ABSTRACT

Title of Dissertation:	NOVEL USES OF TURFGRASSES FOR EQUINE OPERATIONS
	Aubrey Lowrey Jaqueth, Doctor of Philosophy, 2018
Dissertation directed by:	Dr. Amy O. Burk, Department of Animal and Avian Sciences

Dry lots, or small paddocks bare of vegetation, are commonly used to manage over-conditioned equids in order to restrict the diet by offering hay lower in digestible energy and non-structural carbohydrates (NSC) compared to unrestricted pasture access. However, the lack of vegetation in dry lots often caused by overgrazing and heavy traffic has been associated with negative environmental impacts such as soil erosion. Turfgrasses may be suitable as ground cover in dry lots because they are tolerant of traffic and close mowing (e.g. grazing) and may be low to moderate in both yield and NSC. The objective of this body of work was to 1) characterize the prevalence of over-conditioned equids in MD and whether dry lots were being used for their management, and 2) to assess the relative traffic tolerance, nutritional composition, and palatability of commercially available seeded cultivars of cool-season (CS) and warm-season (WS) turfgrasses for their potential use on horse farms. An online survey of licensed stable operators revealed that ~ 40% of horses in MD

were over-conditioned and feeding hay in dry lots was a preferred practice despite requiring more maintenance and management time. Two additional studies evaluating wear tolerance of 8 CS and 6 WS cultivars exposed to either no, low, or high simulated horse traffic found that soil compaction increased as treatment level increased in CS and WS traffic trials (P <0.0001). Persistence was reduced in response to traffic in CS cultivars (P = 0.0003), but not in WS cultivars. Overall, tall fescue and zoysiagrass cultivars were most traffic tolerant, but only zoysiagrass had a more ideal NSC concentration. In the final study, horses exhibited no grazing preference among CS cultivars, whereas among WS cultivars they prefered common bermudagrass and crabgrass (P < 0.02). Several cultivars, including Maestro and Regenerate tall fescue, Zenith zoysiagrass, and Riviera bermudagrass cultivars were closest to meeting desired goals of being traffic tolerant, moderate in yield, and relatively low in NSC, and are thus recommended to be evaluated in future studies for on-farm persistence in dry lots and heavy use areas and for long-term effects of grazing by equids.

NOVEL USES OF TURFGRASSES FOR EQUINE OPERATIONS

by

Aubrey Lowrey Jaqueth

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Advisory Committee:
Professor Dr. Amy O. Burk, Chair
Dr. Bridgett J. McIntosh
Dr. Tom R. Turner
Dr. Lester R.Vough
Dr. Richard A. Erdman

Dedication

This body of work is hereby dedicated to my husband, Benjamin Jaqueth. His unwavering support has been essential in the completion of this degree. From assisting with data collection in the field to proofreading manuscript drafts, he has been with me every step of the way, always reminding me to keep moving forward.

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Thank you!

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Chapter 1: Introduction and Literature Review

1. Introduction

In the equine industry, dry lots (small paddocks bare of vegetation) are a commonly used management tool. Offering complete dietary control, they offer a suitable turnout and housing option for equids which are over-conditioned or metabolically sensitive and require pasture to be limited or removed from the diet. Throughout the United States and internationally, the prevalence of obesity in equine populations is growing and has even been identified as a welfare concern. Welfare concerns stem from both the associated negative health implications of obesity and the altering of normal behaviors that current industry standard management practices impose. Additionally the industry standard practice of housing in dry lots is associated with negative environmental impacts such as soil erosion and nutrient runoff. In the following body of work, equine obesity and management in Maryland will initially be explored to characterize the impact of over-conditioning, referring to equids with above ideal fat deposition, in the Maryland equine community as well as preferences for management of these equids and barriers that may be presented. Following survey results, improvements for industry standard management practices are explored through the novel uses of turfgrasses on equine operations in the Mid-Atlantic region. The following literature review will further explore equine obesity and over-conditioning, as well as current knowledge of turfgrasses in relation to their use on equine operations.

2. Literature Review

2.1 Assessing Obesity

The prevalence of obesity in equines in the U.S. was first studied by a group of veterinarians in Virginia who found that 51% of the equids studied had a body condition score (BCS) greater than 7 [1] on a 1-9 scale. Since then, additional studies in the U.S. and abroad have determined that over-conditioning and obesity in equids occurred in as low as 20.1% [2] and as high as 47% [3; 4; 5; 6] of the population studied. Additionally, obesity has been declared a major welfare concern in the horse industry [7]. In the United States, a 1 (poor) - 9 (extremely fat) system developed by Henneke et al. [8] is predominantly used. Another system developed by Carroll and Huntington [9] is used more frequently in the United Kingdom and Ireland and has 6 levels, with 0 being emaciated and 5 being very fat. Though researchers are inconsistent in their identification of obese and non-obese, the most common division for horses is at the 7-point mark, categorizing horses of a BCS ranging from 7-9 as overweight or obese [10; 11] or at the 4-point mark on the 0-5 scale. Because of the conformational differences between horses and ponies, the Cresty Neck Score (CNS) system was also developed as a result of a study done to evaluate the efficacy of BCS and morphometric measurements for the identification of obesity in ponies [11]. In this study, they found that BCS is suitable for use in ponies but in a more recent study, BCS was found to be less reliable than morphometric measurements [12]. CNS can range from 0 (no visual appearance of a crest or palpable crest) to 5, where the crest is so large that it falls to the side of the neck, and a CNS of 3 or higher indicates obesity due to regional adiposity. Other locations of regional adiposity exist such as the tailhead, withers, behind the shoulder and along the back. To evaluate these sites, morphometric measurements were evaluated and it was found that measurements of girth:height, 0.50 neck, and crest:height were reflective of BCS in both horses and ponies and useful in determining obesity [11].

In general, ponies are more at risk for developing obesity [13] and certain breeds of horses are also more at risk. In horses the breeds that are more prone to obesity are warmbloods [1], baroque and stock type horses such as Morgans, Paso Finos, Quarter Horses and Appalossas [11; 13]. Obesity has been successfully induced in both Arabians and Thoroughbreds as well [14; 15]. Gender does not appear to be a risk factor (from anecdotal evidence reported in the discussion section) but age was reported as a factor, noting that in a study by Frank et al. that obesity occurred more often in horses over the age of 10 [10].

2.2 Management of Equine Obesity

Despite obesity being a normal response to the intake of excess calories, the obese state puts horses at risk for developing or advancing associated conditions such as equine metabolic syndrome, insulin resistance, laminitis, lipomas, hyperlipidemia, osteochondritis dessicans and reproductive irregularities [16; 17]. Management is more to blame for the increase in obesity seen in the equine population than genetic predisposition, though genotype has been shown to be a component of obesity risk in sampled populations [18]. Factors that may be contributing to the mismanagement of horses and ponies include but are not limited to social pressure (overfeeding to get the ideal show ring look), guilt (feeding the easy keeper stabled with the hard keeper and wanting to feed them equally), and poor education (not fully understanding the advancements in equine nutrition and that horses with ribs showing can be healthy as long as they have sufficient fat cover elsewhere). Additionally, horses are used for work purposes far less than that they were previously and riding is more of a recreational activity, leading to a decrease in exercise for horses, especially those who are housed in box stalls and allowed limited turnout for voluntary exercise.

To manage obesity, four primary management strategies are used, both alone or in combination and include restriction of dietary intake, increasing exercise, feeding supplements and administering medications [19]. To control weight gain by dietary restriction, multiple approaches exist such as reducing non-structural carbohydrates (NSC) in the diet with a recommendation of <10-12% of the total diet on a dry matter basis for severely metabolic sensitive equids [20; 21] as well as reducing total digestible energy. Previous research found that though weight management was ranked highest priority in a list of equine care activities [22]. However, overfeeding or providing an unbalanced diet is a common practice [23; 24; 25] despite owners acknowledging the over-conditioned state of their equid [23].

Dietary changes can be implemented by reducing or removing commercial grain or concentrate products as well as limiting forage intake. Horses evolved as grazing animals with a unique digestive system that allows for the digestion of both concentrates and forages. Identified as hind-gut fermenters, their digestive system has the advantage of combining the stomach of a monogastric, with both a glandular and non-glandular region, and the capability of microbial fermentation of indigestible fibers in the cecum that in ruminant species occurs in the rumen. When making changes to a feeding program, it is important to be aware of natural grazing behavior and aim to mimic a diet that an equid would encounter naturally. This diet would consist primarily of forage that is high in fiber and low in digestible energy and available for continuous consumption throughout the day as multiple small meals.

Starch and sugar intake from concentrate products requires a simple change of reducing the amount of concentrate feed in the diet. This can be accomplished by feeding either a balancer product or reducing a traditional concentrate and meeting energy needs by feeding a high energy and low simple carbohydrate product such as corn or flaxseed oil. Balancer products were developed with metabolically sensitive equids in mind, as they are nutrient dense products high in protein, energy, vitamins and minerals, while at the same time low in starch and sugar. Due to the density of this product, feeding rates can be reduced and still meet nutritional needs without the risk of overfeeding.

In the case of equids prone to laminitis or other weight related conditions associated with NSC levels in the diet, removing equids from pasture and instead feeding hay at an NSC composition of <10-12% on a dry matter basis at 1.5% of bodyweight [26] is currently recommended. When low NSC hay cannot be purchased or equids are extremely sensitive to NSC concentration, hay can be soaked in water prior to feeding to remove up to 78% of existing NSC composition [20]. To specifically limit forage intake, two industry standard practices are used, grazing muzzles and dry lots. When on pasture, grazing muzzles are pieces of equipment placed over a horse or pony's nose and mouth that limit consumption by reducing bite size and slowing intake. While proven to be effective at reducing forage intake by 30-86% [20; 27; 28] in horses and 75-80% [29; 30; 31] in ponies, muzzles also alter normal grazing behavior, prevent engaging in social behaviors such as mutual grooming and have the potential for the development of destructive behavior towards the muzzle [32]. Dry lots are small turnout areas that are void of vegetation, requiring the feeding of supplemental hay and therefore allowing the diet to be completely controlled in both pounds of intake and specific nutritional components of concern. Supplementary to dry lots is the use of a slow feed hay net which have small 1- to 2-inch square openings that force horses to work a bit harder for their meal and extend the time it takes to consume the hay, similar to when they graze.

Dry lots have their place in equine management due to their ability to offer greater control of the diet, but at the sacrifice of allowing for natural grazing behavior and voluntary exercise. Additionally, barriers to the use of dry lots include the initial cost of construction, storage for bulk hay purchases, increased time required to manage equids on dry lots and negative environmental implications such as soil erosion and nutrient runoff [33]. Overstocked pastures are susceptible to soil compaction and decreased vegetative stands due to high hoof traffic and frequent defoliation of forage as well potential sources of pollution by nutrient runoff if manure is managed improperly [34; 35]. They are also areas for concern over environmental stewardship as poor management of grazing livestock can lead to nutrient, sediment, and pathogen pollution of nearby watersheds resulting in reduced water quality [36]. Environmental stewardship is a concern for those within the Chesapeake Bay watershed as sediment erosion has increased since the 1800's and lead to a decrease in submerged aquatic vegetation. This vegetation is an essential part of the Bay's ecosystem and coupled with declining water quality have led to the Bay being classified as an impaired water body [37]. Sources of erosion result from both agricultural and urban practices and continue to occur despite the development of "Best Management Practices" or BMPs, designed to foster environmental stewardship [33; 37]. On equine operations in particular, overgrazed and high traffic areas of pasture as well as dry or loafing lots have been identified as sources of sediment erosion and nutrient runoff [33] which could be minimized if grazing areas were managed to produce a thick productive stand of vegetation that can anchor soil and slow nutrient runoff [38].

2.3 Obesity Related Health Concerns

Equine Metabolic Syndrome (EMS) is a broad term for the occurrence of obesity, insulin resistance (IR), and prior or current laminitis (often chronic) all occurring at the same time [39; 40]. Horses and ponies with EMS are typically those who have been overweight or obese for an extended amount of time and have now developed IR and display laminitic symptoms such as heat in the hoof, a strong digital pulse and resistance to bare weight in the affected limbs. A key identifier of the EMS horse or pony is regional adiposity along the crest of the neck, at the withers and tailhead, and along the back and behind the shoulder in characteristic “lumps” or “bulges” [39; 40].

In the horse, IR typically occurs in response to obesity [14; 15; 39]. Dysfunction can occur at any phase whether it be secretion or within circulation [17; 18] but for IR, receptor malfunction is typically seen, which can both reduce insulin sensitivity and efficiency. One distinction to make between the human and the horse is the ability to reverse the effects of IR due to horses not suffering from true type II diabetes, whereas with humans, once type II diabetes is reached, there is little that can be done to repair the system. In the case of the horse, exercise and dietary change can be utilized to re-prime insulin receptors and regain insulin sensitivity [41].

Laminitis is a condition referring to inflammation occurring within the laminae of the hoof. It may occur only once, or may be a recurring issue which may develop into a condition called founder. Founder occurs when damage to the laminae is so severe that it degrades and allows for the coffin bone to detach from stabilizing structures and rotate downward toward the sole of the foot. Multiple factors contribute to the risk of developing laminitis including exercise regimen, turnout schedule and management, obesity, insulin resistance, and genetic predisposition [18]. There are three main physiological mechanisms that can induce laminitis in the horse: overload of non-structural carbohydrates [42], mechanical overload and toxicosis. NSC overload occurs from over consumption of grain or lush pasture and is the most researched type of laminitis.

Cushings is a disease that occurs due to dysfunction of the pituitary gland that causes an overproduction of the Adrenocorticotropic hormone (ACTH) which in turn triggers the adrenal gland to overproduce the hormone cortisol [43] and can be diagnosed by evaluating resting cortisol and ATCH levels and administering a Dexamethasone suppression test [10]. In horses and ponies with Cushings, IR is also common. Clinical signs of Cushings are a long shaggy coat that does not shed out, recurrent laminitis, excessive water consumption and urination, weight loss from cortisol signaled protein and fat mobilization and gluconeogenesis, lethargy, poor immune function and blindness [43].

2.4 The Role of Pasture in Obesity

Currently, the majority of seeded pastures for horses are composed of varieties of grasses developed for the livestock industry [44]. These grasses were developed to produce higher yield, to have improved nutritional quality, and to better tolerate stress due to trampling and defoliation by grazing and harvesting [45]. To better recover from these stresses, the grasses have increased capacity for photosynthetic activity and as a result, higher levels of NSC as starch and sugar are end products [44]. These grasses have served the dairy and livestock community well as they can increase average daily gain by providing a greater caloric value than cultivars which were not selectively bred for improved nutritive qualities. Conversely, for horses in need of weight reduction or those that are sensitive to NSC, these improved cultivars can prove to be detrimental.

Plants, including grasses, produce two types of carbohydrates, structural and non-structural. Structural carbohydrates (SC) are primarily made up of cellulose, hemi-cellulose and lignin and found within the cell walls of the plant. Non-structural carbohydrates are found within the cell and are comprised of starch and sugars. The sugar portion of NSC is made up of mono and disaccharides, oligosaccharides and in the case of cool-season grasses, fructan [46]. As the plant grows and matures, the composition of SC and NSC vary with NSC being higher in early vegetative growth when more leaf matter is present, whereas SC accumulate as the plant matures and the stem elongates [44]. Other factors that can alter NSC levels are season, temperature, sun exposure, soil composition, drought, mowing, and traffic [44; 47].

Current management strategies for pasture health and environmental stewardship focus on productive pastures, but for horses who are metabolically sensitive, these systems may not be suitable. Risks to metabolically sensitive equids include the possibility for overconsumption of pasture high in digestible energy with fluctuating NSC composition. Non-structural carbohydrates in the pasture, fructan in particular, have been linked with the onset of laminitis [18; 48], with pasture associated laminitis accounting for the majority of cases in the United States [49].

2.5 Cool-season versus warm-season

Cool-season grasses are common to pastures in the Mid-Atlantic region [50] and overall offer a nutritious forage source, but depending on environmental conditions, they may accumulate NSC to levels that are unsafe for grazing by equids with metabolic sensitivities [44]. Species of cool-season or C3 grasses found in the region include tall fescue, chewings fescue, hard fescue, creeping red fescue, Kentucky bluegrass, creeping bentgrass and perennial ryegrass, as well as others. Warm-season or C4 grasses, include bermudagrass, zoysiagrass and crabgrass, and are also capable of growth in the Mid-Atlantic region [51].

The main difference between cool-season and warm-season grasses is the metabolic pathways utilized to convert sunlight into carbohydrates and associated physiological differences due to these pathways. Described by Betts [52], warm-season grasses are more efficient in their metabolic pathways and also have the advantage of not producing fructans, which may result in a naturally lower NSC value compared to cool-season grasses. Cool-season grasses directly reduce CO_2 by the enzyme ribulose bisphosphate cabozylase in the chloroplast. This process forms 2 molecules of a 3-phosphoglyceric acid (a 3-carbon acid). Warm-season grasses reduce CO_2 to oxaloactetate (a 4-carbon acid) before continuing photosynthesis. Warm-season grasses are much more tolerant of increased temperatures, long photoperiod days, and reduced rainfall , typically when cool-season grasses may become dormant or experience a summer “slump” in productivity. This tolerance of summer weather experienced by warm-season grasses results in their being good pasture grasses in the summer months. Warm-season grasses are more efficient at utilizing carbon dioxide and nitrogen from the environment, and utilizing less water, which increases their survivability during times of drought.

Additionally, even though the warm-season grasses are typically lower in crude protein, their protein is more efficiently used by animals, but because they have thicker cell walls than cool-season grasses, they are higher in structural fiber resulting in lower forage quality. Fructan, a major component of non-structural carbohydrates in cool-season grasses, is not produced in warm-season grasses, resulting in a lower NSC composition observed compared to cool-season grasses [52].

2.6 Potential Uses of Turfgrasses

Similar to pasture grasses, turfgrasses have been selectively bred to be tolerant of traffic, low mowing heights, be resistant to disease and require reduced maintenance [53]. These cultivars are typically used for industrial and residential lawns as well as athletic fields and golf courses but they may also thrive as an alternative ground cover for dry lots. Equids have the capability to overgraze areas when stocking rates exceed the productive ability of the grass. When overgrazing is combined with the physical stress of hoof traffic from horses standing and running, vegetative cover may decline, similar to the response of athletic fields and golf courses under stress from mowing and athletic activity.

In a study simulating horse hoof traffic, results found that Timothy, a forage grass used for hay and sometimes used in horse pasture, was less resistant to traffic than multiple grass species including tall fescue and Kentucky bluegrass cultivars [54]. In a traffic study of cool-season turfgrasses in Italy, relative traffic tolerance has been reported as perennial ryegrass and tall fescue cultivars being more tolerant of traffic than Kentucky bluegrasses, and fine fescues being least tolerant [55]. Similar findings were reported by Harivandi out of the University of California but with the addition of warm season cultivars in traffic tolerance rankings. Zoysiagrass and kikuyugrass were reported to be most tolerant, followed by hybrid bermudagrass, tall fescue, and common bermudagrass, then perennial ryegrass, then Kentucky bluegrass, hard fescue, red fescue and St. Augustine grasses with highland, colonial, and creeping bentgrass ranked as least traffic tolerant with dichondra [56]. Conversely, sheep fescue, chewings fescue, colonial bentgrass and velvet bentgrass were recommended to be suitable as low-input and traffic tolerant species for use on golf course fairways in the northern portion of the United States [57]. Due to the difference in results from traffic trials conducted in various regions, assessment of cultivars should be conducted within the region to which recommendations are being made.

Research within species group has also found differences in traffic tolerance between branches of species and cultivars. In a study by Chen et al. of various fine fescues including chewings, hard and sheep fescue, tolerated traffic better than creeping red fescue [58]. In evaluations of Kentucky bluegrass, Park et al. found that bluegrass tolerated and recovered from traffic best in the fall [59] compared to spring and summer, and that cultivars with compact growing patterns tolerated traffic better than other varieties [60].

Traffic tolerance results may also differ from one study to the next depending on the traffic simulator and protocol used. In studies comparing damage produced by traffic simulators, the Baldree traffic simulator was found to be the most destructive versus the Cady and Brinkman [61]. Additionally, the Cady was found to do more damage than the Brinkman [62] but treatment implemented by the Rutgers traffic simulator resulted in slower recovery after treatment [63].

2.7 Research Objectives and Goals

A major objective of the following body of work is to evaluate the potential of selected turfgrass cultivars for the potential of an alternative ground cover for dry lots and small pastures grazed by over-conditioned equids. The objectives of these studies were:

1. Evaluate the prevalence of obesity in horse and pony populations in Maryland.
2. Identify barriers to management of obese equines and areas of concern that equine owners face related to obesity.
3. Evaluate relative traffic tolerance of warm and cool-season turfgrass cultivars as well their suitability for grazing by determining nutrient composition throughout the growing season.
4. Evaluate relative grazing preference of horses for the warm and cool-season turfgrass cultivars throughout the growing season.
5. Identify turfgrass cultivars that have potential for use in future on-farm studies.

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Chapter 2: Manuscript 1

CHARACTERIZATION OF THE PREVALENCE AND MANAGEMENT OF OVER-CONDITIONED PONIES AND HORSES IN MARYLAND

Aubrey L. Jaqueth, Marie E. Iwaniuk, Amy O. Burk*
The University of Maryland
Department of Animal and Avian Sciences
8127 Regents Drive
College Park, MD 20742

Abstract

It has been estimated in the U.S. and abroad that 20-51% of the equine population suffers from over-conditioning or obesity. The objective of this study was to evaluate the prevalence of over-conditioning in the equine population in Maryland, characterize weight control measures used, and to ascertain how control measures impact the operation. Over-conditioning was defined as a body condition score of 4 or 5 on a 5-point scale. All licensed horse operators in Maryland were invited to participate in an online survey. A total of 93 farm operators completed the survey with 238 ponies and 1,290 horses represented. Nearly all operators (96%) indicated they managed at least one obese pony or horse and that 41% of their ponies (n=97) and 40% of their horses (n=512) were over-conditioned. Over-conditioned ponies had a higher incidence of laminitis and were more heavily managed. Dry lots were the most common management practice used for ponies even though they were time reported to be more consuming and required more maintenance than pasturing horses. Participants were most satisfied with using exercise for weight control followed by dry lots and least satisfied with using grazing muzzles and administering medication.

Operators spent an average of $\$434.18 \pm \$15.19$ more each year to manage their over-conditioned equids. In conclusion, a significant portion of Maryland's horses and ponies are over-conditioned with laminitis occurring more frequently in over-conditioned ponies. Additional or alternative measures to prevent over-conditioning are needed to reduce labor and maintenance costs as well as improve welfare practices.

Key Words: Over-conditioned; Management; Equine; Survey

Highlights

- 40% of equids in Maryland were categorized as over-conditioned.
- Of the over-conditioned ponies, 70% were housed in a dry lot and 50% wore a grazing muzzle.
- Over-conditioned equids cost an additional $434.18 per head, on average, to manage each year compared to non-over-conditioned counterparts.
- Laminitis was the biggest concern for both pony and horse owners.

1. Introduction

1.1 Prevalence of Obesity in Horses and Ponies

Obesity is a serious threat to equine welfare and becoming a greater concern for pony and horse owners throughout the United States and internationally. Horses and ponies are considered overweight or obese if they score between a 7 and 9 on a 1 (thin) to 9 (obese) body condition score (BCS) scale [1] or between 4 and 5 on a 0 (very poor) to 5 (very fat) BCS [2]. BCS is estimated based on fat deposition with an ideal horse or pony having some fat deposition so that the withers, neck and tail head are rounded whereas an under-conditioned horse will lack adequate fat deposition at these same points. An over-conditioned horse has excessive fat deposition that can be palpated and observed across the crest of the neck, along the sides of the withers, across the ribs, behind the shoulders, on top of the loin, and on the sides of the tail head. Over-conditioning has been found to occur in 20 to 51% of observed equid populations [3;4;5;6;7;8]. Obesity has been declared a major welfare concern in the horse industry [9] as it increases the risk of developing weight-related disorders and management practices alter normal grazing behavior.

Disorders related to over-conditioning in equids include equine metabolic syndrome, insulin resistance, laminitis, lipomas, hyperlipidemia, osteochondritis dessicans and reproductive irregularities [10;11]. Equine metabolic syndrome is a term used to describe a set of associated symptoms including obesity and regional adiposity, insulin resistance and previous or current laminitis [10; 12]. Insulin sensitivity is reduced when horses are obese [13], consuming a high-starch diet [14], and when they have reduced exercise [15]. Dietary restriction along with exercise has been found to improve insulin sensitivity [16] and medication has been studied with mixed results [17; 18; 19; 20].

1.2. Management of Over-conditioned Horses and Ponies

The four primary management strategies used alone or in combination for controlling weight gain are restriction of digestible energy and non-structural carbohydrates (NSC) in the diet, increasing exercise, feeding supplements, and administering medications [21]. Nutritional management of equids prone to weight gain is focused on reducing intake of digestible energy in the total diet and to feed a diet <10% NSC, [22; 23]. Two industry standard practices are used to control intake, feeding hay in dry lots and grazing muzzles. Dry lots are small turnout areas that are void of vegetation and therefore allow the diet to be completely controlled both in digestible energy consumed and amount of NSC through the feeding of hay. Grazing muzzles are pieces of equipment placed over a horse or pony's nose and mouth that limit consumption while they are grazing pasture. Studies have shown that grazing muzzles are capable of reducing forage intake by 30-86% [22; 24; 25] in horses and 75-80% [26; 27; 28] in ponies.

Though both feeding a controlled diet in dry lots and the use of grazing muzzles on pasture are successful methods for reducing caloric intake, both practices may alter normal grazing behavior. Dry lots may also decrease voluntary exercise as they do not offer the opportunity to graze and wander in a large pasture due to both the small size of a dry lot and hay typically being offered in a central location. Additionally, dry lots can have negative impacts on the environment as they may become a source of erosion [29] due to their lack of vegetation to anchor soil. Grazing muzzles also offer challenges such as the development of destructive behavior towards the muzzle [30].

1.3. Study Aim

The objective of this study was to evaluate the prevalence of over-conditioning in pony and horse populations in Maryland, characterize weight control measures used, and to ascertain how the control measures impact the operation. Results from this study will allow the Maryland equine population to be compared to others as well as identify if over-conditioning is a prevalent issue in addition to the weight-related disorders of most concern. By identifying barriers to management and areas of concern among the Maryland equine community, targeted prevention methods can be further developed to better promote the welfare of equids.

2. Materials and Methods

A cross-sectional study was conducted using an internet-based survey (surveymonkey.com, San Mateo, CA). The survey was constructed following methods previously described for internet surveys [31] and consisted of 25 questions. Questions were a combination of free response, multiple choice and drop down menu responses whereby participants could indicate how many ponies or horses the question applied to. Initial questions addressed farm demographics including the current number of ponies and horses on each farm and manager demographics including years in horse industry.

To assess BCS of all equids on the property, participants were then provided with drawings adapted from Carroll and Huntington and text descriptions of BCS 0 through 5 (Figure 1). After participants indicated how many equids were of each BCS using the drop down menus, they were asked to answer questions based on their over-conditioned equids only. Remaining questions addressed pasture and dry lot availability, management practices for controlling weight, diet, prevalence of weight-related disorders diagnosed by a veterinarian in the past 5 years, finances related to expenditures for over-conditioned equids, and participant opinions related to managing over-conditioned equids using a 5-point Likert-type scale. Where number of ponies or horses was required, participants were given a drop-down menu for both equid types so that they could select the number that best represented that question. With respect to the disorders and management tool usage, participants were not asked whether equids suffered from multiple conditions at the same time or were managed using multiple tools at the same time, only how many had been diagnosed with each of the weight-related disorders provided or were managed using a specified weight management tool. Expenditures related to over-conditioned equids were reported by participants on an annual basis and consolidated into five categories; medications, specialized feed, hoof care, labor costs, and equipment. Average expense was calculated by determining the total annual cost reported by all participants and then dividing by the total number of over-conditioned equids represented by the survey to get a per equine cost.

Study population consisted of approximately 769 Maryland equine operations licensed with the Maryland Horse Industry Board (Annapolis, MD). Participants were contacted through a multiple wave series of letters and post cards at pre-determined intervals, following recommendations of Dillman [31] for optimal internet-survey response rate. In an effort to maximize survey response, a pre-notice post card was sent to inform participants that a formal letter would be arriving in the mail. Following the formal letter, a reminder post card was sent and subsequently a final contact letter with a hand written "Thank you!" note included. Because of a lower than desired response rate the survey was extended and notification of the extension was sent by a final post card. Mailings were sent after the 4th of July in 2015 and the survey was closed on August 28th, 2015.

Only a person who made management decisions on the farm could participate in the study. The survey was reviewed by an expert with experience in survey design and extension in addition to being piloted by 5 horse farm managers in Virginia, Florida, and Georgia to assess content and face validity prior to administration. The survey and study methodology were approved by the University of Maryland's Internal Review Board (684776-2).

Data were imported into Microsoft Excel 2008 (Microsoft, Redmond, Washington) for summative evaluation. Data are presented as mean ± SE. A participant reported BCS of 4 or 5/5 for the purpose of this paper was considered over-conditioned. Statistical analysis was conducted using SAS 9.3 (SAS Institute, Cary, NC). The frequency procedure was used to conduct a chi-square test of goodness-of-fit for opinion based questions to assess equality of preference or opinion and for questions that characterized the population represented in the survey. The mixed procedure was used to conduct an analysis of variance for questions where ranking of tool usage or satisfaction was evaluated. For all statistical tests an alpha level of 0.05 and a Tukey's adjustment for analysis of variance was utilized.

3. Results

Of the 769 licensed stables mailed a survey, 108 individuals started the survey but only 93 completed it. Sixteen addresses resulted in returned mail, and 3 stables asked to be removed from the mailing list, resulting in a response rate of 12.4%. The majority of respondents had been involved in the horse industry for over 21 years (63.4%) followed by 10 to 15 years (18.3%), 16 to 20 years (10.8%) and 9 or less years (7.5%). The average age of the participants was 55 ± 5.7 yr and the majority of participants were female (87.1%). The primary use of the farms was boarding (54.8%) followed by lessons (21.5%) and training (9.7%).

Ninety-six percent of participants indicated that they had at least one over-conditioned pony or horse on the farm. A total of 238 ponies and 1,290 horses were represented in the survey. The distribution of reported BCS's for ponies and horses was heavily skewed to the right and resulted in 40.7% of ponies and 39.7% of horses being identified as BCS 4 "fat" or 5 "very fat" (Figure 2). Henceforth, equids reported as a 4 or 5 BCS will be referred to as "over-conditioned". There were no differences between the distribution of BCS's between ponies and horses (X^2=0.2584, p=0.8788).

Percentage of over-conditioned ponies and horses reported to have had a veterinarian-diagnosed weight-related disorder in the past five years is shown in Figure 3. In over-conditioned ponies, the most prevalent weight-related disorder reported was laminitis (24%, n=97) followed by insulin resistance (17%) and Cushings syndrome (17%) whereas in over-conditioned horses, arthritis (31.8%; n=512) was most prevalent followed by insulin resistance (21.9%) and laminitis (13.4%). The weight-related disorder reported to affect the most over-conditioned ponies and horses combined (n=609) was insulin resistance (n=198), followed by arthritis (n=167), laminitis (n=113) and Cushings syndrome (n=68).

When asked their level of concern regarding their over-conditioned equids developing weight-related disorders, participants indicated that they were most concerned about laminitis (Table 1). There were effects of both disorder ($p < 0.0001$) and equine type (pony vs horse, p=0.0079) on average concern level. When participants only managed ponies, they had a higher concern level for their ponies getting a weight-related disorder compared to people who only managed horses who didn't seem as concerned about their horses developing a weight-related disorder. When participants only managed ponies or only managed horses, the managers of over-conditioned horses were more concerned about the development of a weight-related disorder (p=0.0049) compared to those that only managed over-conditioned ponies. However, when participants managed a mixed herd of ponies and horses, they were equally concerned about both developing a weight-related disorder.

Management tool usage was found to be different in regard to equid type (pony vs horse, X^2=14.3241, p=0.0008). It was reported that 70.1% of the over-conditioned ponies (n=97) were housed in a dry lot compared to 50.5% that wore grazing muzzles. With respect to the over-conditioned horses (n=512), 16.0% had their weight controlled by a grazing muzzles compared to 14.1% that were housed in a dry lot. In both groups, medication was the least used weight control tool (14.4% and 10.2% respectively).

Of the participants that used dry lots, 75% felt that dry lots required more maintenance compared to housing equids on pastures with vegetation (X^2=14.0000, p=0.0002) and 78% felt that using dry lots increased time spent caring for their over-conditioned equids (X^2=18.4576, p<0.0001).

The most utilized weight management tool for all over-conditioned equids was exercise (95.5%), followed by grazing muzzles (77.5%), dry lots (67.4%), slow feed hay nets (64%), and medication (43.8%). There were differences in how satisfied participants were with using the different weight management tools (p=0.0010), but not as it related to their use on ponies and horses (p=0.2248). Participants indicated that they were most satisfied using exercise as a weight management tool followed by feeding hay to horses in dry lots, feeding hay in slow feed hay nets, administering medication, and use of grazing muzzles (Figure 4).

There was an effect of type of over-conditioned equine managed (ponies only, horses only, or both) on the perceived time required to care for over-conditioned equids ($p<0.0001$). People who only managed over-conditioned ponies more often felt that weight management tools increased their time spent caring for the ponies compared to managers of mixed over-conditioned herds or over-conditioned horses only. On average, it was found that owners of over-conditioned ponies and horses spend $434.18 ± $15.19 per year more each year to manage their over-conditioned equids compared to their non-over-conditioned counterparts. The highest contributing factor to the additional money required was labor costs.

When asked about the diets of the over-conditioned ponies and horses, the majority of participants managing over-conditioned equids formulated their own diets (57.3%) with input from a professional in the equine industry. Grass hay was most often used in pony diets while pasture was most often used in horse diets (Table 2). In both ponies and horses, grain was more often fed than a balancer pellet and horses were more often fed either type of product compared to ponies. Commercially or privately produced concentrate was included in the diet of 52.0% of over-conditioned ponies and 11.5% of over-conditioned horses. Forage balancers were fed to only 12.4% of over-conditioned ponies and 4.1% of over-conditioned horses. In both equid types, grass hay and pasture were more prevalent than legume or grass and legume mixed hay. Supplements were used in the diets of both ponies and horses, but were more prevalent in the diets of over-conditioned horses (Table 2).

4. Discussion

This study demonstrated that a significant portion of Maryland's equine population (40%) was reported to be over-conditioned and that it occurred equally between ponies and horses. These findings are concerning given that over-conditioning is associated with equine metabolic syndrome, insulin resistance, laminitis, lipomas, hyperlipidemia, osteochondritis dessicans and reproductive irregularities [10;11]. Our findings are similar to other studies in the U.S. and abroad that found a similar rate of occurrence of over-conditioning [3; 6; 7; 8]. However, two previous studies assessing BCS in pony and horse populations found that the ponies had a higher BCS than the horses [5; 8]. Another significant finding was that almost all of the horse farm operators we surveyed (96%) were managing one or more over-conditioned equids demonstrating just how prolific of a problem this is. Our findings lend support to the argument that over-conditioning in equids is a significant health issue in the horse industry that requires owner and farm manager education for the proper management and prevention of this condition.

Another important finding was that managing over-conditioned equids comes at a price--$434 per over-conditioned individual. If we extrapolate our data to the U.S. equine population which assumes 40% of the 9.2 billion horses in the U.S. [32] are over-conditioned, we find the economic impact of managing over-conditioned equids in the U.S. to be $1,587,782,400, a value nearly equal to the entire economic impact of Maryland's horse industry [33]. Labor was found to be the largest contributor to the additional costs associated with managing over-conditioned equids. However, costs also arose from purchasing, maintaining and replacing weight management tools (i.e. muzzles and dry lot fenced boards), non-routine veterinary visits, specialized shoeing, and medications. Some of these costs could be reduced by educating horse owners and farm managers how not to contribute to the problem and also how they can best control body condition before it manifests as metabolic disorder.

Overfeeding was a clear contributor to over-conditioning in our study given that the majority of the ponies and horses were still given access to pasture and/or being fed a commercial concentrate. Current dietary recommendations for weight loss in those with equine metabolic syndrome are to initially eliminate pasture from the diet and feed hay that is <10% NSC on a dry matter basis at 1.5% of bodyweight [34]. Perhaps some of the study participants were engaged in this type of weight control diet, but definitely not the majority. Some participants fed over-conditioned equine mixed hays and legume hays as part of their diet which is generally not recommended. Legumes tend to be higher in digestibility energy with variable concentrations of NSC [22]. Both legumes and grass hays vary greatly in nutrient composition and for that reason, testing of hays to be fed to over-conditioned equids is recommended. For instance, grass hays vary widely in digestible energy and NSC concentration, and while mature grass hay can be high in indigestible fiber, NSC concentration relies heavily on plant maturity and environmental conditions at harvest [35]. If testing is not available, owners and/or farm managers can soak the hay of over-conditioned equine as a way of reducing the NSC concentrations up to 78% [22].

Vitamin, mineral, and protein requirements not met by forage-based diets can be provided by feeding a commercially available balancer pellet product. These products are formulated to be fed at low rates due to high nutrient density and low NSC concentrations. Only a small percentage of respondents offered their over-conditioned equids a forage balancer. This was somewhat surprising, however other studies have also found that over-feeding or providing an unbalanced diet is a common practice [36, 37, 38] despite owners acknowledging the over-conditioned state of their pony or horse [36].

Despite a similar rate of over-conditioning in our pony and horse population, the incidence of disorders related to over-conditioning differed. Over-conditioned ponies in our study were much more likely to have laminitis whereas horses were reported to have more problems with arthritis. Due to the severe consequences of laminitis compared to both insulin resistance and arthritis, one can see why laminitis is of higher concern to our participants as it dictates more aggressive treatment and has a greater impact on the health and use of the animal. Previous research has also documented that ponies have a higher risk and incidence of laminitis due to over-conditioning [39] compared to horses. Still, the incidence of laminitis may have been underestimated if horses experienced laminitic episodes that were not recognized by the owner as was the case in a previous study [8]. Arthritis may also be more prevalent in the pony population than indicated in the survey results due to more adults riding horses than ponies. Adult riders may be more aware of arthritic and metabolic changes in their mounts compared to youth riders and as ponies were reported to be less intensely managed, diagnosis of arthritis may be limited. Conditions that require more invasive and expensive testing to diagnose may be underestimated as the survey focused on conditions diagnosed by a veterinarian in the past five years.

Previous research found that weight management was ranked highest priority in a list of equine care activities [40]. Removing over-conditioned equids from pasture is warranted given that pasture-associated laminitis accounts for 54% of the laminitis cases in the US [41]. We observed a high use of feeding hay in dry lots by participants, despite the associated downsides such as cost and time requirements. Feeding hay in a dry lot is an effective method of controlling intake and removes the risk of fluctuating pasture NSC values seen with time of day, season, and weather [42]. Grazing muzzles have also been shown to effectively reduce pasture intake [22; 24; 25; 26; 27; 28]. Ponies being smaller in size, require less housing space and that may explain why participants used dry lots more for the ponies than for the horses. Despite the high use of dry lots and grazing muzzles, participants were not very satisfied with using them most likely because they require more input by the farm manager.

One of the limitations of this study was relying on participant reported BCSs as opposed to having a trained professional assess them out in the field. We tried to minimize error by providing a more simplified BCS scale developed by Carroll and Huntington [2] that was a 0 to 5 scale compared to the 1-9 BCS scale developed by Henneke [1]. We also included text and photos to assist participants with their choices. However, a previous study found that owners had a poor ability to match BCS to images and that they were inherently biased because they thought competition horses should carry more weight than pleasure horses [40]. Other previous studies found that owners had a poor ability to accurately assign a BCS to their ponies and horses, often underestimating adiposity levels [4; 7; 8]. Based on those studies, our findings may actually be an underrepresentation of the occurrence of over-conditioning among the equids in the study population.

In this study, a total of 1,528 equids were represented. A previous study reported that to obtain 80% power level for estimating equine obesity occurring in 15-50% of the equine population with a precision of 3% and 95% confidence, a survey population of 676 animals was required [5]. Therefore, we believe our findings do represent the Maryland equine population. The low response rate may have been due to errors in the mailing list that resulted in undelivered surveys, sampling during a busy time for survey participants (summer), lack of interest in the topic and survey fatigue [43; 44]. We utilized the mailing list of the Maryland Horse Industry Board which often has about 10-15% turnover in farm owners each year [R. Peddicord, personal communication].

5. Conclusions

In conclusion, a significant portion of Maryland's ponies and horses and ponies are over-conditioned and the cost of managing them is a significant economic burden to the industry. While prevention remains the key to reducing over-conditioning, overfeeding of equids is still occurring. Veterinarians, agricultural educators and equine professionals should be alerted to these findings so that they can continue to educate horse owners about prevention of over-conditioning in the ponies and horses. Lastly, weight control methods require further optimization to reduce labor and maintenance costs as well as improve equine welfare practices.

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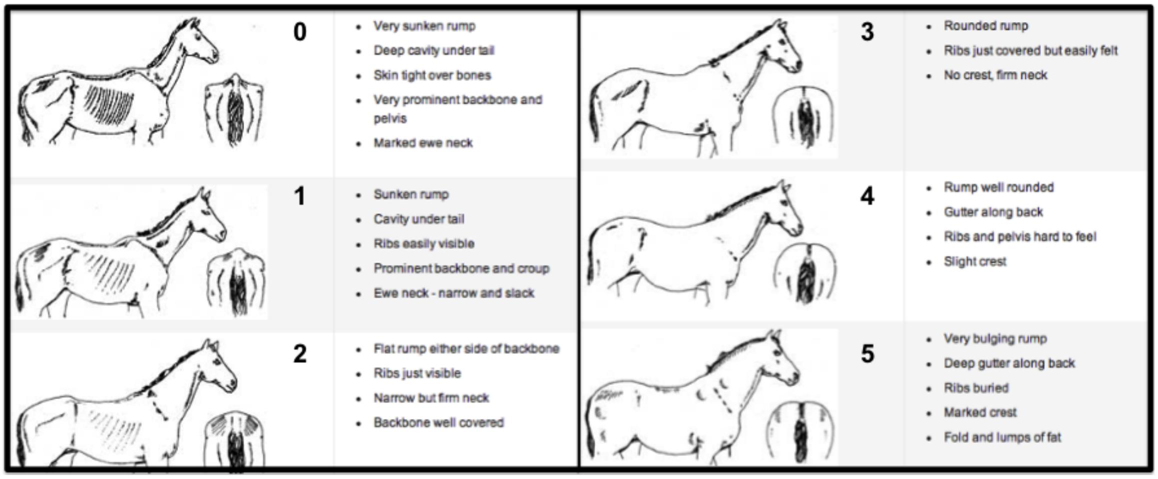

Figure 1. Body condition score chart and description provided to participants.

Adapted from Carroll and Huntington [2]

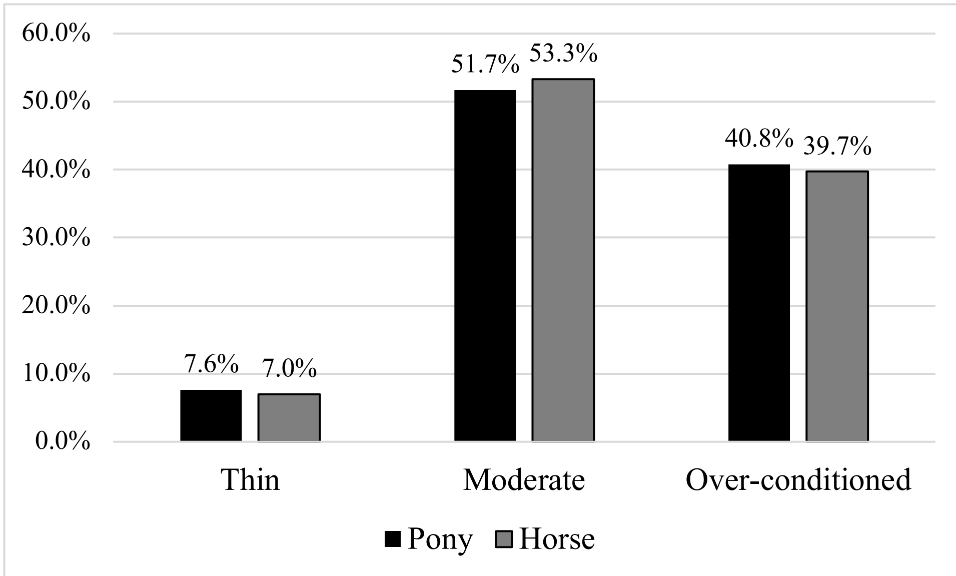

Figure 2. Percentage of ponies and horses reported as having a thin (0-2), moderate (3) or over-conditioned (4-5) body condition score.

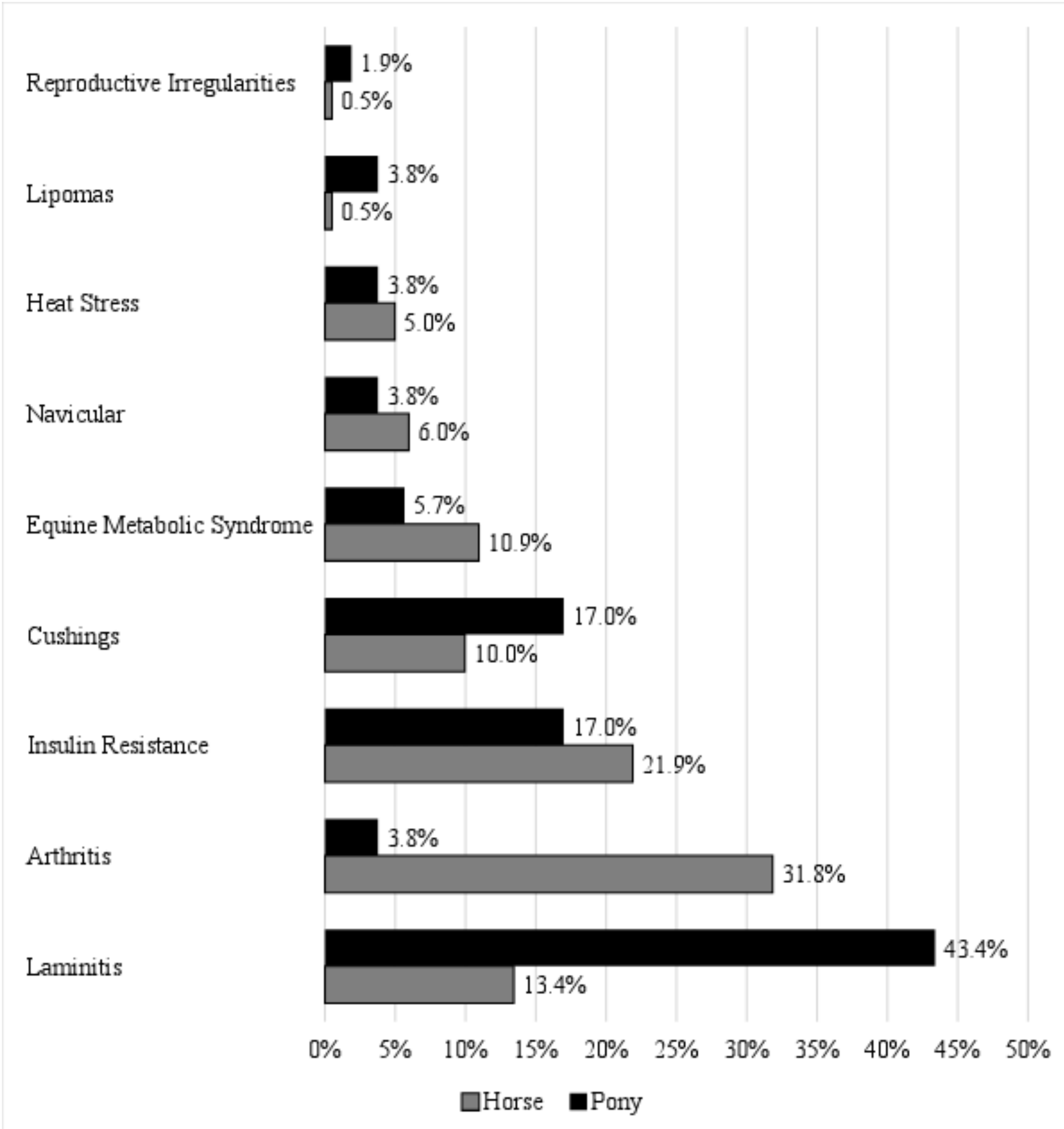

Figure 3. Percentage of over-conditioned ponies and horses reported to have had a veterinarian-diagnosed weight-related disorder in the past five years.

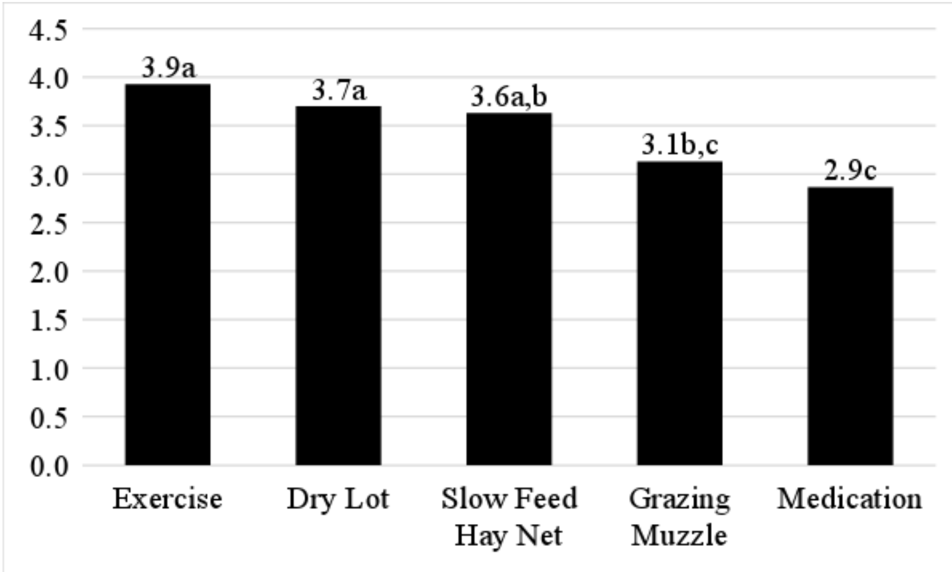

Figure 4. Mean level of participant satisfaction with weight management tools using a 1 to 5 scale (1 = not at all, 2 = slightly satisfied, 3 = moderately satisfied, 4 = very satisfied, 5 = extremely satisfied) expressed as calculated least squared means.

[a,b,c]Means with unlike superscripts differ ($P < 0.05$).

Table 1. Mean Level of Participant Concern for Development of Weight-Related Disorders in their Over-Conditioned Ponies and Horses[1]

Weight-Related Disorder	LSM	Significance
Laminitis	1.98	a
Insulin Resistance	1.58	b
Cushings	1.53	b, c
Arthritis	1.40	b, d
Heat Stress	1.38	b, e
Equine Metabolic Syndrome	1.30	c, d, e
Navicular	1.25	e
Lipomas	1.07	e
Reproductive Irregularities	1.07	e

[1]Scale: (1 = not concerned, 2 = moderately concerned, 3 = extremely concerned) and reported as least squared means (LSM).

[a,b,c,d,e]Means within unlike superscripts differ ($P < 0.05$)

Table 2. Percentage of Diet Components Fed to Over-Conditioned Ponies and Horses

		Ponies (n=50)	Horses (n=83)
Forages	Pasture	68.0%	80.7%
	Grass Hay	74.0%	71.1%
	Mixed Hay	26.0%	28.9%
	Legume Hay	4.0%	6.0%
Concentrates	Grain	52.0%	71.1%
	Balancer Pellet	24.0%	25.3%
Other	Supplement	42.0%	54.2%

Chapter 3: Manuscript 2

RELATIVE TRAFFIC TOLERANCE OF COOL-SEASON TURFGRASS CULTIVARS AND THEIR SUITABILITY FOR GRAZING BY EQUINE

Aubrey L. Jaqueth[1], Thomas R. Turner[1], Marie E. Iwaniuk[1], Bridgett J. McIntosh[2], Amy O. Burk*[1]
[1]The University of Maryland, Department of Animal and Avian Sciences
8127 Regents Drive, College Park, MD 20742
[2] Virginia Polytechnic Institute and State University, Middleburg Agricultural Research and Extension Center, 5527 Sullivans Mill Rd, Middleburg, VA 20117

Abstract

Dry lots, or small paddocks bare of vegetation, are a commonly used management tool in the equine industry. Offering complete dietary control, they are popular for over-conditioned equids or those with metabolic sensitivities that require limited dietary intake of digestible energy and non-structural carbohydrates (NSC). Though effective, dry lots are associated with negative environmental impacts such as soil erosion and nutrient runoff. Turfgrasses are tolerant of traffic and close mowing and may be suitable as ground cover in areas subject to high hoof traffic such as dry lots, gates and small paddocks. The objective of this study was to assess relative traffic tolerance and nutritional composition of eight cool-season (CS) turfgrasses. Plots of each cultivar were established via seeding in four replicates. To simulate horse traffic at a trot, a Baldree Traffic Simulator was driven over a section of the plot either 0 (no traffic), 1 (low traffic), or 2 (high traffic) times. Traffic treatment was applied weekly for 6 weeks followed by 4 weeks of rest in the spring, summer, and fall. Plots were assessed for compaction, biomass available for grazing and vegetative cover as a measure of persistence before and after treatment was applied and rest periods. Nutritional composition was assessed throughout the growing seasons by wet chemistry analysis. Creeping bentgrass and chewings fescue cultivars were lowest in average NSC in year 1 and 2, respectively. Soil compaction was increased as treatment level increased (*P* <0.0001). Traffic treatment reduced cultivar persistence following traffic by 18.7 to 36.5% across all trials for year 1 and 2 (*P* = 0.0003). For most trials, biomass available for grazing was reduced following traffic between 19.1 to 43.1% (*P* = 0.02). Overall, tall fescue cultivars were most traffic tolerant, but were not consistently <15% NSC. Cultivars having <15% NSC on average included creeping bentgrass in year 1 and hard fescue and chewings fescue in year 2. Due to relative traffic tolerance, tall fescue and hard fescue cultivars are recommended to be evaluated for on-farm persistence in dry lots and heavy use areas and for long term effects of grazing by equids. Additionally, further study of creeping bentgrass is suggested due to NSC composition.

Key Words: Turfgrass, Traffic, Erosion, Equine, Grazing

Highlights

- The Baldree traffic simulator was effective at applying three distinct levels of traffic.
- Tall fescue cultivars were most traffic tolerant.
- Creeping bentgrass had the lowest NSC concentration on average.

- In general, traffic treatments decreased persistence by 18.7 to 36.5% and biomass by 19.1 to 43.1%.

1. Introduction

1.1 Environmental Impact

Since the 1800's, sediment erosion in the Chesapeake Bay has increased and it has lead to the decrease of submerged aquatic vegetation which is an essential part of the Bay's ecosystem. Coupled with declining water quality, this sediment erosion has led to the Bay being classified as an impaired water body [1]. Sources of erosion result from both agricultural and urban practices and continue to occur despite the development of "Best Management Practices" or BMPs designed to foster environmental stewardship [1; 2]. On equine operations, overgrazed and high traffic areas of pasture as well as dry or loafing lots have been identified as sources of sediment erosion and nutrient runoff due to a lack of vegetation to anchor soil [2]. Though practices exist to reduce nutrient runoff and sediment erosion, they require additional costs to the owner or manager in the form of materials, labor and time [3].

In an effort to improve the current environmental stewardship on equine operations, traffic tolerant ground cover options should be investigated for dry lots and other areas of high traffic, such as feeding stations, gates and small paddocks subject to high stocking rates, as both have been associated with reduced vegetative cover to efficiently anchor soil [2]. Turfgrasses may be suitable for this task as they have been developed over the past several decades to be traffic tolerant for use on athletic fields and industrial lawns despite low mowing heights [4]. Both turfgrasses and pasture grasses have the same origin, but selective breeding was used to make forage-type grasses high yielding and highly nutritious for grazing livestock [4; 5]. These improved pasture grasses are tolerant of defoliation by grazing and animal traffic due to their enhanced capacity for photosynthetic activity, which in turn results in increased levels of non-structural carbohydrates (NSC). High NSC forages are unsuitable for equids that are obese and/or have metabolic disorders thus requiring a diet with a non-structural carbohydrate (NSC) composition <10-12% [6; 7].

1.2 Metabolic Concerns

When pasture is abundant, metabolically sensitive equids are at risk for the development of pasture associated laminitis (PAL), a serious and painful hoof condition that has been associated with the overconsumption of non-structural carbohydrates and is responsible for the majority of cases of laminitis [8] in the US. In a recent survey of owner and managers of over-conditioned equids in Maryland, laminitis was identified as the complication of obesity that they were most concerned about their horses and ponies developing [3]. Specifically related to PAL is fructan, a component of NSC that accumulates in cool-season grasses during periods of increased growth.

Cool-season grasses are common to pastures in the Mid-Atlantic region [9] and overall, offer a nutritious forage source, but depending on environmental conditions, they may accumulate NSC to levels that are unsafe for grazing by equine with metabolic sensitivity. To avoid a bout of laminitis, equine owners and managers are advised to monitor and control body condition as well as insulin sensitivity and to not expose sensitive equine to pasture when NSC levels are anticipated to be high. This is done by reducing NSC to < 10-12% of the entire diet on a dry matter basis [6; 7], reducing caloric intake, and maintaining a set exercise regimen [10]. Dry lots are effective tools for removing or limiting pasture access by confining equids to a small enclosure bare of vegetation and offering a specified amount of hay that is usually low in NSC and digestible energy to account for daily roughage intake. NSC composition of pastures is of importance to equine managers due to the association of overconsumption of non-structural carbohydrates in the pasture [11] with the onset of laminitis proven through the dosing of oral boluses of oligofructoses (i.e. fructans) to successfully induce laminitis [12].

1.3 Objectives

The objective of this study was to evaluate eight cool-season commercially available seeded turfgrass cultivars for their potential as an alternative ground cover in areas subject to high hoof traffic such as dry lots, gates and small paddocks, as well as a nutrition source for grazing horses. Suitable cultivars will be tolerant of traffic, moderate in yield, and low in NSC composition. For the purpose of this study, suitable cultivars will be those with a NSC composition of 15% or less.

2. Materials and Methods

The study had a split plot design and was conducted at the University of Maryland's Paint Branch Turfgrass Research Center in College Park, MD. Weather data during the study was obtained from the National Oceanic & Atmospheric Administration weather station located at Beltsville, MD (USC00180700) approximately 6.4 km from the study site. Data was generated on a monthly basis and addressed mean, mean maximum, and mean minimum temperature as well as total rainfall.

Experimental seeded cool-season cultivars included 'Maestro' and 'Regenerate' tall fescue (*Schedonorus arundinaceus* (Schreb.) Dumort*.,* Landmark Turf and Native Seed, Spokane, WA, 'Predator' hard fescue (*Festuca brevipila* Tracey*,* Pennington Seed Inc., Madison, GA), 'Chantilly' creeping red fescue (*Festuca rubra L. ssp. arenaria* (Osbeck) F. Aresch*,* DLF Pickseed, Halsey, OR), 'Radar' chewings fescue (*Festuca rubra L. ssp. fallax* (Thuill.) Nyman*,* Mountain View Seeds, Salem, OR), 'Midnight' Kentucky bluegrass (*Poa pratensis L. ssp. pratensis,* Turf-Seed, Inc., Gervais, OR), 'Penncross' creeping bentgrass (*Agrostis stolonifera L.,* Pennington Seed Inc., Madison, GA), and 'Accent II' perennial ryegrass (*Lolium perenne L. ssp. perenne,* Jacklin Seed, Liberty Lake, WA). From this point forward, species will be abbreviated as follows: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass. In the case of TF, where two cultivars represent the species, cultivar name will be included in the statement. Cultivars were selected based on their wear tolerance in performance trials such as those conducted by the National

Turfgrass Evaluation Program (NTEP, Beltsville, MD, www.ntep.org) and on their current commercial availability as seeded varieties for future purchase by managers of equine operations. Cultivars were seeded as follows: TF 11.9 kg/m^2, HF 11.9 kg/m^2, RF 6.0 kg/m^2, CF 6.0 kg/m^2, KBG 6.0 kg/m^2, CBG 1.5 kg/m^2 and PRG 7.4 kg/m^2.

Seedbeds were prepared by tilling to 15-20 cm depth using a Soil Renovator (Rotadairon, Anderson, SC), removing rocks, and cultipacking soil until a 0.6 cm depth boot heel impression was left in the soil. Plots were then seeded on September 9, 2015. Four randomly assigned monoculture plots of each cultivar were broadcast seeded in 3.2m x 1.5m plots by use of a drop spreader (Gandy, Owatonna, MN) with each cultivar randomly seeded in adjacent plots and each represented four times. To improve seed contact with soil and reduce losses due to natural rainfall, seeds were lightly raked into the soil at 0.3 cm depth prior to irrigation by above ground sprinkler. Plots were irrigated as necessary to maintain soil moisture until a four-leaf stage was reached. Plots were then mowed to no less than half the height of the each desired grass species as needed to control invasive weeds. Throughout the study, various broadleaf herbicides were applied as needed to control invasive species as follows; Aim EC at a rate of 146.2 mL/ha (FMC Agricultural Solutions, Philadelphia, PA) April 27, 2016, Detonate at a rate of 1169.2 mL/ha (Tenkoz Inc., Alpharetta, GA) October 17, 2016, April 27, 2017 and October 5, 2017, and Prowl H2O at 4.9 L/ha (BASF, Research Triangle Park, NC) April 18, 2017. Soil testing was conducted by the Virginia Tech Soil Testing Lab (Blacksburg, VA). Nitrogen was applied following recommendations from the soil testing lab and phosphorous and potassium were applied following soil test recommendations at seeding and in the spring and fall of years 1 and 2 at a rate of 89.6 kg/ha nitrogen (N), 112 kg/ha phosphorous (P_2O_5), and 112 kg/ha potassium (K_2) each year.

During spring, summer and fall of 2016 (year 1) and 2017 (year 2), each plot received each of three treatments. The three treatments were no traffic (CON), 1 pass of a traffic simulator (LOW), or 2 passes of a traffic simulator (HIGH). Treatments were applied once a week for a period of six weeks followed by four weeks of recovery during which no treatments were applied. NTEP guidelines were followed for administering traffic simulator treatments and as well as resting plots for a minimum of 4 weeks between treatments. A Baldree Traffic Simulator was used by adapting a Jacobsen Ryan GA30 aerator [13]. Adaptations include the construction of four "feet" which replace aerator pedals. For the purposes of this study no golfing cleats were welded to the base of the feet and were left flat with the exception of heads of screws on the underside of the base to better represent a bare horse hoof. This equipment was selected because it produces wear traffic similar to the equine hoof and produces similar vertical force to a horse at a trot. Additionally, it has been shown to produce more traffic per pass than the Cady or Brinkman traffic simulators and is more suited for simulating heavy traffic [13]. Figure 2a shows the feet on the back of the traffic simulator. Figure 2b shows the response of plots to LOW, CON, and HIGH traffic treatments with LOW treatment applied to the left side of plots, CON to the middle section and HIGH to the right side. Treatments were applied within ± 1 day of the scheduled application day if inclement weather interfered with the scheduled days. Footing assessment was determined by walking next to plots and evaluating the depth that a boot heel would sink into the soil. If the impression left by a boot heel was less than 1 cm, traffic was applied. Prior to each traffic treatment, height was assessed by use of a falling plate meter [14] and if any plots measured above 5 cm, biomass samples were harvested from control sections of plots prior to all plots being mowed to approximately 2.5 cm to ensure that grasses would not get caught in the traffic simulator.

Before and after each traffic treatment series, as well as after each rest period, plots were evaluated for biomass, vegetative cover and compaction. Biomass available for grazing was determined by harvesting a 0.25 m x 0.25 m quadrat by hand with shears and drying at 70°C until weight remained constant to determine yield on a dry matter basis. Dry matter weights were then used to determine available forage on a kilogram per hectare basis. A modified line-intercept method [15] using a grid with nine string intersection points was used to measure vegetative cover. Vegetative cover was assessed at each string intersection and classified as either desired species, invasive species, soil, thatch or other, according to what was found at soil level. Frequency for each category was then transformed into percentage values to estimate cover of each category. Compaction was measured by use of a penetrometer (Turf-Tec International, Tallahassee, FL) with three readings taken per treatment area of each plot and then averaged to determine compaction for control, low and high traffic regions of each plot. For both years, biomass for the fall rest period was unable to be collected as the growing season had ceased during the rest period and all cultivars were at a height below 5 cm. At this height, biomass samples were not collected as grass was too short to cut to 2.5 cm without unintentionally clipping below desired height.

Nutritive value of all cultivars was assessed across the growing season to evaluate their potential as a forage for grazing horses. Sampling occurred on May 9, June 30, August 22 and October 25, 2016 and May 16, June 21, August 20 and October 24, 2017. All annual yield values were collected from CON regions of plots, and while these areas were exposed to no traffic treatments, they were managed on the same schedule as traffic regions of plots including mowing to 2.5 cm prior to traffic treatments. Samples were hand-clipped at a height of 2.5 cm from control area on each plot, subsamples were combined, and then then stored in a -80°C freezer until shipped on dry ice to a commercial laboratory (Equi-Analytical, Ithaca, NY). Combined samples were analyzed for nutrient composition including an estimation of digestible energy (DE) and wet chemistry analysis of crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), water soluble carbohydrates (WSC), starch, and non-structural carbohydrates (NSC) following approved AOAC laboratory methods.

Data was analyzed using the mixed procedure of SAS 9.3 (SAS Institute, Cary, NC) to conduct an ANOVA using orthogonal contrasts for least-squares mean comparisons. Separate analysis was run for each traffic treatment and each rest period. Variables analyzed were compaction, vegetative cover, biomass, and nutrient composition. Covariates were utilized in the evaluation of vegetative cover and biomass in response to traffic treatments and recovery periods. Fixed model effects included cultivar, treatment and cultivar*treatment interaction and the random effect was plot. Assumptions of normality and homogeneity of variances were found normal by examination of the residual plots. For data following traffic treatments, covariates were measurements taken prior to each traffic series and for rest periods, covariates were measurements taken after the completion of each traffic series, immediately prior to rest. Results were considered significant at the $P < 0.05$ level. Response variable means were reported as Least Squares Means (LSM) ± Standard Error (SE) and Tukeys' adjustment was used for least squares mean comparisons. Relative traffic tolerance was determined by the frequency of each cultivar and traffic level being a top performer in either vegetative cover or biomass available for grazing for both traffic and rest periods for each season. Frequency of top performance was then summed and cultivars were ranked with "1" being awarded to cultivars with the highest frequency of top performance.

3. Results

3.1. Weather

Average monthly temperature was similar for year 1 and year 2, but total rainfall was different. In year 1, total rainfall accumulation over the growing season was 75.2 cm and in year 2, total accumulation was 89.9 cm. Additionally, in year 2, monthly total rainfall had greater fluctuation compared to year one (Figure 1).

3.2. Compaction.

Compaction of cultivars in response to traffic treatment and rest following treatment in the spring, summer and fall of year 1 is shown in Appendix Tables 1 and 2. There was a main effect of treatment for all traffic trials with an increase in compaction scores as traffic treatment increased ($P < 0.0001$). During the spring and fall, there also was a main effect of cultivar with TF (Maestro and Regenerate) having the lowest compaction values ($P<0.0001$). In the spring of year 1, there was a treatment*cultivar interaction where within LOW, CBG had the highest compaction score whereas HF had the lowest compaction score ($P=0.0097$). After rest, the effect of treatment remained significant ($P<0.0001$) across all seasons of year 1.

Compaction of cultivars in response to traffic treatment and rest in the spring, summer and fall of year 2 is shown in Appendix Tables 3 and 4. Again, there was a main effect of treatment for all traffic trials with an increase in compaction scores as traffic treatment increased ($P < 0.0001$). An effect of cultivar was only seen in the spring and summer traffic trials with the TF (Maestro and Regenerate) having the lowest compaction in the spring ($P < 0.0001$). In the summer, one TF (Maestro) had the lowest compaction whereas CBG had the highest level of compaction (P=0.0046).

3.3. Persistence. Persistence by percent desired species in response to traffic treatments applied during years 1 and 2 are shown in Tables 1 and 2, respectively. For both years across all traffic trials, there was a main effect of treatment with percent desirable species decreasing as traffic treatment levels increased (P < 0.0003).

There was a main effect of cultivar with the TF cultivars having the most persistence across all traffic trials and CBG having the least persistence across all traffic trials ($P < 0.006$). In the summer of both years, there was a treatment*cultivar interaction ($P < 0.03$). In summer of year 1, all cultivars had reduced persistence as traffic treatment levels increased with the exception of CBG which had the greatest persistence for HIGH, followed by LOW and then CON. In the summer of year 2, KBG also showed this pattern. However, in year 2 CBG was highest for CON, then HIGH, then LOW. Regenerate TF also showed a different pattern with LOW regions having more desirable species than CON and HIGH.

Persistence by percent desired species in response to rest after traffic treatment applied during years 1 and 2 is shown in Tables 3 and 4, respectively. With the exception of the summer in year 2, similar patterns were observed for cultivar persistence following rest with a decline in percent desirable species as traffic treatment level increased ($P < 0.04$). After rest, TF cultivars continued to be the most persistent across all traffic trials with CBG having the least persistence ($P < 0.05$). Interactions occurred in the fall of both years and the summer of the second year. CBG showed good recovery performance in the first spring rest period, but after that showed the lowest ability to recover from traffic. In the first fall traffic trial, most cultivars had greater recovery when exposed to less traffic ($P < 0.0001$). In year 1, CBG did exhibit the best recovery occurring when traffic was highest.

In the summer of year 2, no distinct pattern for persistence was observed despite an interaction present (P = 0.035). In the fall of year 2, recovery had an inverse relationship with traffic treatment with recovery decreasing as traffic levels increase, except for TF and KBG cultivars.

3.4. Biomass. Biomass (kg/ha, DM basis) was used to assess wear tolerance and also to calculate average annual yield for each cultivar. Biomass in response to traffic treatments applied in the spring, summer, and fall and after respective rest periods are shown in Appendix Tables 5, 6, and 7 for year 1 and Appendix Tables 7, 8, and 9 for year 2. In the spring of year 1, there was an effect of cultivar (P=0.0012), treatment (P < 0.001), and their interaction (P =0.016) with all cultivars decreasing in biomass as traffic level increased. There is no data for biomass after rest in the fall of year 1 or 2 because there lacked sufficient growth during the rest period.

For traffic periods, interactions were seen for spring and fall of year 1 and summer and fall of year 2. In the spring of year 1, all cultivars had the most biomass in CON regions, followed by LOW and then HIGH regions. In the fall of year 1 this relationship was still observed for RF, one of the TF cultivars (Maestro), HF, and CF but varied for other cultivars. The relationship continued again in the summer of year 2 with the exception of one of the TF cultivars (Regenerate) which had the highest biomass from LOW and in the fall of year 2 for all cultivars except PRG, KBG and HF which also had highest biomass for LOW. An interaction was also seen after rest, but only for summer 1. In this rest period, the inverse relationship between traffic and biomass continued for PRG, RF, one of the TF cultivars (Maestro), KBG and HF. A difference among annual yield was seen for year 1 (Table 5) and year 2 (Table 6). For year 1 and year 2, HF had the highest yield and KBG, CBG, and PRG had the lowest yields.

3.5. Nutritional Composition. Average nutritional composition of turfgrasses was similar across cultivars (Table 4) with the exception of NSC (WSC + starch). Average NSC (DM basis) across the growing season ranged from 8.1% (CBG) to 19.9% (PRG). In year 1, CBG was lowest for average NSC and in year 2, HF and CF were lowest. Average, minimum and maximum NSC values for each cultivar are expressed in Figure 3 where data is expressed on a monthly basis. In year 1, all cultivars were <15% NSC for June and August, with CBG also <15% in May. In year 2 cultivars <15% NSC included TF (Maestro), HF, RF, CF, and PRG in June and October and KBG and CBG only in October. Peak NSC was observed in the PRG at 31% for May of year 1 and lowest NSC was observed in the CBG at 6.4% for June of year 1.

3.6. Relative Traffic Tolerance Ranking. Traffic and recovery performance consistently resulted in greater performance by the TF cultivars across all seasons (Table 7). KBG, HF and CF also ranked high in traffic tolerance, but below the frequency at which the TF cultivars performed. CBG performance suffered following the first spring traffic treatment and in initial recovery trafficked regions performed better than CON.

4. Discussion

4.1 Suitability of the Baldree Traffic Simulator

Compaction results indicate the effectiveness of the Baldree Traffic Simulator as a suitable method for applying three distinct levels of traffic on turfgrass plots as compaction was significantly increased as traffic level increased. In studies comparing damage produced by traffic simulators, the Baldree traffic simulator was found to be the most destructive versus the Cady and Brinkman [13]. Additionally, the Cady was found to do more damage than the Brinkman [16] but treatment implemented by the Rutgers traffic simulator resulted in slower recovery after treatment [17]. For the purposes of this experiment, the Baldree was most appropriate as it was previously found to apply vertical force at the same capacity as a horse at the trot [13].

4.2 Relative Traffic Tolerance Ranking

Previous research findings both support and refute relative traffic tolerance rankings observed in this study. In a study simulating horse hoof traffic, results found that timothy, a forage grass used for hay and sometimes used in horse pasture, was less resistant to traffic than TF and KBG [25]. In a traffic study of cool-season turfgrasses in Italy, PRG and TF were more tolerant of traffic than KBG, and CF and RF were least tolerant but had higher shoot density [18]. Similar findings were reported by Harivandi out of the University of California with TF being more traffic tolerant than PRG followed by KBG, HF, and RF with Highland bentgrass, colonial bentgrass, and CBG ranked as least traffic tolerant [19]. Conversely, sheep fescue, CF, colonial bentgrass and velvet bentgrass were recommended to be suitable as low input and traffic tolerant species for use on golf course fairways in the northern portion of the United States [20]. Research within species group has also found differences in traffic tolerance between branches of species and cultivars. In a study by Chen et al. of various fine fescues including CF, HF and sheep fescue, tolerated traffic better than creeping red fescue [21]. In evaluations of Kentucky bluegrass, Park et al. found that KBG tolerated and recovered from traffic best in the fall [22] compared to spring and summer, and that cultivars with compact growing patterns tolerated traffic better than other varieties [23]. Due to the difference in results from traffic trials conducted in various regions, assessment of cultivars should be conducted within the region to which recommendations are being made.

One possible reason for the poor performance of CBG after the first traffic series in this study is that performance was not only due to the traffic level, but also the mowing height being too damaging especially as the growing season was entering the warmer temperatures of the summer. When CBG was improving in recovery performance, recovery was best for HIGH regions. This may be due to the simulator breaking up accumulated thatch and preventing the establishment of broadleaf weeds that could block surviving desired species from exposure to sunlight. The other species which struggled throughout the trial was KBG. KBG was slow to establish and consistently grew at shorter heights. Invasive clover was controlled through broadleaf herbicide treatment, but in the event that herbicide were not used, results may have differed significantly. Additionally, performance may have been affected by rainfall as there was greater variability of total rainfall observed by month in year 2 compared to year 1, and biomass was reduced in year 2 compared to year 1 (Figure 1).

4.3 Nutritional Composition

DE, DM, ADF and NDF composition of turfgrasses in this study were found to be similar to previously reported values for forage-type grasses [24-27]. Interesting though was that CP values were similar to those of legumes with a reported range of 16-25% [24; 25]. Allen et al. also saw this in turfgrasses they evaluated which included a KBG hybrid (~20.8% CP), RF (~21.5%), HF (~19.0%), and colonial bentgrass (~20.4%) [28]. Compared to values reported by Allen et al. , starch values in this study were more similar in year 2 than year 1 when values observed were lower than those reported by Allen et al. NSC was also similar as Allen et al. reported that HF and colonial bentgrass were lower in NSC compared to others, which was also observed in this study.

4.4 Yield

Compared to yield data from forage variety trials conducted by the University of Kentucky, the KBG was similar in yield for year 1 only [29] and the turfgrass TF cultivars were higher in yield compared to forage varieties of TF (Jesup MaxQ and Kentucky 31+) in the first year, but also dropped in productivity below values in the Kentucky trials in year 2 [30]. TF yields were also lower than forage yields of ~11,000-15,400 kg/ha annually [27], but it was noted that yields may differ depending on location, management practices and length of growing season. PRG annual yield was previously reported to range from 3380-10,830 kg/ha [31; 32]. Potential sources of the decline in productivity from year 1 to year 2 include the increased variability in rainfall experienced in year 2 (Figure 1) and the stress of frequent short mowing necessary for use of the traffic simulator. Overgrazing has been associated with yield reductions [33] and cultivars in this study were subject to frequent close mowing, whereas forage variety trials are managed similar to hay production practices where harvest occurs less frequently. An additional source of variation in the yield of the turfgrass cultivars may be due to seeding rate. For this study, cultivars were seeded at rates for athletic fields or commercial lawns, much higher than typical pasture rates, which in turn may have caused yields to be higher than if they had been established at pasture seeding rates.

5. Conclusion

Overall, multiple turfgrass cultivars warrant further study and may show promise as either traffic tolerant or low NSC ground cover for use on equine operations, but none were consistently traffic tolerant and low NSC. In regard to traffic tolerance, the TF cultivars (Maestro and Regenerate) were the clear leaders. TF cultivars were also moderate in yield, relative to other cultivars included in the study, but not consistently <15% NSC. Compared to traditional forage-type tall fescue, yield is initially increased, which may be an effect of seeding rate, and declined in the second year in response to cumulative effects of treatment. Of the cultivars evaluated, CBG produced the lowest average NSC in year 1 and HF and CF lowest average NSC in year 2. HF was also well ranked in relative traffic tolerance falling just behind TF cultivars. Due to the comparatively lower NSC level of the CBG there may still be potential for its use on equine operations, but further research in management, stocking rates and persistence is warranted due to poor relative traffic tolerance in this study, as well as performance in northern regions where CBG may be better suited. TF and HF cultivars should also be evaluated for similar performance. Further research should include side-by-side comparison of Maestro, Regenerate, Radar and Penncross cultivars against a forage-type tall fescue such as Kentucky 31 or MaxQ. In addition, establishment methods should be evaluated to determine if seeding at lower rates can still produce a viable stand to withstand the pressures of continuous equine grazing.

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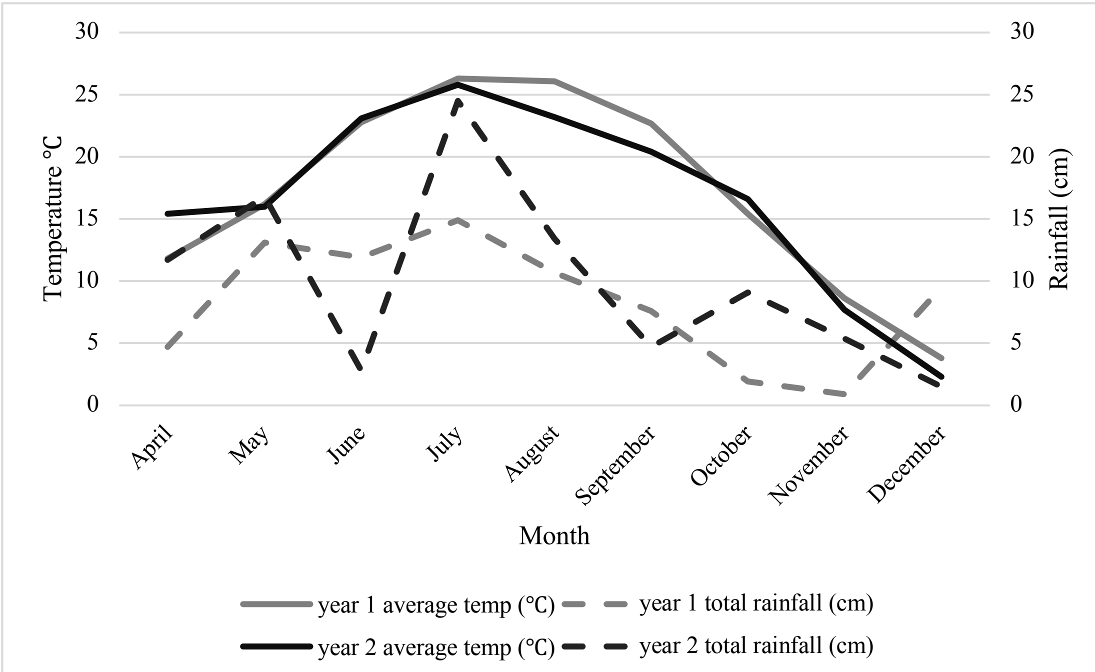


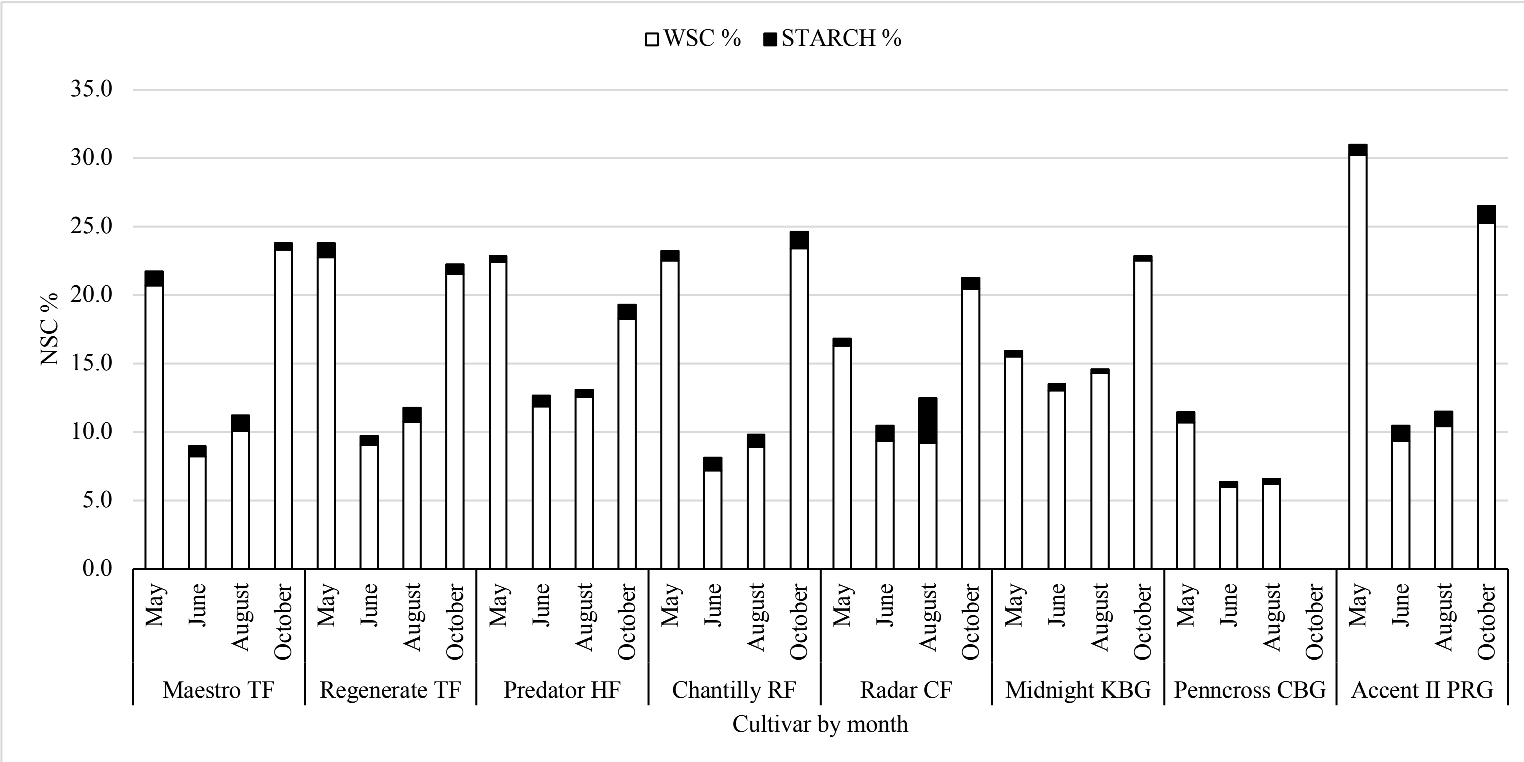
Figure 1. Average temperature and total rainfall by month during year 1 (2016) and 2 (2017).

a. 

b. 

Figure 2. Example of traffic simulator (a.) and response of plots to low, no, and high traffic treatments (b.).

3a.



WSC %
STARCH %
NSC %
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
May
June
August
October
Maestro TF
Regenerate TF
Predator HF
Chantilly RF
Radar CF
Midnight KBG
Penncross CBG
Accent II PRG
Cultivar by month

3b.

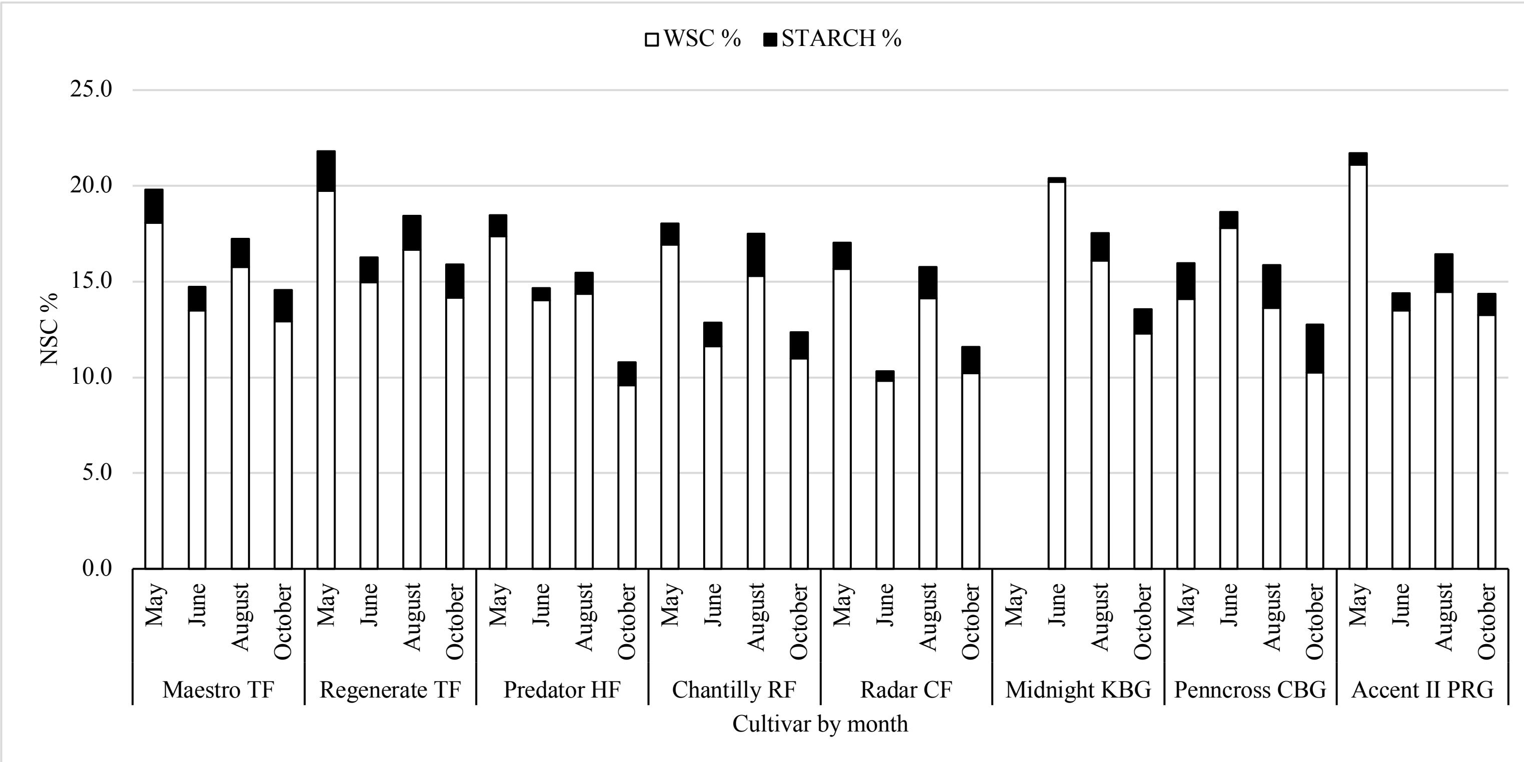
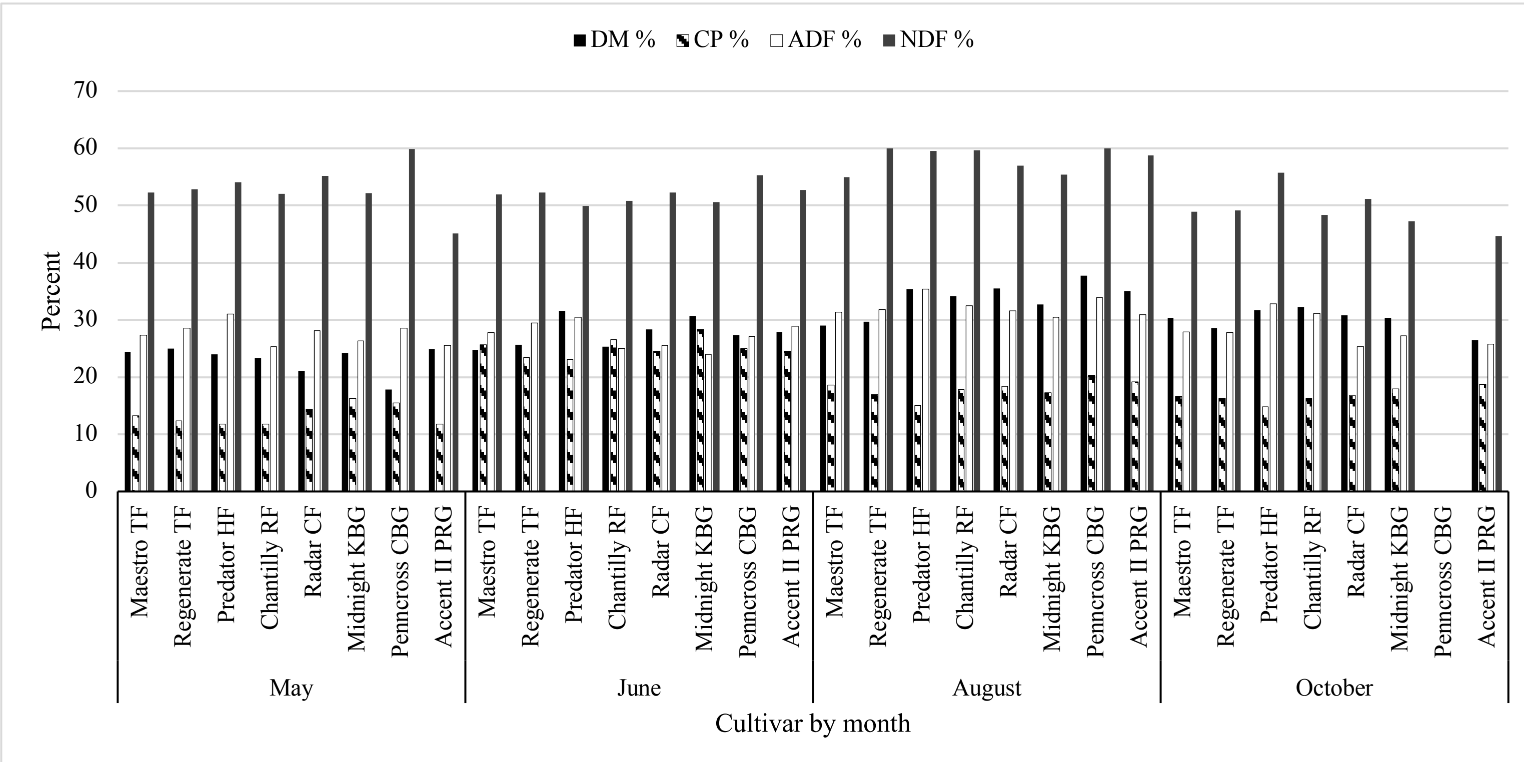


Figure 3. Non-structural carbohydrate composition (Water Soluble Carbohydrate + Starch) of cool-season turfgrass cultivars by month for year 1 (3a., 2016) and 2 (3b., 2017). Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.

4a.



DM %
CP %
ADF %
NDF %
Percent
70
60
50
40
30
20
10
0
Maestro TF
Regenerate TF
Predator HF
Chantilly RF
Radar CF
Midnight KBG
Penncross CBG
Accent II PRG
May
June
August
October
Cultivar by month

4b.

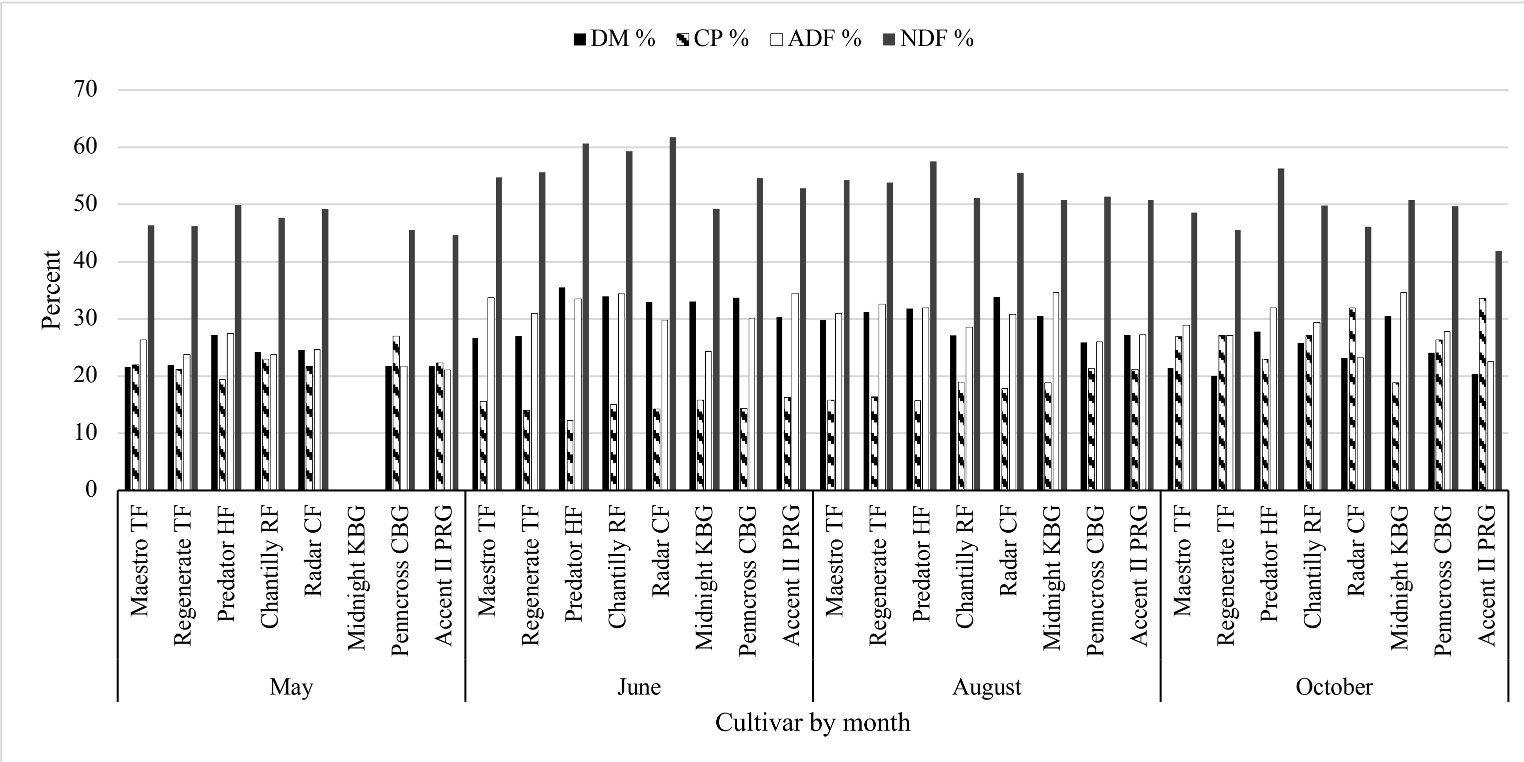


Figure 4. Nutritional composition of cool-season turfgrass cultivars by month for year 1 (4a., 2016) and 2 (4b., 2017). Components represented include dry matter (DM), crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF). Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.

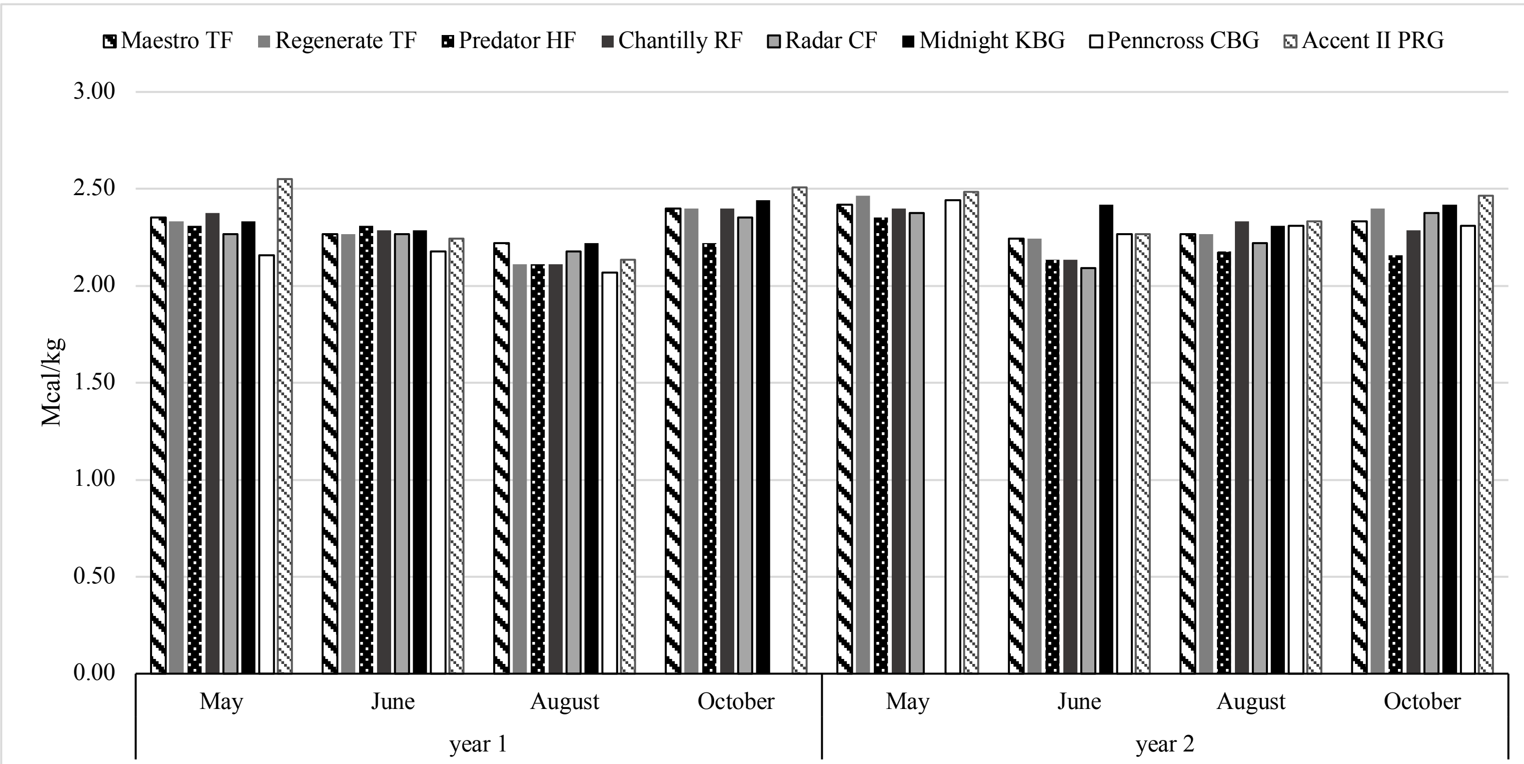


Figure 5. Digestible energy (DE, Mcal/kg) for cool season turfgrass cultivars for year 1 (2016) and 2 (2017). Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.

Table 1. Persistence by percent desired species in response to traffic treatment applied during year 1[1,2].

	Spring				Summer				Fall			
Cultivar[3]	Control	Low	High	Cultivar Average	Control	Low	High	Cultivar Average	Control	Low	High	Cultivar Average
Maestro TF	99.4	82.5	63.4	81.2^{a}	76.8^{a}	65.6^{a}	47.4^{a}	63.3^{a}	69.4	50.0	48.4	$55.9^{a,b}$
Regenerate TF	96.7	82.9	68.3	82.7^{a}	76.8^{a}	60.7^{a}	46.8^{a}	61.4^{a}	69.4	56.7	51.7	$59.3^{a,b}$
Predator HF	89.2	56.6	35.4	60.4^{b}	$68.6^{a,x}$	$37.1^{a,b,y}$	$29.7^{a,b,y}$	$45.1^{a,b}$	68.3	52.5	36.5	52.4^{a}
Chantilly RF	81.0	64.9	32.0	59.3^{b}	$58.6^{a,x}$	$33.1^{a,b,x,y}$	$22.7^{a,b,y}$	38.1^{b}	54.2	42.7	37.3	$44.7^{a,b}$
Radar CF	90.8	74.0	36.8	67.2^{b}	60.3^{a}	40.7^{a}	$32.7^{a,b}$	$44.6^{a,b}$	63.3	45.3	37.6	$48.8^{a,b}$
Midnight KBG	83.9	57.6	45.5	62.4^{b}	63.8^{a}	48.8^{a}	$36.5^{a,b}$	$49.7^{a,b}$	67.1	61.8	48.1	59.0^{a}
Penncross CBG	92.7	63.7	40.5	65.7^{b}	2.4	5.4^{b}	9.4^{b}	5.7	32.2	23.9	29.4	28.5^{b}
Accent II PRG	88.9	68.4	51.0	$69.4^{a,b}$	53.9^{a}	49.2^{a}	$29.2^{a,b}$	$44.1^{a,b}$	68.6	59.0	50.1	59.2^{a}
Treatment Average	90.3^{x}	68.8^{y}	46.6^{z}		57.6^{x}	42.6^{y}	31.8^{z}		61.5^{x}	49.0^{y}	42.4^{z}	
Cultivar	p < 0.0001, SE ± 3.7				p < 0.0001, SE ± 5.1				p = 0.0056, SE ± 5.8			
Trt	p < 0.0001, SE ± 1.7				p < 0.0001, SE ± 2.9				p = 0.0003, SE ± 2.7			
Cultivar*Trt	NS, SE ± 5.5				p = 0.0277, SE ± 7.4				NS, SE ± 7.9			

[1]Values presented are LSMeans on a percent basis.
^{a,b,c}Means within a column with unlike superscripts differ ($P< 0.05$).
^{x,y,z} Means within a row with unlike superscripts differ ($P< 0.05$).
[2]Treatment regions within each plot: control (no treatment), low (1 pass of the simulator per week) and high (2 passes of the simulator per week).
[3]Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.

Table 2. Persistence by percent desired species in response to traffic treatment applied during year 2[1,2].

	Spring				Summer				Fall			
Cultivar[3]	**Control**	**Low**	**High**	**Cultivar Average**	**Control**	**Low**	**High**	**Cultivar Average**	**Control**	**Low**	**High**	**Cultivar Average**
Maestro TF	90.2	84.7	72.8	82.6^{a}	69.1^{a,bx}	65.3^{a,x}	41.5^{y}	58.7^{a,b}	89.7	71.7	70.1	77.2^{a}
Regenerate TF	90.2	78.3	69.1	79.2^{a,b}	65.9^{a,b}	68.7^{a}	57.2	63.9^{a}	94.5	80.2	55.9	77.0^{a}
Predator HF	71.9	64.6	44.7	60.4^{c}	70.3^{a,b,x}	59.3^{a,x,y}	38.3^{y}	56.0^{a}	76.9	61.2	39.1	59.1^{a,b,c}
Chantilly RF	60.9	57.1	37.2	51.7^{c}	74.3^{a,x}	55.9^{a,x,y}	36.7^{y}	55.7^{a}	78.5	53.4	46.1	59.3^{a,b,c}
Radar CF	73.7	64.6	55.4	64.6^{a,b,c}	73.7^{a,x}	62.5^{a,x,y}	45.7^{y}	60.6^{a}	77.7	60.0	53.6	63.8^{a,b}
Midnight KBG	55.1	51.5	53.2	53.2^{c}	31.8^{c}	37.9^{a,b}	42.2	37.3^{b,c}	35.0	49.6	36.5	40.4^{c}
Penncross CBG	50.9	39.9	32.6	41.1^{c}	37.4^{b,c}	18.7^{b}	24.2	26.8^{c}	50.3	45.6	26.3	40.7^{b,c}
Accent II PRG	70	61.6	55.2	62.2^{b,c}	61.1^{a,b}	48.4^{a}	41.1	50.2^{a,b}	83.8	68.2	56.1	69.4^{a}
Treatment Average	70.4^{x}	62.8^{y}	52.5^{z}		60.5^{x}	52.1^{y}	40.9^{z}		73.3^{x}	61.2^{y}	48.0^{z}	
Cultivar	p = 0.0012, SE ± 6.2				p = 0.0004, SE ± 5.0				p = 0.0004, SE ± 5.6			
Treatment	p < 0.0001, SE ± 2.2				p < 0.0001, SE ± 1.9				p < 0.0001, SE ± 2.4			
Cultivar* Treatment	NS, SE ± 7.7				p = 0.0002, SE ± 6.4				NS, SE ± 7.8			

[1]Values presented are LSMeans on a percent basis.
[a,b,c]Means within a column with unlike superscripts differ ($P < 0.05$).
[x,y,z] Means within a row with unlike superscripts differ ($P < 0.05$).
[2]Treatment regions within each plot: control (no treatment), low (1 pass of the simulator per week) and high (2 passes of the simulator per week).
[3]Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.

Table 3. Persistence by percent desired species in response to rest after traffic treatment applied during year 1[1,2].

	Spring				Summer				Fall			
Cultivar[3]	**Control**	**Low**	**High**	**Cultivar Average**	**Control**	**Low**	**High**	**Cultivar Average**	**Control**	**Low**	**High**	**Cultivar Average**
Maestro TF	85.8	75.0	67.1	$76.0^{a,b}$	73.2	58.8	48.9	60.3^{d}	75.4^{b}	64.9	46.6	$62.3^{a,b}$
Regenerate TF	85.8	72.3	69.7	$75.9^{a,b}$	73.2	63.3	48.9	$61.8^{d,e}$	78.2^{b}	67.3	56.6	67.4^{a}
Predator HF	85.9	64.4	47.8	$66.0^{a,b}$	54.1	41.4	28.9	$41.4^{b,e}$	64.1^{b}	56.0	40.1	$53.4^{a,b}$
Chantilly RF	80.6	69.8	42.1	$64.1^{a,b}$	43.9	39.8	20.8	$34.8^{a,b,c}$	58.7^{b}	43.2	33.9	45.3^{b}
Radar CF	85.9	72.4	47.5	$68.6^{a,b}$	51.3	36.6	30.5	39.5^{c}	$50.4^{a,b}$	59.6	55.8	$55.3^{a,b}$
Midnight KBG	69.6	50.2	41.7	53.8^{b}	54.4	41.3	40.7	$45.5^{b,c,d,e}$	62.4^{b}	46.1	49.8	$52.8^{a,b}$
Penncross CBG	94.1	69.5	64.4	76.0^{a}	18.2	19.2	18.2	18.6^{a}	$23.4^{a,x}$	$37.3^{x,y}$	52.0^{y}	37.3^{b}
Accent II PRG	77.7	72.5	61.7	$70.6^{a,b}$	40.2	39.4	33.4	$37.7^{a,b,c}$	$57.2^{a,b}$	52.9	47.8	$52.6^{a,b}$
Treatment Average	83.2^{x}	68.3^{y}	55.2^{z}		51.1^{x}	42.5^{y}	33.8^{z}		58.7^{x}	$53.4^{x,y}$	47.8^{y}	
Cultivar	p = 0.0463, SE ± 4.6				p = 0.0002, SE ± 5.0				p = 0.0370, SE ± 5.5			
Treatment	p = 0.0004, SE ± 3.7				p < 0.0001, SE ± 2.4				p = 0.0353, SE ± 2.6			
Cultivar* Treatment	NS, SE ± 7.7				NS, SE ± 6.2				p = 0.0001, SE ± 7.0			

[1]Values presented are LSMeans on a percent basis.
^{a,b,c}Means within a column with unlike superscripts differ ($P < 0.05$).
^{x,y,z} Means within a row with unlike superscripts differ ($P < 0.05$).
[2]Treatment regions within each plot: control (no treatment), low (1 pass of the simulator per week) and high (2 passes of the simulator per week).
[3]Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.

Table 4. Persistence by percent desired species in response to rest after traffic treatment applied during year 2[1,2].

	Spring				Summer				Fall			
Cultivar[3]	**Control**	**Low**	**High**	**Cultivar Average**	**Control**	**Low**	**High**	**Cultivar Average**	**Control**	**Low**	**High**	**Cultivar Average**
Maestro TF	90.9	84.0	80.3	85.1^{d}	71.7^{a}	78.5^{a}	59.7^{a}	70.0^{b}	83.8^{a}	88.4^{a}	75.6^{a}	82.6^{a}
Regenerate TF	79.9	83.2	74.8	79.3^{d,e}	64.7^{a}	66.8^{a,b}	67.3^{a,b}	66.3^{a,b}	82.6^{a}	77.7^{a,b}	77.8^{a}	79.4^{a}
Predator HF	76.3	51.1	49.1	58.8^{c}	58.6^{a,b}	59.8^{a,b}	42.1^{a,b}	53.5^{a,b}	85.6^{a,x}	79.2^{a,b,x,y}	55.3^{a,b,y}	73.4^{a}
Chantilly RF	61.3	43.6	46.3	50.4^{a,c}	52.8^{a,b}	38.1^{b}	48.5^{a,b}	46.5^{a,b}	82.9^{a,x}	74.5^{a,b,x,y}	54.5^{a,b,y}	70.6^{a}
Radar CF	74.8	63.0	52.1	63.3^{c,e}	54.9^{a,b}	52.5^{a,b}	48.9^{a,b}	52.1^{a,b,c}	91.1^{a}	86.0^{a}	67.7^{a}	81.6^{a}
Midnight KBG	38.2	36.5	41.6	38.7^{a,b}	38.8^{a,b}	34.5^{b}	50.2^{a,b}	41.2^{a,c}	43.8^{b}	57.6^{b,c}	58.2^{a,b}	53.2^{b}
Penncross CBG	28.2	28.1	29.4	28.6^{b}	32.4^{b}	23.2^{b}	21.9^{a,b}	25.8^{c}	46.1^{b}	44.2^{c}	36.3^{b}	42.2^{b}
Accent II PRG	55.6	50.2	45.5	50.4^{a,b,c}	36.3^{a,b}	56.7^{a,b}	41.5^{b}	44.8^{a,c}	82.9^{a}	79.5^{a,b}	67.7^{a}	76.7^{a}
Treatment Average	63.2^{x}	55.0^{y}	52.4^{y}		51.3	51.3	47.5		74.9^{x}	73.4^{x}	61.6^{y}	
Cultivar	$p < 0.0001$, SE ± 5.3				$p = 0.0049$, SE ± 6.5				$p < 0.0001$, SE ± 4.2			
Treatment	$p = 0.0024$, SE ± 2.3				NS, SE ± 2.8				$p < 0.0001$, SE ± 2.1			
Cultivar* Treatment	NS, SE ± 6.9				$p = 0.0346$, SE ± 8.5				$p < 0.0001$, SE ± 6.1			

[1]Values presented are LSMeans on a percent basis.
[a,b,c]Means within a column with unlike superscripts differ ($P< 0.05$).
[x,y,z] Means within a row with unlike superscripts differ ($P< 0.05$).
[2]Treatment regions within each plot: control (no treatment), low (1 pass of the simulator per week) and high (2 passes of the simulator per week).
[3]Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.

Table 5. Average nutritional composition[1] and annual yield (kg/ha) of cool-season grasses in year 1.

Cultivar[2]	DM, %	DE, Mcal/kg	CP, %	ADF, %	NDF, %	WSC, %	ESC, %	Starch, %	NSC, %	Annual Yield, kg/ha
Maestro TF	27.2 ± 1.5	2.3 ± 0.0	18.5 ± 2.6	28.6 ± 0.9	52.0 ± 1.3	15.6 ± 3.8	10.5 ± 1.7	0.8 ± 0.2	16.4 ± 3.7	9896.0[a]
Regenerate TF	27.3 ± 1.1	2.3 ± 0.1	17.2 ± 2.3	29.4 ± 0.9	53.6 ± 2.3	16.0 ± 3.6	9.4 ± 1.3	0.8 ± 0.1	16.9 ± 3.6	9600.0[a,b]
Predator HF	30.7 ± 2.4	2.2 ± 0.0	16.2 ± 2.4	32.4 ± 1.1	54.8 ± 2.0	16.3 ± 2.5	12.8 ± 1.6	0.7 ± 0.1	17.0 ± 2.5	11112.0[a]
Chantilly RF	28.7 ± 2.6	2.3 ± 0.1	18.1 ± 3.1	28.5 ± 1.9	52.7 ± 2.4	15.5 ± 4.3	10.7 ± 2.0	0.9 ± 0.1	16.5 ± 4.3	11024.0[a]
Radar CF	28.9 ± 3.0	2.3 ± 0.0	18.5 ± 2.2	27.6 ± 1.4	53.9 ± 1.3	13.8 ± 2.8	9.7 ± 1.5	1.4 ± 0.6	15.3 ± 2.4	8936.0[a,b]
Midnight KBG	29.5 ± 1.8	2.3 ± 0.0	20.0 ± 2.8	27.0 ± 1.3	51.4 ± 1.7	16.4 ± 2.1	10.6 ± 1.9	0.4 ± 0.0	16.7 ± 2.1	6640.0[b]
Penncross CBG	27.6 ± 5.8	2.1 ± 0.0	20.3 ± 2.8	29.8 ± 2.1	58.4 ± 1.5	7.6 ± 1.5	6.0 ± 1.3	0.5 ±0.1	8.1 ± 1.7	8936.0[a,b]
Accent II PRG	28.6 ± 2.2	2.4 ± 0.1	18.6 ± 2.6	27.8 ± 1.3	50.3 ± 3.4	18.8 ± 5.3	9.9 ± 1.2	1.0 ± 0.1	19.9 ± 5.2	8488.0[a,b]
										p = 0.0030 SE ± 693.5

[1]Abbreviations: DM=dry matter, DE=digestible energy, CP=crude protein, ADF=acid detergent fiber, NDF=neutral detergent fiber, WSC=water soluble carbohydrates, ESC=ethanol soluble carbohydrates, NSC=non-structural carbohydrates (WSC+Starch).
[3]Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.

Table 6. Average nutritional composition[1] and annual yield (kg/ha) of cool-season grasses in year 2.

Cultivar[2]	DM, %	DE, Mcal/kg	CP, %	ADF, %	NDF, %	WSC, %	ESC, %	Starch, %	NSC, %	Annual Yield, kg/ha
Maestro TF	24.9 ± 2.0	2.3 ± 0.0	20.0 ± 2.7	29.9 ± 1.6	51.0 ± 2.1	15.1 ± 1.2	9.3 ± 0.8	1.5 ± 0.1	16.6 ± 1.2	4408.0[a,b,c]
Regenerate TF	25.1 ± 2.5	2.3 ± 0.1	19.7 ± 2.9	28.6 ± 2.0	50.3 ± 2.6	16.4 ± 1.2	10.6 ± 0.8	1.7 ± 0.2	18.1 ± 1.4	4352.0[a,b,c]
Predator HF	30.6 ± 1.9	2.2 ± 0.1	17.6 ± 2.3	31.2 ± 1.3	56.1 ± 2.3	13.8 ± 1.6	10.5 ± 1.0	1.0 ± 0.1	14.8 ± 1.6	6280.0[a]
Chantilly RF	27.8 ± 2.1	2.3 ± 0.1	21.0 ± 2.6	29.0 ± 2.2	52.0 ± 2.5	13.7 ± 1.4	9.0 ± 0.8	1.5 ± 0.3	15.2 ± 1.5	5400.0[a,b]
Radar CF	28.6 ± 2.8	2.3 ± 0.1	21.4 ± 3.8	27.1 ± 1.9	53.2 ± 3.5	12.5 ± 1.4	10.0 ± 1.0	1.2 ± 0.2	13.7 ± 1.6	5440.0[a,b]
Midnight KBG	29.6 ± 2.3	2.4 ± 0.0	21.6 ± 4.4	28.1 ± 3.3	48.1 ± 2.0	16.2 ± 2.3	11.7 ± 1.9	1.0 ± 0.4	17.2 ± 2.0	2024.0[d]
Penncross CBG	26.4 ± 2.6	2.3 ± 0.0	22.3 ± 2.9	26.4 ± 1.8	50.3 ± 1.9	13.9 ± 1.5	8.3 ± 0.5	1.9 ± 0.4	15.8 ± 1.2	2008.0[d]
Accent II PRG	24.9 ± 2.3	2.4 ± 0.1	23.3 ± 3.7	26.3 ± 3.0	47.5 ± 2.6	15.6 ± 1.9	10.6 ± 0.5	1.1 ± 0.3	16.7 ± 1.7	3616.0[c]
										$p < 0.0001$ SE ± 336.6

[1]Nutrition abbreviations: DM=dry matter, DE=digestible energy, CP=crude protein, ADF=acid detergent fiber, NDF=neutral detergent fiber, WSC=water soluble carbohydrates, ESC=ethanol soluble carbohydrates, NSC=non-structural carbohydrates (WSC+Starch).
[3]Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.

Table 7. Relative traffic tolerance ranking of cool-season turfgrasses over a two-year period[1,2].

	Relative Traffic Tolerance Spring		Relative Traffic Tolerance Summer		Relative Traffic Tolerance Fall		Overall Low Traffic	Overall High Traffic	Grand Overall
Cultivar[3]	Low	High	Low	High	Low	High			
Maestro TF	1	2	2	2	2	2	1	2	2
Regenerate TF	3	1	1	1	1	1	1	1	1
Predator HF	2	3	2	4	4	3	2	4	3
Chantilly RF	3	4	3	3	4	3	3	4	4
Radar CF	4	3	4	4	4	3	5	4	6
Midnight KBG	4	4	4	3	3	2	4	3	4
Penncross CBG	3	3	4	4	4	3	4	4	5
Accent II PRG	4	4	4	4	4	3	5	5	7

[1]Relative traffic tolerance determined by frequency of top performance for persistence and biomass after traffic treatment and rest. Ranking from 1 (best) to 8 (worst).
[2]Traffic levels: low (1 pass of the simulator per week) and high (2 passes of the simulator per week) during treatment applications.
[3]Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass

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RELATIVE TRAFFIC TOLERANCE OF WARM SEASON GRASSES AND THEIR SUITABILITY FOR GRAZING BY EQUINE

Aubrey L. Jaqueth[1], Thomas R. Turner[1], Marie E. Iwaniuk[1], Bridgett J. McIntosh[2], Amy O. Burk[1]
[1]The University of Maryland, Department of Animal and Avian Sciences
8127 Regents Drive, College Park, MD 20742
[2] Virginia Polytechnic Institute and State University, Middleburg Agricultural Research and Extension Center, 5527 Sullivans Mill Rd, Middleburg, VA 20117

Abstract

Warm-season (WS) grasses are growing in popularity as a forage for horses all over the United States due to their ability to support grazing in the summer months and lower non-structural carbohydrate (NSC) composition compared to cool-season grass species. Turfgrasses such as bermudagrass and zoysiagrass used on athletic fields and golf courses may be suitable for usage on equine operations as they are tolerant of traffic. Forage cultivars of crabgrass are commercially available for equine operators to establish in pasture but have limited data on traffic tolerance under continuous grazing. The objective of this study was to identify WS cultivars that are tolerant to simulated horse traffic and with a suitable nutritional composition for horses. Five WS turfgrass cultivars of bermudagrass and zoysiagrass and one WS forage-type crabgrass were established by seed in replicated monoculture plots and exposed to three levels of traffic, either none, one or two passes of a Baldree traffic simulator. Traffic was applied weekly for 6 weeks in the summer of 2016 and 2017, with each treatment period followed by a 4-week rest period. Plots were assessed for compaction, biomass available for grazing and vegetative cover as a measure of persistence before and after treatment and rest periods. Nutritional composition was assessed throughout the growing seasons by wet chemistry analysis. Soil compaction was increased as treatment level increased ($P < 0.0001$). Traffic treatment reduced cultivar persistence following traffic by 8.5 to 10.5% although no significant differences were found. Biomass available for grazing was increased 4.2 to 16.3% in year 1 ($P = 0.02$) following traffic treatment.. Both bermudagrass and zoysiagrass cultivars show promise for potential use in areas of heavy traffic on equine operations, but overall, zoysiagrass cultivars show the most promise as being wear tolerant, moderate yielding and low NSC (<15% NSC) for grazing. Future studies to determine stocking rate and evaluate establishment methods as well as on-farm persistence are warranted.

Key Words: Turfgrass, Traffic, Erosion, Equine, Grazing

Highlights

- The Baldree traffic simulator was effective at applying three distinct levels of traffic.
- Zoysiagrass cultivars were most traffic tolerant and lowest in NSC.
- Overall, traffic treatment increased biomass by 16.3% (LOW) and 4.2% (HIGH) in year 1.
- Traffic treatment did not significantly decrease persistence.

1. Introduction

1.1 Environmental Impacts

In the Mid-Atlantic Region, grazing horses on pasture is a common part of equine management and when pastures are managed correctly, can provide a significant portion of the forage in the diet. A survey of equine operations in Maryland identified poor pasture management resulting in overgrazing, high traffic areas of pasture and dry or loafing lots as sources of sediment erosion and nutrient runoff due to a lack of vegetation to anchor soil [1]. These negative impacts are of great concern for areas that are upstream of the Chesapeake Bay, as sediment erosion causes a decrease of submerged aquatic vegetation and when coupled with declining water quality, has led to the Bay being classified as an impaired water body [2] despite the recent development of "Best Management Practices" or BMPs designed to foster environmental stewardship [1].

Conversion of equine operations to lush pasture is ideal in terms of environmental stewardship, but is not always possible due to stocking rates and may not be suitable for metabolically sensitive equids. Equids that suffer from metabolic dysfunction are commonly housed in dry lots as they allow for turnout, but also offer greater control of the diet and eliminate risk of ingesting high levels of non-structural carbohydrates (NSC). Pastures constantly fluctuate in NSC content depending upon stage of growth and environmental conditions [3], and has been associated with life threatening conditions such as laminitis [4]. Pasture associated laminitis (PAL) is responsible for the majority of cases of laminitis in the US [5] and in a recent survey of owners and managers of over-conditioned equids in Maryland, survey participants were most concerned about their horses and ponies developing laminitis [6].

1.2 Potential of Turfgrasses

To improve upon the condition of dry lots and reduce the negative impacts of lack of vegetation due to heavy traffic, alternative ground covers should be investigated. In this study, WS grasses of both turfgrass and forage varieties were evaluated for their potential as traffic tolerant and low NSC grasses suitable for equine grazing. Both turfgrasses and pasture grasses have the same origin, but selective breeding over the past several decades has created the development of two sub-categories; turfgrasses and forage-type grasses [7]. Turfgrasses are used on athletic fields, golf courses and industrial lawns due to their enhanced ability to tolerate traffic and low mowing heights [5]. Forage varieties were developed for the livestock industry and are tolerant of defoliation, high in yield and nutritious [3; 5]. The downside of the improved forage varieties is that their enhanced capacity for photosynthetic activity results in increased NSC levels which some equids cannot safely tolerate. For metabolically sensitive equids such as those who are obese, insulin resistant or prone to laminitis, previous literature recommended limiting NSC in the diet < 10-12% on a dry matter basis [8; 9]. For the purposes of this study <15% NSC will be the target as this value is more realistically attainable.

1.3 Warm-season Versus Cool-season Grasses

Focus on WS grasses is due to their potential for maintaining an actively growing pasture in the summer months when cool-season (CS) grass production declines [10]. Additionally, WS grasses are generally lower in NSC and more traffic tolerant [11; 12; 13; 14] than the CS species which are common the Mid-Atlantic Region. Warm-season grasses also do not produce fructan, and instead utilize starch in the storage of energy. Additionally, previous research has shown that WS grasses are composed of a more digestible form of crude protein, but at the same time have higher levels of indigestible or structural fiber resulting from thicker cell walls and elongated stem regions that reduce overall digestibility [15]. In CS grasses, fructan concentration decreases with plant maturity so feeding first cutting hay that was harvested later in maturity or grazing more mature pasture may reduce the problem.

1.4 Objectives

The objective of this study was to evaluate six WS commercially available seeded grass cultivars for their potential as an alternative ground cover in areas subject to high hoof traffic, such as dry lots, gates areas and small paddocks, and as a nutrition source for grazing horses. Suitable cultivars will be tolerant of traffic, moderate in yield, and low (< 15%) in NSC composition.

2. Materials and Methods

The study had a split plot design and was conducted at the University of Maryland Paint Branch Turfgrass Research Facility in College Park, MD. Weather data during the study was obtained from the National Oceanic & Atmospheric Administration weather station located at Beltsville, MD (USC00180700) located approximately 6.4 km away from the study site. Data was generated on a monthly basis and addressed mean, mean maximum, and mean minimum temperature as well as total rainfall.

WS cultivars evaluated were 'Riviera' bermudagrass (*Cynodon dactylon* (L.) Pers., Johnston Seed Company, Enid, OK), 'Yukon' bermudagrass (*Cynodon dactylon* (L.) Pers., Seed Research of Oregon, Tangent, OR), common bermudagrass (*Cynodon dactylon* (L.) Pers., Seedland, Inc., Wellborn, FL), 'Red River' crabgrass (*Digitaria sanguinalis* (L.) Scop., Dalrymple Farms, Thomas, OK), 'Zenith' zoysiagrass (*Zoysia japonica,* Patten Seed Company, Lakeland, GA), and 'Compadre' zoysiagrass (*Zoysia japonica,* Seed Research of Oregon, Tangent, OR). From this point forward, species will be abbreviated as follows: BG = bermudagrass, ZG = zoysiagrass, CG = crabgrass. Cultivars were selected based on their wear tolerance in performance trials such as those conducted by the National Turfgrass Evaluation Program (NTEP, Beltsville, MD, www.ntep.org) and on their current commercial availability as seeded varieties for future purchase by managers of equine operations. Bermudagrass and ZG cultivars were seeded at 15 kg/ha and Red River CG at 5.6 kg/ha.

Seedbeds were prepared by tilling to 15 to 20 cm depth using a Soil Renovator (Rotadairon, Anderson, SC), removing rocks, and cultipacking soil until a 0.6 cm depth boot heel impression was left in the soil. Plots were seeded on May 8, 2015. CG did not establish satisfactorily and was reseeded July 29, 2015 utilizing aged seed. Four randomly assigned monoculture plots of each cultivar were broadcast seeded in 3.2m x 1.5m plots by use of a drop spreader (Gandy, Owatonna, MN) with each cultivar randomly seeded in adjacent plots and each represented four times. To improve seed contact with soil and reduce losses due to natural rainfall, plots were rolled after seeding prior to irrigation by an above ground sprinkler to ensure seed to soil contact. Plots were irrigated as necessary to maintain soil moisture until a four-leaf stage was reached. Plots were then mowed to no less than half the height of the each desired grass species as needed to control invasive weeds. In both year 1 (2016) and year 2 (2017), broadleaf herbicides plus a non-ionic surfactant were applied in the spring to all plots except those seeded with CG, as necessary to control invasive species. Broadleaf herbicides included Aim EC at a rate of 146.2 mL/ha (FMC Agricultural Solutions, Philadelphia, PA) April 27, 2016, Cimarron at a rate of 91.4 mL/ha (Bayer, Research Triangle Park, NC) in June 7, 2016, Prowl H2O at 4.9 L/ha (BASF, Research Triangle Park, NC) April 18, 2017 and Detonate at a rate of 1169.2 mL/ha (Tenkoz Inc., Alpharetta, GA) April 18, 2017. Soil testing was conducted by the Virginia Tech Soil Testing Lab (Blacksburg, VA). Nitrogen was applied following recommendations from the soil testing lab and phosphorous and potassium were applied following soil test recommendations at seeding and over the growing season of years 1 and 2 at a rates of 134.5 kg/ha nitrogen (N), 112 kg/ha phosphorus (P_2O_5), and 112 kg/ha potassium (K_2).

Traffic treatments were applied in the summers of 2016 (year 1) and 2017 (year 2), each plot receiving each of the three treatments. The three treatments were no traffic

(CON), 1 pass of a traffic simulator (LOW), or 2 passes of a traffic simulator (HIGH). Treatments were applied once a week for a period of six weeks followed by four weeks of recovery during which no treatments were applied. NTEP guidelines were followed for administering traffic simulator treatments and as well as resting plots for a minimum of 4 weeks between treatments. Treatments were applied using a Baldree Traffic Simulator adapted from a Jacobsen Ryan GA30 aerator [16]. Adaptations included the construction of four "feet" which replaced aerator pedals. For the purposes of this study no golfing cleats were welded to the base of the feet and were left flat with the exception of heads of screws on the underside of the base to better represent a bare horse hoof. This equipment was selected because it produces wear traffic similar to the equine hoof and produces similar vertical force to a horse at a trot. Additionally, it has been shown to produce more traffic per pass than the Cady or Brinkman traffic simulators and is more suited for simulating heavy traffic [16]. Traffic was only applied during the growing season, resulting in one summer application per year, and only when footing would be adequate for equine turnout. Treatments were applied within ± 1 day of the scheduled application day if inclement weather interfered with the scheduled days. Footing assessment was determined by walking next to plots and evaluating the depth that a boot heel would sink into the soil. If an impression left by a boot heel was less than 1 cm, traffic was applied. Prior to each traffic treatment, height was assessed by use of a falling plate meter [17] and if any plots measured above 5 cm, biomass samples were harvested from control sections of plots, following protocol explained below, and all plots were mowed to approximately 2.5 cm. This mowing was conducted to assure that grass would not get caught in the traffic simulator.

Before and after the conclusion of each traffic series, as well as after each rest period, plots were evaluated for soil compaction, persistence by vegetative cover to quantify existence of desired species and biomass available for grazing. Compaction was measured by use of a penetrometer (Turf-Tec International, Tallahassee, FL) with three readings taken per treatment area of each plot and then averaged to determine compaction for CON, LOW and HIGH traffic regions of each plot. A modified line-intercept method [18] using a grid with nine string intersection points was used to measure vegetative cover. Vegetative cover was assessed at each string intersection and classified as either desired species, invasive species, soil, thatch or other, according to what was found at soil level. Frequency for each category was then transformed into percentage values to estimate cover of each category. Biomass available for grazing was determined by harvesting a 0.25m x 0.25m quadrat by hand with shears and drying at 70^{O}C until weight remained constant to determine yield on a dry matter basis. Dry matter weights were then used to determine available forage on a kilogram per hectare basis.

Nutritive value of all cultivars was assessed across the growing season to evaluate their potential as a forage for grazing horses. Sampling occurred on July 19, August 15 and September 25, 2016 and July 19, August 20 and September 20, 2017.

Annual yield values were collected from CON regions of plots, and while these areas were exposed to no traffic treatments, they were managed on the same schedule as traffic regions of plots including mowing to 2.5 cm prior to traffic treatments. Samples were hand-clipped at a height of 2.5 cm from control area on each plot, subsamples were combined, and stored in a -80˚C freezer until shipped on dry ice to a commercial laboratory (Equi-Analytical, Ithaca, NY). Combined samples were analyzed for nutrient composition including an estimation of digestible energy (DE) and wet chemistry analysis of crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), water soluble carbohydrates (WSC), starch, and non-structural carbohydrates (NSC) following approved AOAC laboratory methods.

Data was analyzed using the mixed procedure of SAS 9.3 (SAS Institute, Cary, NC) to conduct an ANOVA using orthogonal contrasts for least-squares mean comparisons. Separate analysis was run for each traffic treatment and each rest period. Variables analyzed were compaction, vegetative cover, biomass, and nutrient composition. Covariates were utilized in the evaluation of vegetative cover and biomass in response to traffic treatments and recovery periods. Fixed model effects included cultivar, treatment and cultivar*treatment interaction and the random effect was plot. Assumptions of normality and homogeneity of variances were found normal by examination of the residual plots. For data following traffic treatments covariates were measurements taken prior to each traffic series and for rest periods, covariates were measurements taken after the completion of each traffic series, immediately prior to rest. Results were considered significant at the $P < 0.05$ level.

Response variable means were reported as Least Squared Means (LSM) ± Standard Error (SE) and Tukeys' adjustment was used for least-squares mean comparisons. Relative traffic tolerance was determined by the frequency of each cultivar and traffic level being a top performer in either vegetative cover or biomass available for grazing for both traffic and rest periods for each season. Frequency of top performance was then summed and cultivars were ranked with "1" being awarded to cultivars with the highest frequency of top performance.

3. Results

3.1 Establishment

Cultivars were successfully established and traffic treatment was applied the following summer (year 1). One replicate of the four plots seeded with Compadre ZG did not have sufficient vegetative cover in the first year and was excluded from data collection. In year 2, cover had increased and this replicate was included in traffic treatments.

3.2 Weather

Average monthly temperature was similar from year 1 to year 2 but total rainfall was different. Year 1 total rainfall accumulation was 75.2 cm and year 2 was 89.9 cm. Additionally, in year 2 monthly total rainfall had greater fluctuation compared to year 1 (Figure 1).

3.3 Compaction

Compaction was significant (P < 0.0001, Appendix table 10) at the cultivar and treatment level across both traffic and rest periods for both years with the exception of cultivar for rest, year 1. As traffic increased, soil compaction also increased. These findings verify the validity of the Baldree Traffic Simulator as a suitable method for applying three distinct levels of traffic on turfgrass plots.

3.4 Persistence

Persistence by percent desired species present in plots (via vegetative cover) was significant at the cultivar level (P<0.02) for both traffic and rest, year 1 (Table 1). In year 2, cultivar was significant (P=0.0017) for traffic only (Table 2). In both years, ZG cultivars were highest in cover and common BG was lowest in cover. An interaction of cultivar and treatment (P=0.0003) was seen only in year 2 where common BG had the best cover with the HIGH traffic treatment, then LOW and CON, with HIGH and CON being significantly different. Overall, in year 1 cover decreased as traffic increased, but in year 2 the HIGH treatment had more cover than the LOW treatment. Only one significant difference was observed for percent desirable species after rest periods, that occurred in year 1 for the main effect of cultivar (P=0.0170). Following the rest period of year 1, Zenith ZG was highest in cover and different from one of the Yukon BG and CG, both of which were lowest in cover overall.

3.5 Biomass Available After Traffic and Rest Periods

Over the two-year period of the study, no significant differences in biomass were consistently observed (Appendix tables 1 and 2). In year 1 following traffic, there was a treatment effect (P=0.0193) where biomass was highest for the LOW traffic treatment, followed by CON and then HIGH traffic. Also observed following traffic in year 1 was an interaction between cultivar and treatment (P=0.0463) but, after taking into account the effect of the Tukey's adjustment, no differences between treatment levels within each cultivar were found. In year 2, cultivar was found to be significant in response to treatment application (P=0.0008). Biomass was highest for Riviera BG and both ZG cultivars, all of which were different than the lowest yielding cultivar, common BG. No differences in biomass were seen following rest periods.

3.6 Annual Yield and Nutritional Composition

For both years, there was a difference (P=0.0400) of annual yield across cultivars (Tables 3 and 4). For all cultivars, yield was higher in year 1 than year 2, with the exception of Compadre ZG. Yield was highest for Riviera BG in year 1 and Compadre ZG in year 2. Common and Yukon BG were the lowest yielding for both years. Average nutritional composition of cultivars was similar in year 1 (Table 3) and year 2 (Table 4) with the exception of dry matter (DM) and NSC (WSC + starch). Percent starch, averaged across the growing season, was higher in both years for common BG, Riviera BG, and CG cultivars. NSC values, displaying both WSC and starch fractions, for each cultivar, are expressed by month in Figure 2. DM, CP, ADF, and NDF are displayed by month in Figure 3 and DE by month is displayed in Figure 4.

3.7 Relative Traffic Tolerance Ranking and Suitability for Equine Grazing

Overall, both ZG cultivars (Compadre and Zenith) were the most traffic tolerant (Table 5). Least tolerant of traffic was common BG and Yukon BG. All cultivars had an NSC <15% on average for both year 1 (Table 3) and year 2 (Table 4). Lowest average NSC was observed in ZG cultivars with both years being <10% on average. In year 1, yield of ZG was moderate in comparison to other cultivars, but was highest in year 2.

4. Discussion

4.1 Suitability of the Baldree Traffic Simulator

The Baldree Traffic Simulator was found to be a suitable method to apply three distinct levels of traffic as compaction was significantly increased as traffic level increased. Previous studies comparing damage produced by traffic simulators, found the Baldree traffic simulator to be the more destructive than both the Cady and Brinkman traffic simulators [19]. The Cady simulator has been found to be more damaging than the Brinkman [20] but the Rutgers traffic simulator was associated with slower recovery of vegetation after treatment [21]. Due to the Baldree applying vertical force at the same capacity as a horse at the trot [19], this simulator was most appropriate for this experiment.

4.2 Relative Traffic Tolerance Ranking

Persistence results suggest that when under traffic, ZG cultivars are most resistant to traffic. In general, as traffic increased, persistence decreased. When comparing biomass of treatments, biomass was generally greater in LOW regions compared to HIGH following both traffic and rest periods with CON falling between LOW and HIGH. These results suggest that in terms of recovery performance, after the first year of grazing, light traffic may assist in prompting the recovery of warm season grasses if allowed to rest from continuous grazing, but under heavy traffic, vegetation may decline.

These results agree with previous research which ranked traffic tolerance of ZG above improved varieties of BG which was above common BG [14]. Alternatively, Riviera BG has been ranked more tolerant of traffic than Zenith ZG [22, 23] but it should be noted that both studies were not conducted within the same region resulting in different environmental conditions. It has also been reported that in full sun, BG is more traffic tolerant than ZG, but in when in shade, ZG was more tolerant of traffic than BG [23]. BG has been reported to be tolerant of trampling and overgrazing with excellent grazing tolerance and CG having fair to good grazing tolerance [24]. Traffic tolerance differences have also been reported between BG cultivars, with Riviera being among top ranking cultivars [25].

4.3 Nutritional Composition

Previously reported values for BG (no designation if values for forage or turfgrass) provide a range of CP from 9 to as high as 21.4%, ADF at approximately 27% and NDF at approximately 62.1% [26-29]. Specifically for Yukon and Riviera BG, CP, ADF, and NDF were 20.1%, 26.8% and 60.7% for Yukon and 20.3%, 27.3% and 60.8% for Riviera, respectively [30]. Overall, CP is generally higher for turfgrass cultivars compared to forage cultivars. Nutritional content for BG cultivars in this study align well with previously reported CP and ADF with NDF being slightly higher [26-30]. CP content for CG has been reported to range from 11 to 21%, ADF 27.5 to 42.7% and NDF 55.5 to 69.8% [28; 29], all of which align with nutritional content of Red River CG found in this study.

Nutritional composition of WS cultivars was relatively similar with the exception of NSC (WSC and starch). In a previous study of BG cultivars harvested at 38.1 cm and 50.8 cm, starch was found to be ~4.8% on average and WSC ranged from 7.1 to 7.7% with WSC increasing throughout the day and decreasing as plants grew taller [27]. All WS cultivars were <15% NSC on average but both ZG cultivars were best suited for metabolically sensitive equids as they were <10% NSC on average.

4.4 Yield

In a study conducted by Aiken and Williams where BG cultivars were managed as horse pastures in the upper transition zone, Yukon BG yield was reported at approximately 3432 ka/ha and Riviera BG yield was approximately 2975 kg/ha, both of which were 31 to 40% less than yields of forage cultivars of BG included in the study [30]. Other previously reported yields for BG include a wide range of 4483 to 28021 ka/ha [26]. Compared to previous yield reports, annual yield of BG cultivars was on the low end of ranges reported for BG when cultivar was not identified and above previously reported yield for Yukon and Riviera cultivars. Harvest yield of ZG was limited as ZG is not traditionally utilized as a forage source for equids. In a study where ZG and BG cultivars were maintained under typical golf course conditions, Zenith ZG was among the lowest yielding cultivars and overall, ZG was typically lower yielding (9.1 g/m^2) than BG (14.3 g/m^2) when compared over three clippings in August and September [31].

In a 2005 study conducted in Virginia, forage varieties of tall fescue, BG and CG were evaluated for their production response to harvest. Results of this study found that forage tall fescue, Kentucky 31 and MaxQ, had the highest production yields followed by forage varieties of BG and lowest yields for Red River CG at approximately 4480 to 6725 kg/ha, or less, per year with yield decreasing as harvest frequency increased [10]. Beck et al. also found that yield decreased as harvest frequency increased and reported yields of 2832 to 9654 kg/ha [28] which Red River yields for year 1 and 2 fall into in this studies range. Additionally, Virgrnia Cooperative Extension as reported Red River yields as high as ~8967 to 11208.5 kg/ha under optimum conditions with an expected hay yield of ~4483 to 13450 kg/ha [32].

It should also be noted that Red River CG required special management with both herbicide treatment and restricting traffic and mowing at the end of the growing season. Herbicide selection was difficult as many products labeled for equine operations target CG and therefor required covering crabgrass plots with tarps when treating adjacent plots to ensure that CG was not killed off inadvertently. Due to CG being an annual grass, it was required to allow plots to mature to a reproductive state prior to the end of the grazing season so that plots could re-seed themselves for the following year. This requirement would result in CG having a shorter grazing season compared to BG and ZG, both of which are perennial grasses. One advantage of CG being an annual grass is that in a situation where summer forage is required in a short amount of time, CG can be grazed 30-45 days post seeding, if environmental conditions are favorable for growth [32]. Additionally, producers can further increase forage available for grazing by utilizing 2 year old seed, compared to fresh or 1 year old seed [32].

5. Conclusion

The ZG cultivars (Compadre, and Zenith) evaluated in this study were the most suitable for equine grazing as they were most tolerant of traffic relative to other cultivars in the study, moderate in yield, and an average NSC concentration <10%. A close second would be Riviera BG. Riviera was higher in yield and average NSC than both ZG cultivars, but in regions where ZG is not expected to establish well or when NSC is not required to be <10%, Riviera is a suitable option as on average NSC was <15%, with values over 15% occurring in August of both years. Riviera is also a cold-tolerant variety of bermudagrass and may have more success in northern regions of the Mid-Atliantic. Future studies on the long term performance of these cultivars is recommended and research topics should include grazing palatability, voluntary intake and digestibility, on-farm persistence and stocking rate.

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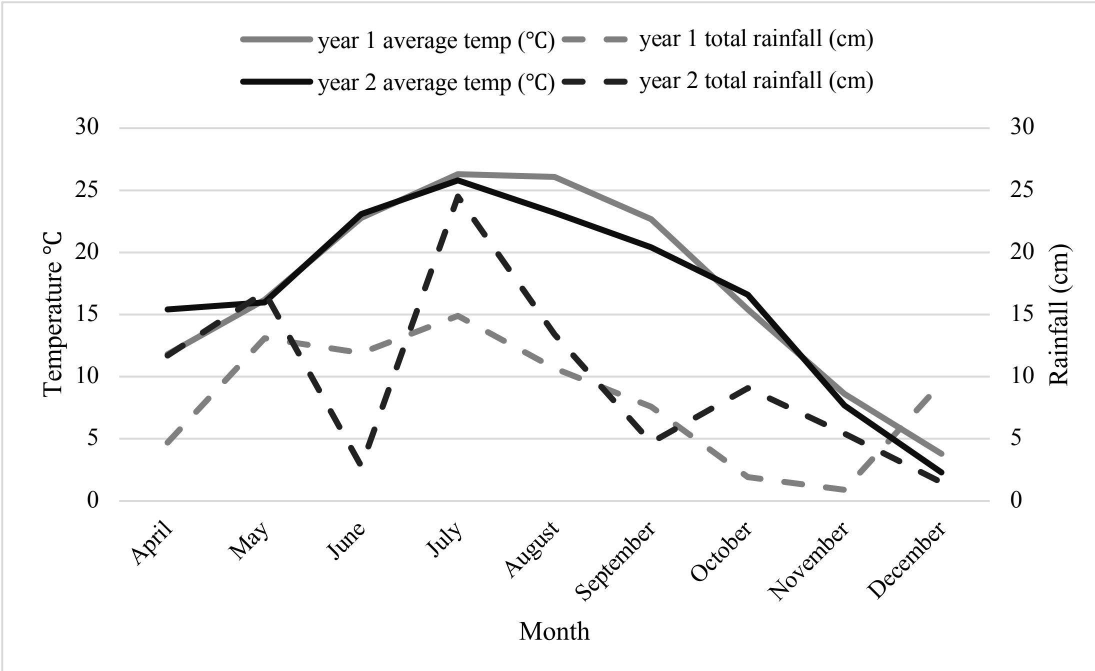


Figure 1. Average temperature and total rainfall by month during year 1 (2016) and 2 (2017).

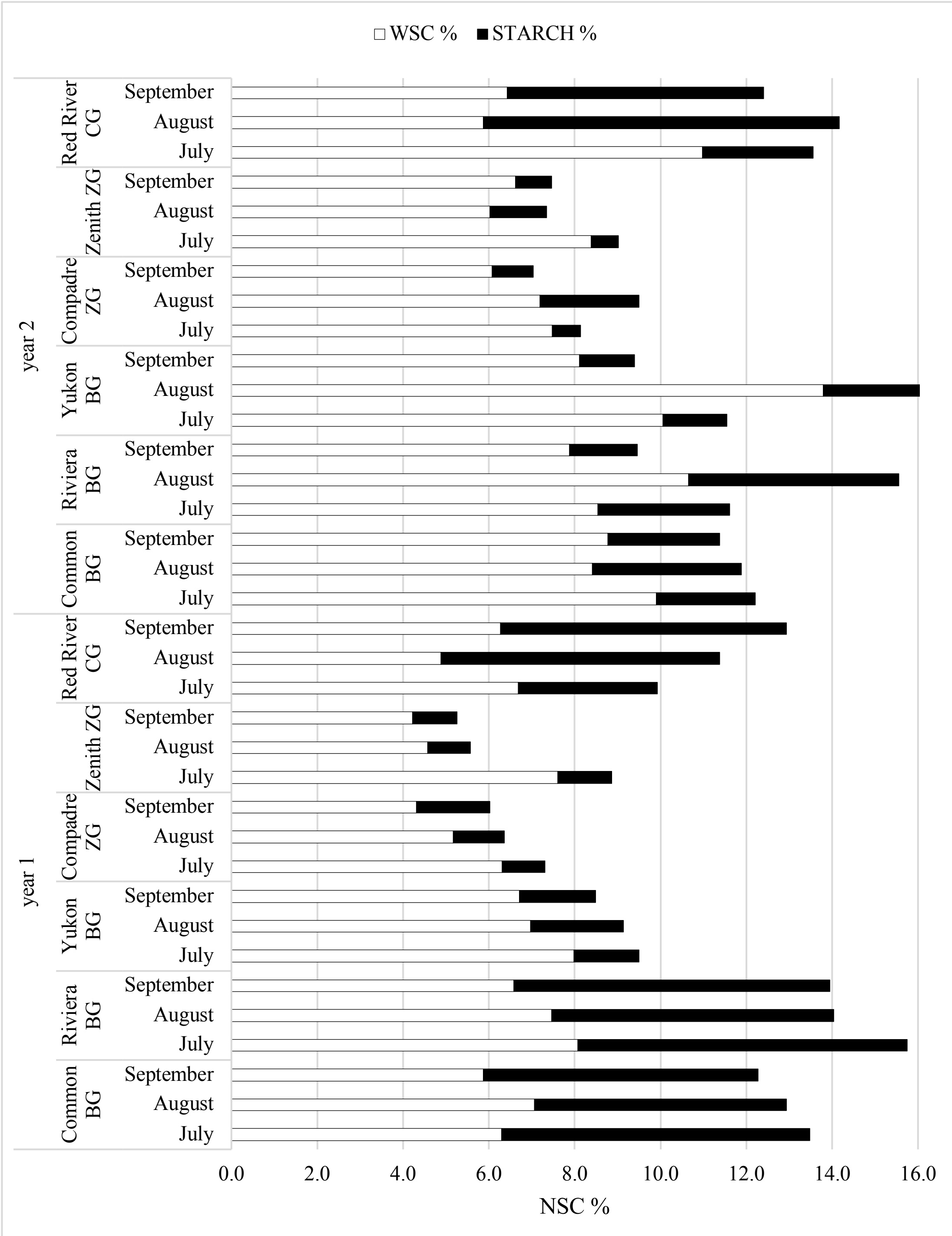
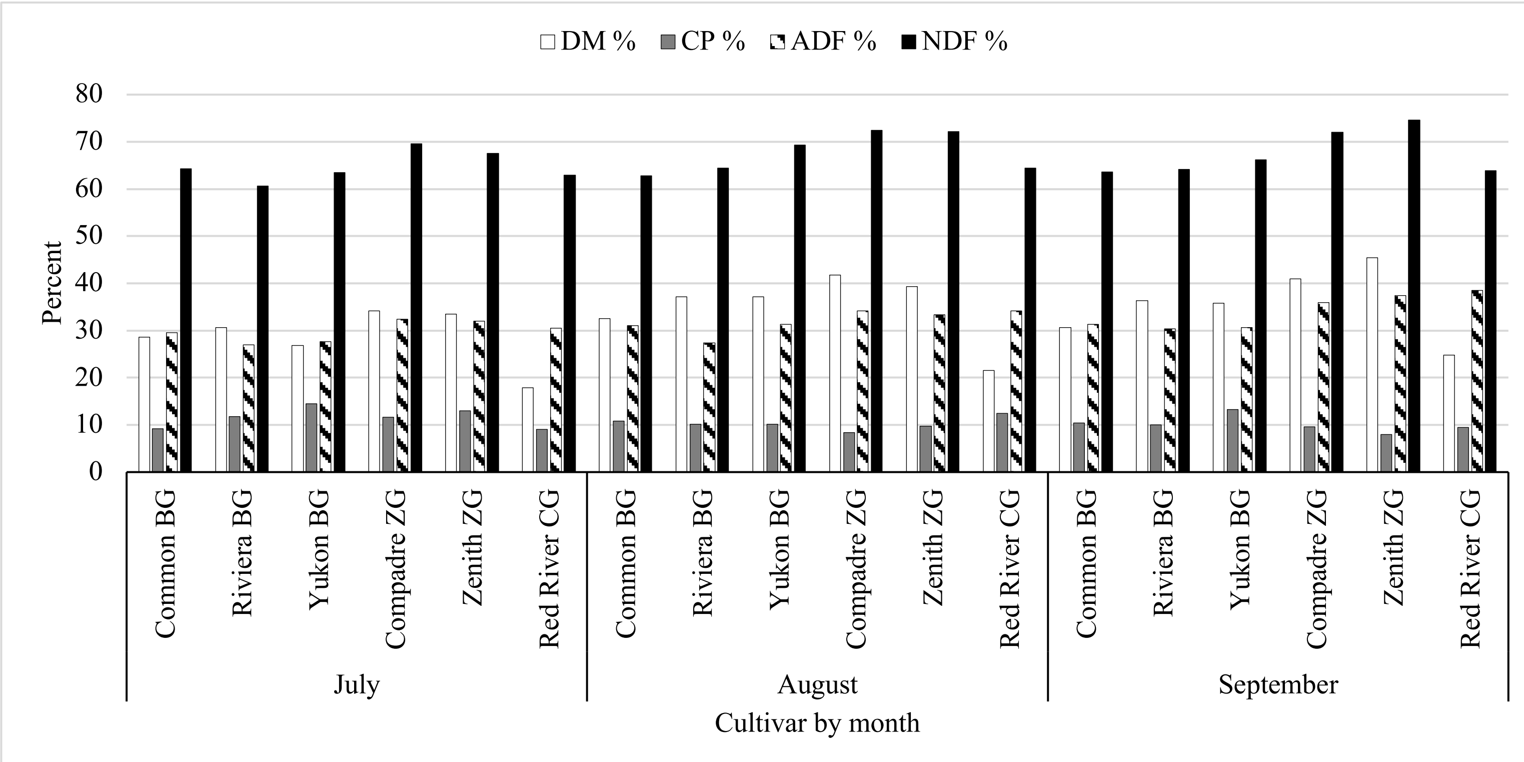


Figure 2. Non-structural carbohydrate composition (NSC, Water Soluble Carbohydrate + Starch) of warm season cultivars by month for year 1 and 2. WSC represented in white and starch represented in black. Species abbreviations: BG=bermudagrass, ZG=zoysiagrass, CG=crabgrass.

3a.



□DM % ■CP % ◪ADF % ■NDF %
80
70
60
50
40
30
20
10
0
Percent
Common BG
Riviera BG
Yukon BG
Compadre ZG
Zenith ZG
Red River CG
Common BG
Riviera BG
Yukon BG
Compadre ZG
Zenith ZG
Red River CG
Common BG
Riviera BG
Yukon BG
Compadre ZG
Zenith ZG
Red River CG
July
August
September
Cultivar by month

3b.

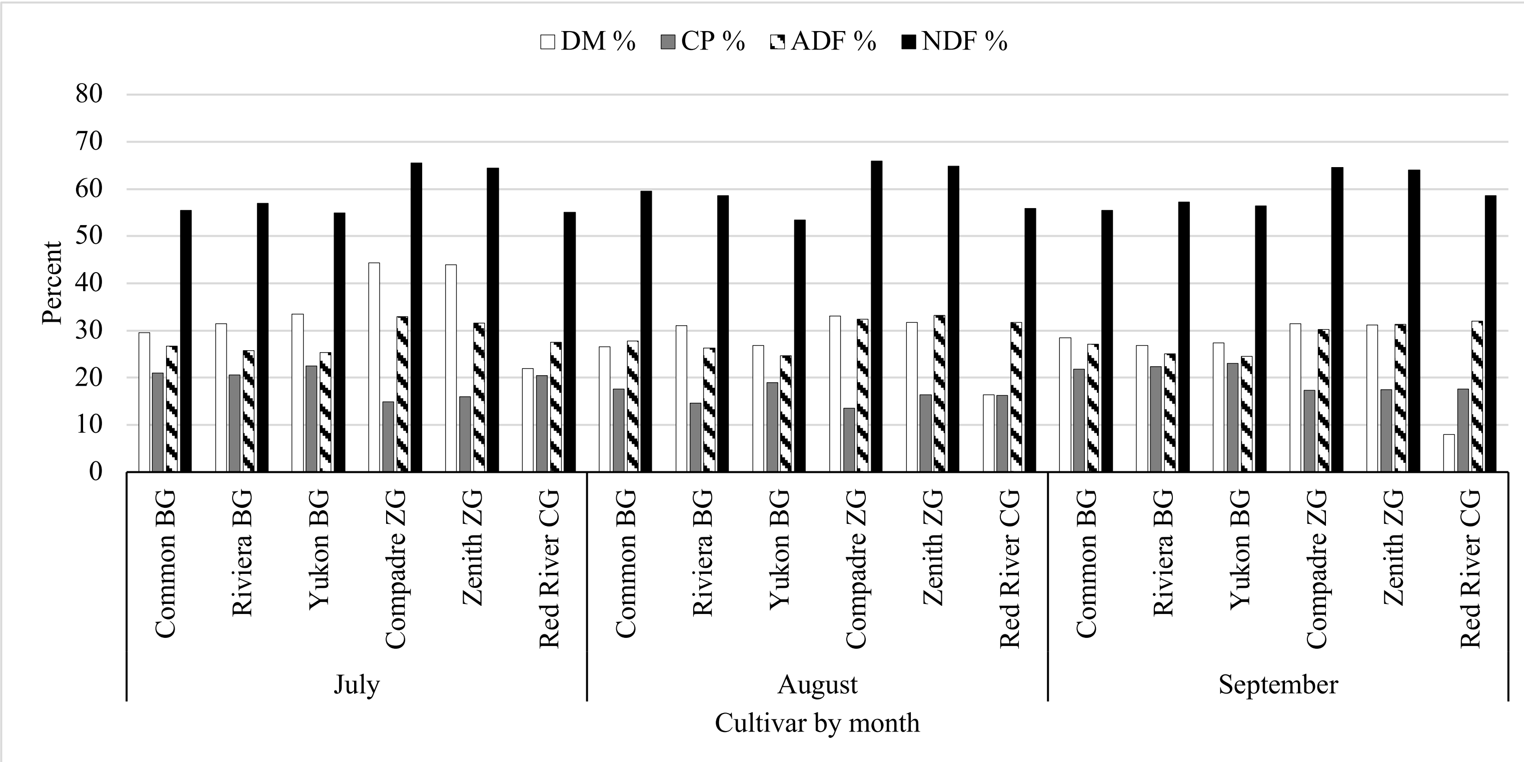


Figure 3. Nutritional composition of warm-season cultivars by month for year 1 (3a.) and 2 (3b.). Components represented include dry matter (DM), crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF). Species abbreviations: BG=bermudagrass, ZG=zoysiagrass, CG=crabgrass.

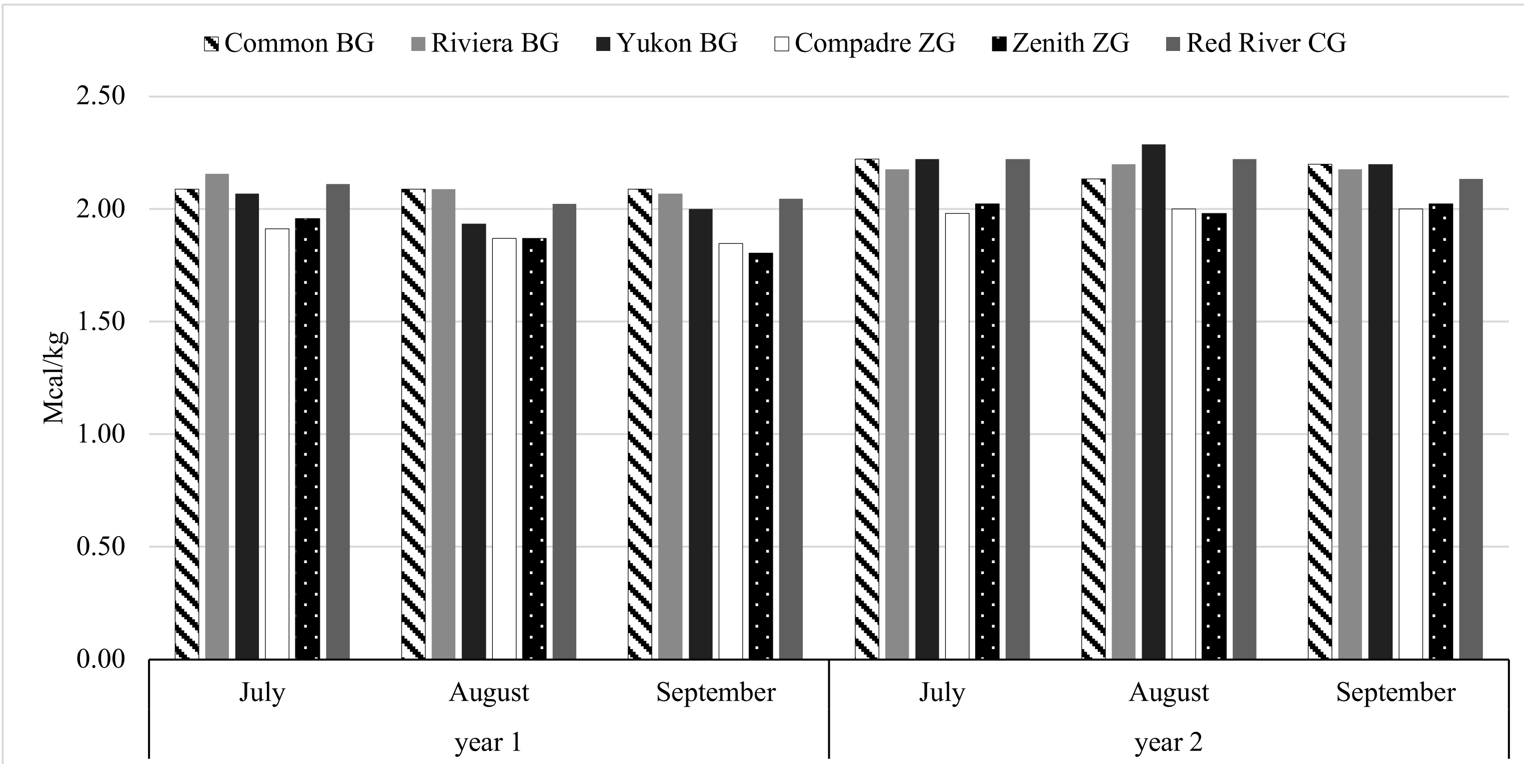


Figure 4. Digestible energy (DE) in Mcal/kg for warm-season cultivars over year 1 (2016) and 2 (2017). Species abbreviations: BG=bermudagrass, ZG=zoysiagrass, CG=crabgrass.

Table 1. Persistence in response to traffic treatment and rest applied during year 1[1,2].

	Traffic Treatment				Rest			
Cultivar[3]	**Control**	**Low**	**High**	**Cultivar Average**	**Control**	**Low**	**High**	**Cultivar Average**
Common BG	32.9	51.7	51.4	45.3[c]	82.9	63.8	76.0	74.2[a,b]
Riviera BG	81.9	68.6	57.6	69.3[a,b]	66.8	74.9	74.8	72.2[a,b]
Yukon BG	62.1	61.1	67.6	63.6[a,b,c]	66.4	62.4	63.7	64.2[b]
Compadre ZG	96.8	68.5	70.3	78.5[a]	83.3	77.7	67.8	76.3[a,b]
Zenith ZG	83.7	74.9	74.7	77.8[a]	85.6	85.5	81.8	84.3[a]
Red River CG	64.9	51.1	31.4	49.1[b,c]	65.2	67.8	55.0	62.7[b]
Treatment Average	70.4	62.6	58.8		75.0	72.0	69.9	
Cultivar	p = 0.0002, SE = 5.4				p = 0.0170, SE = 4.6			
Treatment	NS, SE = 3.6				NS, SE = 2.6			
Cultivar* Treatment	NS, SE = 9.7				NS, SE = 7.5			

[1]Persistence represented by percent desired species within each treatment region of monoculture warm season grass plots. Values presented are LSMeans on a percent basis.
[a,b,c]Means within a column with unlike superscripts differ ($P < 0.05$).
[2]Treatment regions within each plot: control (no treatment), low (1 pass of the simulator per week) and high (2 passes of the simulator per week).
[3]Species abbreviations: BG=bermudagrass, ZG=zoysiagrass, CG=crabgrass.

Table 2. Persistence in response to traffic treatment and rest applied during year 2[1,2].

	Traffic Treatment				Rest			
Cultivar[3]	**Control**	**Low**	**High**	**Cultivar Average**	**Control**	**Low**	**High**	**Cultivar Average**
Common BG	$39.2^{d,x}$	$42.7^{c,x,y}$	63.9^{y}	48.6^{c}	46.5	52.8	61.0	53.5
Riviera BG	$78.7^{a,b,c}$	$65.9^{a,b,c}$	72.5	$72.4^{a,b}$	69.7	63.3	68.1	67.1
Yukon BG	$55.7^{c,d}$	$54.0^{b,c}$	60.4	$56.7^{b,c}$	46.6	63.8	57.1	55.8
Compadre ZG	$92.3^{a,b}$	86.9^{a}	75.0	84.7^{a}	72.2	80.6	84.5	79.1
Zenith ZG	94.2^{a}	$81.3^{a,b}$	75.0	83.5^{a}	83.2	81.5	79.0	81.2
Red River CG	$62.5^{b,c,d}$	$65.5^{a,b,c}$	56.1	$61.4^{b,c}$	60.8	71.8	47.7	60.1
Treatment Average	70.4	66.1	67.1		63.2	69.0	66.2	
Cultivar	p = 0.0017, SE = 5.0				NS, SE = 6.2			
Treatment	NS, SE = 2.2				NS, SE = 2.6			
Cultivar* Treatment	p = 0.0003, SE =6.4				NS, SE = 8.4			

[1]Persistence represented by percent desired species within each treatment region of monoculture warm season grass plots. Values presented are LSMeans on a percent basis.
^{a,b,c}Means within a column with unlike superscripts differ ($P< 0.05$).
^{x,y,z}Means within a row with unlike superscripts differ ($P< 0.05$).
[2]Treatment regions within each plot: control (no treatment), low (1 pass of the simulator per week) and high (2 passes of the simulator per week).
[3]Species abbreviations: BG=bermudagrass, ZG=zoysiagrass, CG=crabgrass.

Table 3. Average nutritional composition[1] and annual yield (kg/ha) of warm-season cultivars in year 1.

Cultivar[2]	**DM, %**	**DE, Mcal/kg**	**CP, %**	**ADF, %**	**NDF, %**	**WSC, %**	**ESC, %**	**Starch, %**	**NSC, %**	**Yield, kg/ha**
Common BG	30.6 ± 1.2	2.1 ± 0.0	10.1 ± 0.5	30.7 ± 0.5	63.5 ± 0.4	6.4 ± 0.3	3.9 ± 0.6	6.5 ± 0.4	12.9 ± 0.4	6056.0[b]
Riviera BG	34.7 ± 2.1	2.1 ± 0.0	10.6 ± 0.6	28.2 ± 1.1	63.0 ± 1.2	7.4 ± 0.4	4.3 ± 0.8	7.2 ± 0.3	14.6 ± 0.6	10104.0[a]
Yukon BG	33.3 ± 3.2	2.0 ± 0.0	12.6 ± 1.3	29.9 ± 1.1	66.4 ± 1.7	7.2 ± 0.4	5.0 ± 0.9	1.8 ± 0.2	9.0 ± 0.3	5776.0[b]
Compadre ZG	39.0 ± 2.4	1.9 ± 0.0	9.9 ± 0.9	34.1 ± 1.0	71.4 ± 0.9	5.3 ± 0.6	3.0 ± 0.5	1.3 ± 0.2	6.6 ± 0.4	6712.0[a,b]
Zenith ZG	39.4 ± 3.4	1.9 ± 0.0	10.3 ± 1.4	34.3 ± 1.6	71.4 ± 2.1	5.5 ± 1.1	3.6 ± 0.9	1.1 ± 0.1	6.6 ± 1.2	8533.3[a,b]
Red River CG	21.4 ± 2.0	2.1 ± 0.0	10.3 ± 1.1	34.4 ± 2.3	63.7 ± 0.4	5.9 ± 0.5	3.8 ± 0.8	5.5 ± 1.1	11.4 ± 0.9	8736.0[a,b]
										p = 0.0191 SE = 690.8

[1]Abbreviations: DM=dry matter, DE=digestible energy, CP=crude protein, ADF=acid detergent fiber, NDF=neutral detergent fiber, WSC=water soluble carbohydrates, ESC=ethanol soluble carbohydrates, NSC=non-structural carbohydrates (WSC+Starch).
[2]Species abbreviations: BG=bermudagrass, ZG=zoysiagrass, CG=crabgrass.

Table 4. Average nutritional composition[1] and annual yield (kg/ha) of warm-season cultivars in year 2.

Cultivar[2]	DM, %	DE Mcal/ kg	CP, %	ADF, %	NDF, %	WSC, %	ESC, %	Starch, %	NSC, %	Yield, kg/ha
Common BG	28.2 ± 0.9	2.2 ± 0.0	20.2 ± 1.3	27.1 ± 0.3	56.8 ± 1.4	9.0 ± 0.5	6.5 ± 1.4	2.8 ± 0.4	11.8 ± 0.2	4008.0[b]
Riviera BG	29.8 ± 1.5	2.2 ± 0.0	19.2 ± 2.3	25.7 ± 0.4	57.6 ± 0.5	9.0 ± 0.8	7.1 ± 0.8	3.2 ± 1.0	12.2 ± 1.8	6272.0[a,b]
Yukon BG	29.3 ± 2.1	2.2 ± 0.0	21.5 ± 1.3	24.8 ± 0.3	54.9 ± 0.9	10.7 ± 1.7	8.2 ± 1.1	1.8 ± 0.4	12.4 ± 2.1	4824.0[a,b]
Compadre ZG	35.6 ± 4.2	2.0 ± 0.0	16.6 ± 0.5	32.1 ± 0.6	64.4 ± 0.3	7.0 ± 0.7	5.9 ± 1.1	0.9 ± 0.2	7.9 ± 0.5	7088.0[a,b]
Zenith ZG	36.3 ± 4.1	2.0 ± 0.0	15.3 ± 1.1	31.9 ± 0.8	65.3 ± 0.4	6.9 ± 0.4	5.1 ± 1.1	1.3 ± 0.5	8.2 ± 0.7	7920.0[a]
Red River CG	15.4 ± 4.0	2.2 ± 0.0	18.1 ± 1.2	30.4 ± 1.5	56.5 ± 1.1	7.8 ± 1.6	5.8 ± 1.0	5.6 ± 1.7	13.4 ± 0.5	5432.0[a,b]
										p = 0.0400 SE = 581.9

[1]Abbreviations: DM=dry matter, DE=digestible energy, CP=crude protein, ADF=acid detergent fiber, NDF=neutral detergent fiber, WSC=water soluble carbohydrates, ESC=ethanol soluble carbohydrates, NSC=non-structural carbohydrates (WSC+Starch).
[2]Species abbreviations: BG=bermudagrass, ZG=zoysiagrass, CG=crabgrass.

Table 5. Relative traffic tolerance of warm-season cultivars over a two-year period[1,2].

	Relative Traffic Tolerance		
Cultivar[3]	**Low**	**High**	**Overall**
Common BG	4	4	5
Riviera BG	2	3	3
Yukon BG	4	4	5
Compadre ZG	3	2	2
Zenith ZG	1	1	1
Red River CG	3	3	4

[1]Relative traffic tolerance determined by frequency of top performance for persistence and biomass after traffic treatment and rest. Ranking from 1 (best) to 6 (worst). In the event of multiple cultivars performing equally, a ranking may be assigned twice.
[2]Traffic levels: low (1 pass of the simulator per week) and high (2 passes of the simulator per week).
[3]Species abbreviations: BG=bermudagrass, ZG=zoysiagrass, CG=crabgrass.

Chapter 5. Manuscript 4

NUTRITIONAL COMPOSITION AND PREFERENCE OF TURFGRASSES AND FORAGE-TYPE CRABGRASS GRAZED BY WARMBLOOD MARES IN THE MIDATLANTIC REGION

Aubrey L. Jaqueth[1], Bridgett J. McIntosh[2], Marie E. Iwaniuk[1], Thomas R. Turner[1], Amy O. Burk[1]
[1]The University of Maryland, Department of Animal and Avian Sciences
8127 Regents Drive, College Park, MD 20742
[2] Virginia Polytechnic Institute and State University, Middleburg Agricultural Research and Extension Center, 5527 Sullivans Mill Rd, Middleburg, VA 20117

Abstract

Horses are large, athletic, selective grazers, and if not properly managed, they can quickly compact soils, eliminate vegetative cover, and ultimately increase soil and nutrient losses from the farm. Unlike forage-type grasses that were developed to be highly nutritious and high yielding, turfgrasses were developed to be tolerant of wear and close mowing for use on golf courses and athletic fields. A potential exists for turfgrasses to be used in small pastures and high traffic areas for horses provided they don't overgraze them. The objective of this study was to investigate grazing preference of cool and warm-season turfgrass cultivars, along with one forage type crabgrass cultivar, with the aim of identifying those that were less preferred by the equine in an effort to prevent overgrazing. For two consecutive years, horses grazed 8 cultivars of cool-season grasses for a 9 h period from 0700 to 1600 in May, June, August, and October, and grazed 6 cultivars of warm-season grasses for the same period of time in July, August, and September. Grazing preference was estimated by measuring the difference in pre- and post-grazing grass heights. Nutritional analysis was also performed to investigate relationships between grazing preference and nutrient composition. No differences were observed in grazing preference for cool-season turfgrass cultivars. For warm-season cultivars, differences in grazing preferences were observed for all trials ($P = 0.0174$) with the exception of the September 2017. Overall, 'Riviera' and 'Yukon' bermudagrasses were more preferred. Grazing preference was positively correlated with dry matter for both cool-season ($P < 0.0001$) and warm-season turfgrass cultivars ($P = 0.0307$). Grazing preference was negatively correlated with initial grass height, DE (Mcal/kg) and maturity ($P < 0.0001$, $P=0.0006$, $P=0.0312$) for cool-season cultivars. Results from this study support the potential for turfgrass usage on equine operations where maintaining vegetative cover is of priority. Additional review of less preferred species is necessary to evaluate traffic tolerance, persistence and yield under continuous equine grazing as well as long term effects experienced by grazing equids.

Key words: Equine, Grazing, Preference, Turfgrass

Highlights

- Cool-season turfgrass cultivars were equally grazed.
- Cold-tolerant cultivars of bermudagrass were less preferred among warm-season cultivars.
- Amount grazed was positively correlated with dry matter for both cool and warm-season cultivars.

- Warm-season cultivars were consistently <15% in non-structural carbohydrate concentration.

1. Introduction

1.1 Impact of Grazing on Pasture

Overstocked pastures are susceptible to soil compaction and decreased vegetative stands due to high hoof traffic and frequent repeated defoliation of forage that results from grazing by livestock [1]. On equine operations in particular, overgrazed and high traffic areas of pasture as well as dry or loafing lots have been identified as areas of heavy soil erosion [2]. Areas of bare soil are potential sources of pollution by erosion and nutrient runoff if manure and urine are managed improperly [1; 2; 4], resulting in reduced water quality by sediment, nutrient, and pathogen pollution [5]. Sources of erosion result from both agricultural and urban practices and continue to occur despite the development of "Best Management Practices" (BMPs), designed to foster environmental stewardship [2]. Over time, poor environmental stewardship may negatively impact watersheds such as the Chesapeake Bay, which has been classified as an impaired water body [6]. These negative impacts could be minimized if grazing areas were managed to produce a thick productive stand of vegetation that anchors soil and slows nutrient runoff [3].

1.2 Health Concerns Associated with Pasture

Pasture is an important fiber source in a horse's diet, however, overconsumption of pasture can lead to obesity. Equine obesity in the U.S. and abroad has been reported to range from 20.1% [7] to 51% [8 - 13] of the population studied and has been associated with equine metabolic syndrome, insulin resistance, laminitis, as well as other diseases and disorders [14; 15]. Within the US, pasture-associated laminitis accounts for the majority of cases [16] and non-structural carbohydrates (NSC) in the pasture has been linked with the onset of laminitis [17; 18].

Currently, the majority of horse pastures are composed of varieties of grasses developed for the livestock industry [19] to produce higher yields, have improved nutritional quality, and to better tolerate stress due to trampling and defoliation by grazing and harvesting [20]. To better recover from these stresses, traditional pasture grasses have increased capacity for photosynthetic activity and as a result, there is a chance for higher levels of NSC when accumulated in plant tissue [19]. The sugar portion of NSC is made up of mono and disaccharides, oligosaccharides and in the case of cool-season grasses, fructan [21]. In comparison, fructan is not produced in warm-season grasses, thus NSC is generally lower compared to cool-season grasses [22]. NSC content in grasses is dependent on multiple factors including maturity, season, temperature, sunlight, soil composition, drought, mowing, and traffic [19; 23]. In the case of equids prone to laminitis and obesity, removing and/or reducing concentrates and pasture from the diet, as well as reducing NSC in the diet to <10-12% DM [24; 25], and reducing total daily intake to 1.5% of bodyweight DM [26], is currently recommended.

1.3 Potential Usage of Turfgrasses on Equine Operations

Both traditional pasture grasses and turfgrasses come from the same origin but developed into two sub-categories through selective breeding. Traditional pasture grasses were developed to be highly nutritious and high yielding [19; 27], whereas turfgrasses were developed to be tolerant of heavy traffic and close mowing, therefore making them suitable for use on golf courses and athletic fields. Relative traffic tolerance of turfgrasses has previously been studied [28] and found that warm-season cultivars were generally more traffic tolerant than cool-season cultivars. Specifically related to turfgrasses for equine operations, relative traffic tolerance of turfgrasses under simulated equine traffic has been previously studied [13] and found similar results of warm-season cultivars being more traffic tolerant. In a study of cool-season turfgrasses for use on equine operations, it was found that tall fescue and Kentucky bluegrass cultivars were more tolerant of simulated hoof traffic than timothy [29]. Turf-type bermudagrasses, Yukon and Riviera, may also be suitable for use on equine operations as their nutrient content was similar to forage type bermudagrass varieties [30].

Turfgrasses also have a shorter mature height and may potentially have a lower productive yield than pasture varieties. The potential exists for turfgrasses to be used in small pastures, high traffic areas, and dry lots for horses provided they aren't overgrazed. Identifying a cultivar with low palatability and low NSC could be utilized as an alternative ground cover for heavy traffic areas such as dry lots to both anchor soil and provide a safe grazing medium for horses at risk for laminitis.

1.4 Objectives

The objective of this study was to evaluate the nutrient composition and relative grazing preference of eight cool-season and five warm-season turfgrass cultivars, as well as one forage variety of crabgrass. Nutrient composition and grazing preference will provide insight for cultivars suitable for use on equine operations. Cultivars utilized in this study were previously assessed for relative traffic tolerance under simulated equine traffic [13].

2. Materials and Methods

2.1 Grass Plot Establishment

The study was designed as a randomized complete block design with each cultivar (cool-season, n=8; warm-season n=6) replicated four times and was conducted during the growing seasons of 2016 (year 1) and 2017 (year 2) at the Virginia Polytechnic Institute and State University's Middleburg Agricultural Research and Extension Center in Middleburg, VA (38.9687° N, 77.7355° W).

Cool-season (CS) cultivars included 'Maestro' and 'Regenerate' tall fescue (*Schedonorus arundinaceus* (Schreb.) Dumort*,* Landmark Turf and Native Seed, Spokane, WA, 'Predator' hard fescue (*Festuca brevipila* Tracey*,* Pennington Seed Inc., Madison, GA), 'Chantilly' creeping red fescue (*Festuca rubra L. ssp. arenaria* (Osbeck) F. Aresch*,* DLF Pickseed, Halsey, OR), 'Radar' chewings fine fescue (*Festuca rubra L. ssp. fallax* (Thuill.) Nyman*,* Mountain View Seeds, Salem, OR), 'Midnight' Kentucky bluegrass (*Poa pratensis L. ssp. pratensis,* Turf-Seed, Inc., Gervais, OR), ‘Penncross’ creeping bentgrass (*Agrostis stolonifera L.,* Pennington Seed Inc., Madison, GA), and ‘Accent II’ perennial ryegrass (*Lolium perenne L. ssp. perenne,* Jacklin Seed, Liberty Lake, WA). From this point forward, species will be abbreviated as follows: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass. In the case of TF, where two cultivars represent the species, cultivar name will be included in the statement. Experimental seeded WS cultivars included ‘Riviera’ bermudagrass (*Cynodon dactylon* (L.) Pers., Johnston Seed Company, Enid, OK), Yukon bermudagrass (*Cynodon dactylon* (L.) Pers., Seed Research of Oregon, Tangent, OR), Common bermudagrass (*Cynodon dactylon* (L.) Pers., Seedland, Inc., Wellborn, FL), Red River crabgrass (*Digitaria sanguinalis* (L.) Scop., Dalrymple Farms, Thomas, OK), Zenith zoysiagrass (*Zoysia japonica,* Patten Seed Company, Lakeland, GA), and Compadre zoysiagrass (*Zoysia japonica,* Seed Research of Oregon, Tangent, OR). From this point forward, WS species will be abbreviated as follows: BG=bermudagrass, ZG=zoysiagrass, CG=crabgrass.

Cultivars were selected based on their wear tolerance in previous performance trials such as those conducted by the National Turfgrass Evaluation Program (NTEP, Beltsville, MD, www.ntep.org) and on their current commercial availability as seeded varieties for future purchase by managers of equine operations. Cultivars were seeded at the following rates: TF 11.9 kg/m^2, HF 11.9 kg/m^2, RF 6.0 kg/m^2, CF 6.0 kg/m^2, KBG 6.0 kg/m^2, CBG 1.5 kg/m^2, PRG 7.4 kg/m^2, BG 15 kg/ha and CG 5.6 kg/ha.

Seedbeds were prepared by tilling to 15.2 to 20.3 cm depth, removing rocks, and cultipacking soil until a 0.6 cm depth boot heel impression was left in the soil. When necessary, due to thatch buildup from previously established tall fescue, a spring tooth harrow was used to remove thatch from seeding areas. Warm-season plots were seeded on May 27, 2015. Crabgrass plots did not establish well following the May 27 seeding, and was re-seeded July 17, 2015. Cool-season plots were seeded on September 3, 2015. Four randomly assigned monoculture replications of each cultivar were broadcast seeded in 3.0m x 6.1m plots by use of a drop spreader (Gandy, Owatonna, MN) with each cultivar randomly seeded in adjacent plots and each represented four times. To improve seed contact with soil and reduce losses due to natural rainfall, seeds of CS cultivars were lightly raked into the soil prior to irrigation by above ground sprinkler, and seeds for WS cultivars were rolled into the soil prior to irrigation. Plots were irrigated as necessary to maintain soil moisture until a four leaf stage was reached and were mowed to no less than half the height of the desired grass species in each plot as needed to control invasive weeds.

Throughout the study, various broadleaf herbicides with non-ionic surfactant were applied as needed to control invasive species. Applications to CS cultivars were as follows: Aim EC at a rate of 146.2 mL/ha (FMC Agricultural Solutions, Philadelphia, PA) on April 27, 2016; Detonate at a rate of 1169.2 mL/ha (Tenkoz Inc., Alpharetta, GA) on November 2, 2016, April 18, 2017, and September 21, 2017; and Prowl H2O at 4.9 L/ha (BASF, Research Triangle Park, NC) on April 15, 2017. Broadleaf herbicides applied to WS cultivars included: Aim EC at a rate of 146.2 mL/ha (FMC Agricultural Solutions, Philadelphia, PA) on April 27, 2016; Cimarron at a rate of 91.4 mL/ha (Bayer, Research Triangle Park, NC) on June 10, 2016; Prowl H2O at 4.9 L/ha (BASF, Research Triangle Park, NC) on April 15, 2017; and Detonate at a rate of 1169.2 mL/ha (Tenkoz Inc., Alpharetta, GA) on April 28, 2017. Laneways between plots were maintained as needed with applications of glyphosate (Mad Dog Plus, Loveland Products, Inc., Loveland, CO). Soil testing was conducted by the Virginia Tech Soil Testing Lab (Blacksburg, VA). Nitrogen was applied to CS and WS plots following recommendations from the soil testing lab. Phosphorous and potassium were applied following soil test recommendations at seeding and throughout relative growing seasons. In the spring of year 1 and spring and fall of year 2 for CS cultivars were fertilized at annual rates of 89.6 kg/ha nitrogen, 224.2 kg/ha phosphorous, and 168.1 kg/ha potassium. Throughout the summer of years 1 and 2, WS cultivars were fertilized at annual rates of 134.5 kg/ha nitrogen, 168.1 kg/ha phosphorous, and 140.1 kg/ha potassium.

Additionally, a WS grass acclimation pasture featuring one of each of the WS cultivars and a CS grass acclimation pasture featuring one of each of the CS grass cultivars was established following the methods described above. Each pasture was 1.1 hectare in size each and was connected to a small 0.065 hectare bare soil loafing lot with a run in shelter and water source.

In the spring of year 1, prior to grazing, fencing was added to plot areas to create four small 0.016 ha grazing paddocks in each of the CS and WS plot areas (Figure 1). Each paddock was assigned to a horse to be grazed throughout the two years in which grazing events occurred.

2.2 Grazing Event Management

All experimental procedures were conducted according to those approved by the Virginia Polytechnic Institute and State University's Institutional Animal Care and Use Committee (16-073). Four warmblood mares (15-18 years old) grazed research plots over the two year period. Body weights were 668.7 kg ± 1.4 on average (initial 693.5 kg on average) and ranged from 589.7 to 783.4 kg. Average body condition score was 7.2 ± 0.0 out of 9 (initial 7.1, range 6.5 – 8.0) and average cresty neck score was 3.2 ± 0.0 out of 5 (initial 3.2, range 2.3 – 4.3). Prior to each grazing event, horses were assessed for body weight, body condition score [31] and cresty neck score [32]. Once assessments were completed, horses were moved to the acclimation pastures, with access to a loafing lot with shelter and water, where they would remain for 3 d. On the morning of the fourth d, horses were moved to their individual grazing plots at 0700 h, allowed to graze freely for 9 hours, and then removed from grazing plots at 1600h. During each grazing event, horses had access to water and were checked periodically for signs of heat stress as no shade was present on the grazing plots. Grazing events occurred over two consecutive growing seasons with CS cultivars grazed in May, June, August, and October and WS cultivars grazed in July, August and September.

2.3 Weather data

Weather data spanning the grazing season for years 1 and 2 were obtained from the Virginia Agricultural Experiment Station Mesonet (www.vaesmesonet.mt-iv.com) weather station located at the study site. Data were generated on a monthly basis and addressed mean, mean maximum, and mean minimum temperature as well as total rainfall. Only weather data collected during data collection is reported.

2.4 Cultivar Inclusion by Vegetative Cover

One day prior to the start of each grazing event, plots were assessed for vegetative cover using a modified line-intercept method [33] using a grid with twenty-five string intersection. Vegetative cover was assessed at each string intersection and classified as either desired species, invasive species, soil, thatch or other, according to what was found at soil level and repeated so that cover was recorded at fifty intersections per plot. Frequency for each category was then transformed into percentage values to estimate cover of each category. Cultivars were excluded from a grazing event if vegetative cover was below 50% for desired species for more than two of the four replicated plots.

2.5 Nutritional Composition

Nutritive value of all cultivars was assessed following grazing events to evaluate their potential as a forage for grazing horses. Cool-season sampling occurred on May 6, June 23, August 18 and October 20, 2016 and May 19, June 23, August 25 and October 17, 2017. Warm-season sampling occurred on July 14, August 11, and

September 25, 2016 and July 14 and September 12, 2017. On August 17, 2017, samples were collected from WS plots, but grazing was not conducted as vegetation was lacking in all cultivars. Samples were hand-clipped at a height of 2.5 cm with subsamples from each plot combined and then then stored in a -80˚C freezer until shipped on dry ice to a commercial laboratory (Equi-Analytical, Ithaca, NY). Combined samples were analyzed for nutrient composition including an estimation of digestible energy (DE) and wet chemistry analysis of crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), water soluble carbohydrates (WSC), starch, and NSC following approved AOAC laboratory methods.

2.6 Plant Maturity

Plant maturity was estimated by a modified version of a system developed by Moore et al. [34]. In the original system, maturity is estimated by plant stage of growth through use of physical characteristics such as presence of seed heads and nodes. Due to not all cultivars possessing visible nodes, a simplified version was utilized in this study where vegetation was characterized as either germinating (<4 leaf stage), vegetative (4+ leaf stage), reproductive (seed head present), or dormant. Maturity was estimated for each cultivar by an average of five randomly selected points on each plots when samples were harvested to determine nutrient content.

2.7 Endophyte Testing

Endophyte toxin analysis was performed prior to the start of grazing events through the Oregon State University, Endophyte Testing Laboratory (Corvallis, OR) utilizing HPLC-fluorescent analytical methods [35].

2.8 Relative Grazing Preference

Pre-grazing (initial) height was measured using a falling plate meter [36] and was repeated after grazing to estimate amount of vegetation consumed over the nine hour grazing period. Overall grazing preference was determined by ranking cultivars based the change from initial height to post grazing height.

2.9 Biomass

Pre-grazing and post-grazing biomass samples were collected to estimate both amount grazed and yield. Biomass samples were collected by harvesting a 0.25m x 0.25m quadrat by hand with shears and drying at 70^{O}C until weight remained constant to determine yield on a dry matter basis. Dry matter weights were then used to determine available forage on a kg/ha basis.

2.10 Statistical Analysis

Data were analyzed using the mixed and regression procedures of SAS 9.3 (SAS Institute, Cary, NC) with separate analysis run for each grazing event. Mixed procedures produced orthogonal contrasts for least-squares mean comparisons by ANOVA. To determine palatability, the response variable was cm height removed during grazing with the fixed model effect of cultivar and an blocking effect of horse. Assumptions of normality and homogeneity of variances were found normal by examination of the residual plots. Results were considered significant at the $P < 0.05$ level. Response variable means are reported as Least Squared Means (LSM) ± Standard Error (SE) and Tukeys' adjustment was used for least-squares mean comparisons. To further explain palatability of experimental cultivars, regression analyses were run on plant height removed during grazing vs. pre-grazing/initial height, DM, DE, CP, ADF, NDF, WSC, ESC, starch, and NSC.

3. Results

3.1 Weather

Average monthly temperature appeared to be similar in year 1 and 2. Year 2 had greater variability of rainfall on a month to month basis (Figure 2). Total rainfall over the growing season was approximately 58 cm for year 1 and 67 cm for year 2.

3.2 Cultivar Inclusion by Vegetative Cover

In October of year 1, KBG and HF, were excluded from the CS grazing event due to insufficient vegetative coverage (data not shown). In September of year 1 and 2, CG was excluded from the WS grazing event due to low vegetative cover. ZG plots did not establish well and as a result did not provide enough vegetation to be included in any grazing events for both years 1 and 2.

3.3 Nutritional Composition, Plant Maturity and Endophyte Presence

Nutrient content appeared to be similar when comparing CS cultivars to each other and WS cultivars to each other, with the exception of NSC (Figures 3-8). Warm-season cultivars tended to be lower in NSC than CS cultivars, with all WS cultivars averaging <15% NSC across years 1 and 2. Peak NSC occurred in May of year 1 for PRG. Over the two year study period, CF and CBG were more often <15% NSC. Neutral detergent fiber was slightly higher in WS grasses compared to CS grasses and CP was higher in CS cultivars (Tables 1 and 2).

Plant maturity was relatively consistent across both CS and WS trials with vegetative state being most frequently observed (Tables 3 and 4). There were negligible concentrations, as determined by testing facility, of ergovaline and lolitrem B in CS cultivars (Table 5). Alkaloid levels were tested in order to estimate presence of endophytes in CS cultivars. Warm-season cultivars were not tested as there is no known relationship between WS cultivars included in study and endophytes.

3.4 Relative Grazing Preference

Grazing preference was ultimately determined by amount grazed alone as biomass samples did not produce valid data and were therefore not included. No significant effects of cultivar were observed in regard to amount grazed for CS grazing events (Table 6) therefore grazing preference rankings could not be assigned. Grazing preference was influenced by cultivar in WS grazing events ($P < 0.02$) with the exception of the final grazing event (Table 7). Relative grazing preference was highest for CG and BG (Common) for both years 1 and 2. Cold-tolerant varieties of BG (Riviera and Yukon) were least preferred across all grazing events (Table 8).

3.5 Correlations

Correlations for grazing preference as it related to nutrient composition are reported in Table 9. Grazing preference increased as dry matter increased for both CS ($P <$ 0.0001, R^2=0.6317) and WS trials. However, grazing preference decreased as initial height, DE and amount of vegetative grass (compared to reproductive) increased ($P <$ 0.0001, R^2=0.2763; P=0.0006, R^2=0.1801; P=0.0312, R^2=0.0751) for CS cultivars. In WS cultivars, grazing preference also increased as dry matter increased (P=0.0307, R^2=0.2599, Root MSE 3.10645, y=0.26723x + 0.27108).

4. Discussion

4.1 Establishment

The majority of cultivars were successfully established, determined by inclusion in the first grazing event of year 1, with the exception of both ZG cultivars, Compadre and Zenith. ZG plots did germinate following seeding, but the plots did not provide enough vegetation to be included in any grazing event for both years 1 and 2. A potential reason for this may be due to the winter temperatures being too low at the research cite for ZG to thrive. Crabgrass initially did not establish well as limited germination occurred following seeding, but after re-seeding with one-year aged seed, establishment was successful. It should be noted that WS grazing events were initially scheduled to be conducted in June, July and August, but WS cultivars began growth later than expected. Warm-season grazing events were moved to July, August and September, when vegetation was sufficient to support grazing. Crabgrass did appear to have a shorter growing season compared to other WS grasses and were not included in September grazing events. Plots seeded with CG reached a reproductive state earlier in the growing season and declined in actively growing vegetation. All CS cultivars were successfully established and included in the first grazing event of year 1. Spring green-up was later than expected and resulted in the first grazing event being moved from April to May in order to have enough vegetation to determine amount grazed.

4.2 Nutritional Composition

In order to determine if cultivars were suitable for grazing by equine, nutritional analysis was conducted so that DM concentration of nutrients could be compared to previously published values. Overall, DM nutrient concentration was similar for CS and WS cultivars and were similar to previously reported parameters of good quality grass hay with fiber fractions below upper limits which affect palatability [37]. Cool-season turfgrass cultivars in this study had nutrient concentrations more similar to previously reported values for forage type CS pasture grasses, compared to legumes. Similarities extended to DE, DM, ADF and NDF [38-41] but differences were noted for CP. Previously reported CP content for forage type pasture grasses ranged from approximately 11-16% [38-40] and ranged from 16-25% [38; 39] in legumes such as alfalfa and Ladino clover, which was closer to concentrations observed in this study. Crude protein content of turfgrasses being more similar to those of legumes has also been observed by Allen et al. of Rutgers University who reported values ranging from approximately 19 to 21.5% for KBG, RF, HF and colonial bentgrass cultivars [42].

Nutrient content for BG cultivars have been previously reported to range from 9 to 21.4% CP, 27% ADF, and 60-62% NDF [28; 29; 43; 44; 45]. In the case of Yukon and Riviera BG, CP was at the higher end of the range at 20.1% and 20.3% CP respectively [45]. Nutrient concentrations of WS cultivars reported in this study are similar to those previously reported, with the exception of CP, which was slightly below those specifically reported for Yukon and Riviera. Water-soluble carbohydrates have also been reported from a study investigating the effects of NSC of BG at different cutting heights. One study reported NSC at approximately 12.2% (WSC 7.4% ± 0.3, starch 4.8% ± 0.3), with WSC increasing as height decreased and throughout the day [43]. Due to all nutritional samples for this study being collected following grazing in the afternoon, NSC content was expected to be on the high end. However, other factors may have influenced NSC concentrations including maturity, season, temperature, sun exposure, soil composition, drought, mowing, and traffic [19; 23]. The nutrient concentration of CG represented in this study falls within the previously reported values of 11 to 21% CP, 27.5 to 42.7% ADF and 55.5 to 69.8% NDF [28; 44].

One major difference observed was that starch was higher than expected in both CS and WS cultivars. Previous starch concentrations were reported at approximately 1.1 to 1.7% [42] for CS grasses and approximately 4.8% [45] for WS grasses. Sampling methods may have influenced starch content as our methods used cutting heights of 2.5 cm, which is lower than the recommended height at which to discontinue grazing of a pasture. Our sample height was chosen due to the low-growing nature of the cultivars and because of their potential to be used in small acreage areas where overgrazing and close-grazing would occur. Additionally, starch concentrations may be higher in our study as samples were collected at the end of the day, when NSC (which includes starch) had accumulated as an end product of photosynthesis.

In CS grasses, both starch and total NSC tended to be higher in the fall when cultivars were nearing dormancy. This was expected as CS perennials accumulate and store NSC, with the majority being fructan and starch to ensure survival over the winter with storage occurring in the stem, crown, stolons and rhizomes. In WS cultivars, fructan is not produced therefore, starch is the primary storage form of energy which may explain why there was a higher starch concentration in WS cultivars compared to CS. In this study, clipping height was low. In the case of BG, horses were observed consuming the stolonous branches of BG, therefore that portion of the plant was included in nutritional samples. This low clipping height increased the potential for inclusion of regions of the plant where starch is accumulated, resulting in higher that previously published values. In addition, various trends in NSC have been reported, but data has been collected under varying protocols. In the case of turfgrasses, limited information is available therefore we do not know of any expected cultivar differences that may be present. Due to this, further research investigating cultivar differences in NSC should be conducted to further clarify this relationship.

4.3 Relative Grazing Preference

Relative grazing preference was determined by ranking cultivars based on amount grazed by height removed during grazing events. This was done to identify less palatable cultivars in order to prevent overgrazing. No differences were observed among CS cultivars, but among WS cultivars, 'Riviera' and 'Yukon' were less preferred.

In previous studies, grazing preference of horses has been linked to sward height [46 - 48], location of feces and associated parasite larvae [49], and biomass and maturity [50]. Sward height data are inconsistent from one study to another with heights of 6-7 cm, 17 cm, and 15.5 cm [46-48] being reported as the preferred grazing height. Sward height has also been shown to influence bite dimensions with number of bites increasing with sward height [48; 51]. It has also been observed that horses continuously sample their environment but return back to taller patches of pasture where there is a greater return for energy expended while grazing [48]. It should be noted that grazing preference ranking is relative to other grazing options provided and may be confounded by other factors such as forage biomass and maturity [52]. When DE was consistent but sward height was different, preference was for the higher sward height [47]. In this study DE and grazing heights appear similar for CS cultivars, which may explain why no differences were observed. In WS grazing trials, DE also appeared to be similar across all cultivars. One difference that was observed was that CG was typically taller in height (more vertical growth pattern) and was also more preferred over Yukon and Riviera BG which have a more horizontal growing pattern. In a previous study of grazing preference conducted by Martinson et al. [53], forage-type varieties of perennial CS grasses were grazed and differences were found with preference for mixtures of TF, PRG, KBG and timothy over mixtures with >30% orchardgrass.

Correlations between amount grazed and DM nutritional composition did not agree with previous findings, again calling attention to a theory proposed by Naujeck and Hill [51] that there may be complex factors which impact grazing preference which we have not yet identified. Additionally, methods utilized for grazing studies are not uniform across the field and while results are comparable, differences in methodology should be considered as this may influence results. Throughout this study, biomass samples did not produce usable data and offered values where post grazing biomass was greater than pre grazing biomass. Samples were collected following protocol, but were not consistently taken by one person, which may be have been a contributing factor. Also, the sampling method utilized in this study may not have been optimal for small plot work despite efforts to avoid sampling error. Three quadrats were collected per plot to determine an average biomass value, but due to inconsistency in vegetation height, quadrats would consistently get caught on high patches of grass, which may have also led to the variability in samples.

5. Conclusions

Overall, CS cultivars were grazed equally and of WS cultivars, cold-tolerant varieties of BG were less preferred. All cultivars included in this study are suitable for grazing by equine and appear to similar in nutritional composition to forage-type grasses. Nonstructural carbohydrates were higher in CS cultivars than WS cultivars but exceeded 20% NSC on average, which is the approximate NSC concentration in the diet of an average horse in work. Warm-season cultivars were closer to values recommended for metabolically sensitive equids, but caution should be utilized when grazing as NSC levels can rise in response to environmental conditions. Alkaloid testing to determine the presence of endophytes confirmed that the CS cultivars included in this study were safe for grazing by non-pregnant equids, but endophyte levels may vary from one bag of seed to the next. Cool-season turfgrass seed should be tested for endophytes prior to planting and any cultivars which may be infected with should be avoided by breeding stock. Continued research on identified cultivars is warranted and future studies should include annual yield, stocking rates, voluntary intake, dry matter digestibility and long term effects of grazing on both horse and environmental health.

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Figure 1. Horses grazing plots of 8 cool-season (CS) turfgrasses in year 1.

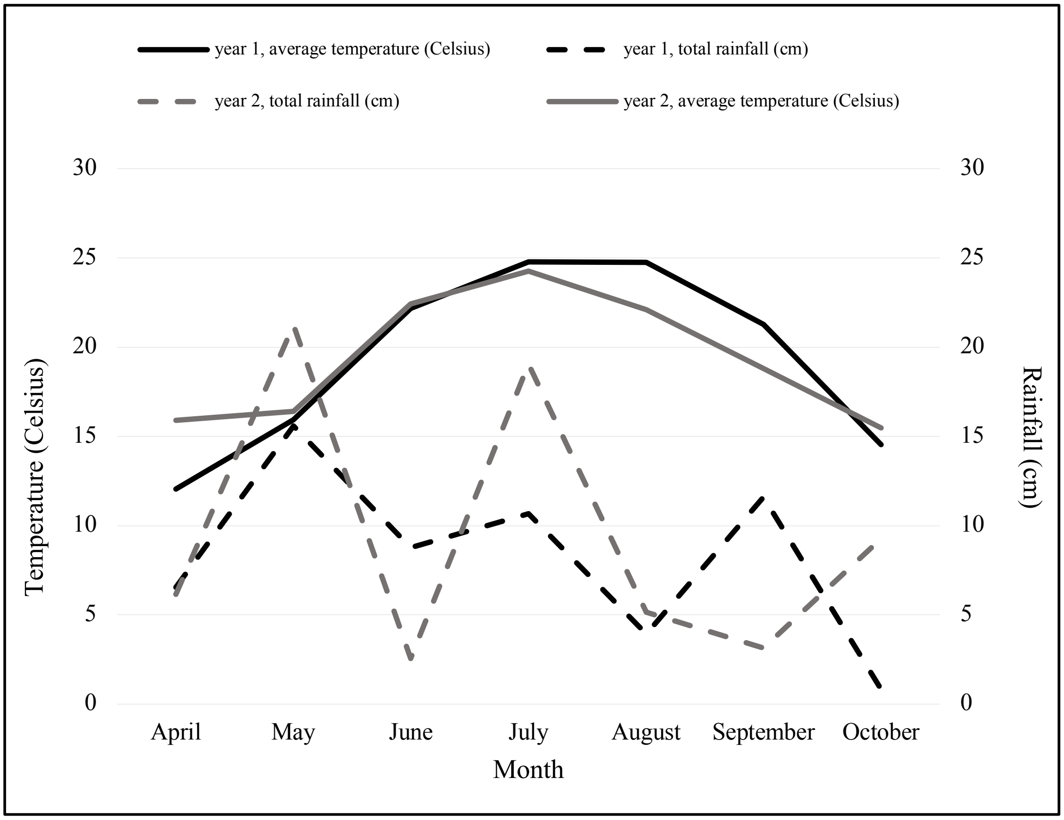
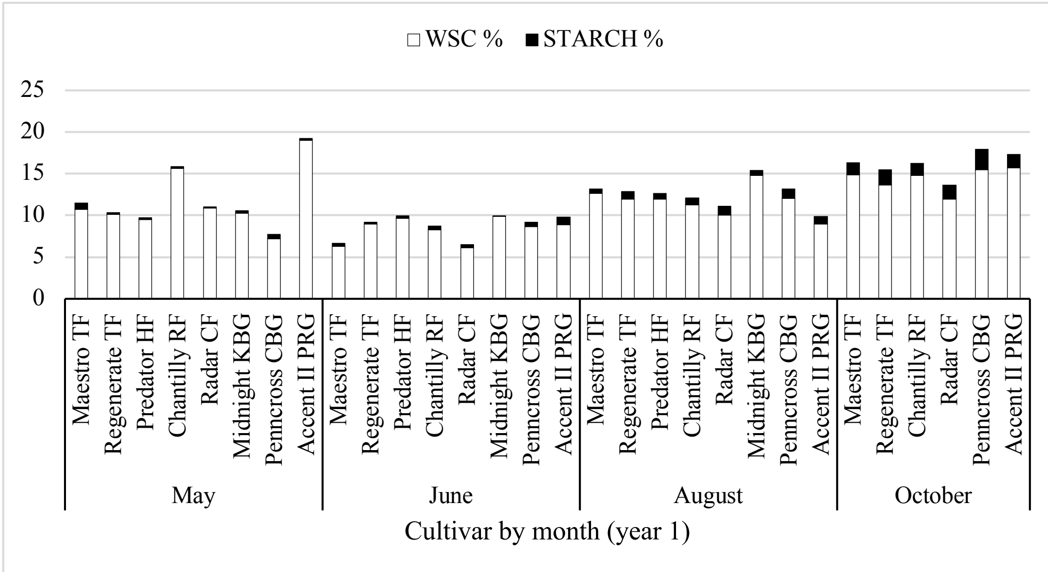


Figure 2. Average temperature (°C) and total rainfall (cm) by month during year 1 (2016) and 2 (2017).

3a.



3b.

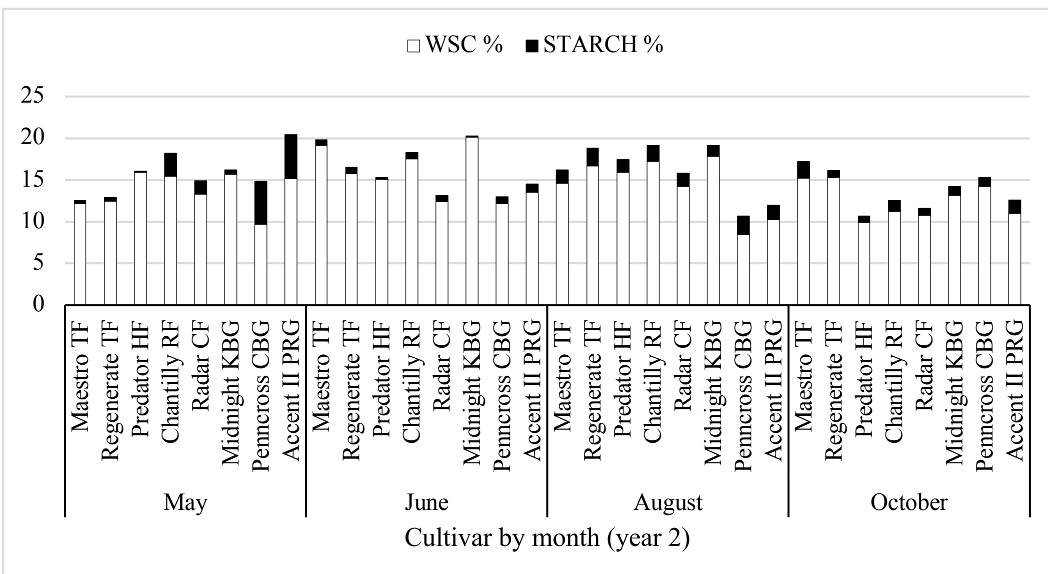
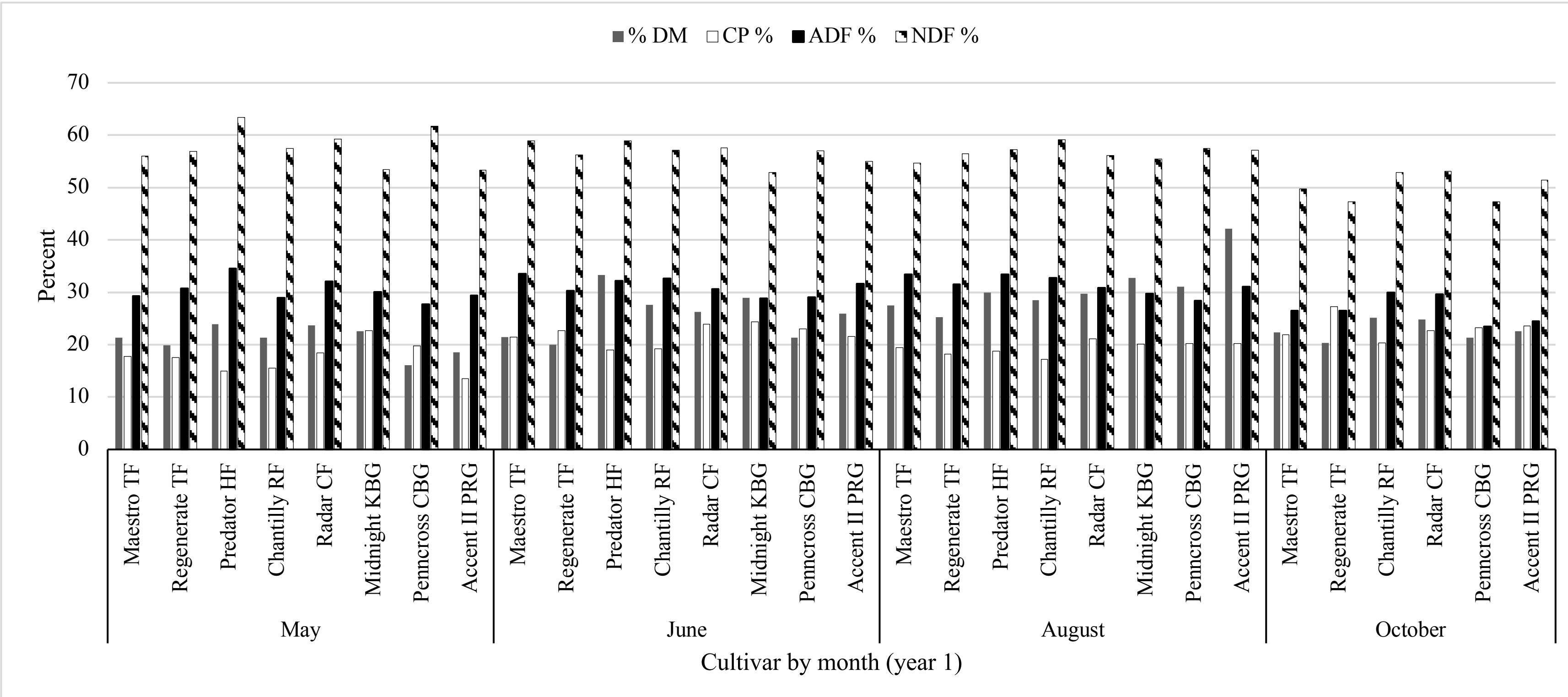


Figure 3. Non-structural carbohydrate composition (NSC, Water Soluble Carbohydrate + Starch) of cool-season cultivars by month for years 1 (3a.) and 2 (3b.). WSC represented in white and starch represented in black. Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.

4a.


% DM
CP %
ADF %
NDF %
Percent
0
10
20
30
40
50
60
70
Maestro TF
Regenerate TF
Predator HF
Chantilly RF
Radar CF
Midnight KBG
Penncross CBG
Accent II PRG
May
June
August
October
Cultivar by month (year 1)

4b.

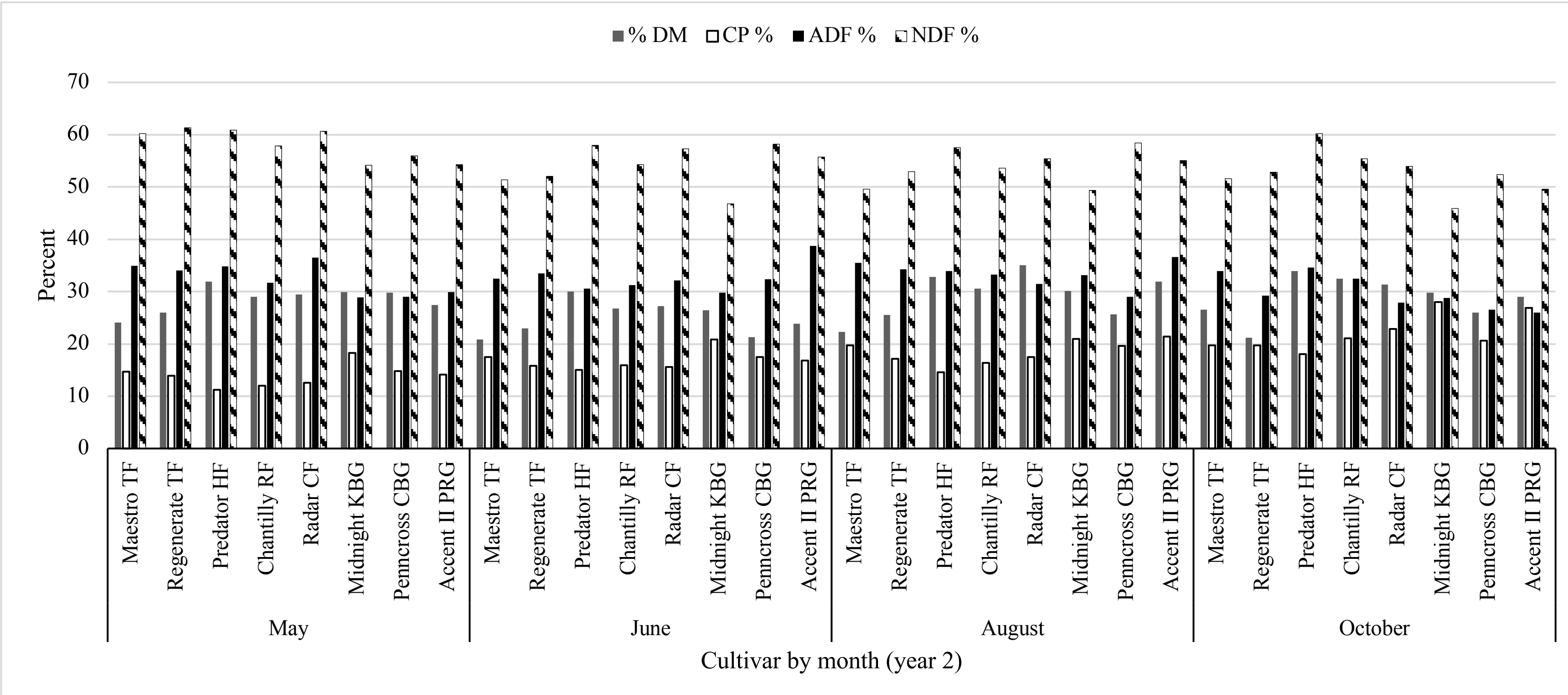


Figure 4. Nutrient content of cool-season cultivars by month for year 1 (4a.) and 2 (4b.). Components represented include dry matter (DM), crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF). Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.

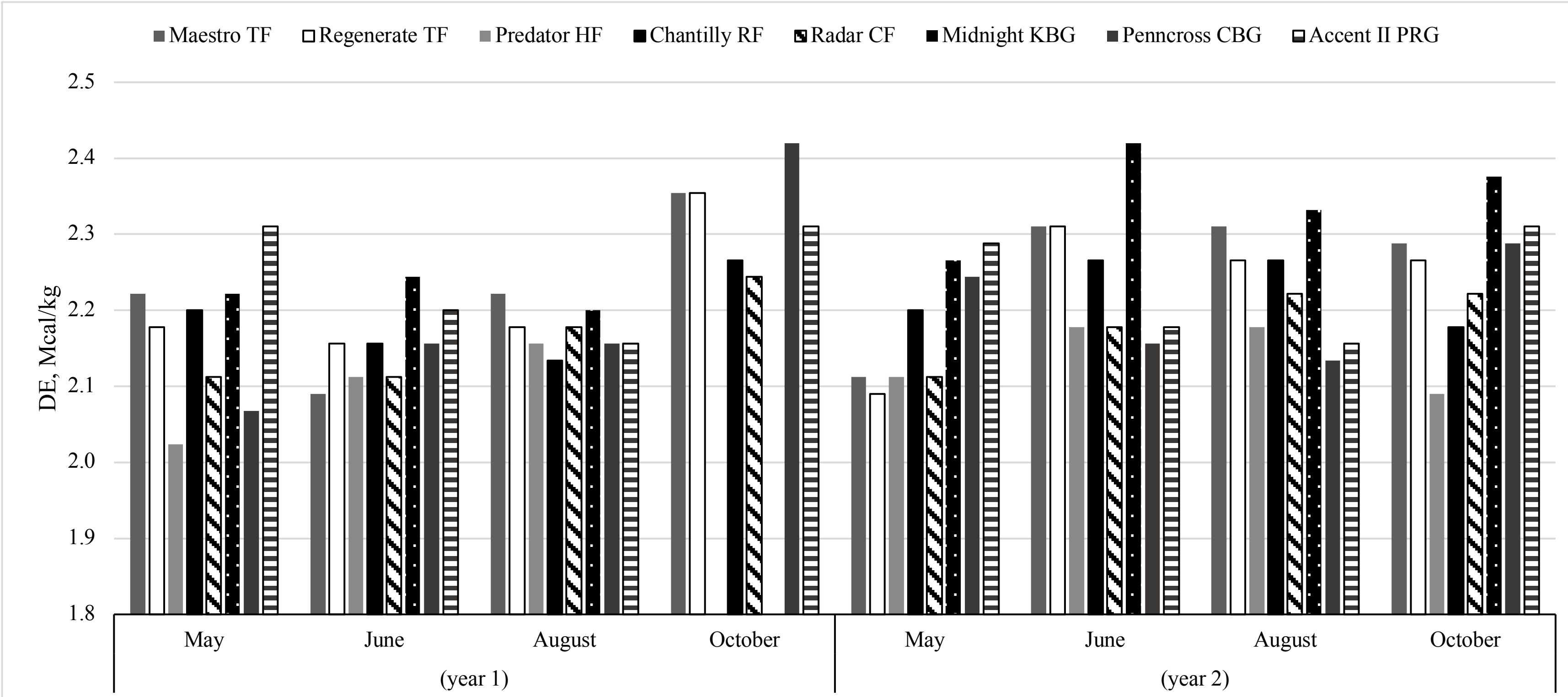
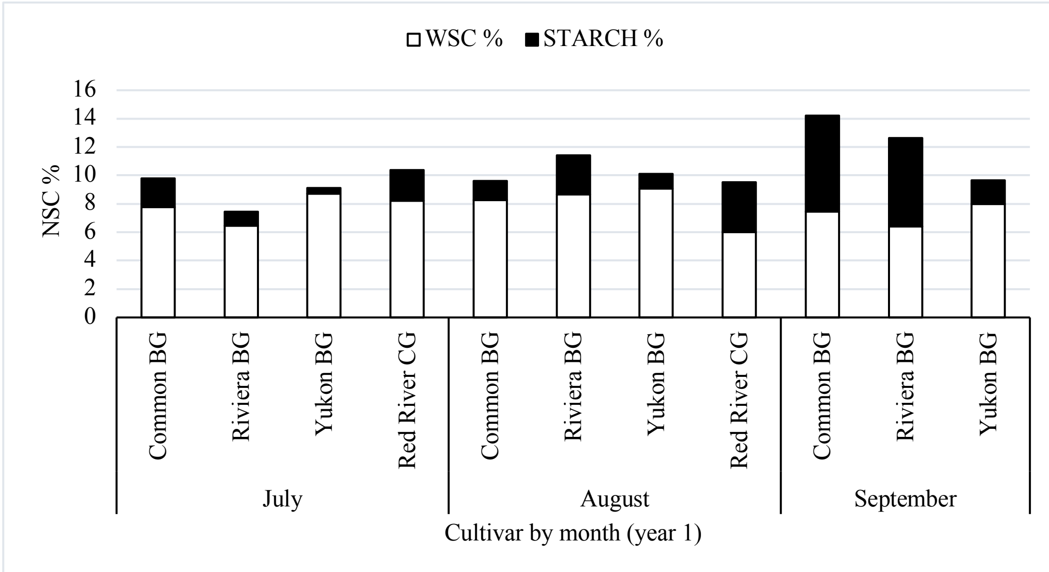


Figure 5. Digestible energy (DE, Mcal/kg) of cool-season cultivars for year 1 (2016) and 2 (2017). Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.

6a.



6b.

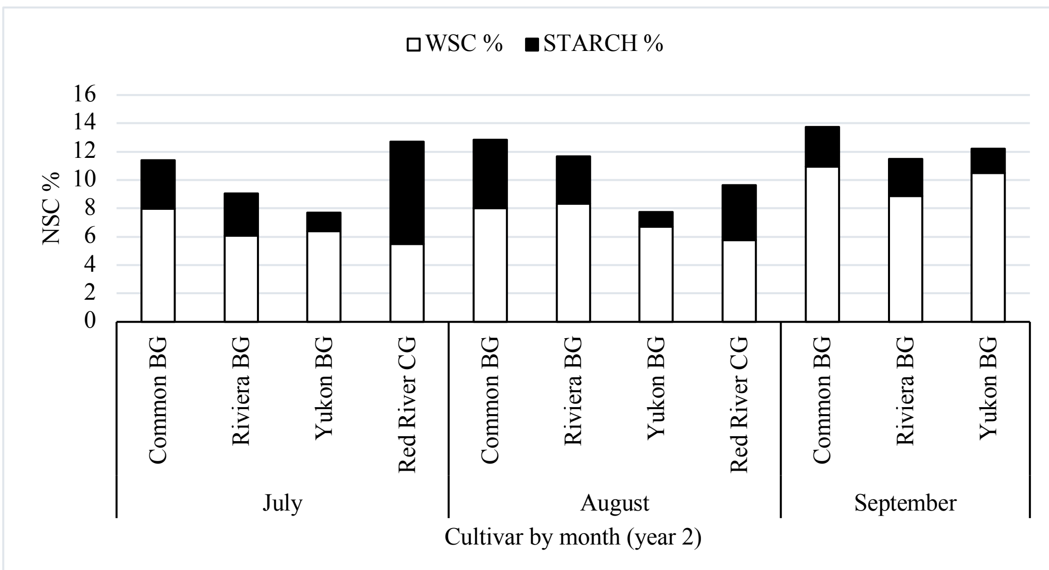
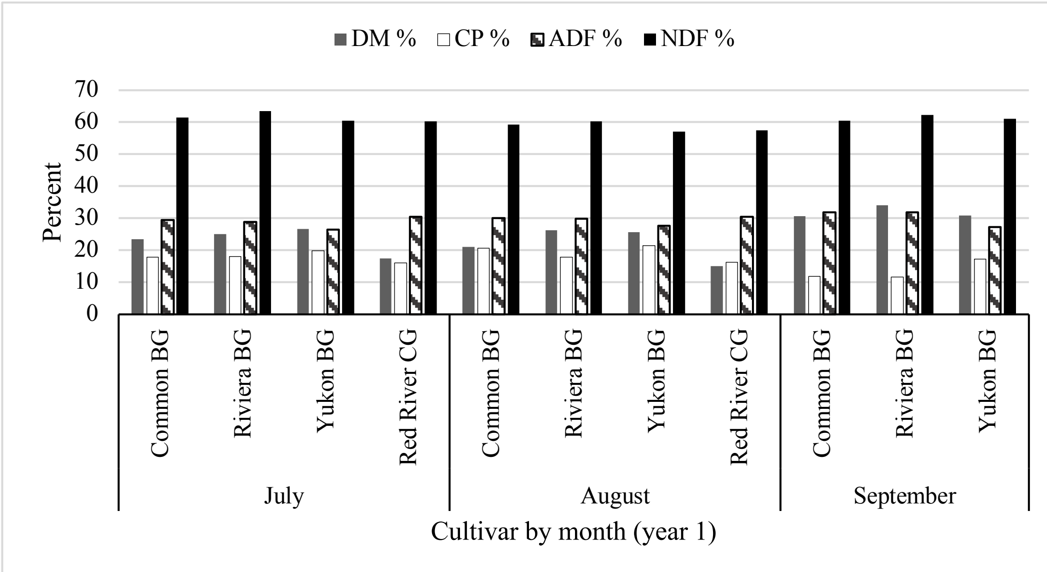


Figure 6. Non-structural carbohydrate composition (NSC, Water Soluble Carbohydrate + Starch) of warm-season cultivars by month for year 1 (6a.) and 2 (6b.). WSC represented in white and starch represented in black. Species abbreviations: BG=bermudagrass, CG=crabgrass.

7a.



7b.

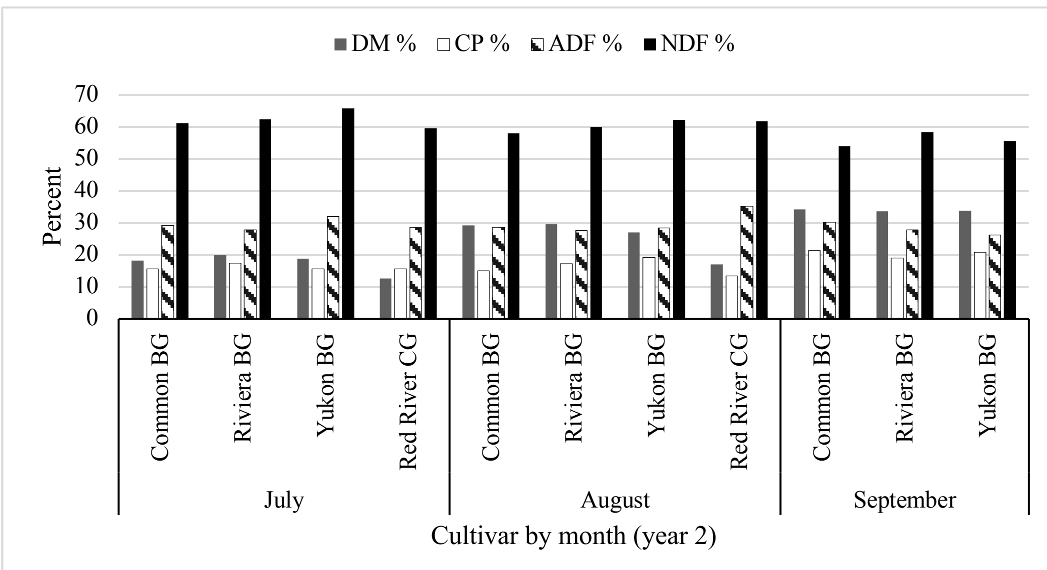


Figure 7. Nutritional composition of warm-season cultivars by month for year 1 (7a.) and 2 (7b.). Components represented include dry matter (DM), crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF). Species abbreviations: BG=bermudagrass, CG=crabgrass.

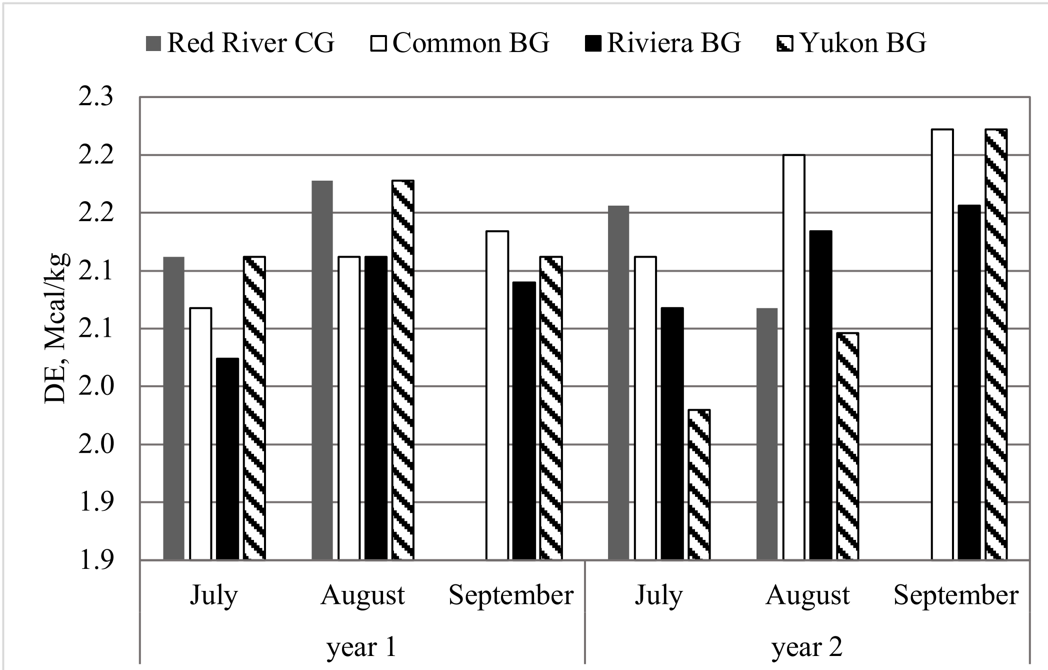


Figure 8. Digestible energy (DE, Mcal/kg) of warm-season cultivars for year 1 (2016) and 2 (2017). Species abbreviations: BG=bermudagrass, CG=crabgrass.

Table 1. Nutrient composition[1], dry matter basis, of cool-season cultivars during year 1 (2016) and 2 (2017) expressed as Mean ± SE.

Cultivars[2]	DM, %		CP, %		ADF, %		NDF, %		DE, Mcal/kg		NSC, %	
	Year 1	**Year 2**	**Year 1**	**Year 2**	**Year 1**	**Year 1**	**Year 2**	**Year 2**	**Year 1**	**Year 2**	**Year 1**	**Year 2**
Maestro TF	23.2 ± 1.5	23.5 ± 1.4	20.1 ± 1.0	17.9 ± 1.4	30.7 ± 1.7	43.2 ± 0.8	54.8 ± 1.9	53.2 ± 2.8	2.2 ± 0.05	2.3 ± 0.06	11.9 ± 2.0	16.5 ± 1.8
Regenerate TF	21.4 ± 1.3	23.9 ± 1.3	21.4 ± 2.3	16.7 ± 1.4	29.7 ± 1.1	32.8 ± 1.4	54.3 ± 2.3	54.8 ± 2.5	2.2 ± 0.05	2.2 ± 0.06	12 ± 1.6	16.1 ± 0.9
Predator HF	29.1 ± 2.8	32.2 ± 1.0	17.6 ± 1.3	14.7 ± 1.6	33.4 ± 0.7	33.5 ± 1.1	59.8 ± 1.8	59.1 ± 1.0	2.1 ± 0.04	2.1 ± 0.03	10.8 ± 2.1	14.9 ± 1.4
Chantilly RF	25.6 ± 1.6	29.7 ± 1.2	18.1 ± 1.1	16.4 ± 1.9	31.1 ± 1.0	32.2 ± 0.5	56.7 ± 1.3	55.3 ± 0.9	2.2 ± 0.03	2.2 ± 0.02	13.2 ± 2.0	17.1 ± 2.1
Radar CF	26.1 ± 1.3	30.8 ± 1.6	21.5 ± 1.2	17.1 ± 2.2	30.8 ± 0.5	32.0 ± 1.8	56.5 ± 1.3	56.8 ± 1.5	2.2 ± 0.03	2.2 ± 0.03	10.6 ± 1.4	13.9 ± 1.4
Midnight BG	28.1 ± 1.4	28.9 ± 0.7	22.4 ± 1.4	22.2 ± 1.6	29.5 ± 0.8	28.6 ± 1.7	53.9 ± 2.8	48.2 ± 1.7	2.2 ± 0.06	2.4 ± 0.04	12 ± 2.3	9.9 ± 2.6
Penncross CB	22.5 ± 3.1	25.7 ± 2.0	21.5 ± 0.9	18.1 ± 1.5	27.2 ± 1.3	29.2 ± 1.4	55.8 ± 3.1	56.3 ± 1.6	2.2 ± 0.08	2.2 ± 0.04	12 ± 2.8	13.5 ± 2.4
Accent II RG	27.3 ± 5.2	28.1 ± 1.9	19.7 ± 2.2	19.8 ± 3.3	29.2 ± 1.6	32.8 ± 3.4	54.2 ± 1.2	53.7 ± 1.6	2.2 ± 0.04	2.2 ± 0.04	14.1 ± 1.0	14.9 ± 2.1

[1]Nutrition abbreviations: DM=dry matter, DE=digestible energy, CP=crude protein, ADF=acid detergent fiber, NDF=neutral detergent fiber, WSC=water soluble carbohydrates, ESC=ethanol soluble carbohydrates, NSC=non-structural carbohydrates (WSC+Starch).
[2]Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.

Table 2. Nutrient composition[1], dry matter basis, of warm-season cultivars during year 1 (2016) and 2 (2017) expressed as Mean ± SE.

Cultivars[1]	DM, %		CP, %		ADF, %		NDF, %		DE, Mcal/kg		NSC, %	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Common BG	25.0 ± 2.9	27.2 ± 4.8	16.8 ± 2.6	17.4 ± 2.1	30.5 ± 0.7	29.4 ± 0.5	60.5 ± 0.6	57.8 ± 2.1	2.1 ± 0.02	2.2 ± 0.03	11.2 ± 1.9	12.7 ± 1.6
Riviera BG	28.5 ± 2.8	27.7 ± 4.0	15.8 ± 2.1	17.9 ± 0.6	30.2 ± 0.9	27.8 ± 0.1	62.0 ± 1.0	60.3 ± 1.1	2.1 ± 0.03	2.1 ± 0.03	10.5 ± 2.2	10.8 ± 1.1
Yukon BG	27.8 ± 1.6	26.6 ± 4.3	19.5 ± 1.2	18.5 ± 1.5	27.1 ± 0.3	28.9 ± 1.7	59.6 ± 1.3	61.3 ± 3.0	2.1 ± 0.02	2.1 ± 0.07	9.6 ± 0.7	9.3 ± 1.5
Red River CB	16.3 ± 1.3	14.9 ± 2.2	16.1 ± 0.1	14.5 ± 1.2	30.4 ± 0.1	31.9 ± 3.2	58.9 ± 1.5	60.7 ± 1.1	2.2 ± 0.03	2.1 ± 0.04	9.9 ± 1.8	11.2 ± 1.8

[1]Abbreviations: DM=dry matter, DE=digestible energy, CP=crude protein, ADF=acid detergent fiber, NDF=neutral detergent fiber, WSC=water soluble carbohydrates, ESC=ethanol soluble carbohydrates, NSC=non-structural carbohydrates (WSC+Starch).
[2]Species abbreviations: BG=bermudagrass, CB=crabgrass.

Table 3. Pre-grazing plant maturity of cool-season cultivars[1].

	Year 1				Year 2			
Cultivar[2]	May	June	August	October	May	June	August	October
Maestro TF	80	100	100	100	95	100	100	100
Regenerate TF	80	100	100	100	100	100	100	100
Predator HF	60	100	100	N/A	100	100	100	100
Chantilly RF	75	95	100	100	85	100	100	100
Radar CF	80	100	100	100	40	95	100	100
Midnight KBG	85	85	100	N/A	100	90	100	100
Penncross CBG	100	65	100	100	100	85	100	100
Accent II PRG	100	75	100	100	100	70	100	100

[1]Expressed as an average percent of four plots that were scored as being in either a vegetative (100) or reproductive (0) state.
[2]Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.

Table 4. Pre-grazing plant maturity of warm-season cultivars[1].

	Year 1			Year 2		
Cultivar[2]	**July**	**August**	**September**	**July**	**August**	**September**
Common BG	85	100	30	70	N/A	90
Riviera BG	55	100	55	85	N/A	70
Yukon BG	85	100	90	40	N/A	80
Red River CB	70	55	N/A	30	N/A	N/A

[1]Expressed as an average percent of four plots that were scored as being in either a vegetative (100) or reproductive (0) state.
[2]Species abbreviations: BG=bermudagrass, CB=crabgrass.

Table 5. Endophyte alkaloid analysis[1] of cool-season cultivars.

Cultivar[2]	**Ergovaline, ppb**	**Lolitrem B, ppb**
Maestro TF	162	<100
Regenerate TF	147	<100
Predator HF	<100	<100
Chantilly RF	<100	<100
Radar CF	<100	<100
Midnight KBG	<100	<100
Penncross CBG	<100	<100
Accent II PRG	<100	113

[1]Analysis conducted by Oregon State University, Endophyte Testing Laboratory (Corvallis, OR).
[2]Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.

Table 6. Average reduction in cool-season plot height (cm) in response to grazing.

	Year 1				**Year 2**			
Cultivar[1]	May	June	August	October	May	June	August	October
Maestro TF	4.4	1.8	1.7	2.3	1.6	1.3	2.2	1.3
Regenerate TF	6.8	2.2	1.8	1.9	0.7	1.3	2.9	1.2
Predator HF	3.7	2.4	1.0	N/A[2]	0.9	1.0	1.3	1.3
Chantilly RF	1.3	2.1	1.9	2.4	1.3	1.2	2.5	1.2
Radar CF	4.0	3.2	2.2	2.3	1.4	1.2	1.5	1.2
Midnight KBG	2.0	2.2	1.7	N/A[2]	1.0	1.8	1.7	1.6
Penncross CBG	2.7	2.4	1.1	1.2	1.4	0.9	1.4	1.2
Accent II PRG	4.8	2.2	0.7	2.8	1.6	2.1	2.2	1.6
p-value[3]	NS	NS	NS	NS	NS	NS	NS	NS
SE	1.4	0.6	0.4	0.4	0.2	0.5	0.5	0.3

[1]Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.
[2]N/A = ranking not applicable due to not being included in grazing event.
[3]NS = not significant

Table 7. Average reduction in warm-season plot height (cm) in response to grazing.

	Year 1			Year 2		
Cultivar[1]	**July**	**August**	**September**	**July**	**August**	**September**
Common BG	7.0^{a}	3.9^{b}	8.6^{a}	1.0^{b}	N/A	1.7
Riviera BG	2.0^{b}	3.6^{b}	2.0^{b}	0.7^{b}	N/A	0.8
Yukon BG	2.1^{b}	2.2^{b}	1.4^{b}	1.1^{b}	N/A	1.2
Red River CB	4.3^{b}	14.5^{a}	N/A	4.1^{a}	N/A	N/A
P-value	0.0174	0.0158	0.0002	0.0001	---	NS
SE	1.0	2.3	0.8	0.4	---	0.2

[1]Species abbreviations: BG=bermudagrass, CB=crabgrass.
[a,b,c]Means with unlike superscripts differ ($P < 0.05$) down collumns.

Table 8. Relative grazing preference ranking of warm-season cultivars.

	Year 1				Year 2				2-year Overall
Cultivar[1]	**July**	**August**	**September**	**Overall**	**July**	**August**	**September**	**Overall**	
Common BG	1	2	1	1	3	N/A[2]	1	2	1
Riviera BG	4	3	2	3	4	N/A[2]	3	3	2
Yukon BG	3	4	3	4	2	N/A[2]	2	2	2
Red River CB	2	1	N/A[2]	2	1	N/A[2]	N/A[2]	1	1

[1]Species abbreviations: BG=bermudagrass, CB=crabgrass.
[2]N/A = ranking not applicable due to not being included in grazing event.

Table 9. Variables having a significant correlation with average reduction of cool-season turfgrass plot height (cm) in response to grazing.

Variable[1]	P	Root MSE	R^2	y=mx+b
Initial height	<0.0001	0.9040	0.2763	y = -0.23619x + 3.00538
Dry Matter	<0.0001	0.6449	0.6317	y = 0.25916x - 0.32728
Digestible Energy	0.0006	0.9622	0.1801	y = -0.09353x + 4.42286
Maturity	0.0312	1.0219	0.0751	y = -0.02410x + 4.20830

[1] n=62.

Chapter 6: Summary and Conclusion

1. Key Insights and Relation to the Equine Industry

1.1 Prevalence of and Impacts of Over-conditioning

Results of the survey study presented in Chapter 2 provide support for continued improvement of prevention and management methods for over-conditioned equids. The prevalence of over-conditioned equids in Maryland was ~ 40%, which is consistent with previous reports [1-6], further emphasizing that a large portion of the equine community is affected. Obesity is primarily a management problem as it occurs due to a misbalance between diet and exercise, a relationship that can be prevented by the owner and/or manager. There also may be a genetic component as some breeds are more prone to over-conditioning than others, however that was not an objective of our study. Additionally, the prevention of the over-conditioned state can assist in reducing the risk of weight related disorders such as equine metabolic syndrome, insulin resistance, and laminitis [7; 8]. Future efforts to educate owners and managers should focus first on prevention methods such as understanding dietary needs of equids at various activity levels, how to properly balance a diet to avoid over and underfeeding, and how to properly use management tools such as grazing muzzles and dry lots.

Further research should also be conducted to improve management strategies, as current industry standard tools were found to be costly as well as requiring additional time and labor. These tools were not utilized by all participants and varying levels of satisfaction were associated with each practice. There was a misalignment between usage and satisfaction, indicating an opportunity to improve on current management tools. Also, industry standard practices such as grazing muzzles have been called into question in regard to welfare as they alter normal grazing behavior [9] and dry lots have been found to be sources of erosion and nutrient runoff due to a lack of vegetative cover [10; 11]. The potential for negative effects of dry lots, combined with their high level of usage by survey participants, signals a need to investigate alternative ground cover options capable of anchoring soil and slowing runoff.

1.2 Potential Uses of Turfgrasses on Equine Operations

Cultivars most suitable for use on equine operations should be tolerant of traffic and less preferred for grazing. Additionally, cultivars should be similar in nutritional composition to currently utilized pasture grasses and in the case of metabolically sensitive equids, non-structural carbohydrates (NSC) should ideally be <10 to 15% on average [12]. Results of the studies presented in Chapters 3 through 5 identified multiple promising cultivars, both cool-season (CS) and warm-season (WS), that have potential for use on equine operations. Of the CS cultivars, 'Maestro' and 'Regenerate' tall fescue, 'Predator' hard fescue, and 'Penncross' creeping bentgrass show promise for use on equine operations. Of the WS cultivars, 'Zenith' and 'Compadre' zoysiagrasses and 'Riviera' and 'Yukon' bermudagrasses were most promising. Care should be taken when recommending the cultivars we found to be most promising because cultivar selection should be based on the needs of the equine manager, soil type, and geographic location of the establishment site.

In more northern areas of the Mid-Atlantic region, CS cultivars may be more suitable over WS cultivars as they better tolerate colder winter temperatures and offer a longer growing season, extending the duration where pasture can be grazed. Of the CS cultivars evaluated, tall fescue varieties were overall the most traffic tolerant, with hard fescue following closely behind. Cool-season cultivars in the studies from Chapters 3 and 5 began to grow in the mid-April, but were not productive enough to be grazed until May and growth continued until the end of October to mid-November. As expected, CS cultivars experienced the best growth in the spring and fall with summer growth being slower in comparison but dependent on environmental conditions such as temperature and rainfall.

Southern portions of the Mid-Atlantic region where winter temperatures are higher on average, are regions where WS cultivars may thrive. Northern areas of the Mid-Atlantic region may benefit from use of cold-tolerant bermudagrasses, which have better survivability in cold temperatures than common varieties. Warm-season cultivars may also be more suitable for carbohydrate sensitive equids as they were generally lower in NSC than CS cultivars. One downside of WS cultivars is the short growing season that they offer compared to CS grasses. In the studies presented in Chapters 4 and 5, WS cultivars were expected to grow from June to the end of August, but instead did not become dormant until the end of September. Growth was also slower than expected in June, which is why grazing events did not begin until July.

The authors believe that the Crabgrass cultivar ‘Red River’ limited potential as it was less tolerant of traffic and close mowing and also required special management due to it being an annual grass. Annual grasses must be re-established each year, either by broadcast seeding or allowing pasture to enter a reproductive state to facility self-seeding. This will result in a shorter grazing season compared to zoysiagrass and bermudagrasses. One advantage that annual grasses present is the ability to provide emergency forage with a shorter time from seeding to grazing. However, turf-type crabgrass seed was difficult to obtain as it was not commercially available, which is why a forage-type crabgrass was included in these studies. Currently, two forage-type cultivars, ‘Red River’ and “Quick-N-Big’, are commercially available and can be purchased as fresh or aged seed.

Non-structural carbohydrate level was of interest due to the high usage of dry lots for over-conditioned equids found in Chapter 2 and turfgrasses potentially being alternative ground cover options for dry lots in the future. If turfgrasses were to be used in dry lots, NSC should be lower in an effort to prevent carbohydrate overloading of sensitive equids. NSC was higher in the spring and fall for all CS cultivars compared to summer concentrations. Two cultivars showed promise as lower NSC options; creeping bentgrass and hard fescue. Creeping bentgrass had poor traffic performance relative to other cultivars, but this may be due partially to an intolerance of close mowing when the daily temperature and humidity increased going into summer as this weakness has been previously reported [13]. Additionally, other types of bentgrass exist that may be more suitable while still providing lower NSC values. Hard fescue should also be considered as it was also lower in NSC and tolerant of traffic.

Results from grazing preference trials discussed in Chapter 5 indicated that cold-tolerant varieties of bermudagrass (Yukon and Riviera) were less preferred than Common bermudagrass and Red River crabgrass. Relative preference was not determined for CS cultivars as they were grazed equally. That finding was suprising because previous study of grazing preference did find differences among CS species [14]. One potential reason for CS grasses to have been grazed equally is because plots were generally the same height, maturity stage and endophyte alkaloid levels were similar, all of which have been previously associated with palatability [15-19]. Preference data should be used in selecting cultivars depending on if grass is intended more for grazing or ground cover. For example, less palatable grasses may be more suitable for a primary usage of ground cover, as they may be left un-grazed if a more preferred hay was also offered alongside.

Nutritional analysis confirmed that turfgrass cultivars were mostly within ranges for grass cultivars currently used for grazing. One exception to this similarity was that crude protein was more similar to values expected of legumes. No palatability data was gathered on zoysiagrass cultivars as plots were not successfully established at the research site. In future studies, nutritional information should continue to be evaluated and dry matter digestibility determined, in order to make concise conclusions regarding suitability for different physiological classes of equids with varying metabolic needs.

1.3 Challenges to Turfgrass Management on Equine Operations

The primary challenge to using of turfgrasses on equine operations is the lack of knowledge present about how to manage them in that situation. This includes establishment and management methods, response to grazing, animal performance as well as expected annual yield under grazing and associated stocking rates. Data obtained in this body of work established relative traffic tolerance and relative grazing preference, but effects of grazing pressure in different locations, may result in different animal and plant performance.

Both WS and CS cultivars were established in the same year with the initial goal of seeding at rates similar to those recommended for pasture. This was done in an effort to evaluate yield against comparable forage-type grasses. It was also done to reduce costs because turfgrass seed is more expensive than traditional pasture grass seed. Warm-season cultivars were seeded at lower rates than recommended for athletic fields and industrial lawns but due to concern over invasive weed presence during germination and early in the four-leaf stage, the seeding rate for CS cultivars was increased to those used in the turfgrass industry. This change may have been a factor in the high yields observed in year 1 following establishment.

One reason to seed at lower rates would be to decrease the cost per acre as seed costs are prohibitive for large acreage areas at rates recommended for athletic fields and lawns. An example of this cost difference can be seen when comparing the cost per acre of Riviera bermudagrass (marketed for turf) and Wrangler bermudagrass (marketed for pasture). 'Riviera' bermudagrass (Johnston Seed Company, Enid, OK) costs ~$1600/acre to seed at recommended rates (12.2 kg/m^2) which is much higher than 'Wrangler' (Johnston Seed Company, Enid, OK) at ~$97/acre (12.3 kg/ha). If Riviera were seeded at the same rate as Wrangler, the cost would decrease to ~$162/acre. This cost difference also occurs in CS cultivars when comparing 'Regenerate' tall fescue (Landmark Turf and Native Seed, Spokane, WA), which is marketed as a turfgrass and 'MaxQ' tall fescue (Pennington Seed Inc., Madison, GA), which is marketed as a pasture grass. Regenerate is recommended to be seeded at 11.9 kg/m^2, costing ~$823/acre compared to MaxQ (22.4 kg/ha) at ~$78/acre.

Following cost, establishment is the next challenge that equine operators may face. Good seedbed preparation is important and special attention must be paid to ensure that existing vegetation is completely killed off as established pasture may outcompete newly seeded turfgrass and no information is available regarding the success rate of overseeding turfgrass into an existing pasture.

It is recommended that existing vegetation in the establishment area be killed off with a glyphosate product and then allowed to rest prior to tilling to ensure that vegetation has completely died off. If weeds are present or pasture grass returns, herbicide should be re-applied. Once existing vegetation is completely removed, the soil should be tilled and then rested again to allow any weed seeds that were brought to the surface to germinate and then to repeat the glyphosate application and tilling if needed. Once tilling is complete, the area to be seeded should be firmed using a cultipacker. Rest time following glyphosate application should follow label directions for time required for herbicide to have its full effect but no longer impact germination. By taking time to properly prepare seedbeds, turfgrasses have increased opportunity for successful establishment and decreased chance of pressure from invasive species. This is in contrast to traditional grass pastures that can be established via tilling or no till drill. Currently, no till establishment is not recommended as it has not yet been tested as an establishment method. In Chapter 5, establishment was challenged by tall fescue. This tall fescue was treated with glyphosate prior to preparing seedbeds, but some vegetation was not fully killed off. The surviving tall fescue, crowded out germinating seeded cultivars and required additional management to allow for seeded cultivars to thrive, which may also be an challenge if seeding by no-till into an established pasture.

Turfgrasses in the early stages of growth that are under invasive weed pressure require special care as herbicides can be damaging to new vegetation. Until herbicides can be utilized, mowing can be used to control invasive species by preventing the development and release of seeds as well as removing leaf matter and disrupting photosynthetic activity. Once new vegetation reaches a four-leaf stage, it should be mowed, ensuring to take no more than half of the height of existing plant.

Grass should also be allowed to reach the desired grazing height prior to mowing in order to ensure that root development and future leaf matter is not stunted.

Herbicides used for turfgrasses on athletic fields have limited crossover for use on pasture as not all products are labeled for both usages. Additionally, some chemicals also require application to WS grasses when dormant only, resulting in fewer herbicides available for use during the growing season. In the studies, best results for invasive species control was found when using an herbicide containing dicamba such as Detonate, at a rate of 1169.2 mL/ha (Tenkoz Inc., Alpharetta, GA) along with a non-ionic surfactant. A potential reason for other herbicides not working as well include the application rate being too low for control of invasive species as rate was limited by the age and sensitivity of cultivars. Examples of cultivars with herbicide sensitivity are creeping bentgrass, which is sensitive to 2,4-D and tall fescue which is sensitive to metsulfuron.

1.4 Future Research

Future research should focus on three topics; equid response to long term grazing, on-farm persistence, and environmental impacts of turfgrasses on equine operations. Through investigating these broad topics, standards for establishment and management can be developed, facilitating the easy adoption of turfgrasses on equine operations.

1.4.1 Equid Response to Long-term Grazing

Equids should be monitored for changes in weight, body condition and metabolic response over multiple grazing seasons. No data has presented on this topic which raises concern for equine health when grazing turfgrass. Due to grazing in Chapter 5 being conducted in short sessions, future studies should use caution to ensure than longer exposure does not induce negative effects. Due to our proposed usage of turfgrasses being an alternative ground cover for dry lots in carbohydrate sensitive equids, understanding changes in insulin resistance while grazing turfgrasses would be of value. Dry matter digestibility and voluntary intake should also be evaluated as this could help determine if turfgrasses are safer for grazing by carbohydrate sensitive equids compared to traditional pastures.

Further exploration of nutritional composition should be conducted to increase knowledge of expected nutritional composition of turfgrasses under varying management conditions and environmental stresses. Additionally, in future nutritional analysis of turfgrasses, wet chemistry methods should continue to be used as no standard equation for NIR analysis is available for turfgrass samples. For NIR analysis, nutritional values are estimated based off of equations, and though reliable for pasture grasses, equations have not been established for turfgrasses. In the future, if more information is collected on nutritional composition of turfgrasses, NIR equations can be created so that NIR analysis of turfgrasses becomes more accurate. By utilizing wet chemistry, true values are obtained for most nutritional components. The exception is digestible energy, which is estimated by an equation that uses the values determined by the wet chemistry analysis. Researchers should also ensure that crude fat and ash composition are included in nutritional analysis as this can help further explain the nutritional composition of turfgrasses. Nutritional analysis presented in chapters 3, 4, and 5 did not include these components, which could have provided greater insight when evaluating results. A specific result which could have been further explained by having values for crude fat and ash, was crude protein as it was higher than expected and more similar to values previously reported for legumes.

One nutritive factor of potential concern would be the presence of endophytes. Some CS turfgrasses such as fescues and ryegrasses, have endophytes present as they are able to help increased hardiness of the plant which is an advantage for use on golf courses and athletic fields. While results from analysis in Chapter 5 yielded negligible values of alkaloids produced by endophytes, researchers should be aware of the risk of its presence and evaluate each bag of seed prior to use in grazing studies. Additionally, turfgrasses are not recommended for use with breeding stock due to the risk of alkaloid presence.

1.4.2 On-farm Persistence and Environmental Impact

On-farm trials to evaluate plant and animal performance outside of a research setting are necessary to determine if turfgrasses are truly suitable for their proposed usages. When evaluating establishment, future objectives should be to determine if seeding rate can be reduced while still producing suitable vegetative cover, in an effort to reduce establishment costs. Additionally, cultivars should be evaluated in mixes with other turfgrasses and pasture grasses, as well as combinations of WS and CS cultivars, to determine if cultivars will outcompete each other. When establishing monoculture plots for studies presented in Chapter 3, 4, and 5, there was a need to kill off existing tall fescue, and in cases where tall fescue crowns were not fully killed off or removed from the research site, they would re-establish and put turfgrasses at risk for being outcompeted. Due to this observation, turfgrasses are not currently recommended for over-seeding into existing pastures.

Response to hoof traffic under continuous grazing will also be necessary to determine if cultivars are truly suitable for their intended use. Productive yield and vegetative cover should be evaluated in an effort to better determine stocking rate. This information can be combined with nutritional analysis and the equid response to grazing to determine if turfgrasses can be the sole source of forage in the diet. This information is key to developing recommendations for on-farm usage.

Evaluation of the ability of turfgrass to prevent erosion and nutrient runoff should be conducted alongside grazing persistence trials as this will closely represent the performance of cultivars when utilized by equine operators. Previously, researchers identified sediment erosion and nutrient runoff as potential negative environmental impacts of equine operations when soil is bare from heavy traffic and/or overgrazing [10; 11]. Therefore, research efforts should focus on evaluating the ability of turfgrasses to prevent these negative impacts when managed in an active grazing system or turnout system. An additional topic that should be considered is irrigation requirements. Turfgrasses for athletic fields are highly managed due to traffic stress and mowing heights far below what would be observed on pastures. To ensure that turfgrasses maintained at these low moving heights (ex: putting green) are able to survive periods of drought, irrigation is often utilized. Research has been conducted to evaluate drought resistance of cultivars utilized for athletic fields, industrial lawns and golf courses, but none has been conducted where turfgrasses are utilized in a grazing system.

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Appendices

Appendix Table 1. Compaction in response to traffic treatment year 1 in Manuscript 2[1,2].

	Spring Traffic Treatment				Summer Traffic Treatment				Fall Traffic Treatment			
Cultivar[3]	**Control**	**Low**	**High**	**Cultivar Average**	**Control**	**Low**	**High**	**Cultivar Average**	**Control**	**Low**	**High**	**Cultivar Average**
Maestro TF	6.7	7.6	8.0	7.4^{b}	7.1	7.7	8.1	7.6^{b}	7.3	8.1^{a,b}	8.5	8.0
Regenerate TF	6.6	7.6	8.1	7.5^{b}	6.8	8.0	8.3	7.7^{b}	7.4	8.4^{a,b}	8.5	8.1
Predator HF	7.3	8.1	8.5	8.0^{a}	6.9	8.2	8.6	7.9^{a,b}	7.8	7.5^{b}	8.9	8.1
Chantilly RF	7.5	8.1	8.6	8.1^{a}	7.6	8.3	8.6	8.2^{a}	7.9	8.6^{a}	8.6	8.4
Radar CF	7.4	8.1	8.4	8.0^{a}	7.3	8.1	8.6	8.0^{a,b}	7.7	8.4^{a,b}	8.6	8.3
Midnight KBG	7.6	8.3	8.6	8.2^{a}	7.3	8.1	8.3	7.9^{a,b}	7.5	8.4^{a,b}	8.5	8.1
Penncross CBG	7.3	8.1	8.2	7.9^{a,b}	7.4	7.9	8.5	7.9^{a,b}	7.4	8.4^{a,b}	8.5	8.1
Accent II PRG	7.1	7.9	8.5	7.9^{a,b}	7.4	8.1	8.5	8.0^{a,b}	7.3	8.3^{a,b}	8.6	8.1
Treatment Average	7.2^{z}	8.0^{y}	8.4^{x}		7.2^{z}	8.1^{y}	8.4^{x}		7.5^{z}	8.2^{y}	8.6^{x}	
Cultivar	$p < 0.0001$, SE ± 0.1				$p = 0.0154$				NS			
Treatment	$p < 0.0001$, SE ± 0.1				$p < 0.0001$				$p < 0.0001$			
Cultivar* Treatment	NS, SE ± 0.1				NS				$p = 0.0097$			

[1]Compaction represented as a value on a 0-10 scale to quantify soil compaction. 1=no compaction, 5= moderate compaction (50% soil, 50% air), 10= complete compaction. Values presented are means.
[a,b,c]Means within a column with unlike superscripts differ ($P < 0.05$).
[x,y,z]Means within a row with unlike superscripts differ ($P < 0.05$).
[2]Treatment regions within each plot: control (no treatment), low (1 pass of the simulator per week) and high (2 passes of the simulator per week) during treatment applications.
[3]Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.

Appendix Table 2. Compaction in response to traffic treatment year 2 in Manuscript 2[1,2].

	Spring Traffic Treatment				**Summer Traffic Treatment**				**Fall Traffic Treatment**			
Cultivar[3]	**Control**	**Low**	**High**	**Cultivar Average**	**Control**	**Low**	**High**	**Cultivar Average**	**Control**	**Low**	**High**	**Cultivar Average**
Maestro TF	6.7	7.4	7.7	7.3[b]	4.9	5.8	6.6	5.8[b]	4.3	5.5	6.2	5.3
Regenerate TF	6.8	7.3	7.6	7.3[b]	5.0	5.9	6.6	5.8[a,b]	4.7	5.6	6.0	5.4
Predator HF	7.2	7.8	8.3	7.8[a]	5.2	6.3	6.7	6.1[a,b]	4.8	5.7	6.6	5.7
Chantilly RF	7.5	8.1	8.2	7.9[a]	5.9	6.5	7.3	6.6[a]	5.0	5.9	6.8	5.9
Radar CF	7.1	8.0	8.2	7.8[a]	5.5	6.3	7.2	6.3[b]	4.9	6.0	6.6	5.8
Midnight KBG	7.5	8.0	8.1	7.9[a]	5.6	6.5	6.8	6.3[a,b]	5.1	5.8	6.4	5.8
Penncross CBG	7.6	7.8	8.2	7.9[a]	5.4	6.2	7.1	6.2[a,b]	4.9	6.1	6.8	5.9
Accent II PRG	7.0	7.8	8.2	7.6[a,b]	5.2	6.4	6.9	6.2[a,b]	4.7	5.6	6.2	5.5
Treatment Average	7.2[z]	7.8[y]	8.1[x]		5.3[z]	6.2[y]	6.9[x]		4.8[z]	5.8[y]	6.5[x]	
Cultivar	$p < 0.0001$, SE ± 0.1				$p = 0.0046$, SE ± 0.1				NS, SE ± 0.1			
Treatment	$p < 0.0001$, SE ± 0.0				$p < 0.0001$, SE ± 0.1				$p < 0.0001$, SE ± 0.1			
Cultivar* Treatment	NS, SE ± 0.1				NS, SE ± 0.2				NS, SE ± 0.2			

[1]Compaction represented as a value on a 0-10 scale to quantify soil compaction. 1=no compaction, 5= moderate compaction (50% soil, 50% air), 10= complete compaction. Values presented are means.
[a,b,c]Means within a column with unlike superscripts differ ($P< 0.05$).
[x,y,z]Means within a row with unlike superscripts differ ($P< 0.05$).
[2]Treatment regions within each plot: control (no treatment), low (1 pass of the simulator per week) and high (2 passes of the simulator per week) during treatment applications.
[3]Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.

Appendix Table 3. Compaction in response to rest following traffic treatment year 1 in Manuscript 2[1,2].

	Spring Recovery				Summer Recovery				Fall Recovery			
Cultivar	**Control**	**Low**	**High**	**Cultivar Average**	**Control**	**Low**	**High**	**Cultivar Average**	**Control**	**Low**	**High**	**Cultivar Average**
Maestro TF	7.4	8.0	8.2	7.8	7.5	8.1	8.5	8.0	5.1	6.3	7.2	6.2
Regenerate TF	7.5	8.2	8.3	8.0	7.3	7.9	8.3	7.8	5.2	7.0	7.0	6.4
Predator HF	7.8	8.0	8.6	8.1	7.4	8.2	8.6	8.1	5.4	6.9	7.4	6.6
Chantilly RF	8.1	8.1	8.4	8.2	7.6	8.2	8.5	8.1	6.1	7.1	7.4	6.9
Radar CF	7.7	8.0	8.3	8.0	7.4	7.4	8.4	7.8	5.7	6.6	7.6	6.6
Midnight KBG	8.0	8.2	8.4	8.2	7.5	8.4	8.1	8.0	5.3	6.3	7.0	6.2
Penncross CBG	7.9	8.2	8.5	8.2	7.5	8.1	8.4	8.0	5.9	6.7	7.5	6.7
Accent II PRG	7.8	8.0	8.3	8.0	7.6	8.2	8.4	8.1	5.3	6.4	7.0	6.2
Treatment Average	7.8^{y}	8.1^{x}	8.4^{x}		7.5^{z}	8.1^{y}	8.4^{x}		5.5^{z}	6.7^{y}	7.3^{x}	
Cultivar	NS, SE ± 0.1				NS, SE ± 0.2				NS, SE ± 0.2			
Treatment	$p < 0.0001$, SE ± 0.0				$p < 0.0001$, SE ± 0.1				$p < 0.0001$, SE ± 0.1			
Cultivar*Treatment	NS, SE ± 0.1				NS, SE ± 0.2				NS, SE ± 0.3			

[1]Compaction represented as a value on a 0-10 scale to quantify soil compaction. 1=no compaction, 5= moderate compaction (50% soil, 50% air), 10= complete compaction. Values presented are means.
[a,b,c]Means within a column with unlike superscripts differ ($P < 0.05$).
[x,y,z]Means within a row with unlike superscripts differ ($P < 0.05$).
[2]Treatment regions within each plot: control (no treatment), low (1 pass of the simulator per week) and high (2 passes of the simulator per week) during treatment applications.
[3]Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.

Appendix Table 4. Compaction in response to rest following traffic treatment year 2 in Manuscript 2[1,2].

	Spring Recovery				Summer Recovery				Fall Recovery			
Cultivar[3]	**Control**	**Low**	**High**	**Cultivar Average**	**Control**	**Low**	**High**	**Cultivar Average**	**Control**	**Low**	**High**	**Cultivar Average**
Maestro TF	6.8	7.6	7.9	7.4^{b}	5.8	6.1	6.8	6.3^{b}	5.4	6.0	6.4	5.9^{b}
Regenerate TF	7.2	7.6	7.6	7.5^{b}	6.0	6.2	6.9	$6.3^{b,c}$	5.6	6.1	6.3	$6.0^{a,b}$
Predator HF	7.1	7.8	8.2	$7.7^{a,b}$	6.0	6.6	7.1	$6.6^{a,b,c}$	5.8	6.3	6.9	$6.3^{a,b}$
Chantilly RF	7.4	8.1	8.4	7.9^{a}	6.2	7.0	7.5	6.9^{a}	6.0	6.6	6.9	$6.5^{a,b}$
Radar CF	7.3	7.6	8.1	$7.7^{a,b}$	5.9	6.8	7.3	$6.7^{a,b,c}$	5.6	6.4	6.8	$6.3^{a,b}$
Midnight KBG	7.2	7.8	7.9	$7.6^{a,b}$	6.4	6.8	7.2	6.8^{a}	6.1	6.6	6.9	6.5^{a}
Penncross CBG	7.2	7.9	8.4	$7.8^{a,b}$	6.1	6.8	7.4	$6.8^{a,c}$	5.9	6.5	7.1	$6.5^{a,b}$
Accent II PRG	7.0	7.8	8.0	$7.6^{a,b}$	6.0	6.6	7.0	$6.5^{a,b,c}$	5.7	6.6	6.9	$6.4^{a,b}$
Treatment Average	7.1^{z}	7.8^{y}	8.1^{x}		6.1^{z}	6.6^{y}	7.2^{x}		5.8^{z}	6.4^{y}	6.8^{x}	
Cultivar	p = 0.0091, SE ± 0.1				p = 0.0005				p = 0.0100			
Treatment	p < 0.0001, SE ± 0.0				p < 0.0001				p < 0.0001			
Cultivar* Treatment	NS, SE ± 0.1				NS				NS			

[1]Compaction represented as a value on a 0-10 scale to quantify soil compaction. 1=no compaction, 5= moderate compaction (50% soil, 50% air), 10= complete compaction. Values presented are means.
[a,b,c]Means within a column with unlike superscripts differ (P< 0.05).
[x,y,z]Means within a row with unlike superscripts differ (P< 0.05).
[2]Treatment regions within each plot: control (no treatment), low (1 pass of the simulator per week) and high (2 passes of the simulator per week) during treatment applications.
[3]Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.

Appendix Table 5. Biomass (kg/ha) in response to spring traffic treatment and rest during year 1 in Manuscript 2[1,2].

	Spring Traffic Treatment				Spring Recovery			
Cultivar[3]	**Control**	**Low**	**High**	**Cultivar Average**	**Control**	**Low**	**High**	**Cultivar Average**
Maestro TF	593.5[b,c]	470.9	277.0	447.1[b,c]	903.9	827.6	696.0	809.2
Regenerate TF	716.9[a,b,c,x]	460.7[x,y]	316.6[y]	498.1[a,b]	841.8	794.8	929.7	855.4
Predator HF	1054.5[a,x]	535.8[y]	287.8[y]	626.0[a,b,c]	544.2	672.6	466.4	561.0
Chantilly RF	690.3[b,c,x]	385.3[x,y]	266.8[y]	447.5[b,c]	1057.0	1122.6	719.1	966.2
Radar CF	925.0[a,b,x]	554.1[y]	289.3[y]	589.5[a,b,c]	399.8	458.9	391.1	416.6
Midnight KBG	498.8[c]	460.1	241.1	400.0[c]	482.8	566.7	438.9	496.1
Penncross CBG	909.6[a,b,x]	685.2[x,y]	334.5[y]	643.1[a]	1021.4	717.7	750.5	829.9
Accent II PRG	676.4[b,c]	496.7	329.2	500.8[a,b,c]	933.7	919.7	791.3	881.6
Treatment Average	758.1[x]	506.1[y]	292.8[z]		773.1	760.1	647.9	
Cultivar	p = 0.0012, SE ± 44.7				NS, SE ± 165.4			
Treatment	p < 0.0001, SE ± 23.8				NS, SE ± 91.2			
Cultivar*Treatment	p = 0.0157, SE ± 69.5				NS, SE ± 236.5			

[1]Biomass represented as dry matter yield of desired species on a kg/ha basis within each treatment region of monoculture cool season grass plots. Values presented are LSMeans on a kg/ha basis.

[a,b,c]Means within a column with unlike superscripts differ ($P < 0.05$).

[x,y,z]Means within a row with unlike superscripts differ ($P < 0.05$).

[2]Treatment regions within each plot: control (no treatment), low (1 pass of the simulator per week) and high (2 passes of the simulator per week) during treatment applications.

[3]Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.

Appendix Table 6. Biomass (kg/ha) in response to summer traffic treatment and rest during year 2 in Manuscript 2[1,2].

	Summer Traffic Treatment				Summer Recovery			
Cultivar[3]	**Control**	**Low**	**High**	**Cultivar Average**	**Control**	**Low**	**High**	**Cultivar Average**
Maestro TF	491.9	439.1	385.5	438.8[a]	552.2[a]	478.0[a]	309.5	446.6[a,b]
Regenerate TF	374.3	451.1	400.7	408.7[a,b]	514.1[a]	524.3[a]	492.9	510.4[a]
Predator HF	426.3	500.7	264.7	397.2[a,b]	635.2[a,x]	403.7[a,b,x,y]	244.5[y]	427.8[a,b]
Chantilly RF	489.5	436.7	263.9	396.7[a,b]	316.8[a,b]	152.8[a,b]	135.3	201.6[b,c]
Radar CF	485.5	370.3	264.7	373.5[a,b]	378.6[a,b]	228.4[a,b]	318.2	308.4[a,b,c]
Midnight KBG	522.3	459.1	430.3	470.6[a]	643.7[a,x]	231.7[a,b,y]	138.1[y]	337.8[a,b,c]
Penncross CBG	47.1	211.9	35.1	98.0[b]	59.5[b]	31.9[b]	71.5	54.3[c]
Accent II PRG	294.3	348.7	350.3	331.1[a,b]	385.5[a,b]	295.2[a,b]	250.7	310.5[a,b,c]
Treatment Average	391.4[x,y]	402.2[x]	299.4[y]		435.7[x]	293.3[y]	245.1[y]	
Cultivar	p = 0.0271, SE ± 70.0				p = 0.0005, SE ± 61.9			
Treatment	p = 0.0240, SE ± 39.2				p < 0.0001, SE ± 27.9			
Cultivar*Treatment	NS, SE ± 94.2				p = 0.0081, SE ± 82.5			

[1]Biomass represented as dry matter yield of desired species on a kg/ha basis within each treatment region of monoculture cool season grass plots. Values presented are LSMeans on a kg/ha basis.
[a,b,c]Means within a column with unlike superscripts differ ($P < 0.05$).
[x,y,z]Means within a row with unlike superscripts differ ($P < 0.05$).
[2]Treatment regions within each plot: control (no treatment), low (1 pass of the simulator per week) and high (2 passes of the simulator per week) during treatment applications.
[3]Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.

Appendix Table 7. Biomass (kg/ha) in response to fall traffic treatment during year 1 and 2 in Manuscript 2[1,2].

	Fall Traffic Treatment year 1				Fall Traffic Treatment year 2			
Cultivar[3]	**Control**	**Low**	**High**	**Cultivar Average**	**Control**	**Low**	**High**	**Cultivar Average**
Maestro TF	246.2[a,b]	201.5	160.5	202.8	569.0[a,b]	526.8	319.5	471.8[a,b]
Regenerate TF	184.6[a,b]	231.7	177.2	197.9	710.8[a]	517.3	427.9	552.0[b]
Predator HF	443.8[a,x]	228.0[y]	108.1[y]	45.1	410.4[a,b]	430.0	230.1	356.9[a,b,c]
Chantilly RF	239.0[a,b]	157.6	72.0	156.2	669.3[a,x]	244.6[y]	163.9[y]	359.3[a,b,c]
Radar CF	189.2[a,b]	131.8	113.4	44.6	668.6[a,x]	401.8[x,y]	316.6[y]	462.3[a,b,c]
Midnight KBG	266.9[a,b]	162.9	190.8	206.9	237.4[b]	280.3	192.3	236.7[c]
Penncross CBG	12.2[b]	12.2	12.2	49.2	412.0[a,b]	252.0	119.6	261.2[a,c]
Accent II PRG	158.1[a,b]	169.1	186.9	171.4	441.7[a,b]	466.4	399.5	435.9[a,b,c]
Treatment Average	217.5[x]	161.9[y]	127.6[y]		514.9[x]	389.9[y]	271.2[z]	
Cultivar	NS, SE ± 49.2				p = 0.0018, SE ± 55.0			
Treatment	p = 0.0004, SE ± 19.7				p < 0.0001, SE ± 24.8			
Cultivar*Treatment	p = 0.0008, SE ± 55.3				p = 0.0091, SE ± 76.4			

[1]Biomass represented as dry matter yield of desired species on a kg/ha basis within each treatment region of monoculture cool season grass plots. Values presented are LSMeans on a kg/ha basis.
[a,b,c]Means within a column with unlike superscripts differ (P< 0.05).
[x,y,z]Means within a row with unlike superscripts differ (P< 0.05).
[2]Treatment regions within each plot: control (no treatment), low (1 pass of the simulator per week) and high (2 passes of the simulator per week) during treatment applications.
[3]Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.

Appendix Table 8. Biomass (kg/ha) in response to spring traffic treatment and rest during year 2 in Manuscript 2[1,2].

	Spring Traffic Treatment				Spring Recovery			
Cultivar[3]	**Control**	**Low**	**High**	**Cultivar Average**	**Control**	**Low**	**High**	**Cultivar Average**
Maestro TF	274.8	381.2	365.2	340.4[b,c]	402.3	398.9	359.0	386.7[a,b]
Regenerate TF	352.7	449.1	388.9	396.9[a,b,c]	379.8	380.3	445.2	401.8[a,b]
Predator HF	749.9	861.2	561.7	724.3[a,b]	666.9	565.9	505.0	579.3[a]
Chantilly RF	748.2	662.6	499.8	636.9[a,b,c]	565.4	405.6	477.9	482.9[a]
Radar CF	808.7	844.5	791.3	814.8[a]	421.2	540.4	426.1	462.6[a]
Midnight KBG	390.6	499.8	393.0	427.8[a,b,c]	255.9	180.4	247.0	227.8[b,c]
Penncross CBG	362.0	258.0	361.4	327.2[b,c]	180.8	191.4	179.1	183.8[c]
Accent II PRG	258.4	296.4	232.4	262.4[c]	289.7	240.7	183.2	237.9[b,c]
Treatment Average	493.2	531.6	449.2		395.2	362.9	352.8	
Cultivar	p = 0.0028, SE ± 106.0				p < 0.0001, SE ± 42.6			
Treatment	NS, SE ± 44.4				NS, SE ± 18.4			
Cultivar*Treatment	NS, SE ± 134.1				NS, SE ± 55.4			

[1]Biomass represented as dry matter yield of desired species on a kg/ha basis within each treatment region of monoculture cool season grass plots. Values presented are LSMeans ± SE on a kg/ha basis.
[a,b,c]Means within a column with unlike superscripts differ ($P< 0.05$).
[2]Treatment regions within each plot: control (no treatment), low (1 pass of the simulator per week) and high (2 passes of the simulator per week) during treatment applications.
[3]Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.

Appendix Table 9. Biomass (kg/ha) in response to summer traffic treatment and rest during year 2 in Manuscript 2[1,2].

	Summer Traffic Treatment				Summer Recovery			
Cultivar[3]	**Control**	**Low**	**High**	**Cultivar Average**	**Control**	**Low**	**High**	**Cultivar Average**
Maestro TF	413.2^{c}	400.3^{a,b}	358.0	390.5^{b,c}	390.4	416.5	411.7	406.2^{a,b}
Regenerate TF	463.1^{b,c}	485.2^{a,b}	298.6	415.6^{b,c}	407.1	509.0	464.2	460.1^{a,b}
Predator HF	1084.1^{a,x}	714.6^{a,x,y}	310.0^{y}	702.9^{a}	654.2	570.2	266.3	496.9^{a,b}
Chantilly RF	900.5^{a,b,x}	492.5^{a,b,x,y}	273.8^{y}	555.6^{a,c}	641.1	694.1	557.5	630.9^{a}
Radar CF	920.7^{a,b,x}	558.4^{a,b,x,y}	328.7^{y}	602.6^{a,c}	463.6	285.0	453.1	400.6^{a,b,c}
Midnight KBG	206.3^{c}	173.9^{a,b}	163.3	181.2^{b,d}	274.3	243.4	159.6	225.7^{b,c}
Penncross CBG	127.8^{c}	47.8^{b}	-16.2	53.2^{d}	208.6	131.1	99.4	146.4^{c}
Accent II PRG	311.5^{c}	288.2^{a,b}	199.8	266.5^{b,d}	477.8	470.8	423.2	457.2^{a,b}
Treatment Average	553.4^{x}	395.1^{y}	239.5^{z}		439.6	415.0	354.4	
Cultivar	p = 0.0003, SE ± 64.0				p = 0.0002, SE ± 58.0			
Treatment	p < 0.0001, SE ± 31.1				NS, SE ± 30.4			
Cultivar*Treatment	p = 0.0046, ± 106.9				NS, SE ± 93.4			

[1]Biomass represented as dry matter yield of desired species on a kg/ha basis within each treatment region of monoculture cool season grass plots. Values presented are LSMeans on a kg/ha basis.
^{a,b,c}Means within a column with unlike superscripts differ ($P< 0.05$).
^{x,y,z}Means within a row with unlike superscripts differ ($P< 0.05$).
[2]Treatment regions within each plot: control (no treatment), low (1 pass of the simulator per week) and high (2 passes of the simulator per week) during treatment applications.
[3]Species abbreviations: TF=tall fescue, HF=hard fescue, RF=creeping red fescue, CF=chewings fescue, KBG=Kentucky bluegrass, CBG=creeping bentgrass, PRG=perennial ryegrass.

Appendix Table 10. Compaction in response to traffic treatment years 1 and 2 in Manuscript 3[1,2].

	Year 1								Year 2							
	Traffic Treatment				Recovery				Traffic Treatment				Recovery			
Cultivar[3]	**Low**	**Control**	**High**	**Cultivar Average**	**Low**	**Control**	**High**	**Cultivar Average**	**Low**	**Control**	**High**	**Cultivar Average**	**Low**	**Control**	**High**	**Cultivar Average**
Common BG	7.4	6.8	8.0	$7.4^{a,b}$	8.1	7.7	8.2	8.0	6.0	5.3	6.2	5.8	6.0	5.5	6.4	$6.0^{a,b}$
Riviera BG	7.7	7.0	7.8	$7.5^{a,b}$	7.8	7.3	8.0	7.7	5.4	4.6	5.8	5.3	5.5	5.4	5.9	5.6^{b}
Yukon BG	7.5	6.6	7.8	7.3^{b}	7.9	7.5	8.1	7.9	5.5	5.0	5.7	5.4	5.8	5.5	6.3	5.8^{b}
Compadre ZG	7.5	7.1	7.9	$7.5^{a,b}$	7.8	7.5	7.9	7.7	5.5	4.6	6.0	5.4	6.0	5.4	6.3	5.9^{b}
Zenith ZG	7.8	7.5	8.1	$7.8^{a,b}$	7.7	7.4	8.0	7.7	5.4	4.5	5.7	5.2	5.7	5.4	5.9	5.7^{b}
Red River CG	7.8	7.3	8.6	7.9^{a}	8.1	7.8	8.6	8.2	5.9	5.4	6.1	5.8	6.3	6.1	6.5	6.3^{a}
Treatment Average	7.6^{z}	7.1^{y}	8.0^{x}		7.9^{y}	7.5^{z}	8.1^{z}		5.6^{y}	4.9^{z}	5.9^{x}		5.9^{y}	5.6^{z}	6.2^{x}	
Cultivar	$p = 0.0129$, SE = 0.1				NS, SE = 0.2				$p = 0.0400$, SE = 0.2				$p = 0.0003$, SE = 0.1			
Treatment	$p < 0.0001$, SE = 0.1				$p < 0.0001$, SE = 0.1				$p < 0.0001$, SE = 0.1				$p < 0.0001$, SE = 0.1			
Cultivar* Treatment	NS, SE = 0.2				NS, SE = 0.2				NS, SE = 0.2				NS, SE = 0.1			

[1]Compaction represented as a value on a 0-10 scale to quantify soil compaction. 1=no compaction, 5= moderate compaction (50% soil, 50% air), 10= complete compaction. Values presented are means.
[a,b,c]Means within a column with unlike superscripts differ ($P< 0.05$).
[x,y,z]Means within a row with unlike superscripts differ ($P< 0.05$).
[2]Treatment regions within each plot: control (no treatment), low (1 pass of the simulator per week) and high (2 passes of the simulator per week) during treatment applications.
[3]Species abbreviations: BG=bermudagrass, ZG=zoysiagrass, CG=crabgrass.

Appendix Table 11. Biomass (kg/ha) in response to traffic treatment and rest applied in year 1 in Manuscript 3[1,2].

	Traffic Treatment				Recovery			
Cultivar[3]	**Control**	**Low**	**High**	**Cultivar Average**	**Control**	**Low**	**High**	**Cultivar Average**
Common BG	292.1^{b}	685.0	523.3	500.2	531.4	768.2	718.4	672.7
Riviera BG	$746.1^{a,b}$	911.8	704.7	787.5	1216.9	1146.7	752.3	1038.6
Yukon BG	$430.4^{a,b}$	601.2	608.6	546.7	548.8	910.9	791.1	750.2
Compadre ZG	$668.3^{a,b}$	894.2	719.9	760.8	863.6	1042.4	1040.4	982.2
Zenith ZG	$722.9^{a,b}$	700.9	752.4	725.4	1035.1	906.9	769.0	903.6
Red River CG	951.4^{a}	873.1	461.8	762.1	963.6	730.5	749.6	814.6
Treatment Average	635.2^{y}	777.7^{x}	628.5^{y}		859.9	917.6	803.5	
Cultivar	NS, SE = 100.3				NS, SE = 102.1			
Treatment	p = 0.0193, SE = 49.1				NS, SE = 56.6			
Cultivar*Treatment	p = 0.0463, SE = 133.9				NS, SE = 150.4			

[1]Biomass represented as dry matter yield of desired species on a kg/ha basis within each treatment region of monoculture warm season grass plots. Values presented are LSMeans on a kg/ha basis. [a,b,c]Means within a column with unlike superscripts differ ($P < 0.05$).
[x,y,z]Means within a row with unlike superscripts differ ($P < 0.05$).
[2]Treatment regions within each plot: control (no treatment), low (1 pass of the simulator per week) and high (2 passes of the simulator per week).
[3]Species abbreviations: BG=bermudagrass, ZG=zoysiagrass, CG=crabgrass.

Appendix Table 12. Biomass (kg/ha) in response to traffic treatment and rest applied in year 2 in Manuscript 3[1,2].

	Traffic Treatment				**Recovery**			
Cultivar[3]	**Control**	**Low**	**High**	**Cultivar Average**	**Control**	**Low**	**High**	**Cultivar Average**
Common BG	323.0	433.4	430.4	395.6^{b}	684.8	734.4	1015.8	811.7
Riviera BG	795.6	845.7	1011.1	884.1^{a}	988.4	900.4	877.4	925.4
Yukon BG	717.8	643.8	721.9	694.5^{a,b}	738.0	701.6	588.9	676.2
Compadre ZG	594.5	799.7	727.5	707.3^{a}	1757.0	1334.5	1293.8	1461.8
Zenith ZG	844.1	947.6	804.5	865.4^{a}	1386.2	1273.6	1000.8	1220.2
Red River CG	666.3	676.2	608.8	650.5^{a,b}	1494.4	1383.1	1580.9	1486.1
Treatment Average	656.9	724.4	717.4		1174.8	1054.6	1061.3	
Cultivar	p = 0.0008, SE = 73.3				NS, SE = 216.8			
Treatment	NS, SE = 50.1				NS, SE = 104.7			
Cultivar*Treatment	NS, SE = 128.5				NS, SE = 267.2			

[1]Biomass represented as dry matter yield of desired species on a kg/ha basis within each treatment region of monoculture warm season grass plots. Values presented are LSMeans ± SE on a kg/ha basis.
[a,b,c]Means within a column with unlike superscripts differ ($P < 0.05$).
[2]Treatment regions within each plot: control (no treatment), low (1 pass of the simulator per week) and high (2 passes of the simulator per week).
[3]Species abbreviations: BG=bermudagrass, ZG=zoysiagrass, CG=crabgrass.

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