6.4 a	6.3 ab	6.3 a	6.4 a	6.3 b	6.0 b	5.4 b
3	5.6	6.6 a	6.4 a	6.4 a	6.5 a	6.6 a	6.3 a	5.8 a

† Visual quality was rated on a 1 – 9 scale where, 1 = worst, 6 = acceptable quality, and 9 = best. Data was pooled across all experimental runs.

‡ Nitrogen (N) (Urea 46-0-0)

§ Weeks after initiation of traffic. Urea treatments (46-0-0) were applied in split half rate applications at trial initiation, and eight weeks after. Urea treatments were applied with a shaker jar in at least two directions. Nitrogen treatment applications were watered in immediately after application with 0.25 inch of water.

Means in a column with like letters are not statistically different according to Fisher’s protected LSD test, ($P \leq 0.05$).

Table 3-4. Traffic effects on visual quality of ‘Cody’ buffalograss at the Rocky Ford Turfgrass Research Center in Manhattan, KS in 2014 and 2015.

	Visual Quality†							
	WAI‡							
Traffic (passes/week)	0	2	4	6	8	10	12	14
0	5.6	6.6 a§	6.8 a	6.9 a	7.1 a	7.2 a	6.9 a	6.4 a
2	5.5	6.5 a	6.4 b	6.8 a	6.7 b	6.6 b	6.2 b	5.8 b
4	5.7	6.5 a	6.4 b	6.1 b	6.3 c	6.3 b	5.8 c	5.3 c
8	5.5	6.1 b	5.8 c	5.8 c	5.9 d	5.8 c	5.1 d	4.7 d
16	5.7	5.6 c	5.4 d	5.3 d	5.3 e	5.1 d	4.6 e	3.5 e

† Visual quality was rated on a 1 – 9 scale where, 1 = worst, 6 = acceptable quality, and 9 = best. Data was pooled across all experimental runs.

‡ Weeks after initiation of traffic. Plots designated to receive traffic treatments were trafficked twice per week with the traffic simulator at 0, 1, 2, 4, or 8 passes/day to achieve the full weekly rates. Traffic treatments were conducted for all 14 weeks of the trial period.

§ Means in a column with like letters are not statistically different according to Fisher’s protected LSD test, ($P \leq 0.05$).

Table 3-5. N rate effects on visual color of ‘Cody’ buffalograss at the Rocky Ford Turfgrass Research Center in Manhattan, KS in 2014 and 2015.

	Visual Color†							
	WAI§							
Nitrogen Level (lb N‡/1000 ft^2)	0	2	4	6	8	10	12	14
0	5.6 b#	5.7 c	5.6 c	5.9 c	5.7 c	5.6 d	4.7 d	4.2 d
1	5.7 b	6.4 b	6.2 b	6.1 b	6.0 b	6.4 c	5.5 c	4.7 c
2	5.6 b	6.7 a	6.6 a	6.4 a	6.6 a	7.00 b	6.5 b	5.4 b
3	5.9 a	6.9 a	6.7 a	6.6 a	6.6 a	7.5 a	7.0 a	5.9 a

† Visual color was rated on a 1 – 9 scale where, 1 = straw brown, 6 = acceptable green color, and 9 = dark green. Data was pooled across all experimental runs.

‡ Nitrogen (N) (Urea 46-0-0)

§ Weeks after initiation of traffic. Urea treatments (46-0-0) were applied in split half rate applications at trial initiation, and eight weeks after. Urea treatments were applied with a shaker jar in at least two directions. Nitrogen treatment applications were watered in immediately after application with 0.25 inch of water.

Means in a column with like letters are not statistically different according to Fisher’s protected LSD test, ($P \leq 0.05$).

Table 3-6. Traffic effects on visual color of ‘Cody’ buffalograss at the Rocky Ford Turfgrass Research Center in Manhattan, KS in 2014 and 2015.

	Visual Color †							
	WAI‡							
Traffic (passes/week)	0	2	4	6	8	10	12	14
0	5.7	6.9 a§	6.9 a	6.8 a	6.7 a	6.9 a	6.6 a	6.0 a
2	5.6	6.6 b	6.7 b	6.5 b	6.4 ab	6.9 a	6.3 a	5.4 b
4	5.7	6.5 b	6.4 c	6.3 c	6.3 bc	6.6 b	5.9 b	5.1 c
8	5.6	6.3 c	5.9 d	5.9 d	6.1 c	6.5 b	5.5 c	4.6 d
16	5.7	5.9 d	5.6 e	5.7 e	5.7 d	6.3 c	5.3 c	4.2 e

† Visual color was rated on a 1 – 9 scale where, 1 = straw brown, 6 = acceptable green color, and 9 = dark green. Data was pooled across all experimental runs.

‡ Weeks after initiation of traffic. Plots designated to receive traffic treatments were trafficked twice per week with the traffic simulator at 0, 1, 2, 4, or 8 passes/day to achieve the full weekly rates. Traffic treatments were conducted for all 14 weeks of the trial period.

§ Means in a column with like letters are not statistically different according to Fisher’s protected LSD test, ($P \leq 0.05$).

Table 3-7. Traffic effects on penetrometer measurements at a 0 – 4 inch depth under ‘Cody’ buffalograss at the Rocky Ford Turfgrass Research Center in Manhattan, KS in 2014 and 2015.

	Average PSI for 0 – 4 inch Soil Depth †							
	WAI‡							
Traffic (passes/week)	0	2	4	6	8	10	12	14
0	149.7	303.2 b§	435.6	279.7 b	339.4	249.3 c	340.1 c	371.3 b
2	144.0	303.5 b	441.0	283.0 b	338.9	265.6 bc	364.8 bc	412.1 b
4	142.2	316.6 b	449.0	286.7 b	331.6	279.1 bc	326.0 c	378.0 b
8	139.3	294.1 b	449.9	290.2 b	363.1	296.2 ab	393.8 b	417.7 b
16	141.4	356.3 a	449.6	353.8 a	385.3	333.7 a	448.5 a	476.7 a

† Penetrometer ratings were taken with the FieldScout SC 900 Soil Compaction Meter at 1 inch increments from 0 – 4 inches. Readings from each depth were averaged for a composite compaction rating for each plot. A penetrometer is an instrument that measures soil strength and is measured as energy expended per unit depth (PSI). Data was pooled across all experimental runs.

‡ Weeks after initiation of traffic. Plots designated to receive traffic treatments were trafficked twice per week with the traffic simulator at 0, 1, 2, 4, or 8 passes/day to achieve the full weekly rates. Traffic treatments were conducted for all 14 weeks of the trial period.

§ Means in a column with like letters are not statistically different according to Fisher’s protected LSD test, ($P \leq 0.05$).

Chapter 4 - Turfgrass Colorant Longevity and Buffalograss Recovery as Affected by Winter Golf Cart Traffic

This chapter has been prepared using style guidelines for the journal of *Crop, Forage, and Turfgrass Management*

ABSTRACT

Buffalograss [*Buchloe dactyloides* (Nutt.) Engelm] is a warm-season turfgrass species that is dormant between October and May in Kansas. Turfgrass colorants have been evaluated for increasing green color during buffalograss winter dormancy. Little information is available on how golf cart traffic affects the color intensity and longevity of buffalograss treated with colorants. Objectives of this study were to determine the influence of simulated golf cart traffic on color persistence of buffalograss treated with colorants, and buffalograss recovery from winter traffic. Field trials were initiated in the fall of 2014 and 2015 at the Rocky Ford Turfgrass Research Center in Manhattan, KS on 'Cody' buffalograss. Factors were colorant treatments (5), and traffic rates (4). Colorant treatments included Endurant, Endurant Premium, and GreenLawnger turfgrass colorants applied at 10.16 fl oz/1,000 ft^2; perennial ryegrass (*Lolium perenne* L.) seeded at 10 lb/1,000 ft^2; and a non-treated control. Traffic treatments were applied once weekly totaling 0, 2, 4, and 8 passes/week, with a custom-built golf cart traffic simulator. Traffic applied to buffalograss treated with colorants decreased percent green cover, visual color, and visual quality when compared to turf receiving no traffic. Endurant Premium numerically performed best of all colorant treatments resulting in higher than 50% green cover 0 – 5 weeks after treatment in 2014 and 0 – 4 weeks in 2015 when traffic was applied. Overseeding with perennial ryegrass reduced buffalograss cover during the spring transition period. Turfgrass colorants have the ability to increase the length of green winter cover, but persistance and green color is reduced when traffic is applied.

INTRODUCTION

Alternative warm-season turfgrass species have long been considered for use on golf course fairways in the transition zone for the ability to survive under reduced irrigation and maintenance. Buffalograss [*Buchloe dactyloides* (Nutt.) Engelm] is a drought tolerant warm-season turfgrass species that has been cultivated for use in low-input lawns, parks, roadsides, athletic fields, and golf courses in the Great Plains (Wenger, 1943; Beard, 1973; Fry, 1995; McCarty, 1995; Fry and Huang, 2004). Acceptable visual quality of 'NE-91-118', '378', and 'Cody' buffalograss maintained at fairway heights of 1 inch have been observed in Kansas and Nebraska. (Frank et al., 2004).

Although buffalograss maintains acceptable quality during summer months with reduced irrigation and maintenance, its prolonged winter dormancy is of concern due to its unacceptable brown appearance (Severmutlu et al., 2005). Similar to other warm season turfgrass species cultivated in the transition zone, buffalograss will lose its green color at the onset of cooler temperatures in the early fall, and will not regain full color until later in the spring (Hoyle et al., 2014). To achieve prolonged winter color, turfgrass managers in the transition zone commonly overseed bermudagrass [*Cynodon* spp.] with cool-season turfgrass species, or more recently, apply turfgrass colorants. Overseeding can provide extended playability during the winter months, but this process can be very costly in terms of money, irrigation, and disruption of the primary turfgrass stand (Horgan and Yelverton, 2001; Briscoe et al., 2010). Therefore, turfgrass managers have begun using turfgrass colorants to reduce cost and potential issues associated with overseeding warm-season turf (Briscoe et al., 2010).

Various turfgrass colorants have been evaluated on multiple warm-season turfgrass species, and can extend green color and quality during the winter dormancy period. LESCO Green (LESCO, Strongsville, Ohio) applied to buffalograss at of 8.25 fl oz/1,000 ft^2 improved visual color and quality ratings in comparison to untreated turf (Shearman et al., 2005). During this study, the labeled rate for turfgrass colorant application provided higher than acceptable quality (≥ 6) throughout the study period, although, applications at twice the labeled rate (16.5 fl oz/1,000 ft^2) provided enhanced color and quality ratings (Shearman et al., 2005). Buffalograss treated with Green Lawnger (BASF Corp., Research Triangle Park, North Carolina), Wintergreen Plus (Precision Laboratories, Inc., Waukegan, Illinois), and Endurant (Geoponics Corp., Naples, Florida) turfgrass colorants (1:6 colorant to water dilution) at 100 gal/acre had acceptable turfgrass color ratings 8 – 12 weeks after application, whereas applications at 160 gal/acre increased acceptable color for an additional week (Braun, 2014). Therefore, increased intensity and longevity of green color during winter dormancy can be achieved with higher application rates and spray volumes. In low-input turfgrass management systems, higher application rates are not cost effective, and lower application rates need to be considered. Additionally, golf course turf treated with colorants may still experience stresses from golf carts in the winter, which may also reduce the longevity of green color from turfgrass colorants.

Traffic from golf carts during the dormancy period has the potential to greatly decrease the quality of a turfgrass stand. Golf cart traffic imposes stress on the turf through wear and compaction (Beard, 1973; Kohlmeier and Eggens, 1983; Carroll and Petrovic, 1991; Carrow and Johnson, 1996; Trenholm et al., 2000; Trenholm et al., 2001; Samaranayake et al., 2008). Movement across turf with golf carts can physically abrade, scuff, or tear turfgrass leaf tissue from a golf cart tire (Beard, 1973). Compaction from repeated trafficking also has the ability to affect turfgrass growth during the growing season by limiting oxygen in the root zone, increasing soil strength, and reducing rooting (Trenholm et al., 2000). Due to the inability of warm-season turfgrass species to recover during winter dormancy, wear from golf cart traffic could potentially result in decreased density. Wear from golf cart tires could also potentially remove leaf material where turfgrass colorants have been applied, resulting in poor quality and color.

Although buffalograss can be maintained as an acceptable fairway turf under minimal irrigation and fertility, its prolonged dormancy period is of concern in the transition zone (Frank et al., 2004). Turfgrass colorants are an option for sustaining green color during winter dormancy of buffalograss, although the longevity and intensity of color from colorant applications needs further investigation when traffic is applied. The objectives of this study were to determine the influence of simulated golf cart traffic on color persistence of turfgrass colorant-treated buffalograss, and buffalograss recovery from winter trafficking.

MATERIALS AND METHODS

Research Site Information

Field studies were initiated on a ‘Cody’ buffalograss fairway maintained at 0.625 inch at the Rocky Ford Turfgrass Research Center in Manhattan, KS on 14 September 2014 and 17

September 2015. The research trial in 2014 was conducted on mature ‘Cody’ buffalograss established in 2006. Soil was a Chase silty clay loam (fine, montmorrillonitic, mesic Aquertic Argiudolls) with a pH of 6.8 and 2.7% organic matter. Prior to study initiation on 17 June 2014 and 1 July 2014, thiencarbazone-methyl + idosulfuron-methyl-sodium + dicamba was applied at 0.085 oz of product/1,000 ft^2 and oxadiazon 3-[2,4-dichloro-5-(1-methyloxy)phenyl]-5-(1,1-dimethylethyl)-1,3,4-oxadiazol-2(3H)-one was applied at 2 lb product/1,000 ft^2, respectively, to remove existing broadleaf and grassy weeds and to prevent annual weed encroachment.

In 2015, research was conducted on ‘Cody’ buffalograss planted 18 May 2015. Buffalograss was seeded at 4 lb/1,000 ft^2 with a slit-seeder in four directions immediately followed by a starter fertilizer (18-24-12) application at 1 lb P_2O_5/1,000 ft^2. After seeding, irrigation was applied three times weekly to provide 1 inch per week for 4 weeks to assist in seeding establishment. Thereafter, irrigation was only applied to prevent drought stress (.25 - .50 inch/week). Two weeks after seeding, quinclorac (3,7-dichloro-8-quinolinecarboxylic acid) was applied at 1.45 fl oz product/1,000 ft^2 for post-emergent grassy weed control. Mesotrione was applied four weeks after seeding at 0.11 fl oz product/1,000 ft^2 for further post-emergent broadleaf and grassy weed control. A second fertilizer (28-0-3) (N source from urea) application was applied six weeks after seeding at 1 lb N/1,000 ft^2. Dormant applications of glyphosate (N-(phosphonomethyl)glycine) were made at both sites at 4 pt or product/acre (GlyphoMate 41, Gordon’s Professional, PBI-Gordon Corp., Kansas City, MO) to remove annual and perennial grassy weeds during the study periods. Spray volume for all herbicide applications was 43 GPA.

Field Study Design

Field studies were arranged in a strip-plot design with a 5 × 4 factorial treatment structure. Main effects included winter color (5) and simulated golf cart traffic rates (4). Colorant treatments were: untreated turf, Endurant (E) (Geoponics Corp., Naples, Florida), Endurant Premium (EP) (Geoponics Corp., Naples, Florida), GreenLawnger (GL) (BASF Corp., Research Triangle Park, North Carolina), and overseeded perennial ryegrass (*Lolium perenne* L.) (OPR) (Champion GQ perennial ryegrass blend: 39.48% Sideways perennial ryegrass; 38.86% Exacta II GSLR perennial ryegrass; and 19.33% SR4600 perennial ryegrass). Simulated golf cart traffic rates consisted of 0, 2, 4, and 8 passes/week. Colorants were applied to the whole plots (20 ft × 5 ft), with traffic treatments striped across the whole plots (5 ft × 25 ft).

Treatment Application

Colorants were applied at 10.16 fl oz/1,000 ft^2 using a three-nozzle, CO_2 pressurized hand-held sprayer with 8002VS nozzles with a calibrated spray volume of 1 gal/1,000 ft^2. Colorants were mixed and applied at a 1:6 colorant to water dilution in accordance with label recommendations. Colorants were applied in one direction to each respective whole plot. Colorant applications were made on 24 October 2014 and 5 November 2015 for each study respectively when the 'Cody' buffalograss was visually determined to have approximately 10 to 20% green canopy color remaining during the onset of winter dormancy.

Perennial ryegrass was seeded into established buffalograss on 14 September 2014 and 17 September 2015. Perennial ryegrass was slit seeded (walk-behind Ryan Mataway overseeder) at 5 lb/1,000 ft^2 in two directions. A starter fertilizer (18-24-12) was broadcast applied to the whole plots receiving perennial ryegrass treatments immediately following seeding. Overseeded plots were irrigated with a hand-held hose as needed until the perennial ryegrass was established. In order to determine buffalograss recovery, perennial ryegrass was removed with flazasulfuron applications on 24 April 2015 and 8 April 2016 at 0.034 oz product/1,000 ft^2.

Simulated golf cart traffic treatments were applied once per week to provide 0, 2, 4, or 8 passes. Traffic treatments were applied with a custom built golf cart traffic simulator pulled behind a turf utility vehicle. The traffic simulator consisted of two trailers, each with a single axle, containing five golf cart tires (Watkins et al., 2010). Each trailer was fitted with two 55 gal barrels which were filled with water so that each trailer weighed 1,000 lb, which was equivalent to an electric-powered golf cart holding two occupants and two sets of golf clubs.

Data Collection and Analysis

Data were collected monthly after trial initiation until perennial ryegrass removal. Additional ratings were conducted on 16 June 2015 and 20 May 2016 to evaluate buffalograss recovery from winter traffic and OPR removal. At trial initiation and termination of both study years, bulk density was determined by Equation 1 in accordance to USDA-NCRS methods:

$$Bulk\ Density\ \left(\frac{g}{cm^3}\right) = \frac{Dry\ Weight\ of\ Soil\ Core\ (g)}{Volume\ of\ Soil\ Core\ (cm^3)}$$

where volume of the soil core was 132.37 cm^3 (USDA-NCRS). One soil bulk density sample was collected from each traffic treatment in all replications.

Visual evaluations included visual turfgrass color and quality. Turfgrass color was rated on a 1 - 9 scale, where 1 = straw brown, 6 = acceptable color, and 9 = dark green color (Morris and Shearman, 2014). Quality evaluations were also evaluated based on a 1 - 9 scale, where 1 = poor, 6 = acceptable quality, and 9 = best (Morris and Shearman, 2014).

Digital images were collected on each rating date with a Nikon D5000 digital camera (Nikon Inc., Tokyo, Japan) and a custom built camera light box (20 inch × 24 inch × 22 inch). Digital image analysis was conducted according to the methods of Richardson et al., 2001 and Karcher and Richardson, 2005. Images were analyzed in SigmaScan Pro 5.0 (50 – 107 hue and 0 – 100 saturation) (v. 5.0, 1998; Systat Software, Inc., San Jose, CA). Dark green color index (DGCI) values were calculated from digital images according to Karcher and Richardson (2003) shown in Equation 2:

$$DGCI\ value = \frac{[\frac{(hue - 60)}{60} + (1 - saturation) + (1 - brightness)]}{3}$$

DGCI values range from 0 to 1, where 0 = no green color, and 1 = dark green color.

Additionally, during the 2014 – 2015 study, soil temperature and turfgrass canopy temperature were evaluated on 13 May 2015, 27 May 2015, and 10 April 2015. Soil temperature was measured at a 2 inch depth and averaged from three samples in each plot with a digital T-bar thermometer (Argus Realcold Property Ltd., Coopers Plains, Australia). Turfgrass canopy temperatures were measured from a height of 4 ft using a handheld infrared thermometer (Model #IR002, Ryobi, One World Technologies Inc., Anderson, South Carolina).

Main effects and their interactions were analyzed using Proc Glimmix in SAS (SAS Institute, 2008). Mean separation was determined using Fisher’s Protected LSD procedure at $P \leq 0.05$. A significant treatment by year interaction was observed for digital percent green cover ($F = 13.46$, $P = <0.0001$), DGCI ($F = 22.02$, $P = <0.0001$), visual green color ($F = 4.19$, $P = <0.0001$), and visual quality ($F = 13.55$, $P = <0.0001$); Therefore data were not combined across years.

RESULTS AND DISSCUSSION

Effect of Winter Color and Traffic Treatments on Digital Percent Green Cover

For the 2014 winter trial, significant main effects of traffic rate (F = 200.76, P = <0.0001) and winter color (F = 28.23, P = <0.0001) were observed. In addition, a traffic rate by color (F = 3.32, P = 0.0011) interaction occurred for green cover. Similarly, significant traffic rate (F = 484.13, P = <0.0001) and color (F = 18.59, $P < 0.0001$) main effects, and traffic rate by color (F = 3.09, P = 0.0020) interaction was observed for the 2015 winter trial. Within each year, as traffic rate increased, the digital percent green cover of buffalograss treated with turfgrass colorants decreased over time. Furthermore, turfgrass colorant treatments varied in digital percent green cover across each experimental run.

Prior to colorant treatment application in 2014, buffalograss percent green cover was 30.7%, with OPR averaging 95.8% green cover. Before turfgrass colorant application in 2015, buffalograss green cover over all traffic and colorant applications was 9.6%, and OPR plots were 85.7%. Turfgrass colorant products applied to semi-dormant turfgrass is preferred to fully dormant turf due to greater background color at colorant application (Miller, 2011). In 2015, a rapid temperature decrease resulted in the buffalograss entering winter dormancy faster than expected. This lower initial percent green cover of buffalograss led to lower green cover values after colorant application and throughout the 2015 study. Immediately after turfgrass colorant application in 2015, green cover for OPR, EP, E, GL, and untreated turf (across all traffic rates) were 86.4, 88.0, 65.9, 42.5, and 6.40%, respectively (Table 4-2) Whereas in 2014, green cover for OPR, EP, E, GL, and untreated turf were 96.1, 95.7, 71.2, 71.5, and 32.3%, respectively (Table 4-1).

Endurant Premium numerically performed best of all colorant treatments applied in 2014. Four WAT, percent green cover ratings for EP with 0, 2, 4, and 8 passes/week of traffic were 85.36, 75.55, 64.58, and 64.27%, respectively, which were different than values for E and GL. Sixteen WAT, EP with traffic rates of 0, 2, 4, and 8 passes/week resulted in higher percent green cover values which were different than OPR. Overseeded perennial ryegrass has long been the preferred method for sustaining green color and playability of bermudagrass during the winter months. In the past, the cost associated with overseeding greens on a golf courses ranged from \$2,500 - \$5,000 per acre, while applications of turfgrass colorants would cost between \$700 -

$2,000 (Liu et al., 2007; Briscoe et al., 2010). During 2014 of this study, percent green cover for EP at 0, 2, 4, and 8 passes/week were 69.53, 43.50, 29.47, and 22.66%, respectively, when compared to 18.35, 10.42, 7.00, and 4.57%, respectively for OPR. Therefore, during the 2014 study period, EP would be more cost effective, and sustained green cover longer than OPR during winter dormancy.

In 2015, EP performed numerically best of all colorant treatments applied, although, lower initial values for percent cover were observed immediately after colorant application. Four WAT, buffalograss treated with EP had 63.2, 43.94, 46.81, and 31.01% green cover for 0, 2, 4, and 8 passes/week, respectively, which were higher than the values for E and GL under the same traffic conditions (Table 4-2). Sixteen WAT, green cover of turf for EP at 0 passes/week was 56.22%, when compared to 54.50% for OPR (not statistically different). Although, OPR 16 WAT with traffic rates of 2, 4, and 8 passes/week resulted in 52.06, 45.76, and 49.05%, respectively, in comparison to 28.10, 26.95, and 14.33% for EP. During the 2015 study, buffalograss receiving OPR had higher values for percent green cover longer than colorants. Turfgrass colorant performance can be highly variable based on application conditions. As previously mentioned, turfgrass colorant applications to semi-dormant turf performed better than when applications made to fully dormant turf (Miller, 2011). During 2014, colorant applications were made when the average green cover of buffalograss was 30.7%, this resulted in more initial background color in the turfgrass canopy, allowing for better turfgrass colorant performance, with EP sustaining higher values of green cover in comparison to all other winter color treatments. Colorant applications in 2015 were applied to buffalograss with 9.6% green cover, resulting in lower green cover values initially and throughout the study. Although OPR sustained the highest percent green cover values in 2015, complications from the OPR treatment were observed during both study years.

Issues during the spring transition from overseeded perennial ryegrass to the favored warm-season species can be created due to improved cultivars and varying weather conditions (Horgan and Yelverton, 2001). During the 2014 and 2015 study, OPR treatment was chemically removed once the surrounding buffalograss began to green up after winter dormancy. Significant reductions in percent green buffalograss cover were observed at the recovery rating dates during both studies. Thirty-four WAT (data not presented) in 2014, percent green buffalograss cover (over all traffic rates and colorant treatments) was 54.1%, but 12.4% for OPR (averaged over traffic rates). Similarly, percent green buffalograss cover averaged over all traffic rates and colorant 28 WAT (data not presented) in 2015 was 77.6%, and 44.2% for OPR (averaged over traffic rates). Due to buffalograss' fine-textured canopy, soft leaf blades, slow growth characteristics, and unfavorable competition from OPR, resulted in slow buffalograss recovery rates during the spring transition period (Beard, 1973).

During 2014 and 2015, percent green cover of the buffalograss treated with turfgrass colorants decreased with all traffic rates, although differences were observed for each traffic treatment. Percent green cover for EP, E, and G 4 WAT (2014) with 8 passes/week of traffic resulted in 64.27, 9.48, and 8.87%, respectively. Sixteen WAT (2014), 8 passes/week applied to buffalograss treated with EP, E, and G resulted in 22.66, 2.49, and 2.37% green cover. Stresses from golf cart traffic on the turfgrass is a combination of wear and compaction (Beard, 1973; Kohlmeier and Eggens, 1983; Carroll and Petrovic, 1991; Carrow and Johnson, 1996; Trenholm et al., 2000; Trenholm et al., 2001; Samaranayake et al., 2008). Wear is the direct abrasion, scuffing, or tearing of the leaf tissue from the crown of the plant. Compaction from golf cart traffic affects plant growth during the growing season through the root system by reducing oxygen in the root zone, decreasing root penetration, and reducing rooting. During 2014 and 2015, compaction was evaluated with bulk density measurements; however, no significant main effect or interaction occurred. Furthermore, wear from the golf cart traffic significantly decreased buffalograss color through the abrasion from the tire on the leaf tissue, resulting in a dulling or reduction in green color intensity. Percent green cover reduction under traffic stress can also be attributed to the loss of leaf tissue from the ripping and tearing action of the tire on the leaf blade. The abrasive and compaction forces from a golf cart tire can also greatly decrease the color and quality of a turfgrass stand after applications of turfgrass colorants.

Influence of Traffic and Color Treatments on Turfgrass Color and Quality

Significant main effects and their interaction were observed for visual color during 2014 (Winter Color – $F = 334.31$, $P < 0.0001$; Traffic Rate – $F = 124.04$, $P < 0.0001$; Winter Color × Traffic Rate – $F = 12.19$, $P < 0.0001$) and 2015 (Winter Color – $F = 418.66$, $P < 0.0001$; Traffic Rate – $F = 94.34$, $P < 0.0001$; Winter Color × Traffic Rate – $F = 13.72$, $P < 0.0001$) (Table 4-3). Although an interaction did not occur for traffic rate and winter color treatments, differences in dark green color index were also observed during both years of the study (Appendix Tables C-1 and C-2).

During both study years, visual color of buffalograss receiving all colorant treatments decreased over time, however, the reduction in green color was more rapid with applications of traffic. Buffalograss treated with EP, E, and GL with 2, 4, and 8 passes/week of traffic were only observed to have acceptable color (≥ 6) immediately after colorant application during 2014 and 2015 (Tables 4-4 and 4-5). Four WAT in 2014, when traffic was not applied, color of turf treated with EP and GL were 7.75 and 6.25, respectively. During 2015, 4 WAT, EP and E resulted in buffalograss color ratings of 6.50 and 6.75, respectively, when traffic was not applied. Endurant Premium provided higher than acceptable buffalograss quality for 16 WAT during the 2015 study. Braun (2014) observed acceptable 'Sharpshooter' and 'Cody' buffalograss color ratings 8 to 12 WAT when GL, E, and Wintergreen Plus were applied at 100 gal/acre, and acceptable color for 8 to 14 WAT when colorants were applied at 160 gal/acre. It is widely accepted that increased application volumes for turfgrass colorants will increase green color intensity and persistence. Increasing application volume at the same 1:6 colorant to water dilution will also increase the rate of product used, making the colorant application more costly. The current study has demonstrated that better buffalograss color can be achieved with applications of colorants at lower application volumes; however, duration of acceptable green color will be limited with traffic applications. Furthermore, Endurant Premium sustained higher than acceptable buffalograss color for 16 WAT during the 2015 study when applied at 10.16 fl oz/1,000 ft^2 when traffic was not applied. Traffic applications to buffalograss treated with turfgrass colorants ultimately led to a more rapid reduction in visual green cover, therefore, a similar effect may be observed through visual quality observations.

Main effects (Winter Color – $F = 88.80$, $P = < 0.0001$; Traffic Rate - $F = 76.91$, $P = < 0.0001$) and their interaction ($F = 3.98$, $P = 0.0002$) were only observed to be significant during 2015 for visual buffalograss quality. Regardless of traffic rate, OPR never provided acceptable quality. Quality ratings for buffalograss treated with EP and E were acceptable for 4 WAT when traffic was not applied. Traffic applications of 2, 4, and 8 passes/week to turf treated with EP, E, and GL provided acceptable quality ratings immediately after treatment application, quickly declining after traffic had been applied (Table 4-6). Sixteen WAT, EP, E, and GL at 0 passes/week of traffic resulted in quality values that were higher (5.75, 5.75, and 5.00, respectively) and statistically different than that of OPR (4.25). Shearman et al. (2005) reported that applications of LESCO Green turfgrass colorant increased the turfgrass quality of buffalograss. Ratings for turfgrass quality for 15 January 2002, 28 January 2002, and 23 April 2002 were 6.2, 6.5, and 7.0, respectively. This past research has shown that turfgrass quality can be enhanced with turfgrass colorant application under no traffic situations. Quality of a turfgrass stand will greatly be affected by traffic applications. Past research considering turfgrass quality and traffic has noted that quality ratings of trafficked turf were much lower than untrafficked turf (Trenholm et al., 2001). The main difference between past traffic research and the present study is that the present study was conducted during dormancy. During dormancy the plant is not actively growing, and therefore not able to recuperate from traffic damage. This ripping and tearing action of the leaf tissue from the crown of the plant was the main observation for the reduction in turfgrass quality.

Canopy and Soil Temperatures as Effected by Traffic Rate and Winter Color Treatments

When considering canopy temperature, significant main effects of winter color (F = 21.18, P = <0.0001) and traffic rate (F = 9.29, P = <0.0001) occurred; an interaction was not observed (F = 0.61, P = 0.8286). Statistical similarities for canopy temperature were observed for E, EP, G, and untreated turf, but all had statistically higher canopy temperatures than OPR. Canopy temperature was inversely related to traffic rate; as traffic rates increased canopy temperature decreased. Although canopy temperature was increased by the application of turfgrass colorants, statistical significance was not found for data collected for soil temperature. In theory, the application of turfgrass colorants would increase canopy and soil temperatures to a point that would elicit a quicker spring green-up from the turf. The application of turfgrass colorants in the present study did not increase the spring green-up of buffalograss.

CONCLUSIONS

When traffic is applied to dormant buffalograss that has been treated with turfgrass colorants, percent green cover will decrease more rapidly than when traffic is not applied. Throughout both years of the study, EP performed numerically best out of all colorant treatments, but it was also observed that the longevity of green cover and color from turfgrass colorants can be highly variable from year to year. Buffalograss has shown the ability to recover after repeated winter trafficking when overseeding is not used. Under no or limited traffic situations, turfgrass colorants have the ability to increase the length of green winter cover, while reducing summer irrigation inputs using buffalograss.

REFERENCES

Beard, J.B. 1973. Turfgrass: science and culture. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Braun, R. 2014. Cultural strategies to improve zoysiagrass acceptability and performance in the transition zone. M.S. Thesis. Kansas State Univ., Manhattan, KS.

Briscoe, K., G. Miller, and S. Brinton. 2010. Evaluation of green turf colorants as an alternative to overseeding on putting greens. Online. Applied Turfgrass Science doi:10.1094/ATS-2010-0326-02-RS.

Carroll, M.J. and A.M. Petrovic. 1991. Wear tolerance of Kentucky bluegrass and creeping bentgrass following nitrogen and potassium application. HortScience 26(7):851-853.

Carrow, R.N. and B.J. Johnson. 1996. Turfgrass wear stress: effects of golf car and tire design. HortScience 31(6):968-971.

Frank, K.W., R.E. Gaussoin, T.P. Riordan, R.C. Shearman, J.D. Fry, E.D. Miltner, and P.G. Johnson. 2004. Nitrogen rate and mowing height effects on turf-type buffalograss. CropSci.44:1615-1621.

Fry, J.D. 1995. Establishing buffalograss. Golf Course Management. 63(4): 58-62.

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

Horgan, B.P and F.H. Yelverton. 2001. Removal of perennial ryegrass from overseeded bermudagrass using cultural methods. Crop Sci. 41:118-126.

Hoyle, J.A., S. Keeley, and M. Fagerness. 2014. Buffalograss lawns (MF658). Kansas State University Agricultural Experiment Station and Cooperative Extension Service. Manhattan, KS.

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

Karcher, D.E. and M.D. Richardson. 2005. Batch analysis of digital images to evaluate turfgrass characteristics. Crop Sci. 45:1536-1539.

Kohlmeier, G.P. and J.L. Eggens. 1983. The influence of wear and nitrogen on creeping bentgrass growth. Can. J. Plant Sci. 63:189-193.

Liu, H., B.L. McCarty, C.M. Baldwin, W.G. Sarvis, and S.H. Long. 2007. Painting dormant bermudagrass putting greens. Golf Course Management. 75(11):86-91.

McCarty, L.B. 1995. Buffalograss, description and use. University of Florida Cooperative Extension Service. p. 1-4.

Miller, G. 2011. Turning fields green using turf colorants. SportsTurf. 27(12): 16-19.

Morris, K.N. and R.C. Shearman. 2014. NTEP turfgrass evaluation guidelines. National Turfgrass Evaluation Program. http://www.ntep.org/cooperator.htm (accessed 21 Jun. 2014).

USDA-NCRS. Soil bulk density/ moisture/ aeration. Soil Quality Kit – Guides for Educators. United States Department of Agriculture – Natural Resources Conservation Service.

Richardson, M.D., D.E. Karcher, and L.C. Purcell. 2001. Quantifying turfgrass cover using digital image analysis. Crop Sci. 41:1884-1888.

Samaranayake H., T.J. Lawson, and J.A. Murphy. 2008. Traffic stress effects on bentgrass putting green and fairway turf. Crop Sci. 48:1193-1202.

Severmutlu, S., T.P. Riordan, R.C. Shearman, R.E. Gaussoin, and L.E. Moser. 2005. Overseeding buffalograss turf with fine-leaved fescues. Crop Sci. 45:704-711.

Shearman, R.C., L.A. Wit, S. Severmutlu, H. Budak, and R.E. Gaussoin. 2005. Colorant effects on dormant buffalograss turf performance. HortTechnology 15:244-246.

Throssell, C.S., G.T. Lyman, M.E. Johnson, G.A. Stacey. 2009. Golf course environmental profile measures water use, source, cost, quality, and management and conservation strategies. Online. Applied Turfgrass Science doi:10.1094/ATS-2009-0129-01-RS.

Trenholm, L.E., R.N. Carrow, and R.R. Duncan. 2000. Mechanisms of wear tolerance in seashore paspalum and bermudagrass. Crop Sci. 40:1350-1357.

Trenholm L.E., R.N. Carrow, and R.R. Duncan. 2001. Wear tolerance, growth, and quality of seashore paspalum in response to nitrogen and potassium. HortScience 36(4):780-783.

Wenger, L.E. 1943. Buffalo grass. Agricultural Experiment Station. Kansas State College of Agriculture and Applied Science. Manhattan, KS. Bulletin 32.

Table 4-1. Interaction of winter color treatments and traffic for their effect on green cover at the Rocky Ford Turfgrass Research Center in Manhattan, KS in 2014.

		Green Cover (%)†								
		WAT#								
Winter Color‡	Traffic Rate§	0	4		8		16		24††	
Perennial Ryegrass	0	96.82	74.91	abc¶	55.48	b	18.35	d	73.49	a
	2	96.88	73.04	bc	44.16	c	10.42	efg	71.00	a
	4	95.54	67.29	bcd	34.71	d	7.00	fgh	69.41	ab
	8	94.97	61.21	d	27.51	de	4.57	gh	60.65	b
Endurant Premium	0	95.48	85.36	a	72.71	a	69.53	a	59.91	b
	2	96.35	75.55	ab	46.61	bc	43.50	b	38.21	c
	4	94.23	64.58	cd	31.37	d	29.47	c	32.45	cdef
	8	96.64	64.27	cd	25.57	def	22.66	cd	22.89	ghi
Endurant	0	70.76	25.71	ef	16.52	fgh	15.80	def	36.45	cd
	2	68.18	17.81	efg	9.18	ghi	7.17	fgh	28.31	defg
	4	72.92	10.41	ghi	4.33	i	3.66	gh	26.08	efghi
	8	72.89	9.48	ghi	4.49	i	2.49	gh	20.83	ghi
Green Lawnger	0	70.91	28.74	e	19.73	efg	17.99	de	34.21	cde
	2	69.92	16.16	fgh	9.14	hi	7.59	fgh	27.15	defgh
	4	70.37	13.07	ghi	6.85	hi	4.97	gh	22.45	ghi
	8	74.63	8.87	ghi	3.78	i	2.37	gh	17.66	i
Untreated	0	33.79	5.37	hi	6.13	hi	4.01	gh	19.81	ghi
	2	30.20	1.98	i	2.24	i	1.62	gh	20.45	ghi
	4	31.29	2.30	i	2.93	i	1.66	gh	23.67	fghi
	8	33.82	1.61	i	2.22	i	1.08	h	17.71	hi

† First year of a two year study was conducted during the winter and spring months of 2014 – 2015 with colorant application on 24 October 2014 on ‘Cody’ buffalograss maintained at fairway height. Digital images were analyzed with SigmaScan Pro 5.0 (Hue: 50-107, Saturation: 0-100) for pixel estimation of percent green cover.

‡ The overseeded perennial ryegrass treatment was slit-seeded in two directions at 5 lb/1,000 ft^2 on 14 September 2014. Turfgrass colorant applications were applied using a handheld CO_2 sprayer with 8002VS nozzles at 10.16 fl oz/1,000 ft^2 at a 1:6 colorant to water dilution on 24 October 2014.

§ Plots designated to receive traffic treatments were trafficked once per week with a traffic simulator at 0, 2, 4, or 8 passes/week.

# Indicates weeks after treatment.

¶ Means in a column with like letters are not statistically different according to Fisher’s protected LSD test, ($P \leq 0.05$).

†† Date at which the overseeded perennial ryegrass treatment was removed with flazasulfuron at 0.034 oz product/1,000 ft^2.

Table 4-2. Interaction of winter color treatments and traffic for their effect on green cover at the Rocky Ford Turfgrass Research Center in Manhattan, KS in 2015.

		Green Cover (%)†									
		WAT#									
Winter Color‡	Traffic Rate§	0		4		8		16		22††	
Perennial Ryegrass	0	87.94	a¶	86.48	a	84.13	a	54.50	a	96.97	a
	2	86.60	a	85.98	a	79.69	ab	52.06	ab	98.16	a
	4	84.23	a	84.43	a	75.20	b	45.76	b	96.65	a
	8	86.71	a	84.23	a	76.17	b	49.05	ab	97.49	a
Endurant Premium	0	87.92	a	63.20	b	48.18	c	56.22	a	71.65	b
	2	85.23	a	43.94	c	27.07	d	28.10	c	54.26	d
	4	91.30	a	46.81	c	29.81	d	26.95	c	48.94	e
	8	87.37	a	31.01	d	14.95	ef	14.33	de	40.16	fg
Endurant	0	67.36	bc	29.94	d	17.85	e	23.02	dc	63.68	c
	2	62.30	c	17.31	e	7.58	fgh	9.85	ef	45.95	e
	4	71.53	b	19.28	e	8.30	gf	8.60	efg	41.83	f
	8	62.36	c	10.42	fg	2.94	ghi	2.85	fg	32.40	hi
Green Lawnger	0	44.87	d	12.24	ef	7.52	fgh	4.43	fg	47.70	e
	2	42.62	d	8.90	fg	3.37	ghi	2.23	fg	36.07	gh
	4	35.60	e	5.35	gf	2.46	ghi	1.83	fg	29.73	ij
	8	46.98	d	4.14	gh	1.80	ghi	0.71	fg	29.80	ij
Untreated	0	6.82	f	0.36	h	0.22	hi	0.07	g	29.39	ij
	2	7.78	f	0.24	h	0.14	hi	0.07	g	24.38	jk
	4	4.91	f	0.15	h	0.06	hi	0.05	g	22.13	k
	8	6.08	f	0.39	h	0.14	hi	0.05	g	20.41	k

†Second year of a two year study was conducted during the winter and spring months of 2015 - 2016 with colorant application on 5 November 2015 on ‘Cody’ buffalograss maintained at fairway height. Digital images were analyzed with SigmaScan Pro 5.0 (Hue: 50-107, Saturation: 0-100) for pixel estimation of percent green cover.

‡The overseeded perennial ryegrass treatment was slit-seeded in two directions at 5 lb/1,000 ft^2 on 17 September 2015. Turfgrass colorant applications were applied using a handheld CO_2 sprayer with 8002VS nozzles at 10.16 fl oz/1,000 ft^2 at a 1:6 colorant to water dilution on 5 November 2015.

§ Plots designated to receive traffic treatments were trafficked once per week with a traffic simulator at 0, 2, 4, or 8 passes/week.

# Indicates weeks after treatment.

¶ Means in a column with like letters are not statistically different according to Fisher’s protected LSD test, ($P \leq 0.05$).

†† Date at which the overseeded perennial ryegrass treatment was removed with flazasulfuron at 0.034 oz product/1,000 ft^2.

Table 4-3. Analysis of variance for winter color and traffic rate treatments and their effect on visual color at the Rocky Ford Turfgrass Research Center in Manhattan, KS.

	2014 - 2015		2015 - 2016	
Effect	F Value	Pr > F†	F Value	Pr > F
Winter Color	334.31	<0.0001	418.66	<0.0001
Traffic Rate	124.04	<0.0001	94.34	<0.0001
Winter Color × Traffic Rate	12.19	<0.0001	13.72	<0.0001

†Effects were determined to be statistically significant when $P \leq 0.05$.

Table 4-4. Interaction of winter color treatments and traffic for their effect on visual color at the Rocky Ford Turfgrass Research Center in Manhattan, KS in 2014.

		Visual Color†								
		WAT#								
Winter Color‡	Traffic Rate§	0	4		8		16		24††	
Perennial Ryegrass	0	8.00	7.00	ab¶	4.75	a	3.00	b	6.00	a
	2	8.00	6.25	c	3.75	b	2.00	c	5.50	ab
	4	8.00	5.75	cd	3.25	bc	1.25	d	5.00	bc
	8	8.00	5.00	d	3.25	bc	1.25	d	4.75	bcd
Endurant Premium	0	8.00	7.75	a	5.50	a	4.75	a	6.00	a
	2	8.50	5.75	cd	3.25	bc	2.75	b	3.75	efg
	4	8.25	5.00	d	3.00	bcd	2.00	c	3.75	efg
	8	8.25	4.00	e	2.25	def	2.00	c	3.00	g
Endurant	0	7.50	5.75	cd	2.75	cde	2.50	bc	4.75	bcd
	2	7.75	4.00	e	2.00	efg	1.25	d	3.50	efg
	4	8.00	3.50	ef	1.75	fgh	1.25	d	3.25	fg
	8	7.50	2.00	gh	1.25	gh	1.00	d	3.25	fg
Green Lawnger	0	7.50	6.25	bc	3.50	bc	3.00	b	4.25	cde
	2	7.75	3.00	f	1.50	fgh	1.25	d	4.00	def
	4	7.50	2.75	fg	1.75	fgh	1.00	d	3.25	fg
	8	7.75	1.75	hi	1.00	h	1.00	d	3.50	efg
Untreated	0	3.25	1.25	hi	1.00	h	1.00	d	3.75	efg
	2	3.75	1.00	i	1.00	h	1.00	d	3.50	efg
	4	3.75	1.25	hi	1.00	h	1.00	d	3.50	efg
	8	4.00	1.00	i	1.00	h	1.00	d	3.00	g

† First year of a two year study was conducted during the winter and spring months of 2014 – 2015 with colorant application on 24 October 2014 on ‘Cody’ buffalograss maintained at fairway height. Visual color was rated on a 1 – 9 scale where, 1 = straw brown, 6 = acceptable green color, and 9 = dark green.

‡ The overseeded perennial ryegrass treatment was slit-seeded in two directions at 5 lb/1,000 ft^2 on 14 September 2014. Turfgrass colorant applications were applied using a handheld CO_2 sprayer with 8002VS nozzles at 10.16 fl oz/1,000 ft^2 at a 1:6 colorant to water dilution on 24 October 2014.

§ Plots designated to receive traffic treatments were trafficked once per week with a traffic simulator at 0, 2, 4, or 8 passes/week.

# Indicates weeks after treatment.

¶ Means in a column with like letters are not statistically different according to Fisher’s protected LSD test, ($P \leq 0.05$).

†† Date at which the overseeded perennial ryegrass treatment was removed with flazasulfuron at 0.034 oz product/1,000 ft^2.

Table 4-5. Interaction of winter color treatments and traffic for their effect on visual color at the Rocky Ford Turfgrass Research Center in Manhattan, KS in 2015.

		Visual Color†								
		WAT#								
Winter Color‡	Traffic Rate§	0	4		8		16		22††	
Perennial Ryegrass	0	6.00	6.00	a¶	5.75	ab	4.25	c	6.00	ab
	2	6.25	6.00	a	5.25	bcd	3.75	cd	6.00	ab
	4	6.00	6.00	a	5.25	bcd	3.75	cd	5.75	abc
	8	6.50	6.00	a	5.00	cd	3.25	de	5.75	abc
Endurant Premium	0	6.75	6.50	a	6.25	a	7.25	a	6.50	a
	2	6.50	5.00	b	4.50	de	3.50	d	5.50	bc
	4	7.25	4.00	cd	4.50	de	3.50	d	4.50	de
	8	6.50	3.50	de	3.50	fg	2.75	ef	4.25	def
Endurant	0	7.00	6.75	a	5.50	abc	7.25	a	6.00	ab
	2	7.00	4.75	bc	4.50	de	3.50	d	4.50	d
	4	7.00	4.00	cd	3.50	fg	3.25	de	3.50	fgh
	8	6.75	3.75	d	3.50	fg	2.25	fg	3.75	efg
Green Lawnger	0	6.00	4.75	bc	4.00	ef	5.75	b	5.00	cd
	2	6.00	3.25	de	2.75	gh	2.00	g	4.25	def
	4	5.50	2.75	ef	2.25	hi	1.75	gh	3.50	fgh
	8	6.00	2.00	f	1.75	ij	1.25	hi	3.25	gh
Untreated	0	1.75	1.00	g	1.00	j	1.00	i	3.00	gh
	2	1.75	1.00	g	1.00	j	1.00	i	3.00	gh
	4	1.75	1.00	g	1.00	j	1.00	i	2.75	hi
	8	1.75	1.00	g	1.00	j	1.00	i	2.25	i

†Second year of a two year study was conducted during the winter and spring months of 2015 - 2016 with colorant application on 5 November 2015 on 'Cody' buffalograss maintained at fairway height. Visual color was rated on a 1 – 9 scale where, 1 = straw brown, 6 = acceptable green color, and 9 = dark green.

‡ The overseeded perennial ryegrass treatment was slit-seeded in two directions at 5 lb/1,000 ft^2 on 17 September 2015. Turfgrass colorant applications were applied using a handheld CO_2 sprayer with 8002VS nozzles at 10.16 fl oz/1,000 ft^2 at a 1:6 colorant to water dilution on 5 November 2015.

§ Plots designated to receive traffic treatments were trafficked once per week with a traffic simulator at 0, 2, 4, or 8 passes/week.

# Indicates weeks after treatment.

¶ Means in a column with like letters are not statistically different according to Fisher's protected LSD test, ($P \leq 0.05$).

†† Date at which the overseeded perennial ryegrass treatment was removed with flazasulfuron at 0.034 oz product/1,000 ft^2.

Table 4-6. Interaction of winter color treatments and traffic for their effect on visual quality at the Rocky Ford Turfgrass Research Center in Manhattan, KS in 2015.

		Visual Quality†							
		WAT#							
Winter Color‡	Traffic Rate§	0	4		8	16		22††	
Perennial Ryegrass	0	4.50	5.25	ab¶	5.25	4.25	c	5.75	abc
	2	4.50	4.75	bc	5.25	4.00	c	5.75	ab
	4	4.00	4.50	cd	5.00	3.25	de	5.25	abc
	8	4.25	5.00	bc	4.75	3.00	ef	5.25	abc
Endurant Premium	0	6.25	6.00	a	5.75	5.75	a	6.00	a
	2	6.50	4.75	bc	4.50	3.75	cd	4.75	cde
	4	6.25	4.75	bc	4.25	3.00	ef	3.75	fg
	8	6.50	3.75	def	3.25	2.50	fgh	3.50	fgh
Endurant	0	6.50	6.00	a	4.75	5.75	a	5.25	abc
	2	6.25	3.75	def	4.00	3.25	de	4.00	def
	4	7.00	4.25	cde	3.75	2.75	efg	3.75	efg
	8	6.75	3.50	ef	3.00	2.25	gh	3.25	fghij
Green Lawnger	0	6.00	4.25	cde	4.00	5.00	b	5.00	bcd
	2	6.00	3.50	ef	3.25	2.75	efg	4.00	def
	4	5.75	3.75	def	3.00	2.00	hi	3.25	fghij
	8	6.00	3.25	fg	2.50	1.50	ij	2.50	ij
Untreated	0	3.50	3.00	fg	3.00	2.25	gh	3.25	fghi
	2	3.50	3.00	fg	3.00	2.00	hi	3.00	ghij
	4	3.50	3.00	fg	2.50	2.00	hi	2.50	hij
	8	3.50	2.50	g	1.75	1.25	j	2.25	j

†Second year of a two year study was conducted during the winter and spring months of 2015 – 2016 with colorant application on 5 November 2015 on ‘Cody’ buffalograss maintained at fairway height. Visual quality was rated on a 1 – 9 scale where, 1 = worst, 6 = acceptable quality, and 9 = best.

‡The overseeded perennial ryegrass treatment was slit-seeded in two directions at 5 lb/1,000 ft^2 on 17 September 2015. Turfgrass colorant applications were applied using a handheld CO_2 sprayer with 8002VS nozzles at 10.16 fl oz/1,000 ft^2 at a 1:6 colorant to water dilution on 5 November 2015.

§ Plots designated to receive traffic treatments were trafficked once per week with a traffic simulator at 0, 2, 4, or 8 passes/week.

#Indicates weeks after treatment.

¶ Means in a column with like letters are not statistically different according to Fisher’s protected LSD test, ($P \leq 0.05$).

†† Date at which the overseeded perennial ryegrass treatment was removed with flazasulfuron at 0.034 oz product/1,000 ft^2.

Appendix A - Additional Tables for Chapter 2

Table A-1. N rate effects on the visual color of ‘Cody’ buffalograss at the Rocky Ford Turfgrass Research Center in Manhattan, KS and the Council Grove Country Club in Council Grove, KS in 2014.

	Visual Color†							
	WAI§							
N Level (lb N‡/1000 ft^2)	0	2	3	4	5	6	7	8
0	5.7	5.8	5.6	5.4 c#	6.1	5.4 c	5.4 c	5.7 c
1	5.7	5.9	5.9	5.7 bc	6.3	6.0 b	5.8 bc	6.2 bc
2	5.6	5.9	5.9	6.0 ab	6.4	6.3 ab	6.1 ab	6.4 ab
3	5.8	5.9	6.1	6.2 a	6.7	6.8 a	6.5 a	6.8 a

† Three studies were conducted, two at the Rocky Ford Turfgrass Research Center in Manhattan, KS with initiation dates of 1 July 2014, 1 August 2014, and one at the Council Grove Country Club in Council Grove, KS with initiation on 3 July 2014 on ‘Cody’ buffalograss maintained at 0.625 and 1.00 inch, respectively. Visual color was rated on a 1 – 9 scale where, 1 = straw brown, 6 = acceptable green color, and 9 = dark green. Data pooled across experimental runs.

‡ Nitrogen (N)

§ Indicates weeks after injury. Nitrogen treatments were applied at 0, 1, 2, or 3 lb N/1,000ft^2 with two different nitrogen sources. Urea treatments (46-0-0) were applied in split half rate applications at trial initiation, and four weeks after. PCU treatments (43-0-0) were applied at the full rate at trial initiation. All nitrogen treatments were applied with a shaker jar in at least two directions. Nitrogen treatment applications were watered in immediately after application with 0.25 inch of water.

Means in a column with like letters are not statistically different according to Fisher’s protected LSD test, ($P \leq 0.05$).

Table A-2. N source effects on the visual quality of ‘Cody’ buffalograss at the Rocky Ford Turfgrass Research Center in Manhattan, KS and the Council Grove Country Club in Council Grove, KS in 2014.

	Visual Quality†							
	WAI#							
N Source	0	2	3	4	5	6	7	8
Urea‡	5.5	5.8 a¶	5.8	5.9	6.1 a	5.7	5.7	5.8
PCU§	5.3	5.4 b	5.5	5.6	5.7 b	5.6	5.6	5.7

† Three studies were conducted, two at the Rocky Ford Turfgrass Research Center in Manhattan, KS with initiation dates of 1 July 2014, 1 August 2014, and one at the Council Grove Country Club in Council Grove, KS with initiation on 3 July 2014 on ‘Cody’ buffalograss maintained at 0.625 and 1.00 inch, respectively. Visual color was rated on a 1 – 9 scale where, 1 = straw brown, 6 = acceptable green color, and 9 = dark green. Data pooled across experimental runs.

‡ Nitrogen treatments were applied at 0, 1, 2, or 3 lb N/1,000ft^2 with two different nitrogen sources. Urea treatments (46-0-0) were applied in split half rate applications at trial initiation, and four weeks after.

§ Indicates Polymer Coated Urea (43-0-0). PCU treatments were applied at the full rate at trial initiation

Nitrogen treatments were applied at 0, 1, 2, or 3 lb N/1,000ft^2 applied in split half rate applications at trial initiation, and eight weeks after. Urea treatments were applied with a shaker jar in at least two directions. Nitrogen treatment applications were watered in immediately after application with 0.25 inch of water.

¶ Means in a column with different letters are statistically different according to Fisher’s protected LSD test, ($P \leq 0.05$).

Appendix B - Additional Tables for Chapter 3

Table B-1. Analysis of variance for digital percent green cover of ‘Cody’ buffalograss pooled across all experimental runs at the Rocky Ford Turfgrass Research Center in Manhattan, KS.

	Weeks After Initiation†							
	0	2	4	6	8	10	12	14
N‡ Rate§	*	***	***	***	***	***	***	***
Traffic Rate#	*NS*¶	***	***	***	***	***	***	***
N Rate × Traffic Rate	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*

† Three studies were conducted at the Rocky Ford Turfgrass Research Center in Manhattan, KS with initiation dates of 1 July 2014, 7 July 2015, and 20 July 2015 on ‘Cody’ buffalograss maintained at 3 inch. Digital images were analyzed with SigmaScan Pro 5.0 (Hue: 45-107, Saturation 0-100) for pixel estimation of percent buffalograss green cover.

‡ Nitrogen (N) (Urea 46-0-0)

§ Nitrogen treatments were applied at 0, 1, 2, or 3 lb N/1,000ft^2 applied in split half rate applications at trial initiation, and eight weeks after. Urea treatments were applied with a shaker jar in at least two directions. Nitrogen treatment applications were watered in immediately after application with 0.25 inch of water.

Plots designated to receive traffic treatments were trafficked twice per week with the traffic simulator at 0, 1, 2, 4, or 8 passes/day to achieve the full weekly rates. Traffic treatments were conducted for all 16 weeks of the trial period.

¶ Not significant (*NS*)

*, **, *** indicates significance at 0.05, 0.01, and 0.001 probability level, respectively.

Table B-2. Analysis of variance for Normalized Difference Vegetation Index (NDVI) of 'Cody' buffalograss pooled across all experimental runs at the Rocky Ford Turfgrass Research Center in Manhattan, KS.

	Weeks After Initiation†							
	0	2	4	6	8	10	12	14
N‡ Rate§	*NS*¶	***	***	***	***	***	***	***
Traffic Rate#	*NS*	***	***	***	***	***	***	***
N Rate × Traffic Rate	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*

† Three studies were conducted at the Rocky Ford Turfgrass Research Center in Manhattan, KS with initiation dates of 1 July 2014, 7 July 2015, and 20 July 2015 on 'Cody' buffalograss maintained at 3 inch. NDVI values were obtained using a FieldScout CM 1000 NDVI Chlorophyll Meter. Three measurement were taken from shoulder height, and averaged for a plot mean. NDVI values range from 0.0 to 1.0, with higher values corresponding to greater densities of green leaf tissue.

‡ Nitrogen (N) (Urea 46-0-0)

§ Nitrogen treatments were applied at 0, 1, 2, or 3 lb N/1,000ft^2 applied in split half rate applications at trial initiation, and eight weeks after. Urea treatments were applied with a shaker jar in at least two directions. Nitrogen treatment applications were watered in immediately after application with 0.25 inch of water.

Plots designated to receive traffic treatments were trafficked twice per week with the traffic simulator at 0, 1, 2, 4, or 8 passes/day to achieve the full weekly rates. Traffic treatments were conducted for all 16 weeks of the trial period.

¶ Not significant (*NS*)

*, **, *** indicates significance at 0.05, 0.01, and 0.001 probability level, respectively.

Table B-3. N rate effects on Normalized Difference Vegetation Index (NDVI) of ‘Cody’ buffalograss at the Rocky Ford Turfgrass Research Center in Manhattan, KS in 2014 and 2015.

	NDVI†							
	WAI§							
N Level (lb N‡/1000 ft^2)	0	2	4	6	8	10	12	14
0	0.65	0.62 d#	0.64 d	0.59 c	0.65 c	0.67 d	0.61 d	0.53 d
1	0.65	0.65 c	0.66 c	0.61 b	0.67 b	0.70 c	0.65 c	0.56 c
2	0.64	0.67 b	0.68 b	0.63 a	0.68 ab	0.73 b	0.66 b	0.59 b
3	0.65	0.69 a	0.69 a	0.64 a	0.69 a	0.75 a	0.70 a	0.62 a

† NDVI values were obtained using a FieldScout CM 1000 NDVI Chlorophyll Meter. Three measurement were taken from shoulder height, and averaged for a plot mean. NDVI values range from 0.0 to 1.0, with higher values corresponding to greater densities of green leaf tissue. Data pooled across experimental runs.

‡ Nitrogen (N) (Urea 46-0-0)

§ Weeks after initiation of traffic. Urea treatments (46-0-0) were applied in split half rate applications at trial initiation, and eight weeks after. Urea treatments were applied with a shaker jar in at least two directions. Nitrogen treatment applications were watered in immediately after application with 0.25 inch of water.

Means in a column with like letters are not statistically different according to Fisher’s protected LSD test, ($P \leq 0.05$).

Table B-4. Traffic effects on Normalized Difference Vegetation Index (NDVI) of ‘Cody’ buffalograss at the Rocky Ford Turfgrass Research Center in Manhattan, KS in 2014 and 2015.

	NDVI†							
	WAI‡							
Traffic (passes/week)	0	2	4	6	8	10	12	14
0	0.65	0.68 a§	0.71 a	0.66 a	0.70 a	0.74 a	0.71 a	0.65 a
2	0.64	0.68 a	0.70 a	0.65 b	0.69 a	0.74 ab	0.70 a	0.62 b
4	0.65	0.66 b	0.68 b	0.63 c	0.68 ab	0.72 b	0.66 b	0.58 c
8	0.65	0.65 b	0.64 c	0.60 d	0.67 b	0.69 c	0.63 c	0.53 d
16	0.65	0.62 c	0.61 d	0.56 e	0.63 c	0.68 c	0.60 d	0.49 e

† NDVI values were obtained using a FieldScout CM 1000 NDVI Chlorophyll Meter. Three measurement were taken from shoulder height, and averaged for a plot mean. NDVI values range from 0.0 to 1.0, with higher values corresponding to greater densities of green leaf tissue. Data pooled across experimental runs.

‡ Weeks after initiation of traffic. Plots designated to receive traffic treatments were trafficked twice per week with the traffic simulator at 0, 1, 2, 4, or 8 passes/day to achieve the full weekly rates. Traffic treatments were conducted for all 16 weeks of the trial period.

§ Means in a column with like letters are not statistically different according to Fisher’s protected LSD test, ($P \leq 0.05$).

Table B-5. Analysis of variance for visual quality of ‘Cody’ buffalograss pooled across all experimental runs at the Rocky Ford Turfgrass Research Center in Manhattan, KS.

	Weeks After Initiation†							
	0	2	4	6	8	10	12	14
N‡ Rate§	*NS*	***	***	**	***	***	***	***
Traffic Rate#	*NS*	***	***	***	***	***	***	***
N Rate × Traffic Rate	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*

† Three studies were conducted at the Rocky Ford Turfgrass Research Center in Manhattan, KS with initiation dates of 1 July 2014, 7 July 2015, and 20 July 2015 on ‘Cody’ buffalograss maintained at 3 inch. Visual quality was rated on a 1 – 9 scale where, 1 = worst, 6 = acceptable quality, and 9 = best.

‡ Nitrogen (N) (Urea 46-0-0)

§ Nitrogen treatments were applied at 0, 1, 2, or 3 lb N/1,000ft^2 applied in split half rate applications at trial initiation, and eight weeks after. Urea treatments were applied with a shaker jar in at least two directions. Nitrogen treatment applications were watered in immediately after application with 0.25 inch of water.

Plots designated to receive traffic treatments were trafficked twice per week with the traffic simulator at 0, 1, 2, 4, or 8 passes/day to achieve the full weekly rates. Traffic treatments were conducted for all 16 weeks of the trial period.

¶ Not significant (*NS*)

*, **, *** indicates significance at 0.05, 0.01, and 0.001 probability level, respectively.

Table B-6. Analysis of variance for visual color of ‘Cody’ buffalograss pooled across all experimental runs at the Rocky Ford Turfgrass Research Center in Manhattan, KS.

	Weeks After Initiation†							
	0	2	4	6	8	10	12	14
N‡ Rate§	**	***	***	***	***	***	***	***
Traffic Rate#	*NS*¶	***	***	***	***	***	***	***
N Rate × Traffic Rate	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*

† Three studies were conducted at the Rocky Ford Turfgrass Research Center in Manhattan, KS with initiation dates of 1 July 2014, 7 July 2015, and 20 July 2015 on ‘Cody’ buffalograss maintained at 3 inch. Visual color was rated on a 1 – 9 scale where, 1 = straw brown, 6 = acceptable green color, and 9 = dark green.

‡ Nitrogen (N) (Urea 46-0-0)

§ Nitrogen treatments were applied at 0, 1, 2, or 3 lb N/1,000ft^2 applied in split half rate applications at trial initiation, and eight weeks after. Urea treatments were applied with a shaker jar in at least two directions. Nitrogen treatment applications were watered in immediately after application with 0.25 inch of water.

Plots designated to receive traffic treatments were trafficked twice per week with the traffic simulator at 0, 1, 2, 4, or 8 passes/day to achieve the full weekly rates. Traffic treatments were conducted for all 16 weeks of the trial period.

¶ Not significant (*NS*)

*, **, *** indicates significance at 0.05, 0.01, and 0.001 probability level, respectively.

Table B-7. Analysis of variance for Dark Green Color Index (DGCI) of ‘Cody’ buffalograss pooled across all experimental runs at the Rocky Ford Turfgrass Research Center in Manhattan, KS.

	Weeks After Initiation†							
	0	2	4	6	8	10	12	14
N‡ Rate§	*NS*¶	***	***	***	***	***	***	***
Traffic Rate#	*NS*	***	***	***	***	***	***	***
N Rate × Traffic Rate	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*

† Three studies were conducted at the Rocky Ford Turfgrass Research Center in Manhattan, KS with initiation dates of 1 July 2014, 7 July 2015, and 20 July 2015 on ‘Cody’ buffalograss maintained at 3 inch. Digital images were analyzed with SigmaScan Pro 5.0 (Hue: 45-107, Saturation 0-100) for pixel estimation of percent buffalograss green cover. Using the output values from digital image analysis DGCI was calculated using the following equation on a 0 to 1.0 scale: DGCI value = [(hue – 60)/60 + (1 – saturation) + (1 – brightness)]/3.

‡ Nitrogen (N) (Urea 46-0-0)

§ Nitrogen treatments were applied at 0, 1, 2, or 3 lb N/1,000ft^2 applied in split half rate applications at trial initiation, and eight weeks after. Urea treatments were applied with a shaker jar in at least two directions. Nitrogen treatment applications were watered in immediately after application with 0.25 inch of water.

Plots designated to receive traffic treatments were trafficked twice per week with the traffic simulator at 0, 1, 2, 4, or 8 passes/day to achieve the full weekly rates. Traffic treatments were conducted for all 16 weeks of the trial period.

¶ Not significant (*NS*)

*, **, *** indicates significance at 0.05, 0.01, and 0.001 probability level, respectively.

Table B-8. N rate effects on Dark Green Color Index (DGCI) of ‘Cody’ buffalograss at the Rocky Ford Turfgrass Research Center in Manhattan, KS in 2014 and 2015.

	Dark Green Color Index†							
	WAI§							
N Level (lb N‡/1000 ft^2)	0	2	4	6	8	10	12	14
0	0.40	0.37 c#	0.36 b	0.38 b	0.36 c	0.33 d	0.32 d	0.30 c
1	0.39	0.39 b	0.37 b	0.38 b	0.37 b	0.36 c	0.34 c	0.31 b
2	0.39	0.4 a	0.39 a	0.40 a	0.38 a	0.37 b	0.36 b	0.32 b
3	0.39	0.41 a	0.39 a	0.40 a	0.38 a	0.39 a	0.37 a	0.34 a

† Digital images were evaluated in SigmaScan Pro 5.0 (Hue: 45-107, Saturation 0-100) for percent green cover of ‘Cody’ buffalograss. Using the output values from digital image analysis DGCI was calculated using the following equation on a 0 to 1.0 scale: DGCI value = [(hue – 60)/60 + (1 – saturation) + (1 – brightness)]/3. Data pooled across experimental runs.

‡ Nitrogen (N) (Urea 46-0-0)

§ Weeks after initiation of traffic. Urea treatments (46-0-0) were applied in split half rate applications at trial initiation, and eight weeks after. Urea treatments were applied with a shaker jar in at least two directions. Nitrogen treatment applications were watered in immediately after application with 0.25 inch of water.

Means in a column with like letters are not statistically different according to Fisher’s protected LSD test, ($P \leq 0.05$).

Table B-9. Traffic effects on Dark Green Color Index (DGCI) of ‘Cody’ buffalograss at the Rocky Ford Turfgrass Research Center in Manhattan, KS in 2014 and 2015.

	Dark Green Color Index †							
	WAI‡							
Traffic (passes/week)	0	2	4	6	8	10	12	14
0	0.40	0.41 a§	0.40 a	0.40 a	0.39 a	0.38 a	0.38 a	0.35 a
2	0.39	0.40 a	0.39 a	0.39 b	0.38 ab	0.37 b	0.36 b	0.33 b
4	0.39	0.40 ab	0.38 b	0.39 b	0.37 bc	0.37 b	0.35 c	0.32 c
8	0.39	0.39 b	0.37 c	0.38 c	0.37 c	0.36 c	0.33 d	0.30 d
16	0.39	0.37 c	0.35 d	0.37 d	0.35 d	0.33 d	0.31 e	0.29 e

† Digital images were evaluated in SigmaScan Pro 5.0 (Hue: 45-107, Saturation 0-100) for percent green cover of ‘Cody’ buffalograss. Using the output values from digital image analysis DGCI was calculated using the following equation on a 0 to 1.0 scale: DGCI value = [(hue – 60)/60 + (1 – saturation) + (1 – brightness)]/3. Data pooled across experimental runs.

‡ Weeks after initiation of traffic. Plots designated to receive traffic treatments were trafficked twice per week with the traffic simulator at 0, 1, 2, 4, or 8 passes/day to achieve the full weekly rates. Traffic treatments were conducted for all 16 weeks of the trial period.

§ Means in a column with like letters are not statistically different according to Fisher’s protected LSD test, ($P \leq 0.05$).

Table B-10. Analysis of variance for 0 – 4 inch average penetrometer measurements for ‘Cody’ buffalograss pooled across all experimental runs at the Rocky Ford Turfgrass Research Center in Manhattan, KS.

	Weeks After Initiation†							
	0	2	4	6	8	10	12	14
N‡ Rate§	*NS*¶	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Traffic Rate#	*NS*	*	*NS*	**	*NS*	***	***	***
N Rate × Traffic Rate	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*

† Three studies were conducted at the Rocky Ford Turfgrass Research Center in Manhattan, KS with initiation dates of 1 July 2014, 7 July 2015, and 20 July 2015 on ‘Cody’ buffalograss maintained at 3 inch. Penetrometer ratings were taken with the FieldScout SC 900 Soil Compaction Meter at 1 inch increments from 0 – 4 inches. Readings from each depth were averaged for a composite compaction rating for each plot. A penetrometer is an instrument that measures soil strength and is measured as energy expended per unit depth (PSI).

‡ Nitrogen (N) (Urea 46-0-0)

§ Nitrogen treatments were applied at 0, 1, 2, or 3 lb N/1,000ft^2 applied in split half rate applications at trial initiation, and eight weeks after. Urea treatments were applied with a shaker jar in at least two directions. Nitrogen treatment applications were watered in immediately after application with 0.25 inch of water.

Plots designated to receive traffic treatments were trafficked twice per week with the traffic simulator at 0, 1, 2, 4, or 8 passes/day to achieve the full weekly rates. Traffic treatments were conducted for all 16 weeks of the trial period.

¶ Not significant (*NS*)

*, **, *** indicates significance at 0.05, 0.01, and 0.001 probability level, respectively.

Table B-11. Analysis of variance for soil moisture content of ‘Cody’ buffalograss pooled across all experimental runs at the Rocky Ford Turfgrass Research Center in Manhattan, KS.

	Weeks After Initiation†							
	0	2	4	6	8	10	12	14
N‡ Rate§	*NS*¶	*	*	*NS*	***	***	***	**
Traffic Rate#	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
N Rate × Traffic Rate	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*

† Three studies were conducted at the Rocky Ford Turfgrass Research Center in Manhattan, KS with initiation dates of 1 July 2014, 7 July 2015, and 20 July 2015 on ‘Cody’ buffalograss maintained at 3 inch. Soil moisture content readings were taken with the FieldScout TDR 300 Soil Moisture Meter with 3 inch rods. This moisture meter uses time domain reflectometry for instant percent volumetric water content in the root zone of the soil. Three measurement were taken and then averaged for an experimental plot mean.

‡ Nitrogen (N) (Urea 46-0-0)

§ Nitrogen treatments were applied at 0, 1, 2, or 3 lb N/1,000ft^2 applied in split half rate applications at trial initiation, and eight weeks after. Urea treatments were applied with a shaker jar in at least two directions. Nitrogen treatment applications were watered in immediately after application with 0.25 inch of water.

Plots designated to receive traffic treatments were trafficked twice per week with the traffic simulator at 0, 1, 2, 4, or 8 passes/day to achieve the full weekly rates. Traffic treatments were conducted for all 16 weeks of the trial period.

¶ Not significant (*NS*)

*, **, *** indicates significance at 0.05, 0.01, and 0.001 probability level, respectively.

Table B-12. N rate effects on soil moisture content of ‘Cody’ buffalograss at the Rocky Ford Turfgrass Research Center in Manhattan, KS in 2014 and 2015.

	% Volumetric Water Content†							
	WAI§							
N Level (lb N‡/1000 ft^2)	0	2	4	6	8	10	12	14
0	51.8	40.9 a#	26.1 a	37.7	34.8 b	42.6 ab	38.5 a	25.5 a
1	51.8	39.5 b	25.0 ab	37.9	34.5 bc	41.5 b	37.9 a	24.8 ab
2	51.4	38.8 b	24.5 b	37.2	33.0 c	40.1 c	35.3 b	22.5 c
3	50.9	39.8 ab	26.1 a	37.3	36.5 a	42.8 a	36.1 b	23.9 bc

† Soil moisture content readings were taken with the FieldScout TDR 300 Soil Moisture Meter with 3 inch rods. This moisture meter uses time domain reflectometry for instant percent volumetric water content in the root zone of the soil. Three measurement were taken and then averaged for an experimental plot mean. Data pooled across experimental runs.

‡ Nitrogen (N) (Urea 46-0-0)

§ Weeks after initiation of traffic. Urea treatments (46-0-0) were applied in split half rate applications at trial initiation, and eight weeks after. Urea treatments were applied with a shaker jar in at least two directions. Nitrogen treatment applications were watered in immediately after application with 0.25 inch of water.

Means in a column with like letters are not statistically different according to Fisher’s protected LSD test, ($P \leq 0.05$).

Appendix C - Additional Tables for Chapter 4

Table C-1. Interaction of winter color treatments and traffic for their effect on DGCI at the Rocky Ford Turfgrass Research Center in Manhattan, KS in 2014.

		Dark Green Color Index†				
		WAT#				
Winter Color‡	Traffic Rate§	0	4	8	16	24¶
Perennial Ryegrass	0	0.39	0.43	0.38	0.30	0.41
	2	0.39	0.42	0.36	0.30	0.40
	4	0.40	0.40	0.34	0.28	0.39
	8	0.43	0.40	0.32	0.27	0.38
Endurant Premium	0	0.46	0.45	0.43	0.41	0.39
	2	0.46	0.42	0.38	0.37	0.35
	4	0.45	0.40	0.36	0.34	0.34
	8	0.45	0.39	0.35	0.33	0.33
Endurant	0	0.40	0.37	0.35	0.35	0.36
	2	0.39	0.35	0.32	0.31	0.34
	4	0.38	0.33	0.30	0.29	0.34
	8	0.40	0.33	0.30	0.29	0.33
Green Lawnger	0	0.44	0.38	0.36	0.35	0.35
	2	0.45	0.35	0.32	0.31	0.34
	4	0.43	0.34	0.31	0.30	0.33
	8	0.44	0.33	0.29	0.28	0.32
Untreated	0	0.40	0.29	0.28	0.29	0.33
	2	0.44	0.28	0.25	0.26	0.32
	4	0.45	0.27	0.25	0.26	0.33
	8	0.46	0.27	0.25	0.25	0.32

†First year of a two year study was conducted during the winter and spring months of 2014 – 2015 with colorant application on 24 October 2014 on 'Cody' buffalograss maintained at fairway height. Digital images were analyzed with SigmaScan Pro 5.0 (Hue: 50-107, Saturation 0-100) for pixel estimation of percent buffalograss green cover. Using the output values from digital image analysis DGCI was calculated using the following equation on a 0 to 1.0 scale: DGCI value = [(hue – 60)/60 + (1 – saturation) + (1 – brightness)]/3.

‡The overseeded perennial ryegrass treatment was slit-seeded in two directions at 5 lb/1,000 ft^2 on 14 September 2014. Turfgrass colorant applications were applied using a handheld CO_2 with 8002VS nozzles at a rate of 10.16 fl oz/1,000 ft^2 at a 1:6 colorant to water dilution on 24 October 2014.

§ Plots designated to receive traffic treatments were trafficked once per week with a traffic simulator at 0, 2, 4, or 8 passes/week.

#Indicates weeks after treatment.

¶ Date at which the overseeded perennial ryegrass treatment was removed with flazasulfuron at 0.034 oz product/1,000 ft^2.

Table C-2. Interaction of winter color treatments and traffic for their effect on DGCI at the Rocky Ford Turfgrass Research Center in Manhattan, KS in 2015.

		Dark Green Color Index†				
		WAT#				
Winter Color‡	Traffic Rate§	0	4	8	16	22¶
Perennial Ryegrass	0	0.46	0.44	0.44	0.39	0.49
	2	0.45	0.43	0.42	0.38	0.51
	4	0.45	0.42	0.41	0.37	0.50
	8	0.46	0.41	0.41	0.37	0.50
Endurant Premium	0	0.45	0.37	0.37	0.40	0.39
	2	0.43	0.35	0.34	0.36	0.37
	4	0.44	0.35	0.34	0.35	0.36
	8	0.43	0.33	0.32	0.33	0.35
Endurant	0	0.40	0.34	0.34	0.37	0.39
	2	0.39	0.33	0.32	0.34	0.36
	4	0.41	0.33	0.32	0.34	0.35
	8	0.39	0.31	0.29	0.31	0.34
Green Lawnger	0	0.39	0.33	0.32	0.33	0.37
	2	0.38	0.32	0.30	0.30	0.35
	4	0.37	0.30	0.29	0.30	0.34
	8	0.39	0.30	0.29	0.29	0.34
Untreated	0	0.25	0.25	0.25	0.27	0.35
	2	0.26	0.25	0.24	0.26	0.33
	4	0.24	0.25	0.24	0.26	0.33
	8	0.25	0.24	0.24	0.25	0.32

†Second year of a two year study was conducted during the winter and spring months of 2015 – 2016 with colorant application on 5 November 2015 on ‘Cody’ buffalograss maintained at fairway height. Digital images were analyzed with SigmaScan Pro 5.0 (Hue: 50-107, Saturation 0-100) for pixel estimation of percent buffalograss green cover. Using the output values from digital image analysis DGCI was calculated using the following equation on a 0 to 1.0 scale: DGCI value = [(hue – 60)/60 + (1 – saturation) + (1 – brightness)]/3.

‡ The overseeded perennial ryegrass treatment was slit-seeded in two directions at 5 lb/1,000 ft^2 on 17 September 2015. Turfgrass colorant applications were applied using a handheld CO_2 with 8002VS nozzles at a rate of 10.16 fl oz/1,000 ft^2 at a 1:6 colorant to water dilution on 5 November 2015.

§ Plots designated to receive traffic treatments were trafficked once per week with a traffic simulator at 0, 2, 4, or 8 passes/week.

# Indicates weeks after treatment.

¶ Date at which the overseeded perennial ryegrass treatment was removed with flazasulfuron at 0.034 oz product/1,000 ft^2.