THE EFFECTS OF ROTATIONAL AND CONTINUOUS GRAZING ON HORSES,

PASTURE CONDITION, AND SOIL PROPERTIES

by

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ABSTRACT OF THE THESIS

The Effects of Rotational and Continuous Grazing on Horses, Pasture Condition, and Soil Properties

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Rotational grazing tends be recommended over continuous grazing for its potential improvements to forage quality, yield, and animal gain. However, work comparing these grazing systems using horses is sparse, and it is not appropriate to utilize findings from other livestock species due to differences in equine physiology and grazing behavior. The present study examined the effects of grazing system on horse condition, vegetation attributes, and soil properties for one year. The first objective was to evaluate four methods for estimating plant species composition. Each method agreed with each other method well enough to be used interchangeably. The second objective was to compare the effects of rotational and continuous grazing on horse and pasture condition. Horses were not affected by grazing system, but pasture condition was strongly affected with rotational pastures exhibiting higher production and ground cover than continuous pastures. The third objective was to evaluate the effects of rotational and continuous

grazing on soil chemical, physical, and hydraulic properties. It was found that grazing system had no effect on soil fertility, bulk density, or hydraulic conductivity. Overall, these findings support the recommendation of rotational grazing for improved pasture condition, but do not offer evidence of improved horse or soil condition over continuous grazing.

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INTRODUCTION

In my experience, horse owners often view pastures as a place for their horses to play instead of a source of nutrition. While there are significant horse behavioral and health benefits to being outside rather than in a stall, these horse owners miss out on a potential cost savings as high-quality pasture can be substituted for expensive purchased grain. In fact, high-quality pasture can meet the needs not only of the "pasture pet" horse at maintenance, but even pregnant or lactating horses. Unfortunately, pasture is not the answer for all horses, including "easy keepers" and "metabolically prone" horses which may suffer from obesity or laminitis if given access to free choice pasture.

Many horse owners also do not realize the environmental benefits of a productive pasture. High vegetative cover minimizes exposed bare ground and thus reduces erosion. Thick stands of forage plants can not only slow the flow of nutrient-laden runoff, the result of storm water flowing through manure, but can also improve infiltration and take up the excess nutrients. A well-managed pasture recycles nutrients and minimizes the risk of water pollution from contaminated runoff.

With 42,500 horses in New Jersey alone (as of 2007) and 3.6 million in the country (as of 2012), proper pasture management on horse farms could have a large economic and environmental impact (Rutgers Equine Science Center, 2007; USDA NASS, 2014). Recently in the Mid-Atlantic USA, there has been a push to understand horse owners' attitudes toward best management practices and to teach them how to be better environmental stewards. One such practice is called rotational grazing, which moves a group of horses through a series of pastures in such a way that each pasture is allowed several weeks to rest and regrow after a grazing bout. This alleviates grazing patterns seen in continuous grazing (when pastures are not allowed to rest), where horses overgraze some areas and ignore others, using them as defecation zones. Rotational grazing, and other variations of the practice, has been used in livestock for decades, but is not well understood or utilized by horse owners according to a number of surveys performed in Mid-Atlantic states (Singer et al., 2002; Swinker et al., 2011; Fiorellino et al., 2013).

Proponents of rotational grazing point to increased forage quality and yield, improved farm efficiency in terms of forage utilization and animal gains, and environmental benefits of the system. While many rangeland and pasture studies in livestock such as cattle and sheep have debated this, very few experiments have been performed using horses. Horses have different physiology and grazing habits than other livestock species, so it may not be appropriate to translate livestock research into recommendations for horse farmers. Therefore, additional research is necessary to explore the effects of rotational grazing for horses.

Chapter One: Literature Review

Pasturing is an extremely common way to provide horses with exercise, nutrition, and a host of other benefits (Bott et al., 2013). Horses evolved as grazing animals with a digestive system designed for continuous forage intake (Davidson and Harris, 2007). However, horse grazing has the potential to negatively affect the environment if managed incorrectly. Many horse owners, especially in New Jersey, do not own sufficient land to meet the needs of both the horse and the pasture, and so the environment suffers (Singer et al., 1999).

Nutrition and Health Aspects of Pasture

High-quality pasture has the potential to satisfy the nutritional needs of horses at maintenance (with the possible exception of sodium) and even horses with higher needs such as gestating and lactating mares (Gallagher and McMeniman, 1988; Singer et al., 1999; Hoskin and Gee, 2004). On a daily basis, horses require 1.67 to 3.0 Mcal/kg dry matter (DM) and 6.3 to 13.9 % crude protein (CP), depending on life stage and activity level (Bott et al., 2013; NRC, 2007). A 14 year average on grass forage samples submitted to Equi-Analytical Laboratories (2014) for testing shows digestible energy (DE) and CP averages of 2.27 Mcal/kg DM and 15.4%, respectively. Calcium and phosphorus requirements range from 0.2 to 0.8% and 0.14 to 0.45%, respectively (Bott et al., 2013; NRC, 2007), while pasture samples provide an average of 0.53% Ca and 0.30% P (Equi-Analytical Laboratories, 2014). In pastures low in protein, horses may selectively graze high-protein plants to increase their overall protein intake (McMeniman, 2000). Horses can consume between 1.5 and 5.2% of their body weight (BW) in DM on pasture (McMeniman, 2000). One experiment calculated that feeding horses pasture was approximately half as costly as feeding purchased hay and concentrates (McMeniman, 2000).

Average values do not accurately represent the feeding value of pasture over an entire season or even a single day. Younger plant tissue, especially of the leaves, contains the highest nutritive value due to the higher level of metabolic activity. As the plant matures, quality declines (Huston and Pinchak, 1991; Heady, 1961; Evans, 1995; Undersander et al., 2002). This can be due to a higher proportion of nutrients in undigestible forms such as lignin, or a higher proportion of senescent material remaining on the plant (Huston and Pinchak, 1991; Undersander et al., 2002). Kronfeld et al. (2006) found that starch content in a Virginia pasture increased from 4 to 8% between March and May, and the clover percentage increased over the same time period (clover is high in starch and preferred over grasses). McIntosh (2007) observed the highest nonstructural carbohydrate (NSC) levels in April tall fescue pastures in Virginia compared to May, August, October, and January. Additionally, diurnal variation was observed during the grazing season (April, May, and August) with NSC being lowest in the early morning and highest in the late afternoon. These variations had significant impact on the insulin and glucose levels of grazing horses. Factors which significantly influenced daily and seasonal variations included ambient temperature, solar radiation, and humidity (McIntosh, 2007).

Pasture grasses are an excellent source of water-soluble and fat-soluble vitamins (Hoskin and Gee, 2004). Most minerals are balanced for horse requirements with the possible exceptions of sodium, selenium, and copper in certain regions (Hoskin and Gee, 2004). Salt blocks are commonly provided for free-choice sodium intake (Evans, 1995). Forages are low in total fat but high in the omega-3 and omega-6 fatty acids alpha-linolenic acid and linoleic acid, which are essential nutrients not synthesized by horses (Warren, 2012).

Access to pasture has proven health benefits to horses including reduced incidences of stable vices such as wood chewing, weaving, pawing, and pacing (Houpt, 1981) and disease states such as colic (Hudson et al., 2001), gastric ulcers (Murray, 1994), and chronic obstructive pulmonary disease (Derksen et al., 1985). It also provides the opportunity for voluntary exercise; in the wild, horses have been observed traveling up to 80 km per day (Davidson and Harris, 2007).

There are some potential health risks associated with pasture access. A number of weeds commonly found in pastures contain toxins which can irritate or kill a horse (Pittman, 2009). Many tall fescue varieties contain fungal endophytes which increase plant competitiveness but cause reproductive problems in mares (Monroe et al., 1988). Recently, tall fescue varieties have become commercially available that are either completely free of endophytes or infected with a novel non-toxic endophyte which confers the same plant benefits without toxic effects on horses or other livestock (Parish et al., 2002). Other potential risks include sand colic, pasture-associated laminitis, and gastrointestinal parasites (Singer et al., 1999; Hoskin and Gee, 2004).

Grazing Behavior

Much research has been published on grazing systems and productivity for cattle and sheep (Holechek et al., 1999), but there are some fundamental differences between horses and ruminants that preclude the borrowing of management strategies. Physiologically, the horse has dexterous lips and upper and lower incisors capable of clipping forage closer to the ground (Matches, 1992; Singer et al., 1999) and non-cloven hooves which are often shod, causing greater damage to soil (McClaran and Cole, 1993). Horses are more selective grazers than cattle, preferring to consume grasses over forbs and shrubs (Archer, 1973a; Olson-Rutz et al., 1996). Additionally, objectives in raising cattle and horses on pasture are vastly different. While grazing goals for cattle include maximizing weight gain or milk yields using high-value feeds, horses are performance animals raised for athleticism and hardiness; maximizing growth causes obesity and developmental disease in young stock (Archer, 1973a; Hoskin and Gee, 2004; Davidson and Harris, 2007).

Horses are periodic grazers, consuming small meals throughout the day. Grazing activity has been observed for approximately 14 hours per day, with the longest feeding periods before dawn and after dusk (Mayes and Duncan, 1986; Fleurance et al., 2001; Edouard et al., 2009). Mayes and Duncan (1986) observed free-ranging horses grazing 63-75% during daytime hours and 49-55% at night, while the length of individual meals varied by season and time of day. Fleurance et al. (2001) observed the opposite ratio in confined horses grazing three quarters of nighttime hours and half of daytime hours. Horses may decrease grazing during the peak activity of flies, generally in the summer (Mayes and Duncan, 1986; Singer et al., 1999).

Horses are known to graze pastures unevenly in what has been called a "lawn and rough" pattern (Odberg and Francis-Smith, 1976; Archer, 1973b) where horses graze some areas and defecate in others. Eventually, the nutritive areas become overgrazed (lawns) and the eliminative areas grow tall and overly mature (roughs), as horses avoid grazing near feces. This is thought to be a mechanism for avoiding ingestion of parasite larvae, which are found within 1 m of feces in pastures (Fleurance et al., 2007). Odberg and Francis-Smith (1976) observed pastures divided into 48% lawns, 31% roughs, and 21% bare areas. This means that less than half of the pasture area is used for grazing. However, several management strategies have been shown to minimize this behavior, not necessarily to the advantage of the horse. Very high stocking rates can cause horses to graze in roughs as forage becomes limited (Medica et al., 1996). Mowing can prevent roughs from growing overly mature (Singer et al., 1999), and harrowing spreads out the manure deposited in roughs (Bott et al., 2013). This makes it difficult for horses to avoid defecation areas and increases risk of parasite infection, while also spreading the nutrients in manure evenly throughout the pasture.

Lawn and rough pattern in a pasture.

A number of studies have shown that horses graze with a preference for some grass species over others. Commonly seeded forage species such as timothy, tall fescue, orchardgrass, Kentucky bluegrass, meadow fescue, and perennial ryegrass have had varying degrees of preference reported (Bott et. al., 2013). Seemingly conflicting studies found Kentucky bluegrass, tall fescue, perennial ryegrass, timothy, and meadow fescue to be highly preferred; and tall fescue and orchardgrass to be less preferred (Hayes et al., 2009; Allen et al., 2013; Martinson et al., 2015). Species preference is a very complex process dependent on many factors, including those related to the animal (breed or species, senses, individual variation, past experiences, and physiological condition), the plant (species, variation within the species, chemical composition, morphology, maturity, availability, and effects of management), and the environment (plant diseases, soil fertility, presence of feces, supplemental feed, climate, and seasonal or diurnal variation) (Marten, 1978). However, it is generally accepted that horses prefer grasses over weeds and shrubs (Archer, 1973a); a study on picketed horses found that they consume grasses until they are limited and then resort to eating forbs (Olson-Rutz et al., 1996). Allen et al. (2013) found a positive correlation between preference and non-structural carbohydrate levels and a negative correlation between preference and fiber levels. Similarly, Hoskin and Gee (2004) noted that horses generally seek out young forage with high sugar content over more mature plants.

In addition to preferring certain species over others, horses appear to prefer grazing forage of varying heights. In trials offering horses varying sward heights, results were mixed. Edouard et al. (2009) found that, given an option of three sward heights of similar, good quality forage, horses selected the highest height (17cm). The taller sward also received higher bite mass, lower bite rates, and less chewing, resulting in significantly higher instantaneous intake rate. They hypothesize that horses select taller swards because they can be consumed faster to maximize grazing efficiency. Similarly, Naujeck et al. (2005) found that horses had significantly higher grazing times and number of bites on the tallest of 4 mown sward heights (15 cm, unmown). When the patches were allowed to regrow for 1 week, the effect was less pronounced. This study did not consider forage quality, and the result of the second grazing suggests that the availability of nutritionally superior leaves may have been a factor in patch selection. However, a study by Fleurance et al. (2010) observed the opposite effect of horses selecting intermediate heights (6 to 7 cm) in a heterogeneous sward height pasture ranging from 1 to 56 cm. This was hypothesized to be due to the higher nutrient quality of the short grasses compared to the taller grasses and agrees with the conclusions of Fleurance et al. (2007) that when presented with a rough and lawn environment, horses will avoid tall grasses to minimize parasite exposure and increase nutrient density of the meal.

Factors in Pasture Productivity

Vegetative cover describes the proportion of live vegetation in a pasture, while total cover describes the proportion of any material covering bare soil. It is commonly recommended that farm managers keep vegetative cover greater than 70% (Bott et al., 2013). At levels below 70%, damage to soil has been observed, including increased runoff and soil loss as raindrops dislodge exposed soil particles and water flow carries them away (Costin, 1980; Sanjari et al., 2009; McClaran and Cole, 1993). In addition, the presence of plant cover and residue slows the flow of water, enhances water infiltration rates into the soil, and reduces soil water evaporation (McClaran and Cole, 1993; Castellano and Valone, 2007; Teague et al., 2011). Vegetative cover can be further categorized into species composition, which describes the proportions of individual plant species within a pasture. Species composition may be altered due to grazing practices; it may decrease the competitiveness of certain preferred plants and show a shift toward greater proportions of less preferred plants (Briske, 1991; Weinhold et al., 2001).

In a productive pasture, a large proportion of the total cover should be forage plants. However, not all grass species are equally suited for horse grazing. In addition to being preferentially selected by horses, grasses have different persistence under grazing (Bott et al., 2013). Tall fescue, Kentucky bluegrass, and orchardgrass have been shown to be persistent under horse grazing (Hayes et al., 2009; Allen et al., 2012; Martinson et al., 2015). Physiological characteristics such as timing of stem elongation play a role in the persistence of a given grass specie (Undersander et al., 2002). See the section on Plant Physiological Response to Grazing (page 12) for a more detailed explanation. One mechanism for the high persistence of some tall fescue plants is a symbiotic relationship with an endophytic fungus which confers a competitive advantage to the plant, leading to eventual domination of mixed grass pastures (Arachevaleta, 1989; Singer et al., 1999). It has also been suggested that the competitiveness of tall fescue may be due to its relatively unpalatable nature compared to other grasses which may be offered (Hayes et al., 2009).

Differences in yield have also been reported amongst grass species. Some high-yielding species include orchardgrass, tall fescue, Kentucky bluegrass, and meadow fescue (Allen et al., 2012; Brink et al., 2010). However, other studies have reported no differences in yield for several pasture mixes under horse grazing (Martinson et al., 2015). This may be due to the variation in preference for the species included in the mix. These cool-season grasses produce significant herbage mass during the spring and fall, but generally exhibit slow growth rates in the late summer when temperatures rise in the Mid-Atlantic region (Singer et al., 1999).

Grazing intensity may be the single most important predictor of pasture nutritive potential (Bott et al., 2013; Singer et al., 2002). One indicator of grazing intensity is stocking rate (SR), or animals per unit area of land (alternately expressed as area per animal). Recommended SR for horses in temperate climates ranges from 0.4 to 0.8 ha per horse, depending on seasonal forage growth rates (Singer et al., 2002). In general, as SR increases, grazing selectivity decreases as animals must compete for limited forage (Heady, 1961; Matches, 1992). Singer et al. (2001) found that higher SR increased tall fescue density and decreased weed densities. The same study found significant effects of SR on soil fertility; phosphorus and potassium concentration, pH, and organic matter were all influenced by SR.

One negative consequence of high SR is animal trampling of vegetation. Damage to vegetative cover from horse treading is 6 to 8 times greater than from human treading (Cole and Spildie, 1998). According to Manning (1979), the effects of trampling on soil occur in seven stages: the removal of leaf litter and organic components from the soil surface, reduction of organic matter in the soil, soil compaction, reduced air and water permeability, decreased water infiltration, increased water runoff, and finally increased soil erosion which begins the cycle anew by preventing the accumulation of leaf litter. The author proposes a more complex relationship between steps in the soil cycle and various effects on vegetation, where reduced plant vigor and reduction of ground cover result in reduced plant regeneration, which affects and is affected by the processes occurring in the soil cycle (Manning, 1979). The effects of treading are dependent on plant species (persistence) and soil moisture. The effects of trampling are intensified under dry conditions; twice as much living or dead biomass was detached from plants under severe water stress (Warren et al., 1986; Abdel-Magid et al., 1987a). Plumb et al. (1984) found that horses can reduce total cover by 21 to 60% in the congregation area around a waterer. While trampling is an unavoidable consequence of horse grazing, its negative effects must be balanced with the gains associated with a more uniformly grazed pasture at a moderate SR.

Plant Physiological Response to Grazing

Briske (1991) provides an excellent overview of plant developmental morphology and resistance to defoliation. Grass plants are composed of multiple tillers, which consist of phytomers containing a blade, sheath, node, internode and axillary bud. The apical meristem, located at the base of the plant, forms a leaf primordium and axillary bud. As the leaf primordium grows, cell division becomes limited to intercalary meristems at the base of the blade, sheath, and internode. New tillers develop from the axillary buds of older tillers on the plant. They may grow within the leaf sheath, forming compact bunchgrasses or laterally through the leaf sheath, forming sodgrass with or without the use of rhizomes and stolons. This vegetative growth confers an advantage over other plants which must reproduce from seed using only reserves within the endosperm. Additionally, tillers stressed by defoliation may receive resources from nonstressed tillers on the same plant (Briske, 1991). As tillers become reproductive, new tiller growth stops and existing tillers die.

Grazing resistance is a plant's ability to endure grazing through avoidance and tolerance mechanisms (Briske, 1991). Avoidance describes the plant's ability to escape defoliation and includes mechanical mechanisms such as tissue accessibility (apical meristems located at base of plant and intercalary meristems located on stem), mechanical deterrents (spines, awns, etc.); and biochemical mechanisms wherein the plant produces secondary compounds (alkaloids, cyanogenic compounds, tannins, lignin, resins) to discourage grazing. However, these compounds can be costly to produce and may deem the plant less competitive under non-grazed conditions. Tolerance describes the plant's ability to regrow following defoliation and includes morphological and physiological mechanisms over varying time scales.

Recovery depends on a number of factors, including the genetic tolerance of the plant, the intensity of defoliation, and environmental conditions such as the presence of undefoliated tillers remaining and light or nutrient availability (Richards, 1993). Low-level, continuous defoliation requires a plant to alter its steady state nutrient allocation. Intense defoliation triggers a series of immediate and long-term effects to restore whole-plant carbon balance.

Immediate and transient effects can depend on the amount of light available and the age of remaining leaves and will take place less than 48 hours after defoliation (Richards, 1993). Roots are negatively affected via halting of root elongation, reduction in root respiration and absorption rates, and depletion of root carbohydrate pools. The decline in allocation from the shoots paired with continued utilization lowers the overall

NSC levels in roots. Whole-plant carbon allocation is altered as photosynthesis is reduced and carbon from photosynthetic tissue is allocated to growing regions, while undefoliated tillers may export carbon to attached defoliated tillers within 1 hour of damage. These 2 carbon allocation mechanisms are only useful when an adequate amount of meristematic tissue remains on defoliated plants. Nitrogen allocation is also affected, as plants mobilize nitrogen to growing leaves (Richards, 1993). Photosynthetic rates are reduced on both damaged and undamaged leaves for up to two days following defoliation.

The immediate shift in resource allocation following defoliation allows for the recovery process, which can take up to several weeks. According to Richards (1993), two mechanisms, refoliation and compensatory photosynthesis, are responsible for recovery rate. The key to rapid refoliation is the presence of intercalary meristematic tissue remaining on plants, which allows for leaf expansion rather than creating new leaves. In some cases, the rates of new leaf and tiller development can be higher in defoliated plants than undefoliated plants. Of course, these rates are dependent on environmental factors such as water and nutrient availability and temperature. Compensatory photosynthesis is the enhancement of photosynthetic capacity of existing and new leaves, with rates greater than non-defoliated plants. This phenomenon could be due to the rejuvenation of photosynthetic rates of mature leaves back to that of younger leaves and/or inhibition of the mechanisms which reduce photosynthetic capacity with age. The increased light to these leaves may play a role, as could endogenous signals. Molecular observations associated with compensatory photosynthesis in defoliated plants include increased nitrogen content of leaves which correlates to increased levels of RNA, proteins, and chlorophyll; increased RuBP carboxylase activity, amount, and capacity for regeneration; and increased rates of electron transport (Richards, 1993). Once these processes are underway, continued allocation of carbon and nitrogen to growth regions, both from plant reserves and new photosynthesis, is essential to full recovery and return to whole-plant carbon balance.

Matches (1992) establishes important concepts for grazing management based on plant physiology. Four essential practices include shoot apex movement (not removing shoot meristems during vegetative growth), carbohydrate storage (maintaining high reserves), amount of photosynthetic tissue (avoiding too much or too little), and the efficiency of photosynthesis (keeping leaf area index [LAI] below a level that maximizes net assimilation rate). Overall, Matches (1992) stresses the importance of managing grazing to optimal LAI for maximal plant growth.

Stocking rate has been shown to have an effect on plant response to grazing. Several studies looked at two years of grazing Caucasian bluestem at different SR (Christiansen and Svejcar, 1988; Svejcar and Christansen, 1987a,b). At the high SR, there were more tillers with lower tiller weight, lower root mass, shorter root length, and decreased LAI. One interesting finding was that the ratio of root surface to leaf surface increased with heavy grazing, which reduced water stress by decreasing transpiration and increasing stomatal conductance of leaves. Soil moisture was conserved as less was taken up by plants. However, other studies have found no differences or increases in root mass with grazed versus ungrazed treatments (Bartos and Sims, 1974; Smoliak et al., 1972). In addition, changes in sward morphology have been observed at light versus heavy grazing densities (Matches, 1992).

Grazing Effects on Soil

Soil is truly the basis for the pasture; it serves as the substrate, nutrient, and water source for plant growth in addition to hosting a vast ecosystem of life which helps plants thrive (Weinhold et al., 2001). However, the very act of pasturing large animals has unavoidable consequences on soil quality. Effects have been documented in soil fertility, compaction, and erosion.

Soil fertility in pastures is influenced by the recycling of nutrients via urine and feces. The "lawn and rough" pattern of horse elimination means that a majority of nutrients are deposited in small areas; Archer (1973b) found that potash (K_2O) was up to 379% higher in roughs from overgrazed pastures compared to lawns. Teague et al. (2001) found differences in soil organic carbon (SOC), cation exchange capacity (CEC), pH, magnesium, and sodium between different grazing systems. Airaksinen et al. (2007) observed higher soluble phosphorus levels in water runoff from an uncleaned paddock compared to water from field ditches. This is particularly troublesome because phosphorus in runoff is a major contributor to eutrophication in surface water (Hubbard et al., 2004). It readily binds to iron, aluminum, and calcium in soil, which renders it mobile in surface runoff (Hubbard et al., 2004). In addition, poor management knowledge drives many horse farm owners to apply phosphorus fertilizer annually, even when their fields are already above optimum levels (Singer et al., 2001). The Airaksinen study (2007) also found higher levels of nitrogen in uncleaned paddock runoff; nitrogen is another nutrient causing eutrophication (Hubbard et al., 2004).

Livestock treading reduces the amount of pore space between soil particles (soil compaction), which has a significant impact on water infiltration, runoff, and erosion

(McClaran and Cole, 1993; Undersander et al., 2002; Pietola et al., 2005; Castellano and Valone, 2007). McClaran and Cole (1993) describe a process by which trampling causes soil compaction, resulting in decreased water infiltration and thus greater surface runoff. Livestock shearing, scuffing, and skidding dislodges soil particles which are washed away with the increased runoff, resulting in erosion. Abdel-Magid et al. (1987a), Willatt and Pullar (1984), and Weinhold et al. (2001) observed greater bulk density (BD) and/or lower infiltration rates on soils with higher trampling intensity. Pietola et al. (2005) found that even low grazing intensity affected water infiltration, and that infiltration near a water source was only 20% that of an ungrazed area after one year of trampling. Clay soil showed an even greater effect of compaction with 10-15% infiltration rates compared to the ungrazed area. Bulk density and water infiltration were significantly different between rangeland grazed for over 100 years and exclosures established at different time points within those 100 years (Castellano and Valone, 2007). The smallest difference was observed between grazed land and the most recently established exclosure 14 years before the study began. The study also found that soil compaction, measured by bulk density, recovers faster than water infiltration on trampled soil. Warren et al. (1986) also observed some recovery of compaction measured by BD as a result of trampling and thus found no long-term compaction trends after multiple grazing bouts.

Soil moisture content also plays a role in the consequences of trampling by disturbing soil structure (Bott et al., 2013). Soil remolding under wet conditions causes deterioration of soil structure, and it is generally advised to remove livestock from pastures when soil is near plastic limit (Proffitt et al., 1995; Undersander et al., 2002). Pugging, a process by which livestock hooves penetrate a wet soil surface, is dependent on soil moisture and weakens the soil, causes surface roughness, and can reduce pasture yields (Nie et al., 2001). Proffitt et al. (1995) described the effects of repeated livestock trampling as “a self-perpetuating process” by which soil deformation contributes to lower infiltration rates, which then make soil more vulnerable to additional trampling damage by keeping it saturated more frequently. Warren et al. (1986) observed lower aggregate stability after trampling in wet soil and no changes to aggregate stability in dry soil, while BD increased by a greater degree in dry soil than wet soil. This was explained by the fact that soil pore spaces were filled with water rather than air, and water cannot be compacted. This finding was contradicted by Abdel-Magid et al. (1987a), who found no effect of soil moisture on BD and water infiltration. Overall, soils which have been degraded by trampling are more susceptible to erosion (Pietola et al., 2005).

The vast pore system within a well-structured soil allows for water infiltration, oxygen diffusion, root growth, and faunal mobility (McClaran and Cole, 1993; Proffitt et al., 1995). Macropores are critical for rapid water drainage through a soil profile, while micropores are more often storage areas for soil water (Thomas and Phillips, 1979). Willatt and Pullar (1984) found that trampling caused a reduction in large pore space, and Pietola et al. (2005) asserts that the lower infiltration rates at trampled sites are related to the decreased volume of macropores. Similarly, Proffitt et al. (1995) observed destroyed faunal macropores in heavily grazed pastures, corresponding to wetter topsoil after a rain event in these pastures compared to lightly grazed pastures. Compaction and reduction in macropore volume also impedes the movement of larger soil organisms such as mites, springtails, and earthworms and affects microbial biomass and carbon mineralization (Beylich et al., 2010).

Grazing Systems

Horse farm owners generally use either continuous or rotational grazing systems (Singer et al., 1999). Continuous grazing is common, where animals have unrestricted access to an entire grazing area for the entire grazing season (Heady, 1970). This type of grazing management encourages lawn and rough patterns as described previously because horses selectively graze sites they have already grazed. This results in underutilization of forage, with only 50 to 75% of available forage used (Henning et al., 2000; Singer et al., 2001). Singer et al. (2001) asserts that continuously grazed pastures must be seeded with persistent grass species which tolerate regular grazing to minimize forage loss.

Rotational grazing has been described since the late 1800s (Heady, 1961) and utilizes several smaller pastures, rotating groups of animals through the series of pastures in order to allow each pasture adequate time for recovery and regrowth from defoliation (Heady, 1970; Henning et al., 2000). Systems can be simple, with few paddocks, to quite intensive, using 30 or more paddocks (Undersander et al., 2002). This concentrates animals in smaller areas for short periods of time, forcing them to graze each paddock more uniformly (Matches, 1992). Reported benefits of rotational grazing include reduced costs of machinery and supplemental feed, improved pasture yields and quality, more stable pasture production throughout the grazing season, more uniform manure deposition and soil fertility, and environmental benefits (Henning et al., 2000; Undersander et al., 2002). Observational data from an equine rotational grazing site in Maryland showed increased horse body weight and body condition score, high vegetative cover and low weeds, and economic benefit as forage grown in excess of horses' requirements was harvested for hay (Burk et al., 2011).

Rotational Versus Continuous Grazing

A number of studies have compared the effects of rotational and continuous grazing on animal health, plant performance, and soil quality. Most work has been performed in cattle and other production livestock species, with relatively little work in horses. Holechek et al. (1999) performed a review of livestock grazing studies on rangeland and found inconsistent results between grazing systems. However, across all livestock studies reviewed, forage production was 7% higher using rotational grazing systems compared to continuous systems across rangelands in the U.S., but in humid regions the improvement was 20 to 30%. Overall, continuous grazing on rangeland yielded better animal performance and financial returns (Holechek et al., 1999). An earlier review by Heady (1961) reported little difference in livestock performance and vegetation between the continuous and "specialized" grazing systems on rangeland, and that SR and other management decisions are more important factors in animal and plant performance. The author makes a point that uniform utilization of pastures forces livestock to consume the lower quality forage they would normally avoid, thus lowering the plane of nutrition they receive. Teague et al. (2011) compared multi-paddock (rotational), light continuous, heavy continuous, and no grazing on Texas prairie ranches, and found less bare ground, higher aggregate stability, lower penetration resistance, and higher organic matter and cation exchange capacity in rotational systems compared to continuous grazing. They did not observe grazing systems effects on BD or water infiltration. Unfortunately, livestock type or class and actual stocking rates were not specified. Abdel-Magid et al. (1987b) also observed no differences in BD or infiltration rate between continuous and two methods of rotational grazing.

Rotational versus continuous grazing studies in horses have mostly focused on available forage and horse condition. Webb et al. (1989, 2009, 2011) have conducted several experiments examining these effects. In 1989, they measured forage-on-offer (FOO), forage quality, and average daily gain in yearling horses in continuous and rotational Bermuda grass pastures grazed at varying SR with no replication. The light-stocked continuous pasture (0.23 ha per animal unit [AU; 1 AU equals 454 kg of animal weight]) had the highest FOO, and all rotational SR had similar FOO, which prohibited rotational versus continuous system comparisons within SR. They observed a trend toward higher CP and in vitro dry matter digestibility as FOO increased. Yearlings were then realigned into groups based on FOO, and those in the low FOO group exhibited significantly lower average daily gains than the medium and high groups.

In 2009, Webb et al. compared horse condition and forage availability over 2 years between 1 continuously grazed pasture at an average of 0.50 ha per AU and 1 rotationally grazed pasture at 0.49 ha per AU. In 2007, there were no significant differences in body condition score (BCS) or rump fat thickness between systems, implying adequate forage was available for maintenance of all horses. However, available forage was significantly higher in rotational pastures at the beginning of each 7 day grazing period. Finally, in 2011, Webb et al. published two more years of data utilizing the same experimental setup as the previous study. Again, they found no significant differences in body weight (BW) and BCS between grazing systems. It was theorized that this could be due to variations in rainfall and available forage during some of the grazing periods and low animal numbers. The rotational system again produced more forage than the continuous system. This is particularly interesting because each of the Webb experiments adhered to a strict 7-d graze, 21-d rest schedule, which is not recommended because pasture production can slow in the summer months and need longer recovery times (Henning et al., 2000). Despite the sub-optimal management, the rotational system still outperformed the continuous system.

A study by Jordan et al. (1995) compared forage availability and quality between replicated rotational and continuous pastures over a two-year period. They reported horse condition benefits of rotational grazing numerically, but no statistical analysis was presented. Virostek et al. (2015) compared pasture condition between rotational and continuously grazed pastures over 2 years and observed no difference in biomass yield but a higher proportion of grasses and lower weeds in rotational. Daniel et al. (2015) evaluated forage nutrient composition on the same pastures and found significantly higher DE, water soluble carbohydrates (WSC), and sugar in rotational pastures due to the plants remaining in a vegetative state.

Use of Rotational Grazing and Pasture Best Management Practices (BMPs)

Despite the potential benefits of rotational grazing, it is not widely understood or practiced among horse farm owners in the Northeast as evidenced by a number of survey assessments. In Maryland, horse farm owners considered themselves to possess “very high” knowledge of stocking density and rotational grazing, yet less than a third of respondents reported always using rotational grazing and always resting paddocks long enough for regrowth (Fiorellino et al., 2013). Discrepancies like this encouraged the research team to perform a second study to validate the survey results. Fiorellino et al. (2014) visited 51 horse farms to visually assess BMP use in a number of areas. In terms of grazing practices, 21% of owners reported always using rotational grazing and 54% reported sometimes using it. The authors point out that the way survey questions are written can influence responses, as participants may misunderstand the definition of rotational grazing unless it is explicitly stated in the question. The observed BMPs associated with good grazing management include 92.2% of farms maintaining higher than 70% vegetative cover (average 90.5%), 63.5% having greater than 7.6 cm of grass (average 8.9 cm), 37.9% using a sacrifice lot, and 33.4% attempting to correct soil erosion (Fiorellino et al., 2014). Soil erosion was present in 81% of pastures. The high level of vegetative cover supports the self-reported rate of rotational grazing use, but the moderate sward height, low use of sacrifice lots, and high frequency of erosion shows that correct use of rotational grazing practices could benefit these farms.

Surveys in other states are entirely self-reported. In Pennsylvania, 65% of farm owners reported using a rotational grazing system, and 35% continuously graze (Swinker et al., 2011). While there was a high percentage of rotational grazing, only 24% reported allowing pasture to recover to the recommended grazing height and 45% sometimes rested pastures. This survey illustrates another example of discrepancy between use of rotational grazing and use of rotational grazing concepts. In addition, 93% of the respondents had pasture and nutrient management questions, showing a need for greater education initiatives. In New Jersey, 54% of managers reported practicing rotational grazing (Singer et al., 2002). This survey did not have follow-up questions about rotational grazing concepts. However, it did find that smaller farms with 0-5 horses were more likely to follow recommended stocking rates than larger farms with 11-20 horses. Overall, pasture BMPs are not completely or consistently implemented on horse farms, and farm owners have limited knowledge of pasture management concepts (Bott et al., 2013).

Summary

High-quality pasture has the potential to meet the nutritional needs of horses at maintenance and even those with higher nutritional demands such as exercise or pregnancy. There are proven health and behavioral benefits of pasture access; however, health risks exist as well. Most grazing research has been performed using cattle, but horses have different effects on pasture and different grazing objectives.

Several factors go into the productivity of a pasture, and some of them can be controlled by management practices. Grass species can vary in persistence to grazing and yield. Stocking rate is perhaps the most critical factor to pasture productivity and is associated with trampling damage to plants and soil. Plants use various avoidance and tolerance mechanisms to prevent defoliation and survive and recover from grazing. The practice of grazing livestock has unavoidable effects on soil quality, including soil fertility and physical properties.

Horse farms generally practice one of two grazing systems: continuous and rotational. Rotational grazing has been advocated with a number of production, environmental, and financial benefits. Rotational grazing is not widely used or well understood according to surveys in the Northeast. Several surveys have uncovered a discrepancy between self-reported use of rotational grazing and use of critical concepts in rotational grazing systems.

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Common Abbreviations

- AU = Animal Unit
- BCS = Body Condition Score
- BD = Bulk Density
- BMP = Best Management Practice
- BW = Body Weight
- CONT = Continuous
- CB = Creeping Bentgrass
- CEC = Cation Exchange Capacity
- CP = Crude Protein
- DM = Dry Matter
- EPED = Equine Pasture Evaluation Disc
- FOO = Forage-on-Offer
- GW = Grass Weed
- KB = Kentucky Bluegrass
- LAI = Leaf Area Index
- LPI = Line Point Intercept
- NSC = Nonstructural Carbohydrate
- O = Other
- OG = Orchardgrass
- Q = Quarter
- ROT = Rotational
- Res = Plant Residue
- SOC = Soil Organic Carbon
- StPt = Step Point
- SR = Stocking Rate
- TF = Tall Fescue
- W = Weed
- WSC = Water Soluble Carbohydrates

Research Objectives and Hypothesis

1. **Objective:** To compare mean species prevalence between methods, repeatability of methods, and agreement between methods; and select one to use for future experiments.

   Hypothesis: Line-point intercept, step point, and Equine Pasture Evaluation Disc methods will have different repeatability and the methods will not agree.

2. **Objective:** To compare effects of rotational and continuous grazing on horse health and pasture condition parameters as well as production costs.

   Hypothesis: ROT grazing systems will result in increased horse condition; improved pasture condition and quality; and reduced overall production costs.

3. **Objective:** To compare the effects of rotational and continuous grazing on soil properties.

   Hypothesis: Rotational grazing will result in lower bulk density and higher hydraulic conductivity, and optimal soil fertility.

Chapter Two: Comparing Four Techniques for Estimating Plant Species Composition in Horse Pastures

Abstract

The objective of this study was to select a method of estimating plant species composition in 2 cool-season horse pastures among 4 methods based on repeatability and agreement. The 4 methods included Equine Pasture Evaluation Disc (EPED), Line Point Intercept with 3 transects of 50 observations each (LPI 3-50), Line Point Intercept with 5 transects of 30 observations each (LPI 5-30), and Step Point (StPt). Each method has been evaluated previously, but not against the other three. In terms of estimating species prevalence, the methods did not differ in detecting creeping bentgrass (CB) or orchardgrass (OG), but there were differences for Kentucky bluegrass (KB), tall fescue (TF), and other (O) ($P < 0.05$). Repeatability plots showed a weak trend toward lower method repeatability as species prevalence increased, with EPED displaying the strongest trend and LPI 5-30 showing the lowest maximum standard deviation. Agreement, evaluated by overall and mean bias between species prevalence of pairs of methods, was high. Only 5 pairs of methods showed significant overall bias ($P < 0.05$), and 3 of them were between LPI 3-50 and EPED (for KB, TF, and O). Among the 5 significantly biased pairs, the mean bias was less than 8% for each, and the 95% confidence intervals indicate that the limits of agreement were all within 5% of the mean bias. For the purposes of this project, this agreement is adequate to use the methods interchangeably. Ease of use then became the deciding factor, with StPt selected as being easiest on the observer and least impacted by wind.

Introduction

Species composition is often measured in ecological monitoring studies, but it also has value in pasture research. It is useful for tracking shifts in desired forage species over time, giving useful data about pasture productivity and nutrition, and for analyzing vegetative cover to predict the risk of soil erosion (Burk and Taylor, 2010).

Many different methods for estimating plant species composition have been used in research with varying time and expense requirements (Herrick et al., 2009a,b). They measure either points, transects, or plots both visually or using pins or lasers (Booth et al., 2006). Most research comparing ecological monitoring methods has been conducted in rangeland environments, which differ quite a bit from improved pasture environments. Rangeland generally consists of native vegetation in a dry environment and is minimally managed, while pasture land utilizes introduced forage species and agronomic inputs to produce a dense crop (Sanderson et al., 2009). The density of plants needing to be analyzed in improved pastures precludes the use of some methods altogether, such as the line-intercept method, which measures the width of a given plant along a line (Herrick et al., 2009; Caratti, 2006). The USDA NRCS Pasture Condition Scoring System recommends visual estimation of 10 indicators, including proportion of desirable plants, plant cover, plant diversity, and proportion of legumes to track changes and make management decisions (Sanderson et al., 2009). However, visual estimates have shown to be less precise than and less similar to point-based estimates, with highly precise methods being more repeatable (Godinez-Alvarez et al., 2009).

A commonly used method is the Line Point Intercept (LPI), which is a variant of the point-intercept method and identifies plants at predetermined points along a transect by dropping a long, narrow pin into the canopy (the pin must be taller than the plant height) (Caratti, 2006). The number of transects used can affect the power to detect changes in plant cover (Brady et al., 1995). This method has been called the "pasture research standard" (Foulk et al., 2011) and a highly objective sampling method for cover estimates (Caratti, 2006). It has been used as a standard to analyze new remote sensing techniques (Duniway et al., 2012; Booth et al., 2006). However, it may have limitations in temperate pasture research. Its usefulness in rangeland monitoring comes from the ability to maintain a permanent transect.

A second method, described by Evans and Love (1956) as the Step Point method and later by Herrick et al. (2009a), identifies plants by a pin guided into the canopy by a notch on the sampler's boot at a 30 to 45 degree angle to the ground. This method has been used to document shifts in botanical composition in grazed ranges (Evans and Love, 1956) and can be used as an alternative to LPI as long as a pin is used rather than the toe only (Herrick et al., 2009b). Accuracy has been rated as moderate to low compared with high accuracy of LPI (Herrick et al., 2009b). It has also been recommended to farm owners as a simple and practical method to evaluate their own pastures (Burk and Taylor, 2010).

Pin-based measurements such as LPI and Step Point can be influenced by pin diameter and angle of insertion into the canopy. A narrow pin is ideal, as it is less likely to push foliage out of the way when being inserted into the canopy and less likely to overestimate cover (Goodall, 1952). Tinney et al. (1937) observed that vertically inserted pins are more likely to contact tall plants than low prostrate ones, but inserting the pin at an angle allows it to contact a greater number of the shorter plants. Warren Wilson

(1960) illustrated that a pin inserted at an angle other than 90 degrees has lower variation in relative frequency than one inserted vertically. While these studies record all hits on the pin, Evans and Love (1956) report that composition data using initial hits only does not vary widely from data using all hits for more abundant species.

The Equine Pasture Evaluation Disc (EPED) method was recently developed at the Pennsylvania State University and involves tossing a disc in a "W" pattern through a pasture and recording plants touching an arrow on the side of the disc (Foulk et al., 2011). This method was developed in response to the LPI's inability to represent the entire pasture. Horses graze in distinct patterns with "lawns" composed of short forage where they graze and "roughs" composed of tall, mature forage where they defecate. The species composition in these two areas can be vastly different based on the plants' persistence under grazing (Odberg and Francis-Smith, 1976). A low number of transects will provide data on a limited area, and measuring many transects to achieve representative data would be time-prohibitive. The EPED was designed to collect data representative of the entire pasture in a manner that farm managers can easily practice (Foulk et al., 2011).

Research Objective and Hypothesis

Objective: To compare mean species prevalence between methods, repeatability of methods, and agreement between methods; and select one to use for future experiments.

Hypothesis: Line-point intercept, step point, and Equine Pasture Evaluation Disc methods will have different repeatability and the methods will not agree.

Materials and Methods

Research was conducted on Rutgers University's Best Management Practice Demonstration Horse Farm, Cook Campus in New Brunswick, New Jersey over a 4-week period from August to September 2014. Two 1.6 ha pastures were used and referred to as 3C and 2C. The pastures were plowed and reestablished by planting with orchardgrass (*Dactylis glomerata)*, tall fescue (*Festuca arundinacea*), and Kentucky bluegrass (*Poa pratensis*) in 2012 and not grazed by horses until August 2014. At the beginning of measurement, fields 2C and 3C had sward heights of 24.5 ± 5.0 and 21.0 ± 4.7 cm, respectively. Each of the 4 techniques was performed on each of the 2 pastures on 3 separate dates.

Three methods for determining species composition were compared; 2 variants of the LPI method were performed. Using the LPI method (Herrick et al, 2009a), a 30.5 m tape was laid across the pasture and lifted so a pin could be dropped into the canopy at regular intervals. The first living plant to touch the pin was recorded. Two variants of this method were used; 1) 3 transects per pasture with 50 observations each at 0.6 m intervals (LPI 3-50), and 2) 5 transects per pasture with 30 observations each at 0.9 m intervals (LPI 5-30), each giving a total of 150 observations per field. The transects were placed by visually dividing the pasture into 3 or 5 sections.

Performing the Line Point Intercept method.

A modified Step-Point (StPt) method (Evans and Love, 1956) was used, in which the observer traversed the pasture in approximate transects (1 pass of the field, 5 steps down the fence line, and another pass parallel to the first) and stopped every 30 steps to lower a pin down a notch on the toe of the boot. The pin entered the canopy at a 30 to 45 degree angle to the ground and the observer identified the first living plant to touch the pin. This was repeated for a total of 100 observations, resulting in approximately 25 passes of the field.

Performing the Step Point method.

An EPED (Foulk et al., 2011) was used in a similar manner, being tossed a total of 100 times in a zig-zag pattern across the field, starting at one end and ending at the other. The disc has an arrow on the edge, and the living plant directly under the arrow is identified. All estimates were taken by the same observer.

An Equine Pasture Evaluation Disc.

Desired grass species orchardgrass (OG), tall fescue (TF), and Kentucky bluegrass (KB) were recorded separately. A fourth grass, creeping bentgrass (CB; *Agrostis stolonifera*), became established in large proportions in pasture 3C and was also recorded separately. All weeds, plant residue, and bare ground were recorded as "Other" (O).

All data were analyzed using the SAS System (SAS Institute, Cary, NC). Methods are often compared using correlation coefficients. Bland and Altman (1986) argue that this comparison does not satisfactorily measure agreement since it should be expected that measurements of the same variable would correlate. Instead, we adapted the methods recommended by Bland and Altman. The proportion of each species was plotted against its standard deviation to create a repeatability graph. Low standard deviations indicate high repeatability. Agreement between pairs of methods then was determined by first calculating the overall bias between each pair of methods for each species (averaged across three repetitions and two fields). The null hypothesis was that bias (proportion of species observed with one method minus proportion of species observed with a different method) would be zero. The GLIMMIX procedure of SAS was used to fit a generalized mixed effects model with a logit link to test for differences among each species separately. The model accommodated separate variances for each method and was also used to calculate confidence intervals for estimated prevalence for each method, indicating limits of agreement. When methods were significantly different (α = 0.05), pairwise comparisons were performed using a paired t-test.

Results

Prevalence. The mean prevalence of each individual plant species is shown in Fig. 1A-E. The prevalence of detecting CB and OG was not significantly different among methods (Fig. 1A and 1B, respectively). Both LPI methods detected KB more frequently than EPED, and LPI 3-50 also detected KB more frequently than the StPt method ($P < 0.05$; Fig. 1C). The EPED method detected TF more frequently than both LPI methods ($P < 0.05$; Fig. 1D). The LPI 3-50 method detected O less often EPED and StPt ($P < 0.05$; Fig. 1E).

Repeatability. Repeatability plots (Fig. 2A-D) showed a weak trend toward lower method repeatability as species prevalence increased, with EPED (Fig. 2A) displaying the strongest trend. Standard deviation was below 6% for all species within LPI 5-30 (Fig. 2B).

Agreement. Five of the pairs exhibited significant overall bias ($P < 0.05$), and 3 of them were between LPI 3-50 and EPED. The LPI 3-50 method detected KB significantly more often than EPED ($P = 0.011$) and TF and O significantly less often than EPED ($P = 0.017$ and 0.005, respectively). The other two biased pairs consisted of EPED detecting TF significantly more often than LPI 5-30 ($P = 0.033$) and LPI 5-30 detecting TF significantly less often than StPt ($P = 0.040$) (Table 1).

For all 5 significantly biased pairs, the difference between estimated proportions was less than 8%. The 95% confidence interval around the mean bias indicate the limits of agreement were all within 5% (calculated as half the range of values between upper and lower limit) (Table 1).

Discussion

Prevalence. It is possible that both of the LPI methods detected KB more frequently than EPED because KB is a fine, short grass which tends to be covered by the tall, broad grasses that bend under the weight of the disc. This presents a problematic bias toward taller grasses in the top layer of the canopy when using the EPED. This method may be better suited to shorter pastures, although a similar bias could underestimate bare ground if leaf blades are bent by the disc. However, Foulk et al. (2011) found 100 tosses of the EPED to be statistically similar to 1 LPI transect in Mid-Atlantic horse pastures.

The bias toward more frequent estimation of KB by LPI 3-50 than StPt may be due to the angle of pin insertion into the canopy. However, Tinney et al. (1937) asserts that a vertical angle (used in LPI) will overestimate tall grasses compared to shorter ones. This contradictory data could be due to the fact that these measurements were taken while pastures were tall, and KB did grow to a considerable height in patches. Additionally, Evans and Love (1956) mention that Step Point is more difficult to use in tall, heavy vegetation. However, aside from KB this method was similar in detecting species prevalence to all other methods.

Repeatability. All repeatability graphs showed a trend toward greater variation in prevalence as the species prevalence increased. This is particularly true of CB, which was highly prevalent in field 3C but not 2C and creates 2 easily discernable points on the graph for each field. The field with lower prevalence also had much lower standard deviation, regardless of method. Duniway et al. (2012) observed a similar pattern of increased standard deviation with increased species prevalence when comparing among-observer variability in classifying plants on images. While our prevalence axis ends at 50%, that of Duniway et al. (2012) continues to 100% and they see a decrease in standard deviation as species prevalence increases past 50%. None of the species in our pastures were present at more than 50% prevalence.

Based on trends in the repeatability graphs, LPI 5-30 appeared to be the most repeatable method with lowest overall variation between repetitions (represented on the graph by lower overall standard deviation). This is likely due to the higher number of transects representing a greater area of the pasture than LPI 3-50 and the reported repeatable nature of the LPI method (Herrick, 2009b). However, this data is only being compared visually, so the variation in standard deviation between methods may not represent a significant difference. Evans and Love (1956) reported that the StPt method had little variability due to different operators, with standard deviations in each botanical category of about 5%, which did not change the relative proportions of each category. This indicates that the method was repeatable.

Agreement. Of the 30 pairwise method comparisons by species, only 5 had significant overall bias, meaning that the difference in detecting prevalence between the 2 methods was significantly different from 0. This indicates high agreement between all methods. The pairwise differences mirror the findings of the mean prevalence data for each species. The mean bias data illustrates a difference of less than 8% between proportions of the 5 significantly biased pairs. This, combined with the narrow limits of agreement, gives a statistical argument that all four methods agree well enough to be used interchangeably.

Ease of use. In 1.6 ha pastures with high plant density and height, the StPt and LPI 5-30 methods took approximately 1 h each. The EPED and LPI 3-50 methods took about 45 min. The EPED method was found to be inconvenient because windy days hampered the observer's ability to toss the disc consistently; even a small amount of wind affected the toss direction and length. The LPI methods were tedious and physically demanding due to repeated squatting and kneeling for 45 min to 1 h at a time. Wind also affected the observer's ability to drop the pin vertically into the canopy using the LPI methods. The StPt method was the most user-friendly in terms of ease and physical demand.

Conclusion

There are a number of statistical methods available to compare data gathered using different methods. Without harvesting and sorting samples, there was no way to analyze accuracy of the methods. While Line Point Intercept is commonly accepted as a pasture standard, it may not represent the entire field, especially when a low number of transects are used. Some significant differences were found in prevalence of species by method, and each method appeared to decrease in repeatability as species prevalence increased. However, overall agreement was good enough that for the purposes of this study, all four methods could be used interchangeably. This allows for selection of a method for estimating species composition by ease of use, and the Step Point method was chosen because it was less physically demanding than LPI and less affected by wind than EPED.

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Tables

Table 1. Test of overall bias (*P*-value), mean bias, and 95% limits of agreement between pairs of estimation methods by species, collected in two horse pastures in New Brunswick, New Jersey in August and September 2014. Asterisks indicate pairs of methods with significant overall bias ($P < 0.05$).

Species[1]	Pair of Methods[2]	*P*-value	Mean bias	Lower limit of agreement	Upper limit of agreement
CB	EPED - LPI350	0.4187	-1.1667	-4.5708	2.2375
CB	EPED - LPI530	0.3448	-1.9444	-6.7378	2.8490
CB	EPED - StPt	0.1203	2.8333	-1.0604	6.7271
CB	LPI350 - StPt	0.2135	4.0000	-3.2166	11.2166
CB	LPI530 - StPt	0.1831	4.7778	-3.1736	12.7291
CB	LPI350 - LPI530	0.6598	-0.7778	-5.0545	3.4989
KB	EPED - LPI350 *	0.0114	-7.1667	-11.8846	-2.4487
KB	EPED - LPI530	0.1234	-5.8333	-13.9343	2.2677
KB	EPED - StPt	0.2014	-3.6546	-10.0431	2.7338
KB	LPI350 - StPt	0.0736	3.5120	-0.4871	7.5112
KB	LPI530 - StPt	0.2870	2.1787	-2.5229	6.8803
KB	LPI350 - LPI530	0.4757	1.3333	-3.1135	5.7802
O	EPED - LPI350 *	0.0045	6.2222	2.9581	9.4863
O	EPED - LPI530	0.2168	3.8889	-3.1862	10.9640
O	EPED - StPt	0.5856	1.6271	-5.5547	8.8090
O	LPI350 - StPt	0.0636	-4.5951	-9.5686	0.3785
O	LPI530 - StPt	0.2078	-2.2617	-6.2822	1.7587
O	LPI350 - LPI530	0.2446	-2.3333	-6.8836	2.2169
OG	EPED - LPI350	0.3157	-1.2778	-4.2247	1.6691
OG	EPED - LPI530	0.3814	-1.2778	-4.7011	2.1455
OG	EPED - StPt	0.2918	-2.7182	-8.6503	3.2139
OG	LPI350 - StPt	0.5992	-1.4404	-8.0441	5.1632
OG	LPI530 - StPt	0.4590	-1.4404	-6.0581	3.1772
OG	LPI350 - LPI530	1.0000	0	-3.5398	3.5398
TF	EPED - LPI350 *	0.0170	3.3889	0.9112	5.8666
TF	EPED - LPI530 *	0.0328	5.1667	0.6285	9.7048

Species[1]	Pair of Methods[2]	*P*-value	Mean bias	Lower limit of agreement	Upper limit of agreement
TF	EPED - StPt	0.1239	1.9124	-0.7478	4.5725
TF	LPI350 - StPt	0.2447	-1.4765	-4.3565	1.4035
TF	LPI530 – StPt *	0.0404	-3.2543	-6.2977	-0.2109
TF	LPI350 - LPI530	0.2585	1.7778	-1.8079	5.3634

[1] CB = creeping bentgrass; KB = Kentucky bluegrass; OG = orchardgrass; TF = tall fescue; O = other

[2] EPED = Equine Pasture Evaluation Disc; LPI 3-50 = Line Point Intercept 3-50; LPI 5-30 = Line Point Intercept 5-30; and StPt = Step Point

Figure Captions

Figure 1A-E. Prevalence of detecting creeping bentgrass (A), orchardgrass (B), Kentucky bluegrass (C), tall fescue (D), and other (E) by each method collected in two horse pastures in New Brunswick, New Jersey in August and September 2014. EPED = Equine Pasture Evaluation Disc; LPI 3-50 = Line Point Intercept 3-50; LPI 5-30 = Line Point Intercept 5-30; and StPt = Step Point. Lines indicate standard deviation. Bars with no letters in common differ at $\alpha < 0.05$.

Figure 2A-E. Repeatability graphs (standard deviations vs. the mean prevalences) of forage species (CB = creeping bentgrass, KB = Kentucky bluegrass, OG = orchardgrass, TF = tall fescue, and O = other) collected by the Equine Pasture Evaluation Disc (A; EPED), Line Point Intercept with 5 transects of 30 observations each (B; LPI 5-30), Line Point Intercept with 3 transects of 50 observations each (C; LPI 3-50), and Step Point (D; StPt) methods in two horse pastures in New Brunswick, New Jersey in August and September 2014. Each point represents 3 repetitions of the method. Each symbol represents a different forage species.

Figure 1A.

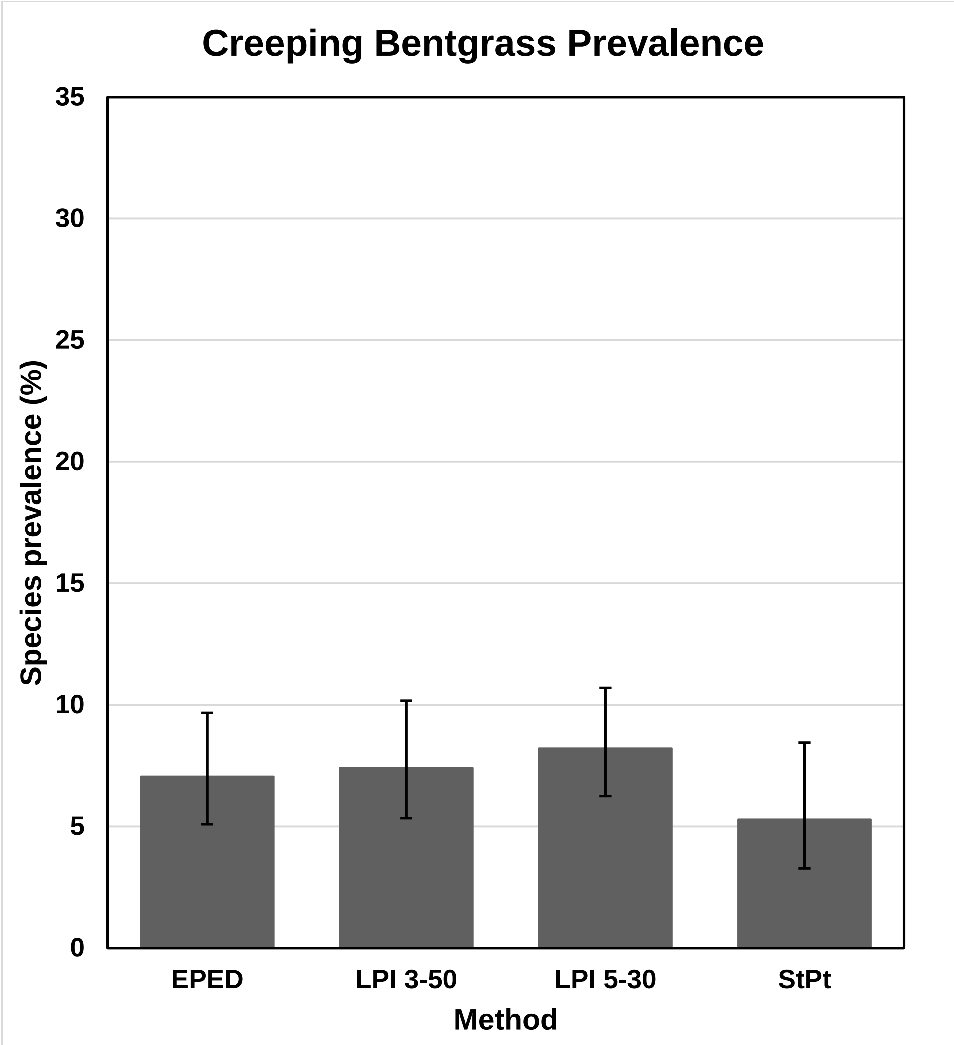

Creeping Bentgrass Prevalence
35
30
25
20
15
10
5
0
Species prevalence (%)
EPED
LPI 3-50
LPI 5-30
StPt
Method

Figure 1B.

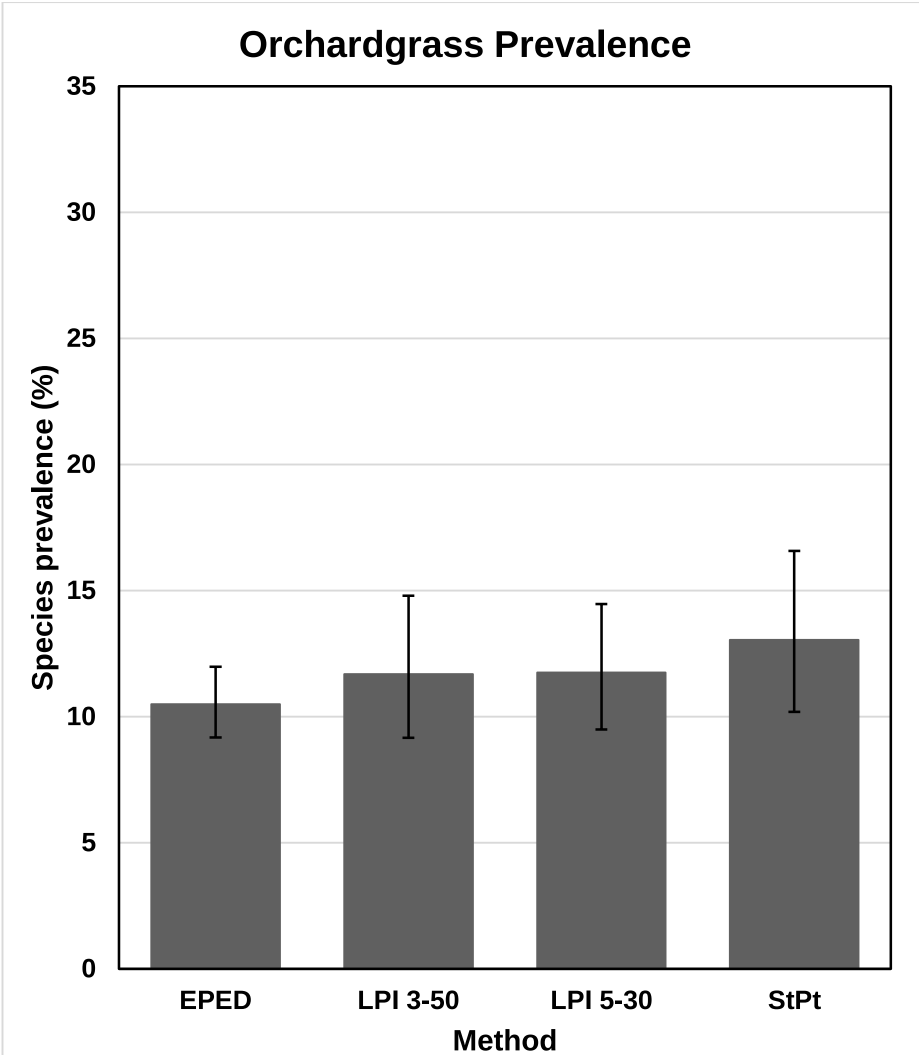

Orchardgrass Prevalence
Species prevalence (%)
35
30
25
20
15
10
5
0
EPED
LPI 3-50
LPI 5-30
StPt
Method

Figure 1C.

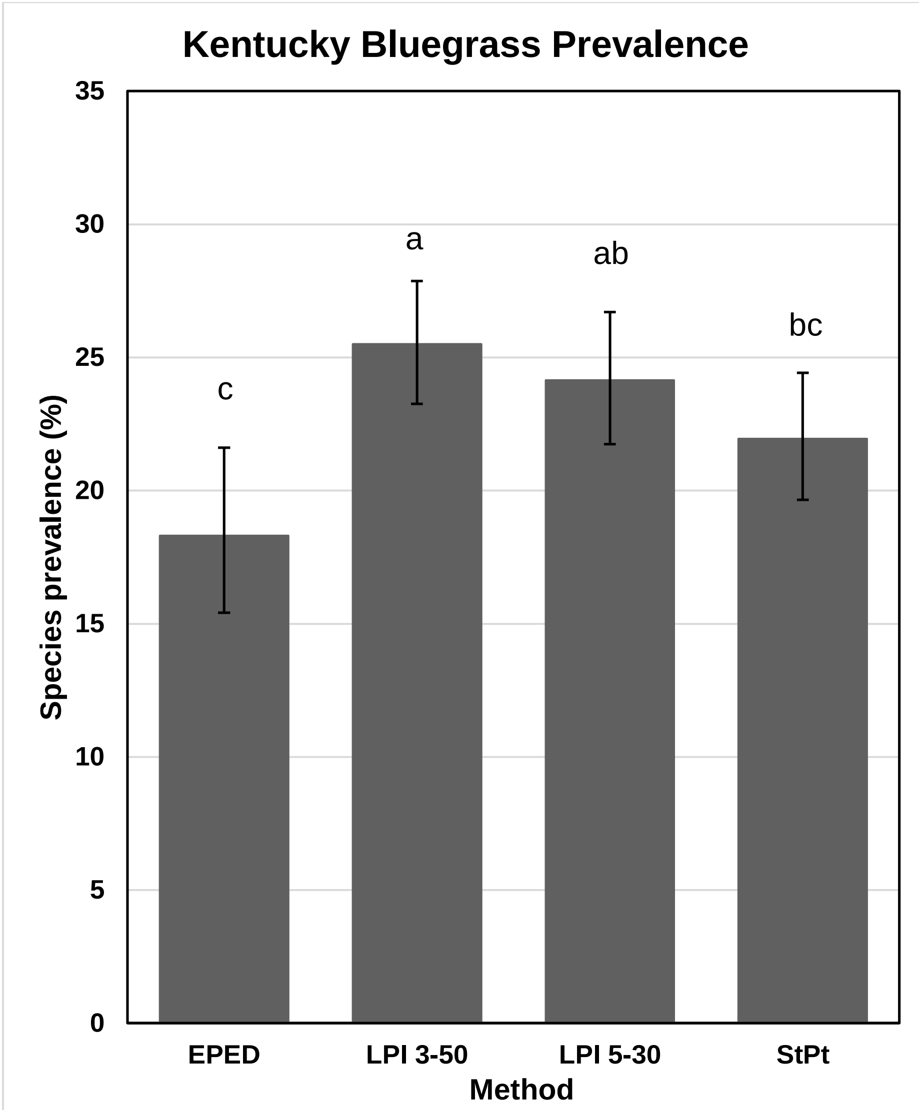

Kentucky Bluegrass Prevalence
Species prevalence (%)
35
30
25
20
15
10
5
0
c
a
ab
bc
EPED
LPI 3-50
LPI 5-30
StPt
Method

Figure 1D.

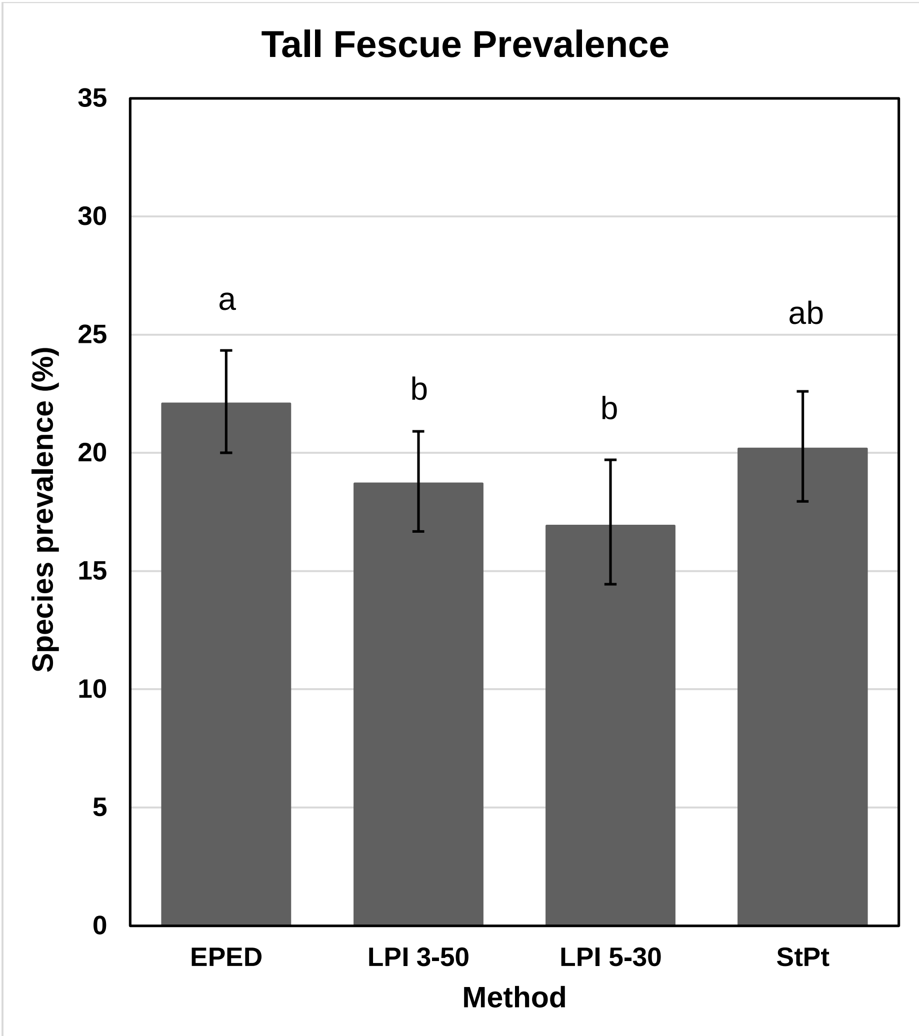

Tall Fescue Prevalence
Species prevalence (%)
35
30
25
20
15
10
5
0
a
b
b
ab
EPED
LPI 3-50
LPI 5-30
StPt
Method

Figure 1E.

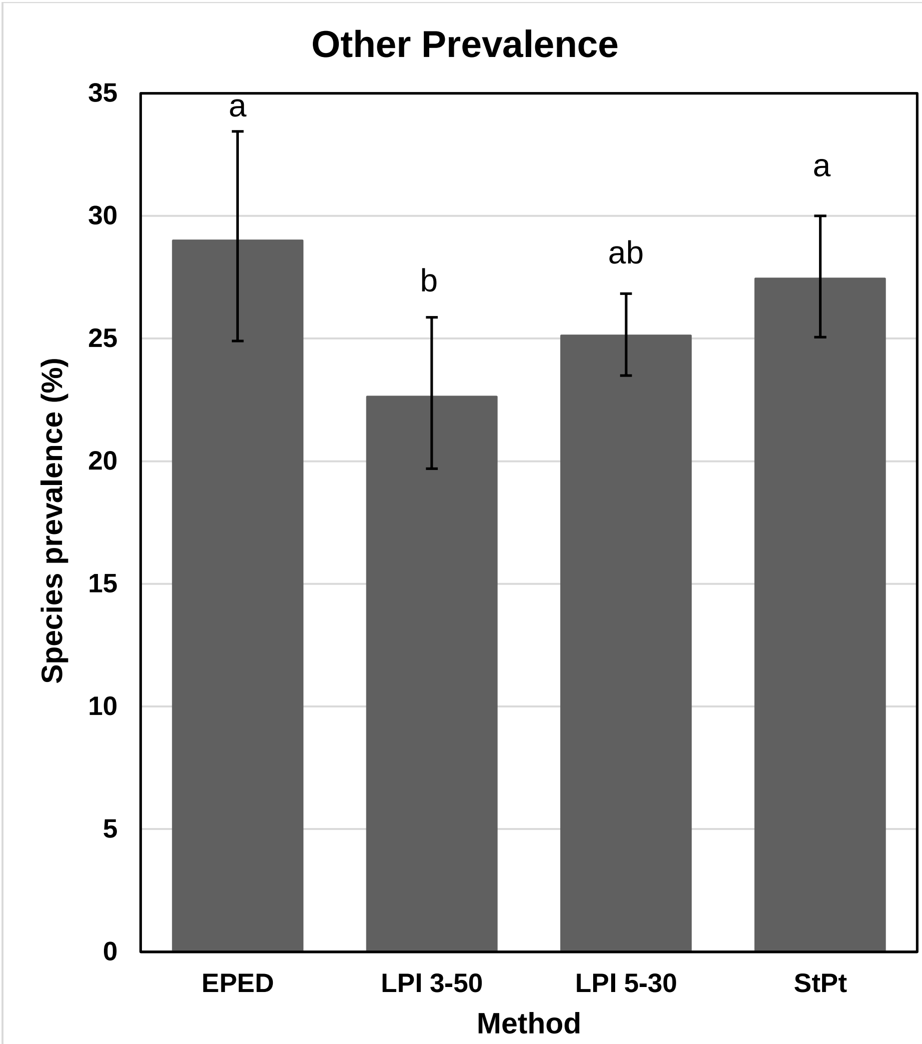

Other Prevalence
Species prevalence (%)
35
30
25
20
15
10
5
0
a
b
ab
a
EPED
LPI 3-50
LPI 5-30
StPt
Method

Figure 2A.

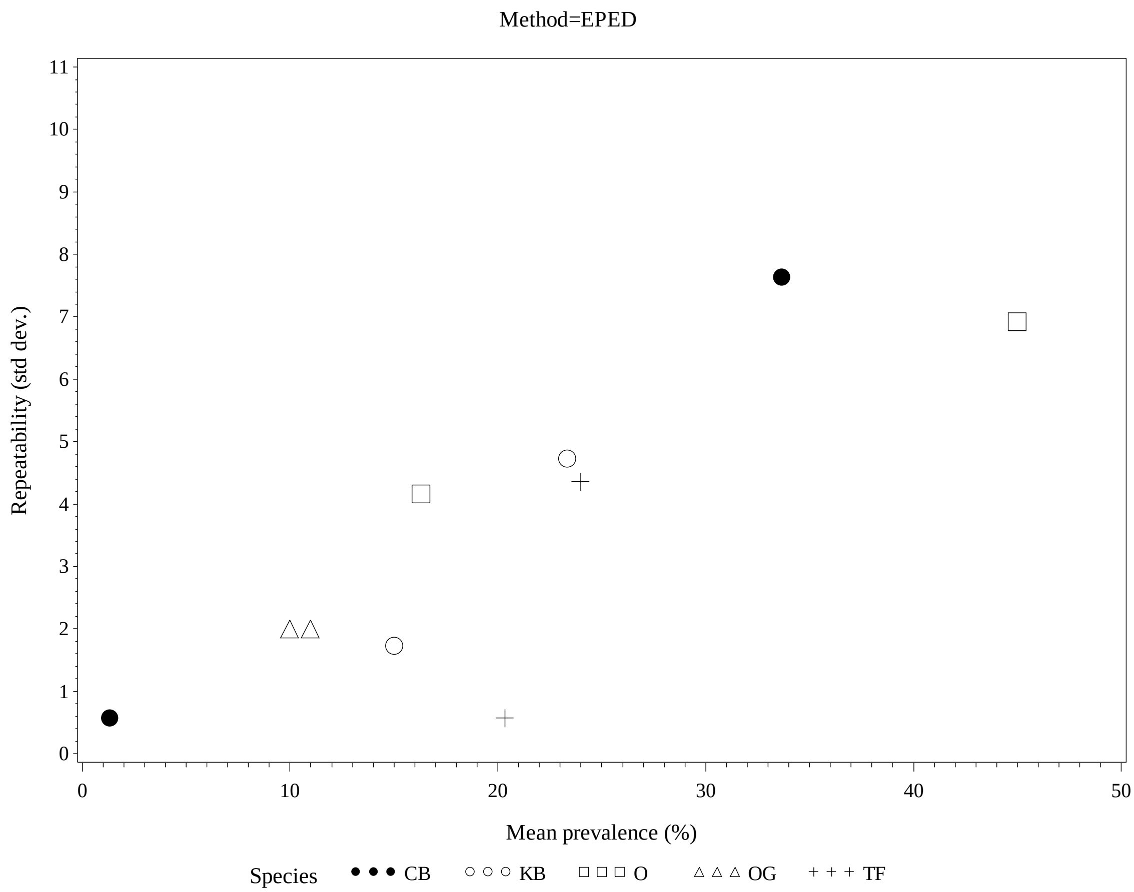

Method=EPED
Repeatability (std dev.)
0
1
2
3
4
5
6
7
8
9
10
11
0
10
20
30
40
50
Mean prevalence (%)
Species
CB
KB
O
OG
TF

Figure 2B.

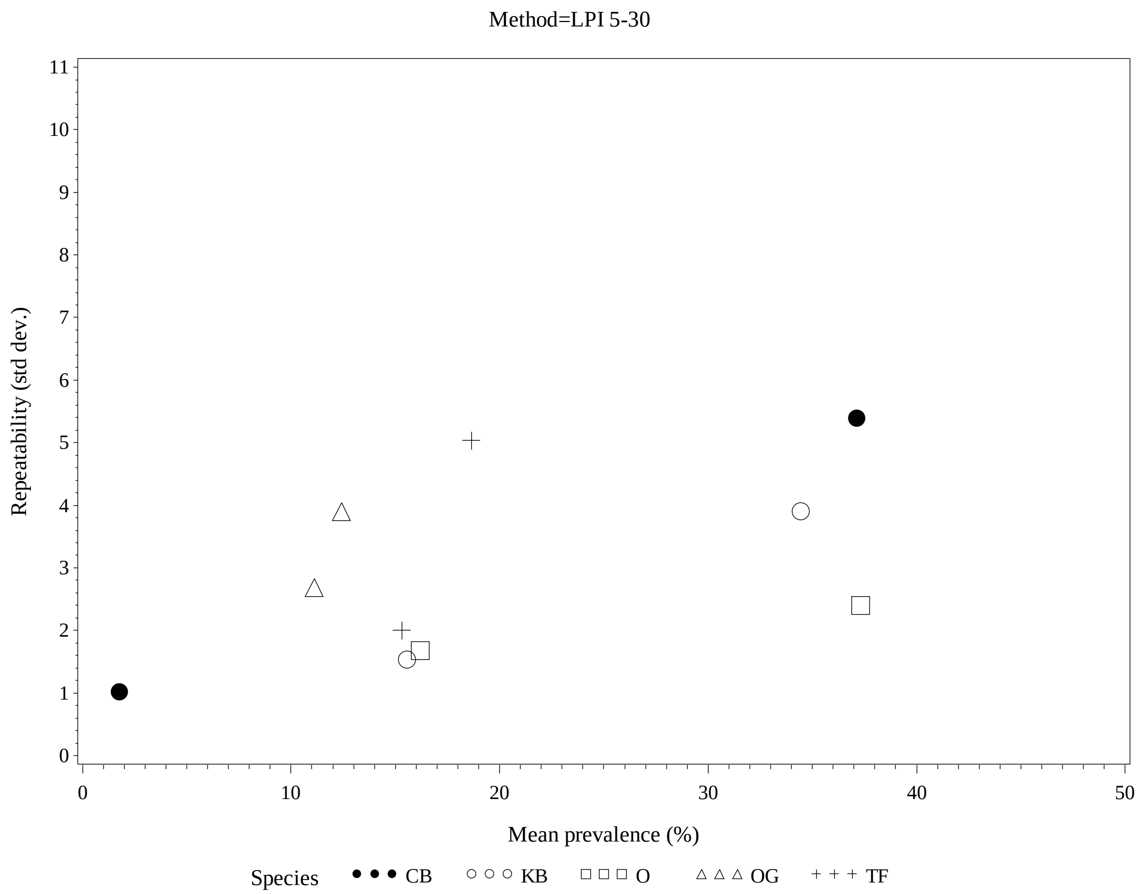

Method=LPI 5-30
Repeatability (std dev.)
0
1
2
3
4
5
6
7
8
9
10
11
0
10
20
30
40
50
Mean prevalence (%)
Species
CB
KB
O
OG
TF

Figure 2C.

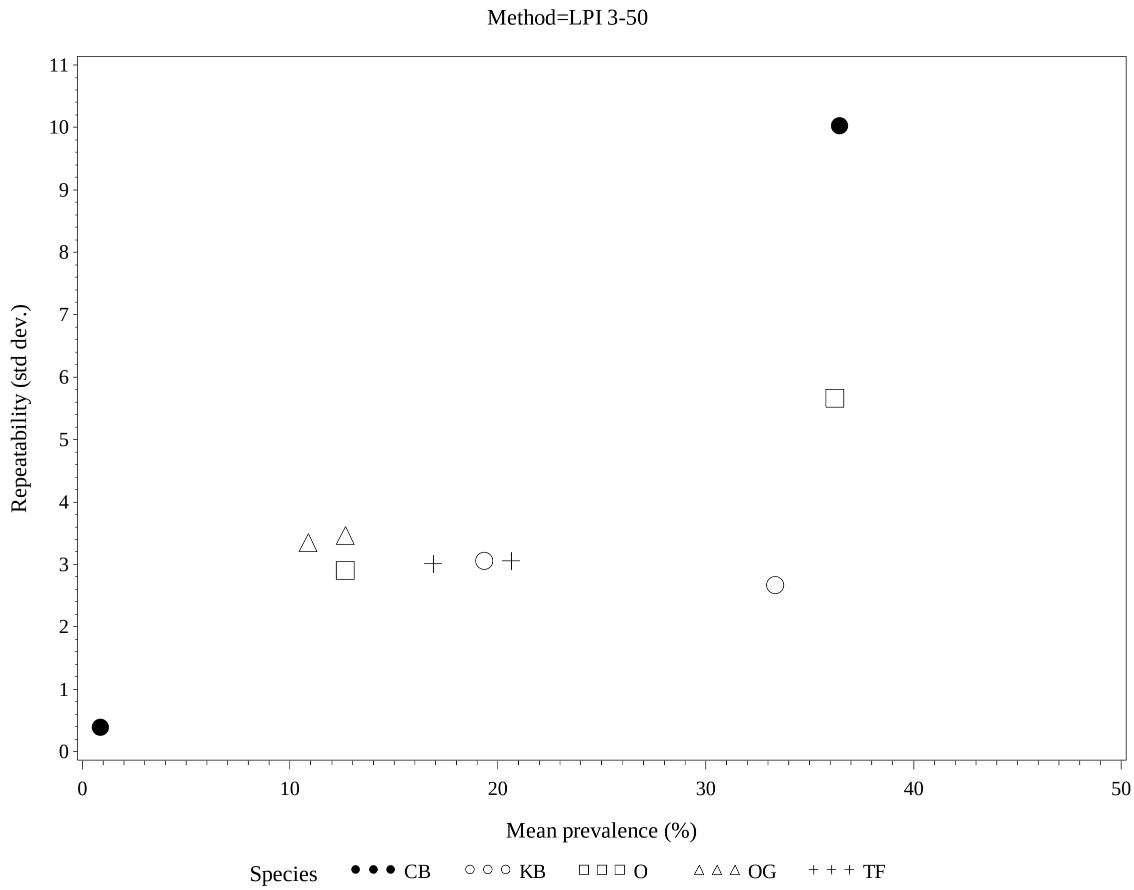
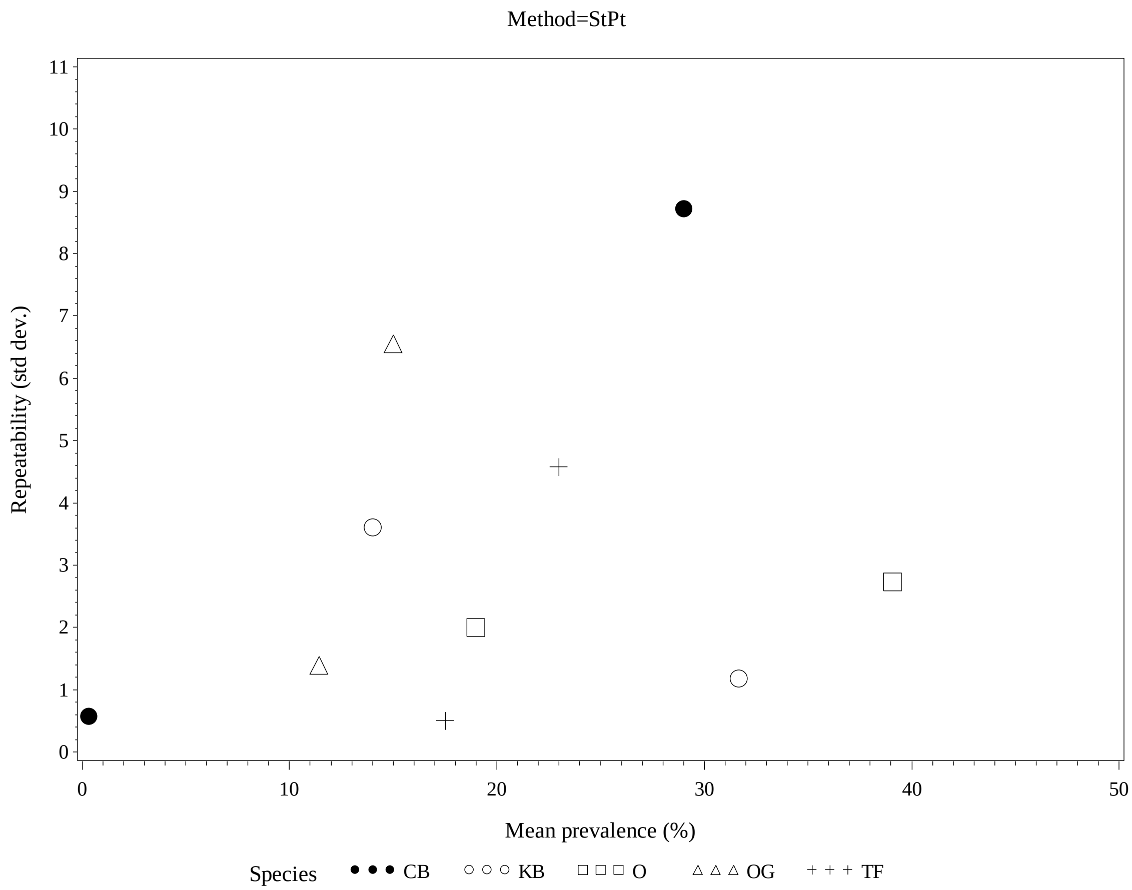

Method=LPI 3-50
Repeatability (std dev.)
0
1
2
3
4
5
6
7
8
9
10
11
0
10
20
30
40
50
Mean prevalence (%)
Species
CB
KB
O
OG
TF

Figure 2D.


Method=StPt
Repeatability (std dev.)
0
1
2
3
4
5
6
7
8
9
10
11
Mean prevalence (%)
0
10
20
30
40
50
Species
CB
KB
O
OG
TF

Chapter Three: Effects of Rotational and Continuous Grazing on Horses and Pasture Condition

Abstract

The objective of this study was to determine whether rotational grazing has horse, pasture, or cost benefits over continuous grazing. The study established two replicates of rotational (ROT) and continuous (CONT) grazing systems (treatments) averaging 1.57 ha each. A total of 12 Standardbred mares were grazed for an overall stocking rate of 0.52 ha/horse. Recommended management practices for each grazing system were followed for 1 yr including 2 grazing seasons (September 2014 to August 2015). Horse condition, measured by body weight, body condition score, and body fat did not differ by treatment, although quarterly differences existed ($P < 0.013$) with increased condition during grazing seasons. Horse voluntary movement did not differ by treatment, but time spent in grazing areas differed by treatment and season ($P < 0.0001$). Pre-graze sward height and herbage mass were greater in ROT pastures ($P < 0.0001$) and also exhibited treatment by month effects, with sward height taller in ROT for all grazing months ($P < 0.05$) and herbage mass greater in ROT in months 9, 10, and 11 ($P < 0.05$). Sward height and herbage mass also had significant effects of month, quarter, and treatment by quarter ($P < 0.007$). Vegetative and total cover were higher in ROT ($P < 0.001$), and species composition varied by treatment and quarter with higher proportions of desirable grasses during the grazing seasons ($P < 0.05$) and higher proportions of plant residue, non-grass weeds, and other during the non-grazed months for ROT pastures ($P < 0.05$). Nutrient composition did not differ by treatment but some components showed monthly ($P < 0.05$) and quarterly ($P < 0.05$) differences. Hay fed and production cost did not differ by

treatment. This study is one of few replicated experiments that compares rotational and continuous grazing for horses, and supports the recommendation of rotational grazing for environmental and ecological purposes. There were no advantages to rotational grazing in terms of horse condition or farm costs; however, this study only considers the first year of grazing pastures which were initially similar. The second grazing season showed more pasture differences between ROT and CONT than the first. Pasture degradation by grazing is a continuous process, and a longer sampling period would likely show greater differences between the two grazing systems.

Introduction

Grazing is an economical and efficient way to feed horses, provide voluntary exercise, and reduce certain behavioral and health problems (Houpt, 1981; McMeniman, 2000; Hoskin and Gee, 2004; Davidson and Harris, 2007; Bott et al., 2015). Nutrition derived from high quality pasture can meet the needs of horses at maintenance and even those with higher nutritional needs, such as growing or lactating horses (Gallagher and McMeniman, 1988). However, the practice of grazing has unavoidable effects on pasture land. Horses are particularly selective grazers with the ability to overgraze preferred plants, ultimately changing the species composition of the pasture (Briske, 1991; Martinson et al., 2015). Trampling also damages plants and reduces vegetative cover (Manning, 1979; Plumb et al., 1984).

Grazing systems and stocking rates (SR) have been studied extensively for production livestock such as cattle and sheep on rangeland (Heady, 1961; Holechek et al., 1999), but little work has been done specifically with horses in temperate pastures. An observational study in Maryland reported benefits of rotationally grazing horses at a low SR (0.49 ha per horse), although it was not compared with continuous grazing. Benefits included increased horse body weight (BW) and body condition score (BCS), high vegetative cover and low weeds, and economic value as forage grown in excess of horses' requirements was harvested for hay (Burk et al., 2011).

Webb et al. (1989) grazed yearling horses in CONT and ROT Bermuda grass pastures at various SR (0.23, 0.20, and 0.16 ha per animal unit [AU; 1 AU equals 454 kg of animal weight]). They found that the lightly-stocked CONT pasture had similar forage-on-offer (FOO) to all ROT pastures regardless of SR. Since the ROT pastures had similar FOO, they were unable to compare CONT and ROT FOO by SR. Nutritionally, they observed a trend toward higher crude protein (CP) and in vitro dry matter (DM) digestibility as FOO increased. When yearlings were realigned into groups based on FOO, significantly lower average daily gains were observed in the low FOO group than the medium and high groups (Webb et al., 1989).

The same author (Webb et al., 2009) compared adult horse condition and forage availability over 2 years between 1 CONT grazed pasture at an average of 0.50 ha per AU and 1 ROT grazed pasture at 0.49 ha per AU. During these 2 years, no significant differences were observed between the grazing systems for BCS or rump fat thickness. However, available forage was significantly higher in ROT pastures at the beginning of each 7 d grazing period. In 2011, Webb et al. published 2 more years of data utilizing the same experimental setup as the previous study. The third and fourth years of grazing continued to show no significant differences in BCS and BW, but the ROT pastures again produced more forage than the CONT pastures. Unfortunately, none of the Webb studies were replicated.

Jordan et al. (1995) did report numerical advantages of ROT grazing in both horse condition and forage availability over a 2 yr period. While the study was replicated, no statistical analyses were presented.

Virostek et al. (2015) compared the effects of ROT and CONT grazing on pasture condition over 2 years at a SR of 0.6 ha per horse. They observed no difference in biomass yield between the systems but botanical composition shifted towards a higher proportion of grasses and lower weeds in the ROT pasture. Daniel et al. (2015) evaluated forage nutrient composition on the same pastures and found significantly higher digestible energy (DE), water soluble carbohydrates (WSC), and sugar in ROT pastures due to the plants remaining in a vegetative state. Additionally, DE, WSC, and sugar were higher before a grazing bout compared to after. These 2 studies also were not replicated.

There is clearly a need for more research studying horse grazing in improved pastures with replication and sound statistics.

Research Objective and Hypothesis

Objective: To compare effects of rotational and continuous grazing on horse health and pasture condition parameters as well as production costs.

Hypothesis: ROT grazing systems will result in increased horse condition; improved pasture condition and quality; and reduced overall production costs.

Materials and Methods

General Grazing System. The Rutgers University Institutional Animal Care and Use Review Board approved all methods and procedures used in this experiment (Protocol # 04-005). The study site was the Ryders Lane Best Management Practice Demonstration Horse Farm at Rutgers University, Cook Campus in New Brunswick, NJ (Fig. 1). Areas 2 and 3 (3.19 and 3.06 ha, respectively) were used, totaling 6.25 ha. These areas were previously used for grazing horses, and were chemically treated to eliminate the existing vegetation, plowed to a depth of approximately 18 cm, disced, and vegetation was reestablished starting in 2012. Soil fertility was adjusted to optimum with lime and fertilizer, and pastures were seeded with Jesup MaxQ endophyte-friendly tall fescue (*Festuca arundinacea*; Pennington Seed, Madison, GA) at 7.9 kg per ha, Camas Kentucky bluegrass (*Poa pratensis*) at 12.9 kg per ha, and Potomac orchardgrass (*Dactylis glomerata*) at 8.2 kg per ha (both from Chamberlin & Barclay, Cranbury, NJ). The following year, due to poor growth of the grasses, pastures were overseeded with the same species at 3.6 kg per ha, 14.5 kg per ha, and 7.3 kg per ha of the same seed, respectively, to establish a better stand. Pastures were maintained without grazing until August 2014 using mowing, chemical weed control, and nitrogen fertilizer as needed. Four grazing areas (two replicates of each grazing system) were established with fencing to be as equal in size as possible (Table 1). The ROT pastures are referred to as 2R and 3R, and the CONT pastures are referred to as 2C and 3C (Fig. 1). The CONT fields contained temporary run-in shelters, water sources, and hay feeders. The ROT fields contained 0.17 and 0.16 ha (2R and 3R, respectively) stress lots with permanent shelters, water sources, and hay feeders; and 4 pastures sectioned off using temporary horse-friendly fencing (electric tape).

Baseline samples of all measures were collected in July 2014 (month 0) and horses were turned out on August 1, 2014 at a SR of 0.52 ha per horse as recommended by Singer et al. (2002) and Burk et al. (2011). The first monthly samples were collected in September 2014 (month 1; all subsequent months to be referenced by consecutive numbers) to allow the pastures 1 full month of grazing. Weather data was tracked using the Rutgers Historical Monthly Station Data website (Rutgers Office of the State Climatologist, 2015) for the New Brunswick station and included average daily temperature, daily precipitation, and relative humidity, which was summarized by month

(Table 2). Twelve Standardbred mares were used, aged 14 ± 2 years, and 544 ± 47 kg body weight (mean ± SD); they were paired by BW and BCS and randomly assigned to either the ROT or CONT grazing system. Prior to the start of grazing (at least 2 months), horses were housed in the groups on dry lots and fed hay at 2% of their BW.

Throughout the project, recommended pasture management practices were followed as they relate to each system (Foulk et al., 2004; Burk et al., 2011). Specifically, for the ROT system, horses were grazed when forage was taller than 15.2 cm and removed from pasture when reached 7.6 cm. The average length of grazing bouts was 10 days. Immediately after grazing (prior to the rest period), each pasture was dragged (to disperse manure) and mowed to a height of 10 cm. Continuously grazed pastures were mowed and dragged as needed to help control weeds and manure build up (approximately twice per growing season). Mowing and dragging events were recorded to track cost of pasture maintenance. Chemical weed control was not performed so as to track changes in plant species composition including natural weed growth.

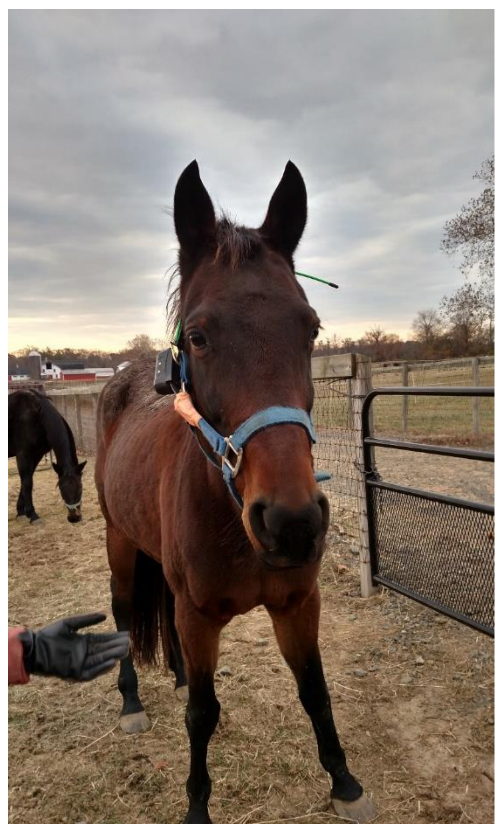
When ROT horses did not have adequate grass due to poor weather conditions (i.e. drought, snow, plant senescence), they were confined to a stress lot and fed grass hay to meet nutritional requirements (NRC, 2007). Continuous horses were offered hay when forage was low, and all hay offered was recorded. During times of no pasture availability, hay was fed at 2% BW. During times of limited pasture availability, hay was fed based on overall body condition. Over the winter, horse condition decreased enough that supplemental concentrate was fed at the rate of 1.8 kg per horse (EQUI-PRO *E-TEC,* Poulin Grain, Newport, VT).

Production Cost. The costs of each system were compared by recording the amount of supplemental hay offered to each group and the number of times each pasture unit was mowed and dragged. Hay was purchased through a local vendor in early winter 2014 and pasture maintenance was performed by the Rutgers University Department of Animal Care.

Horse. The effect of grazing system on horse health was measured monthly using several tests including BCS (Henneke et al., 1983). This scoring system estimates the amount of fat cover over 5 different areas of the body (crest of neck, topline, over ribs, behind shoulder, and over tailhead) on a scale of 1 to 9, with 1 being emaciated and 9 being obese. Each horse was given an average score after manual palpation of each body part. Body weight (BW) of the horses was measured using an IND221 electronic scale (Mettler Toledo, Columbus, OH), and percent body fat was determined by ultrasound (Aloka SSD-500V with linear 3.5mhz probe, Tokyo, Japan) of the thickness of subcutaneous fat on a specific measured point on the rump (Westervelt et al., 1976). The fat thickness was measured on both sides of the rump and averaged, then entered into a regression equation to give overall body fat percentage (Westervelt et al., 1976).

Measuring rump fat using ultrasound.

Voluntary movement and time spent in grazing areas versus non-grazing areas was measured seasonally using a GPS tracking device (Garmin Astro DC-20 Dog Tracking System, Olathe, KS) affixed to the animals' halters for three 24-hour periods and viewed in MapSource software (Garmin, Olathe, KS). Winter was skipped, as the ROT horses were confined to stress lots. The GPS units recorded location at intervals ranging from 1 second to 6 minutes, which could not be adjusted. Accuracy is reported to be within 10-15 feet 95% of the time



GPS collar affixed to horse halter.

(Garmin International, 2009). GPS units occasionally ran out of battery before the 24-hour period, so all recordings were cut down to the minimum recorded time of 19 hours. Time spent in grazing areas was calculated by filtering intervals to 1 minute or more, sorting the coordinates in Excel (Microsoft Corp., Redmond, WA), and removing those that fall within non-grazing areas.

Vegetation. The effect of grazing system on vegetation was measured monthly using several estimates, weather permitting. Measures were not taken when ground was snow covered. Vegetative cover (which measures living plant cover) and total cover (which measures anything covering the soil, dead or alive) were estimated using a modified Step Point method (Evans and Love, 1956) with 100 observations per field. Data collected with this method also allowed for estimation of the species composition of the pastures, including tall fescue (TF), Kentucky bluegrass (KB), orchardgrass (OG), creeping bentgrass (CB), grass weeds (GW), weeds (W), and other (O). Available herbage mass was estimated by clipping sixteen ½ m by ½ m quadrats per field and drying at 65º C for at least 36 hr in a Thermocore oven (Cayley and Bird, 1996). For ROT fields, herbage mass was sampled immediately prior to grazing to estimate the amount of forage available to the horses.

Collecting herbage mass.

Sward height was measured by dropping a Styrofoam plate down a meter stick and recording the height where it rested on the forage, as described by Burk et al. (2011). This was performed 100 times per pasture and also sampled immediately prior to ROT grazing bouts. Forage nutritional composition was sampled by collecting forage clippings from 0800 to 1000. When forage was tall, samples were clipped to 7 to 10 cm (grazing height) and when forage was overgrazed, samples were clipped at ground level to imitate horse grazing. The samples were weighed before and after drying at 65º C for at least 36 hours in a Thermocore oven to calculate dry matter (DM) and then ground to 1 mm using a Wiley Mill and sent to Equi-Analytical Laboratories (Ithaca, NY) for wet chemistry (DE, CP, acid detergent fiber (ADF), neutral detergent fiber (NDF), WSC, ethanol soluble carbohydrates (ESC), starch, Ca, and P on a DM basis.

Collecting forage samples for quality analysis.

Statistical analysis. All statistics were analyzed in R (R Foundation for Statistical Computing, Vienna, Austria). Data was analyzed using ANOVA and Tukey HSD as a post-hoc analysis. Data was analyzed for differences between treatments, months, quarters, treatment by month, and treatment by quarter. Quarters combined monthly data to correspond to grazing seasons and winter. Quarter 1 (Q1; the first grazing season) includes July to October 2014 (months 1-2), Quarter 2 (Q2; early winter) includes November 2014 to January 2015 (months 3-5), Quarter 3 (Q3; late winter) includes February to April 2015 (months 6-8), and Quarter 4 (Q4; second grazing season) includes May to August 2015 (months 9-12). Significance was set at $P < 0.05$. All means are presented ± SEM.

Results

Production data. Continuous horses were on pasture for a total of 396 d (August 1, 2014 to August 31, 2015) and ROT horses were on pasture for an average of 189 d total. There were no significant differences between treatments for amount of hay fed or cost of pasture maintenance. Continuous horses were fed 566 ± 77 kg and ROT horses were fed 578 ± 75 kg of hay per mo on average. Pasture maintenance on CONT fields cost $19.63 ± 6.38 and on ROT fields cost $26.16 ± 6.18 per mo on average. Cost was not significantly different by mo, but it did differ by quarter ($P = 0.034$). Hay differed by mo and quarter ($P = 0.033$ and $P < 0.0001$, respectively).

Horse condition. There was no significant difference between treatments, mo, or interactions for BW, BCS, or fat. However, a quarterly difference existed ($P < 0.013$) for each. For BW, Q1 was significantly higher than Q3 ($P = 0.009$; Fig. 2). For BCS, Q1 and Q4 were significantly higher than Q2 and Q3 ($P < 0.0024$; Fig. 3). For fat, Q3 was significantly lower than each other quarter ($P < 0.022$; Fig. 4).

Voluntary movement. Total distance traveled did not differ significantly between CONT and ROT treatments. However, there were differences between season ($P = 0.0074$), field (P = 0.0011), and horse ($P = 0.026$) (Table 3). Time spent in grazing areas was significantly higher for CONT horses than ROT ($P < 0.0001$) with ROT horses spending 55.2 ± 2.0 and CONT horses spending 79.7 ± 2.0% of time in grazing areas. There was also a significant effect of season ($P < 0.0001$), with Fall-1 (September and October) having the most time in grazing areas, Fall-2 (November and December) having the least, and Spring (May and June) being intermediate (Table 3).

Pasture condition. Over the year of sampling (mo 1 to 12), average temperature was similar to the historical average, and average precipitation was 5 cm lower than historical average for the New Brunswick weather station (Rutgers Office of the State Climatologist, 2015).

All pasture measures had a significant effect of treatment. For sward height, there were significant effects of treatment ($P < 0.0001$), month ($P = 0.006$), quarter, ($P < 0.0001$), treatment by mo ($P < 0.0001$), and treatment by quarter ($P < 0.0001$). Rotational fields contained significantly higher swards than CONT in months 1, 2, 8, 9, 10, 11, and 12 (P < 0.00012; Fig. 5).

Herbage mass differed ($P < 0.0001$ for each) by treatment, mo, quarter, treatment by mo, and treatment by quarter. Rotational and CONT fields had similar herbage mass until months 9, 10, and 11 when ROT was significantly higher ($P < 0.014$; Fig. 6).

Vegetative cover differed between treatment ($P < 0.0001$), quarter ($P < 0.0001$), and treatment by quarter ($P = 0.0006$). Rotational fields had a higher percentage of vegetative cover than CONT in Q2, 3, and 4 ($P < 0.049$; Fig. 7). With both treatments combined, Q1 and Q4 were significantly higher than Q2 and Q3, and Q2 was significantly lower than Q3 ($P < 0.0001$; Fig. 7). Despite a lack of overall monthly difference, monthly pairwise analysis showed months 5, 8, and 9 having significantly ($P < 0.049$) higher vegetative cover in ROT treatments.

Total cover differed by treatment ($P > 0.0001$), mo ($P = 0.0024$), quarter ($P > 0.0001$), treatment by mo interaction ($P = 0.0009$), and treatment by quarter interaction ($P > 0.0001$). Rotational fields had a higher percentage of total cover in months 5, 8, and 9 compared to CONT ($P = 0.0045$ for each; Fig. 8).

Species composition showed some treatment and quarterly differences (Tables 4 and 5). Creeping bentgrass (CB; $P = 0.0064$) was higher in CONT pastures, and tall fescue (TF; $P = 0.0022$) and weeds (W; $P = 0.0073$) were higher in ROT pastures. Kentucky bluegrass (KB), TF, orchardgrass (OG), W, and other (O) were significantly different between quarters ($P < 0.05$). Grass weeds had no significant differences.

The nutrient content measured in forage quality all differed significantly by quarter ($P < 0.011$) except for starch, which had no significant differences (Table 6). Some nutrients had significant monthly differences (DE, $P = 0.005$; CP, $P = 0.048$; NDF, $P = 0.027$; Ca, $P = 0.016$; P, $P = 0.032$) and some had significant treatment by quarter effects (CP, $P = 0.015$, ADF, $P = 0.019$; NDF, $P = 0.027$; P, $P = 0.047$).

Discussion

Production cost. Horses were fed similar amounts of hay throughout the study. It was anticipated that CONT horses would require more hay than ROT horses due to diminished pasture conditions, but several factors contributed to this not being the case. The CONT horses did not have a large impact on pasture condition until the second grazing season. Therefore, in the fall there were few differences between treatments and the CONT horses had adequate nutrition from pasture until October, when all horses received partial hay supplementation, and ROT horses were mostly confined for the winter in November. During the winter, all horses were fed a full hay diet at 2% BW and identical amounts of concentrate to maintain body condition (fed mo 5 through 7). When forage began to regrow and horse BCS increased, concentrate was discontinued but hay was still fed. Continuous horses had access to early spring pasture and required less hay while ROT horses were still confined until forage reached an appropriate height to graze. Once ROT horses were returned to pastures, they required less hay or none at all, while CONT horses needed more supplementation due to the damage caused to their pastures over the winter. All fields received some supplementation through the early spring and late summer to prevent weight loss, and hay had to be increased during a period of very low rainfall in the mid-summer when pastures became dormant. July (mo 11) and August (mo 12) precipitation was 6.7 and 3.0 cm, respectively, while the historic mean for those months in New Brunswick is 12.3 and 11.9 cm, respectively (Rutgers Office of the State Climatologist, 2015). The observed monthly and quarterly differences in hay fed are more a result of management decisions relating to horse condition than anything else.

Pasture maintenance also did not differ between treatments. Continuous fields were mowed and dragged twice during the first grazing season, then dragged in the early spring to disperse manure accumulated over the winter, and mowed and dragged once in the summer to even forage height and control weeds. Rotational units were mowed and dragged monthly when forage was growing (after horses had been removed from the unit), but they were smaller areas of land and therefore cost less per mowing/dragging.

Similarly to the hay data, the observed quarterly production cost difference is a result of management decisions based on pasture conditions.

During the study, there were times (especially in the spring) when forage grew too quickly for the ROT horses to graze before it became mature, and we had to choose whether to graze the overly mature forage or mow it. If haymaking equipment had been available, this could have been an opportunity to preserve the forage as hay and realize a cost savings, as illustrated by Burk et al. (2011) who harvested approximately 4,030 kg of hay from 2.08 ha of ROT pastures over 2 years.

Horse condition. Overall, horse condition was higher during the grazing season and lower during the winter. The nutritional composition of the pastures during grazing seasons (Q1 and Q4; Table 6) and the hay (Table 7) consumed during the winter was similar, so the decreased body condition may be due to controlled feed intake, as hay was limited to 2% BW. Some horses needed additional calories via commercial grain to maintain their BW, possibly due to an apparent dislike of the hay offered. However, it is important to note that the winter BCS were above 5, which is considered ideal, so the horses were not underfed. The lack of difference between ROT and CONT grazing mirrors livestock research summarized by Holechek et al., (1999) and the equine research by Webb et al. (1989, 2009, 2011). Burk et al. (2011) did find increased horse BW and BCS in a rotational grazing system; however, there was no continuous data to compare. Heady (1961) notes that, in an attempt to uniformly defoliate the pasture, ROT grazing forces animals to consume the lower quality forage that normally would be ignored. The forage quality in each grazing unit would initially be high, then would decrease as animals graze the high-quality forage. However, the implication of the findings in the present study is that throughout the grazing season, all horses had adequate forage to increase body condition above winter and baseline values prior to the start of grazing.

Voluntary movement. The fact that there were significant differences between fields and between horses for total distance traveled may partially explain why there was no treatment effect. The ROT systems had different shapes; one system (2R) had a central stress lot which did not require much travel to access the pastures, whereas the other system (3R) had a stress lot attached to each pasture by a long laneway. When horses in 3R were grazing the farthest pasture, they needed to travel approximately 0.2 km to access water and shelter. The habits of individual horses may have played a role as well. With only 3 horses per field, a more active horse can shift the average distance traveled considerably. Seasonal differences are likely due to the fact that hay was fed to horses during the Fall-2 measurements (ROT horses still had access to pasture, but it was low quality) which reduces their need to travel to find nutrition. Hay was also offered during the Spring measurements, but the pasture forage was higher quality during those months, which may have contributed to the extra distance traveled.

The time spent in grazing areas was higher in CONT pastures, which is likely due to poorly defined non-grazing areas in the CONT fields. The non-grazing area was considered the area around feeders, waterers, and shelter, but there were several other areas throughout the CONT fields in which those horses loafed, and they could not all be identified. These poorly-defined non-grazing areas were smaller than the large stress lots in which ROT horses loafed or consumed hay and water, explaining the significant difference observed. However, the seasonal differences observed relate to the times hay was offered. No hay was fed during Fall-1, which had highest time spent in grazing areas, and hay was incrementally increased during Fall-2 (lowest time spent in grazing areas) as pasture quality diminished. Rotational horses were allowed access to pasture during all GPS recordings.

Burk et al. (2011) tracked horses by GPS for 22.5 h in a 2.08 ha (smaller than the present study) ROT grazing system and found that they traveled an average of 11.1 km and spent approximately 71.2% of the period in the grazing areas. The average distance traveled observed in the present study was 10.4 km, which is very similar considering the 2.5 h difference in time tracked. Wild horses have been observed traveling up to 80 km per d (Davidson and Harris, 2007), but the plains they travel are more sparsely vegetated than the improved pastures that captive horses graze, and water sources are generally farther away. Captive horses do not need to travel as far to find and consume a similar amount of energy.

Rotational horses spent an average of 55% time in grazing areas, which is lower than the 71% found by Burk et al. (2011) in a ROT system. Grazing times of 14 h, or 60% of a 24 h period, have been reported by Fleurance et al. (2001) and Edouard et al. (2009). However, those studies observed horses for the full 24 h period and recorded different activities, while the present study estimates grazing time by location alone. Without observations, it is impossible to know whether the horses in the present study were grazing during the entire time they spent in the grazing area.

Pasture condition. Rotational grazing is designed to preserve the pasture forages in order to provide more feed to livestock, so it is not surprising that the ROT fields performed significantly better than the CONT fields. Sward height and herbage mass were measured before ROT horses were allowed into a pasture to gauge the conditions that were available to horses. This means that the pastures had 3 or more weeks of regrowth before the measurements were made, as compared to the CONT fields which were never rested, and these measurements also represented forage available to the horses.

While herbage mass was significantly higher for ROT fields, even the baseline yields were lower than some previously reported values. The highest mean yield was in month 0 (before grazing) and was 2,546 kg per ha, compared to a range of 6,100 to 7,082 kg per ha observed in cool-season pasture mixtures grown in Minnesota before grazing (Martinson et al., 2015). However, Jordan et al. (1995) reported initial herbage mass ranges of 1,588 to 4,070 kg per ha in ROT tall fescue pastures over a 2 year period. McIntosh (2007) found forage biomass yield in tall fescue pastures of 2,612 kg per ha. The lower herbage mass values seen in the present study may be due to soil physical properties or weather conditions, as soil fertility was optimized before the study began. Webb et al. (2009, 2011) also measured pre-grazing herbage mass and found that a ROT grazing system produced higher yield over a 4 year period than CONT grazing. Similar SR to the present study were used.

Pre-graze sward heights were significantly taller in ROT fields due to the rest period when pastures could regrow. Pre-graze height values reported by Burk et al. (2011) for ROT fields only were 28.2 ± 2.8 cm and 18.3 ± 3.3 cm in years 1 and 2, respectively. Values from the present study are similar, with ROT pre-graze ranging from 12.7 ± 0.3 to 24.4 ± 0.7 cm during the grazing months.

However, taller swards and more available forage per ha do not necessarily equate to a higher plane of nutrition for the horses. As grasses mature, their nutritional quality declines (Heady, 1961; Evans, 1995). In the present study, DE was highest in Q1, the first grazing season; Q3, April only; and Q4, the final growing season. The young, rapidly growing plants seen in April are immature and contain a high level of sugars, which contributes to the high DE. In fact, WSC (includes sugars and fructans) and ESC (sugars only) were highest in Q3. This agrees with work by McIntosh (2007), who found that sugars, fructans, and starches in a tall fescue pasture were highest in April. While the forage quality was high in April, herbage mass and sward height were actually quite low at that time.

Neutral detergent fiber and ADF describe fiber fractions and have implications in digestibility. Both NDF (cellulose, hemicellulose, and lignin) and ADF (cellulose and lignin) were highest in Q1 and Q2 and lowest in Q4. This suggests that the forage was least fibrous and most digestible in Q4, also having high DE and moderate carbohydrate levels. Fleurance et al. (2010) found varying NDF values based on forage height, with short swards (1 to 8 cm) ranging from 50.0 ± 3.3 to 52.6 ± 2.5% NDF and intermediate swards (9 to 24 cm) ranging from 62.2 ± 2.3 to 66.5 ± 1.1% NDF. Present study values fell within this range except for Q3 at 44.9 ± 1.5%. This quarter represents April, at which time most grasses were short and actively growing, while Fleurance (2010) measured NDF during July and September.

Forage quality values of the pastures were slightly lower than those reported by McIntosh (2007) in Virginia tall fescue pastures. Digestible energy ranged from 2.1 ± 0.01 to 2.8 ± 0.01 Mcal per kg, whereas the present study included a range from 1.9 ± 0.03 to 2.2 ± 0.13 Mcal per kg. This inconsistency could be due to the warmer weather in a more southern climate allowing pastures to be productive through the winter. Crude protein, ADF, NDF, Ca, and P values followed similar seasonal patterns to McIntosh (2007). Ethanol soluble carbohydrate levels were lower in the present study compared to the sugar measured in McIntosh (2007), which may be due to a difference in analysis methods or the fact that their pastures were somewhat higher quality (based on DE reported). However, the condition of the horses did not suffer while they were grazing, so it is clear that the quality was adequate in all pastures. Coleman and Barth (1973) found that grazing animals may consume a higher quality diet than the average quality of the pasture by selecting certain plants over others.

While no treatment effects were observed, several nutrition components had treatment by quarter interactions. The lack of overall treatment difference may be due to the similarity of the CONT and ROT pastures for the first grazing season or the height of the forage in ROT pastures may have reduced its quality. Crude protein, ADF, NDF, and P had treatment by quarter interactions, meaning they differed by treatment only during certain quarters. A different study (McIntosh et al., 2015) found significant overall differences in nutrient composition between ROT and CONT grazing; higher DE, WSC, sugar, P, and K were observed in ROT pastures and lower ADF, NDF, and lignin.

Vegetative cover and total cover are similar but have slightly different implications. Vegetative cover is an indicator of the proportion of green forage available to horses in a pasture, while total cover includes any item which covers the soil, living or dead, and is a better indicator of soil condition and erosion risk (Herrick 2009). Vegetative cover and total cover may be used interchangeably in the literature, but in general 70% or higher vegetative cover is recommended. The pastures in this study remained above 70% vegetative cover during all quarters except Q2 when both CONT and ROT fields dropped below that value. This may be explained by the fact that Q3 included only the month of April because ground was snow covered during February and March. Brown senescent plants were not counted as green forage, so during the winter months, vegetative cover was reduced (as seen during Q2). However, senescent plants began to regrow in April, so the Q3 measurement was skewed toward spring values by not including February and March. Rotational pastures had higher vegetative cover than CONT for the last 3 quarters, likely due to the fact that CONT horses were constantly grazing and reducing cover while the ROT fields were rested during the winter. Vegetative cover values during the grazing season are higher than those reported by Burk et al. (2011) of 78 ± 3 and 80 ± 2% (yr 1 and 2, respectively), which are still acceptable by the 70% rule. Additionally, CONT pastures developed large bare spots near water and feed sources which were not present in ROT pastures because of the stress lots. Plumb et al. (1984) also observed large decreases in cover extending up to 61 m away from a water source when used by horses and/or cattle.

Total cover was quite high and remained above 80% at all times. There were only 3 months when ROT fields had higher total cover than CONT fields: January, April, and May. Similarly to the vegetative cover data, these months were when ROT fields were rested but CONT fields were grazed. The cover removed by the CONT horses was not replaced until plants began to regrow in the spring. These months were also significantly different in the vegetative cover analysis for the same reason. Teague et al. (2011) found that “multi-paddock” (ROT) grazing pastures had less bare ground than CONT pastures at 2 different SR. Olson-Rutz et al. (1996) found that horse grazing did not affect litter or rock cover (contributing to the difference between vegetative cover and total cover) as much as it affected vegetative cover. This was also found to be true in the present study.

Shifts in species composition were seen between treatments and quarters. Creeping bentgrass was more prevalent in CONT fields and did not vary by quarter. This cool-season sod grass was not initially seeded, but established itself in large proportions in wet areas of fields 2R and 3C and spread by stoloniferous growth. The seed may have been in soil reserves or carried in by farm equipment; a turf research area exists across a highway from the equine research farm. It did not appear to be highly preferred by the horses, which may have contributed to its high prevalence. Of the seeded grasses, only TF differed by treatment, with higher prevalence in ROT fields. Tall fescue is a highly persistent grass (Martinson et al., 2015) which may have been outcompeted by CB in wet areas of all pastures. Tall grasses TF and OG were significantly less prevalent during the winter quarters (Q2 and Q3), and short grass KB was highest in Q3 (April). It is possible that KB survived the winter better under a protective layer of residue from the tall grasses, or that tiny immature grasses were mistakenly identified as KB in April, or a combination of both. Singer et al. (2001) observed higher densities of grasses in the spring compared to the summer. In the present study, this pattern was observed only for KB, whereas TF and OG were statistically similar between Q2 and Q4. Teague et al. (2011) found that “multi-paddock” (ROT) grazing had a higher proportion of tall grasses to short grasses and forbs. This was found to be true for the tall grass TF and the weed category, but not tall grass OG and short grass KB.

Weeds, Res, and O were generally higher during Q2 and Q3 when grasses were low, and GW did not vary by season. Residue was highest in Q2 as the grasses began to go senescent and by April (Q3), had decreased to a similar level as Q1 and Q2. This could be from removal by CONT horses foraging or even geese, which also grazed the pastures in the winter. Weeds were more prevalent in ROT pastures than CONT, which is interesting considering TF was also more prevalent in ROT and OG and KB were similar. The higher proportion of weeds does not appear to reflect lower proportions of desirable grasses, so it may reflect lower proportions of Res, GW, and O combined.

When considering this data, it is important to note that the 4 pastures were initially very similar. There was high vegetative cover, tall swards, and high herbage mass. The impact of grazing was not immediate, as it took time for trampling and grazing to damage the pastures. Winter turnout of CONT horses had an effect on vegetation, as seen in sward height, herbage mass, and vegetative cover. After plant parts were removed and trampled, the plants in CONT fields took longer to recover to the level of those in ROT fields. By August 2015, CONT sward height and vegetative cover had not returned to ROT levels. This implies that one year of grazing may not be long enough to fully understand the effects that horses have on the pastures. It is likely that CONT pastures will be further degraded by constant trampling and grazing, while ROT pastures will be managed to minimize these effects. One option when comparing ROT and CONT grazing is to observe pastures which have historically been managed using each method, which bypasses this problem (Teague et al., 2011). However, by establishing each pasture similarly, we can observe how much each pasture has deviated from a similar baseline and compare variables across pastures. It also allows us to track shifts in species composition over time, knowing that each pasture was seeded identically.

Conclusion

This study is one of few exploring the impacts of ROT and CONT grazing of horses, and one of even fewer replicated studies. Most previous studies have used other livestock animals, such as cattle and sheep, which have different grazing habits than horses. Overall, effects of grazing system on horses were absent, with horses maintaining high condition during the two grazing seasons. Horses in both systems traveled similar distances and spent different proportions of time in their grazing areas, though that may be an effect of poorly-defined non-grazing areas in the continuous fields. Effects of grazing season on pasture condition were significant, with ROT pastures showing higher sward heights, herbage mass, vegetative cover, and total cover.


Left, CONT pasture in May. Right, ROT pasture in May.

However, these differences did not translate into higher quality pasture as evidenced by nutrient composition and the fact that horse condition did not vary by treatment. There were also no differences in production cost between the systems. The results presented in year 1 of grazing for this experiment do not support the recommendation of ROT grazing solely for horse health or farm cost; however the vegetation differences support the use of ROT grazing for environmental and conservation reasons. High plant cover improves water quality by reducing erosion, taking up nutrients that may otherwise leave the pasture in storm water runoff, and slowing the flow of surface water which may be contaminated by nutrients or sediment (Hubbard, 2004).

This study reflects one full year of grazing in addition to baseline samples. All pastures started out similar in terms of sward height, herbage mass, and vegetative and total cover. Due to the time it takes for grazing horses to impact vegetation, no differences were observed in horse condition during their first grazing season. The continued trampling and grazing of CONT pastures over the winter created some significant differences in the springtime which persisted into the second grazing season. It is expected that a second year of sampling will show more overall significant differences between grazing seasons as the CONT pastures become more degraded, and will provide valuable insight into the long-term effects of horse grazing.

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Tables

Table 1. Sizes of continuous and rotational fields at the Ryders Lane Best Management Practices Horse Farm in New Brunswick, NJ, used for a grazing trial. Continuous fields are denoted "C" and rotational fields are denoted "R." Values in the "Rotational Fields" column are the size of each of the four grazing units in that system; all four are equally sized.

Field	Total Size, ha	Rotational Fields, ha
2C	1.61	
2R	1.59	0.40
3C	1.58	
3R	1.50	0.37

Table 2. Monthly weather conditions during each month of a year-long experiment grazing horses in New Brunswick, NJ plus the month of baseline sampling, July 2014.

Month No.	Month and Year	Average Temperature, °C	Total Precipitation, cm	Average Relative Humidity, %
0	July 2014	21.7	4.8	73.4
1	September 2014	19.4	3.1	75.7
2	October 2014	14.2	10.3	78.2
3	November 2014	5.8	12.0	69.8
4	December 2014	3.7	12.0	73.5
5	January 2015	-1.9	12.3	66.5
6	February 2015	-5.4	5.6	64.4
7	March 2015	2.2	11.8	65.4
8	April 2015	11.6	5.9	59.3
9	May 2015	19.0	5.1	66.7
10	June 2015	21.0	15.5	77.3
11	July 2015	24.4	6.7	72.3
12	August 2015	23.9	3.0	67.3

Table 3. Distance traveled by horses and time spent in grazing areas during a 19-hour period measured by GPS. Distance had no effect of treatment, so CONT and ROT data were combined. There was a significant effect of treatment for time spent in grazing area, but data were combined due to poorly defined non-grazing areas in CONT pastures. Fall-1 measurements were taken from September to October, Fall-2 measurements were taken from November to December, and Spring measurements were taken from May to June. Data are presented as the means ± SEM.

Variable	**Fall-1**	**Fall-2**	**Spring**
Distance, km	10.5 ± 0.4 [ab]	9.4 ± 0.4 [a]	11.2 ± 0.4 [b]
Grazing Area, %	79.8 ± 2.5 [a]	55.0 ± 2.7 [b]	67.2 ± 3.0 [c]

[a,b,c] Different letters within rows differ at $P < 0.05$.

Table 4. Mean prevalence of each plant species category by treatment (continuous [CONT] or rotational [ROT] grazing) and quarter (Q1 includes July to October 2014, Q2 includes November 2014 to January 2015, Q3 includes February to April 2015, and Q4 includes May to August 2015). Residue means any brown plant parts, whether attached or not. Grass weeds include any grasses not seeded (other than creeping bentgrass). Weeds include any non-grass plants. Other includes anything else: bare ground, rocks, etc. Data are presented as the means ± SEM.

	Q1		**Q2**		**Q3**[2]		**Q4**	
Species[1]	**CONT**	**ROT**	**CONT**	**ROT**	**CONT**	**ROT**	**CONT**	**ROT**
TF	35.7 ± 2.7	56.3 ± 1.2	18.5 ± 10.5	28.5 ± 7.5	21.0	34.0	28.0 ± 2.4	50.8 ± 6.0
KB	57.3 ± 7.5	42.0 ± 4.7	46.5 ± 8.5	60.0 ± 8.0	77.0	88	54.0 ± 9.5	42.0 ± 5.5
OG	25.0 ± 3.0	24.7 ± 3.7	9.5 ± 4.5	10.0 ± 4.0	17.0	24.0	19.0 ± 3.3	26.5 ± 2.3
CB	30.7 ± 1.5	18.0 ± 1.0	23.5 ± 4.5	10.5 ± 3.5	13.0	10.0	22.5 ± 5.4	15.8 ± 1.54
Res	12.0 ± 6.1	7.0 ± 5.1	49.0 ± 19.0	49.5 ± 23.5	14.0	9.0	5.0 ± 2.8	3.25 ± 2.6
GW	15.0 ± 7.0	8.0 ± 0.6	3.0 ± 2.0	1.5 ± 0.5	9.0	2.0	27.5 ± 10.2	11.0 ± 3.1
W	20.0 ± 1.5	38.0 ± 2.0	11.5 ± 3.5	24.0 ± 10.0	2.0	13.0	26.5 ± 5.5	46.3 ± 5.1
O	4.3 ± 2.6	6.0 ± 2.1	38.5 ± 14.5	16.0 ± 9.0	47	20	17.3 ± 3.6	4.5 ± 0.5

[1] TF = tall fescue, KB = Kentucky bluegrass, OG = orchardgrass, CB = creeping bentgrass, Res = plant residue, GW = grass weed, W = weed, O = other.

[2] Q3 only includes one month, so SEM could not be calculated.

Table 5. *P* values by treatment (continuous or rotational grazing) and quarter (Q1 includes July to October 2014, Q2 includes November 2014 to January 2015, Q3 includes February to April 2015, and Q4 includes May to August 2015) for plant species categories. Residue means any brown plant parts, whether attached or not. Grass weeds include any grasses not seeded (other than creeping bentgrass). Weeds include any non-grass plants. Other includes anything else: bare ground, rocks, etc.

Category[1]	**Treatment**	**Quarter**
TF	0.003	0.007
KB	0.458	0.044
OG	0.302	0.010
CB	0.006	0.107
Res	0.789	0.002
GW	0.096	0.153
W	0.010	0.004
O	0.068	0.001

[1] TF = tall fescue, KB = Kentucky bluegrass, OG = orchardgrass, CB = creeping bentgrass, Res = plant residue, GW = grass weed, W = weed, O = other.

Table 6. Nutritional composition by quarter. No treatment difference existed, so means among treatments (continuous or rotational grazing) have been combined. Q1 includes July to October 2014, Q2 includes November 2014 to January 2015, Q3 includes February to April 2015, and Q4 includes May to August 2015. Data are presented as the means ± SEM.

Nutrient [1]	**Q1**	**Q2**	**Q3**	**Q4**	***P*-value**
DM, %	35.5 ± 1.9 [ab]	44.3 ± 5.7 [a]	26.9 ± 1.5 [ab]	26.4 ± 1.1 [b]	0.00224
DE, Mcal/lb	2.08 ± 0.02 [a]	1.88 ± 0.03 [b]	2.16 ± 0.13 [a]	2.09 ± 0.03 [a]	< 0.0001
CP, %	13.4 ± 0.3 [a]	13.8 ± 0.8 [a]	22.4 ± 0.7 [b]	15.6 ± 0.9 [a]	< 0.0001
ADF, %	36.7 ± 0.6 [ac]	39.5 ± 0.6 [a]	27.7 ± 1.1 [b]	35.7 ± 0.9 [c]	< 0.0001
NDF, %	62.0 ± 0.9 [ac]	64.1 ± 1.3 [a]	44.9 ± 1.5 [b]	58.6 ± 1.3 [c]	< 0.0001
WSC, %	8.18 ± 0.44 [a]	5.38 ± 0.60 [b]	14.78 ± 2.28 [c]	9.19 ± 0.50 [a]	< 0.0001
ESC, %	6.18 ± 0.43 [a]	3.58 ± 1.57 [b]	10.65 ± 1.35 [c]	6.47 ± 0.59 [a]	< 0.0001
Starch, %	0.34 ± 0.06	0.63 ± 0.21	0.40 ± 0.14	0.44 ± 0.05	0.423
Ca, %	0.50 ± 0.04 [ab]	0.39 ± 0.18 [a]	0.53 ± 0.04 [ab]	0.57 ± 0.04 [b]	0.0109
P, %	0.36 ± 0.19 [a]	0.21 ± 0.02 [b]	0.39 ± 0.02 [a]	0.39 ± 0.02 [a]	< 0.0001

[1] 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; Ca, calcium; P, phosphorus.

[a,b,c] Different letters within rows differ at $P < 0.05$.

Table 7. Nutritional composition of grass hay fed to all horses during winter months and times of insufficient forage in a rotational versus continuous grazing experiment to maintain body condition.

Nutrient [1]	**Farm Hay**
DM, %	92.2
DE, Mcal/kg	2.05
CP, %	10.7
ADF, %	41.3
NDF, %	63.3
WSC, %	8.7
ESC, %	8.8
Starch, %	1.7
Ca, %	0.63
P, %	0.21

[1] DM, dry matter; DE, digestible energy; CP, crude protein; ADF, acid detergent fiber; NDF, neutral detergent fiber; WSC, water soluble carbohydrates; ESC, simple sugars; Ca, calcium; P, phosphorus.

Figure Captions

Figure 1. Map of pasture layout at the Ryders Lane Best Management Practices Horse Farm in New Brunswick, NJ. Black lines indicate permanent fencing and white lines indicate temporary electric tape fencing separating rotational fields. The 3R stress lot connects to a laneway with openings into each rotational field. The 2R stress lot has gates opening into each rotational field.

Figure 2. Horse weight (kg) by quarter and treatment. Q1 includes July to October 2014, Q2 includes November 2014 to January 2015, Q3 includes February to April 2015, and Q4 includes May to August 2015. Treatment CONT is continuous grazing and treatment ROT is rotational grazing. Bars with no letters in common differ between quarters at $P < 0.05$ using combined treatment data. Data are presented as the means ± SEM.

Figure 3. Horse body condition score (1 to 9 scale) by quarter and treatment. Q1 includes July to October 2014, Q2 includes November 2014 to January 2015, Q3 includes February to April 2015, and Q4 includes May to August 2015. Treatment CONT is continuous grazing and treatment ROT is rotational grazing. Bars with no letters in common differ between quarters at $P < 0.05$ using combined treatment data. Data are presented as the means ± SEM.

Figure 4. Horse body fat (%) by quarter and treatment. Q1 includes July to October 2014, Q2 includes November 2014 to January 2015, Q3 includes February to April 2015, and Q4 includes May to August 2015. Treatment CONT is continuous grazing and treatment ROT is rotational grazing. Bars with no letters in common differ between

quarters at $P < 0.05$ using combined treatment data. Data are presented as the means ± SEM.

Figure 5. Sward height (cm) by month and treatment. Treatment CONT is continuous grazing and treatment ROT is rotational grazing. Month 0 was baseline sampling before pastures were grazed, and month 1 was the first grazed sample. Months 4, 6, and 7 were skipped during the winter when the ground was snow covered. Asterisks indicate significant differences between treatments at $P < 0.05$. Data are presented as the means ± SEM.

Figure 6. Herbage mass (kg/ha) by month and treatment. Treatment CONT is continuous grazing and treatment ROT is rotational grazing. Month 0 was baseline sampling before pastures were grazed, and month 1 was the first grazed sample. Months 4, 5, 6, and 7 were skipped during the winter when the ground was snow covered. Asterisks indicate significant differences between treatments at $P < 0.05$. Data are presented as the means ± SEM.

Figure 7. Vegetative cover (%) by quarter and treatment. Q1 includes July to October 2014, Q2 includes November 2014 to January 2015, Q3 includes February to April 2015, and Q4 includes May to August 2015. Treatment CONT is continuous grazing and treatment ROT is rotational grazing. Bars with no letters in common differ between quarters at $P < 0.05$ using combined treatment data. Asterisks indicate significant differences between treatments at $P < 0.05$. Data are presented as the means ± SEM.

Figure 8. Ground cover (%) by month and treatment. Treatment CONT is continuous grazing and treatment ROT is rotational grazing. Month 0 was baseline sampling before

pastures were grazed, and month 1 was the first grazed sample. Months 4, 6, and 7 were skipped during the winter when the ground was snow covered. Asterisks indicate significant differences between treatments at $P < 0.05$. Data are presented as the means ± SEM.

Figures

Figure 1.

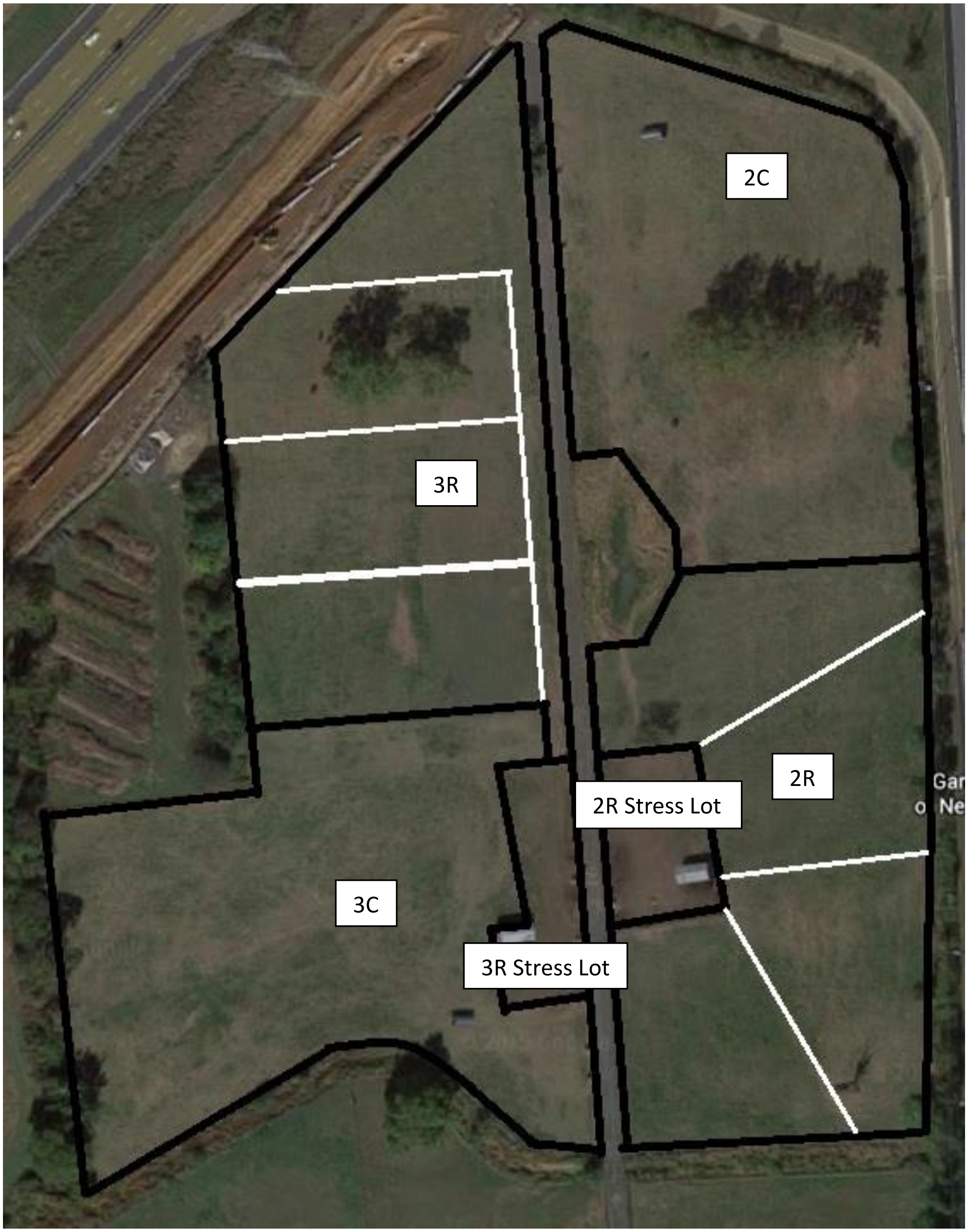


Figure 2.

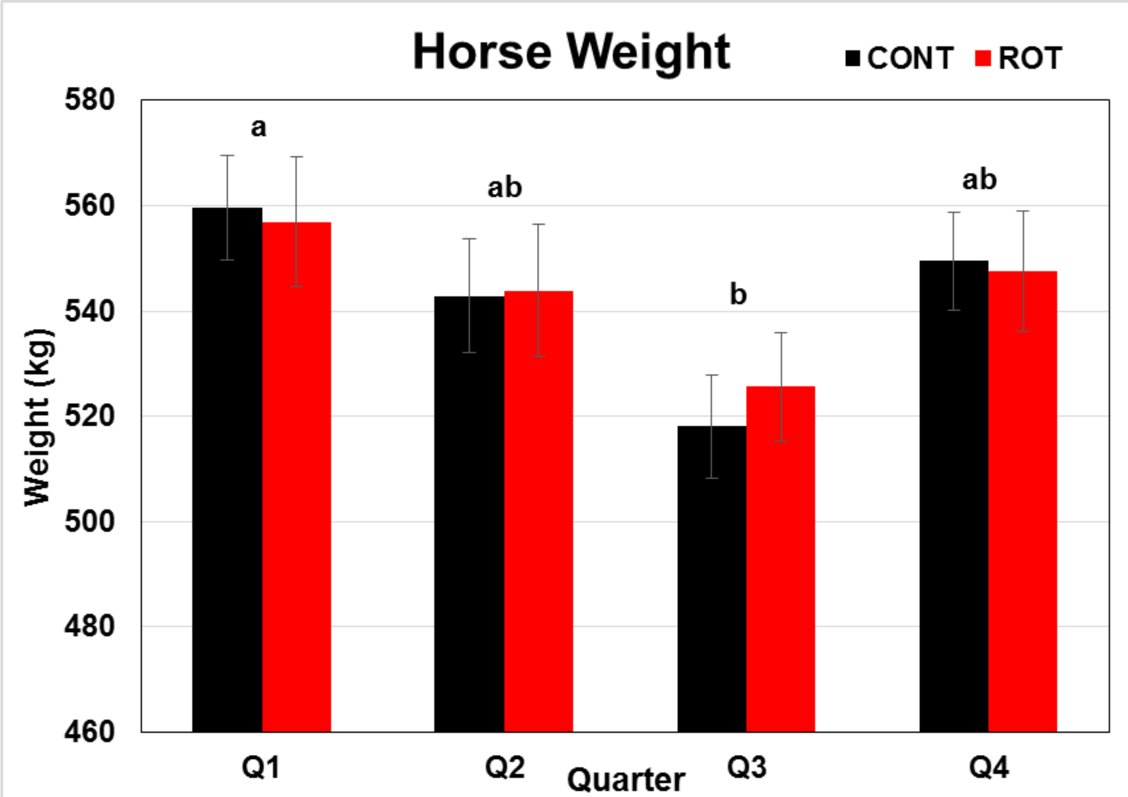

Horse Weight
CONT
ROT
580
560
540
520
500
480
460
Weight (kg)
a
ab
b
ab
Q1
Q2
Q3
Q4
Quarter

Figure 3.

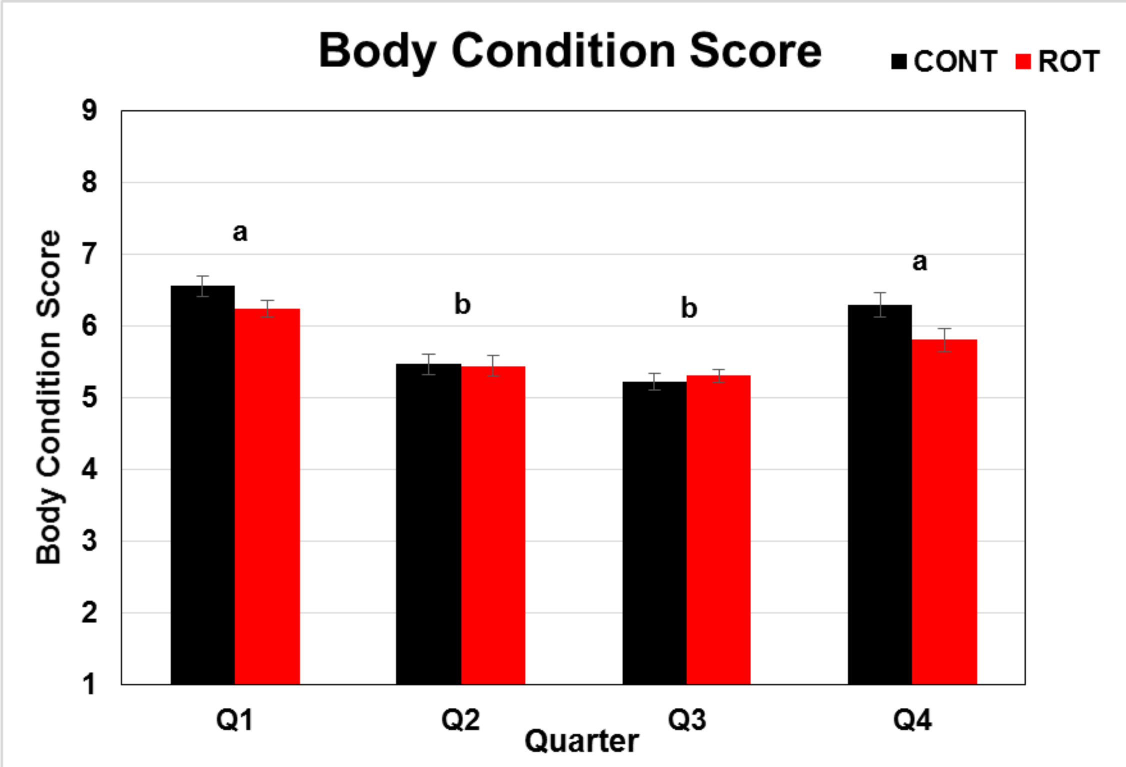
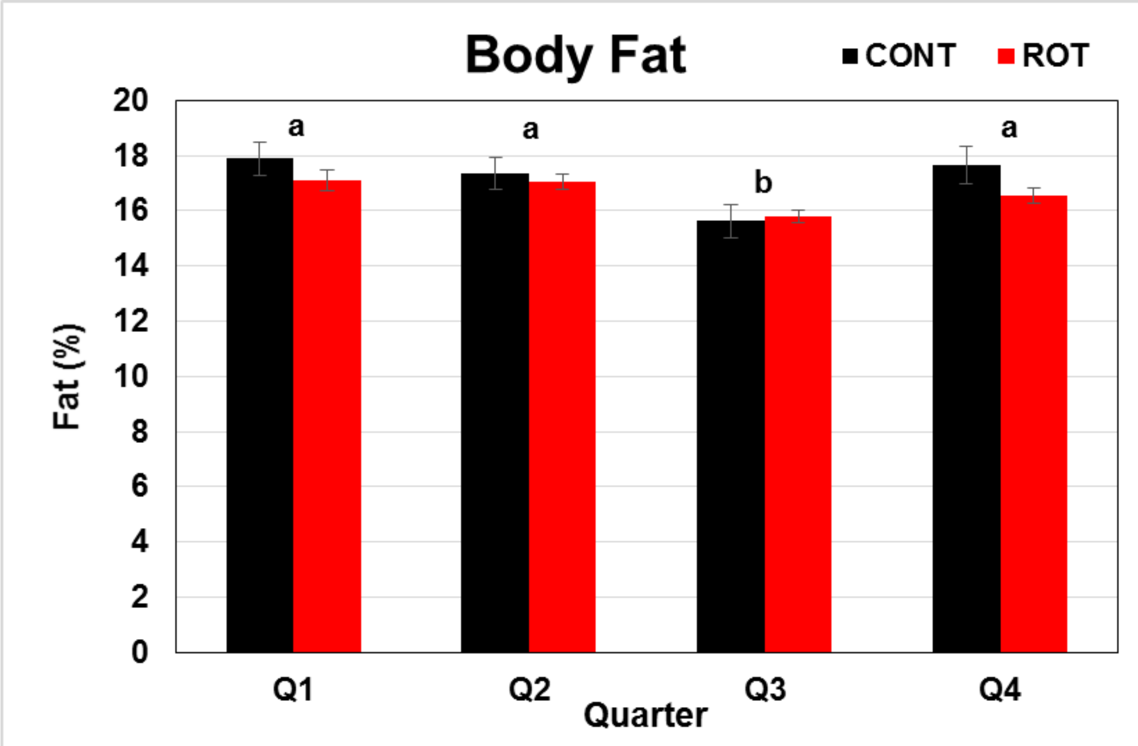

Body Condition Score
CONT
ROT
Body Condition Score
9
8
7
6
5
4
3
2
1
a
b
b
a
Q1
Q2
Q3
Q4
Quarter

Figure 4.



Body Fat
CONT
ROT
Fat (%)
20
18
16
14
12
10
8
6
4
2
0
a
a
b
a
Q1
Q2
Q3
Q4
Quarter

Figure 5.


Sward Height
CONT
ROT
Height (cm)
30
25
20
15
10
5
0
*
0
1
2
3
5
8
9
10
11
12
Month

Figure 6.

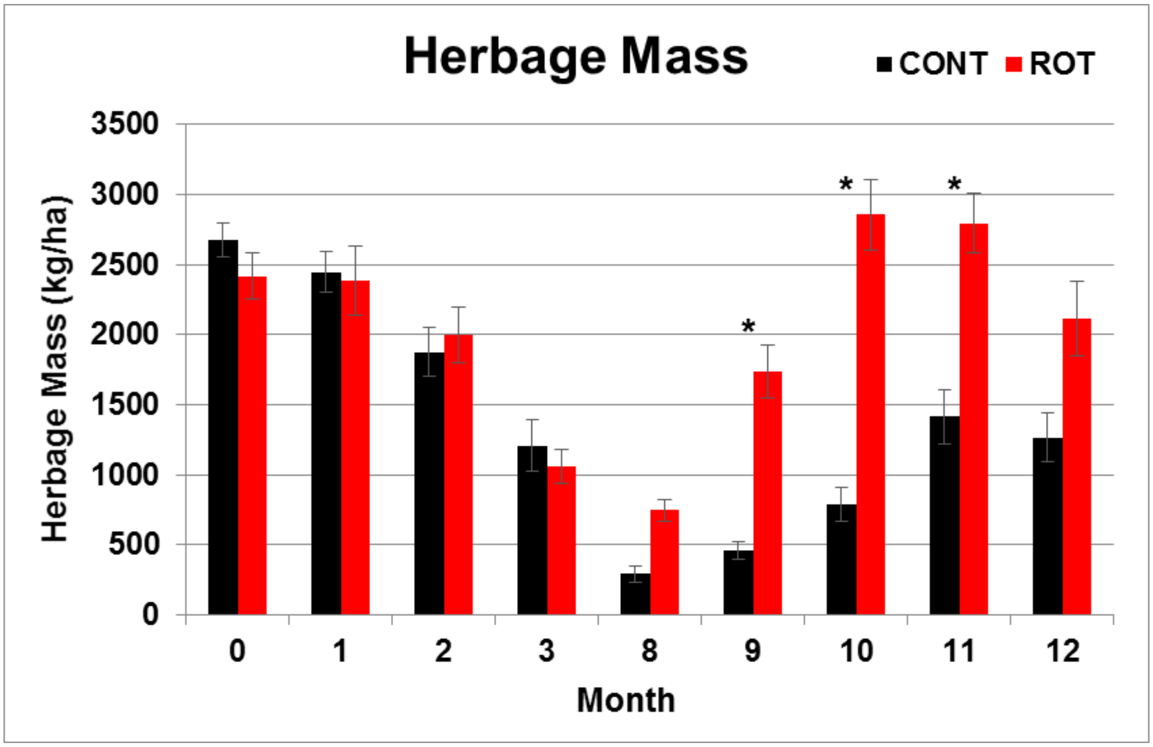

Herbage Mass
CONT
ROT
Herbage Mass (kg/ha)
3500
3000
2500
2000
1500
1000
500
0
*
*
*
0
1
2
3
8
9
10
11
12
Month

Figure 7.

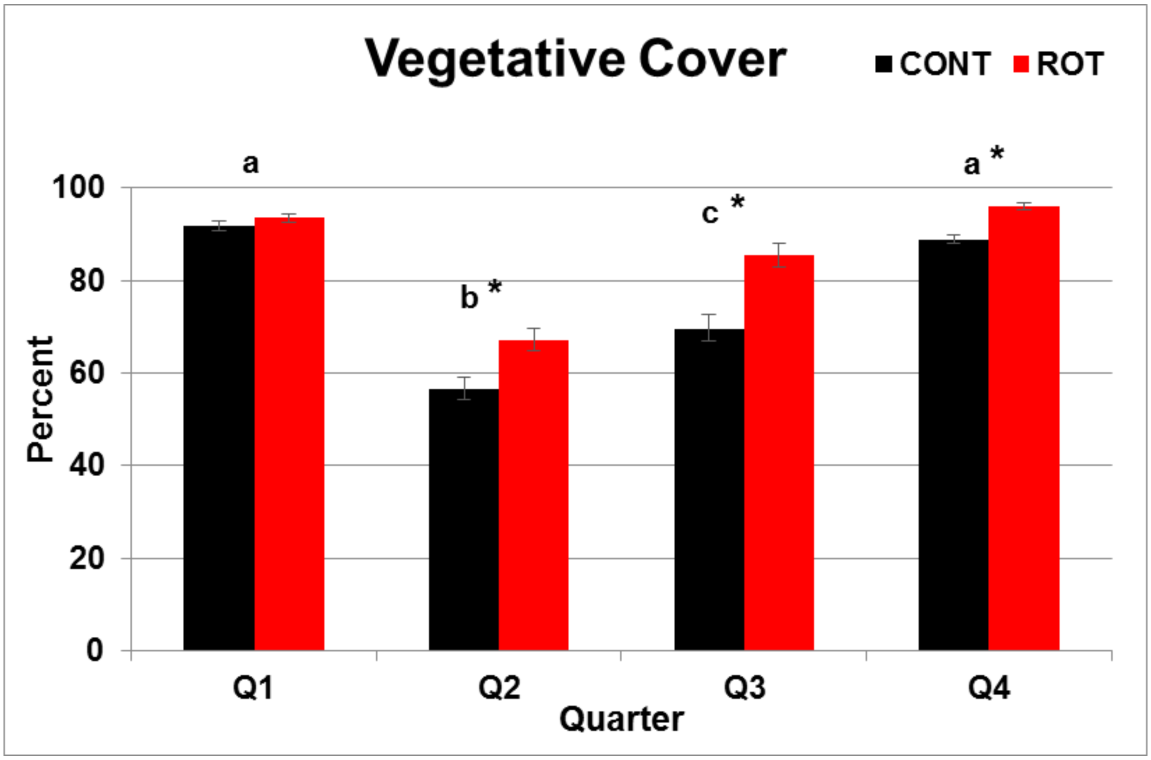
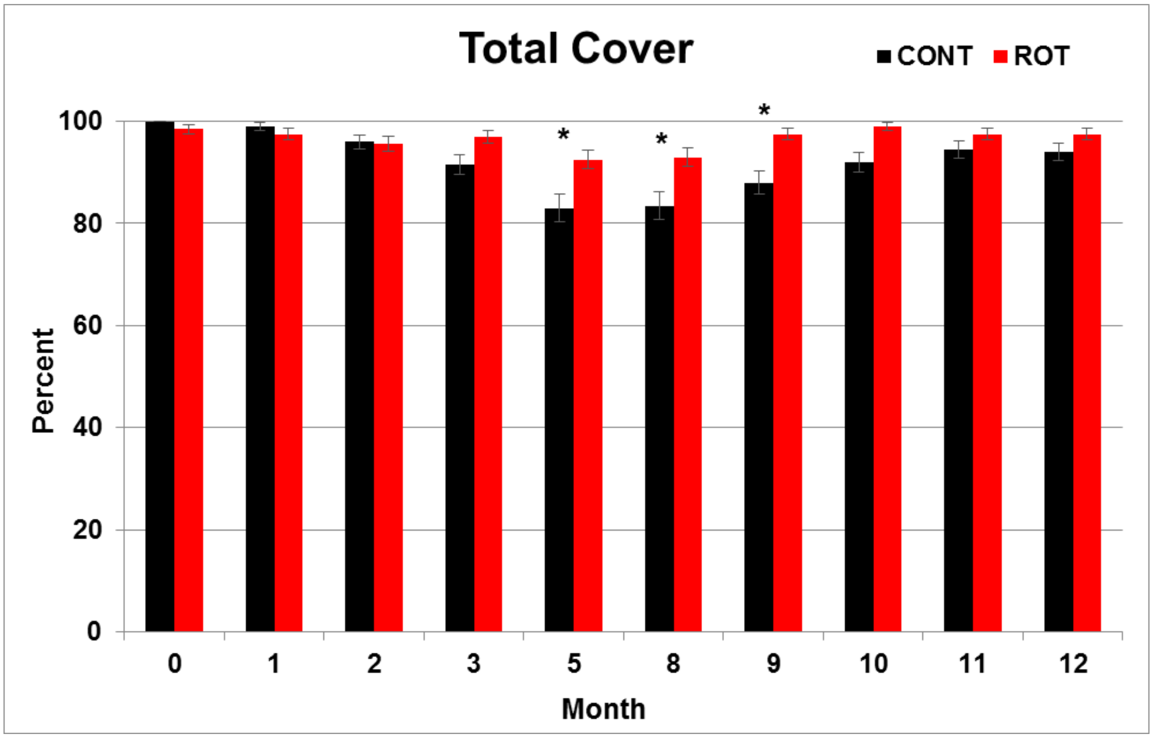

Vegetative Cover
CONT
ROT
Percent
100
80
60
40
20
0
a
b *
c *
a *
Q1
Q2
Q3
Q4
Quarter

Figure 8.


Total Cover
CONT
ROT
100
80
60
40
20
0
Percent
*
*
*
0
1
2
3
5
8
9
10
11
12
Month

Chapter Four: Effects of Equine Rotational and Continuous Grazing on Soil Properties

Abstract

The objective of this study was to examine the effects of rotational and continuous grazing of horses on soil fertility, bulk density, and hydraulic conductivity in pastures. The study established two replicates of rotational (ROT) and continuous (CONT) grazing systems (treatments) averaging 1.57 ha each. A total of 12 Standardbred mares were grazed for an overall stocking rate of 0.52 ha/horse. Recommended management practices for each grazing system were followed for 1 yr including 2 grazing seasons (September 2014 to August 2015). Soil fertility did not differ by grazing system, but some chemical components did differ between pre and post grazing ($P < 0.05$). Bulk density also did not differ between grazing systems or months, but did show significant differences by depth ($P < 0.0001$). Saturated hydraulic conductivity and α, an indicator of relative pore size distribution, were determined by tension infiltrometer and also displayed no treatment differences. The lack of differences between grazing systems and over time suggest that both systems have a similar effect on soil properties, but may also reflect a low stocking rate and short period of sampling. A heavier stocking rate could compact soils more and show greater effects on bulk density and hydraulic conductivity, and a longer sampling period would highlight the long-term effects of grazing horses.

Introduction

Grazing is an excellent way to meet the nutritional needs of horses and other livestock, but it has unavoidable effects on soil properties. The role of soil health in a pasture is critical, as it holds nutrients and water for the plants and affects root growth (Weinhold et al., 2001). Livestock grazing can alter soil properties including soil fertility, bulk density (BD), and water infiltration.

Adult horses can produce 23 kg of raw waste per day (Foulk et al., 2004). In one year, a single adult horse continuously on pasture will deposit 46 kg of N, 8 kg of phosphorus, and 32 kg of potassium on that field (Foulk et al., 2004). While plants will uptake some of the nutrients, an overstocked and overgrazed pasture will begin to build up nutrients and pose an environmental risk. Nitrogen and phosphorus in particular are the cause of eutrophication of surface water, a process in which excessive algae and plant growth pollute water bodies (Hubbard et al., 2004). The anion nitrate (NO_3^-) is not readily adsorbed to negatively charged clay particles and therefore tends to move with water flow. Phosphate (PO_4^{3-}) is also an anion, but it tends to bond with ions such as aluminum, iron, and calcium, which makes it less likely to move through the soil profile by leaching (Hubbard et al., 2004). Airaksinen et al. (2007) found greater phosphorus and nitrogen levels in water runoff from an uncleaned horse paddock compared to a paddock that regularly had manure removed. Horses also defecate in a specific pattern when turned out on pasture continuously; they graze some areas and eliminate in other areas, defined as a “lawn and rough” pattern (Odberg and Francis-Smith, 1976). Archer (1973) found that potassium oxide (K_2O) levels were over 300% higher in roughs than in lawns. The rotational grazing system proposed for horses has the potential to evenly spread out and even decrease nutrient deposition on pastures because horses rotate through several pastures and have access to a stress lot which is regularly cleaned of manure.

The force exerted upon a soil surface by a heavy animal like a horse can reduce pore space and compact soil. A cycle proposed by Manning (1979) describes the effects of trampling: leaf litter and organic components are removed from the soil surface, organic matter in the soil is reduced, soil becomes compacted, soil air and water permeability is reduced, water infiltration decreases, water runoff increases, and finally soil erosion increases which begins the cycle anew by preventing the accumulation of leaf litter. Bulk density and water infiltration are often measured to estimate the degree of soil compaction. A number of studies have demonstrated higher BD and lower infiltration rates with increasing trampling intensity (stocking rate) (Willatt and Pullar 1984; Abdel-Magid et al., 1987a; and Weinhold et al., 2001). Heavily trampled areas such as water sources have been shown to infiltrate water at 10 to 20% of the rates on un-trampled areas (Pietola et al., 2005). Soil texture can also play a role in water infiltration; Pietola et al. (2005) found that highly trampled watering areas on clay soils had lower infiltration rates than on sandy loam soils. They also found differences in BD between soil textures and soil profile depth.

Water infiltration rates are often converted to hydraulic conductivity. Hydraulic conductivity (K) describes the ease with which a fluid can move through a porous media and is determined by the properties of the media (such as structure and texture) and the fluid (density and viscosity) (Hillel, 2008). Saturated hydraulic conductivity (K_{sat}) refers to the constant value of K when a soil's pores are completely filled with water. This is difficult to achieve in the field, so a series of measurements can be taken in unsaturated conditions and used to estimate K_{sat} (Logsdon and Jaynes, 1993). Dry soil possesses a negative pressure potential (h) due to a combination of capillary and adsorptive forces that retain water inside soil pores, while pure water at a fixed elevation has a pressure potential of h = 0. Water moves from areas of high potential to low potential and has a physical affinity to soil, so dry pores have the ability to draw water into the soil matrix (Hillel, 2008). The hydraulic conductivity of unsaturated soil depends on the pressure potential of the pores in the soil and therefore cannot be compared across soils or pressure potentials. Tension infiltrometers work by applying suction to the soil-water interface of a water-filled disc (Perroux and White, 1988). A reservoir tower holds a volume of water and connects to the disc, while a bubble tower sets the tension and is connected by flexible tubing to the reservoir. The bubble tower contains an air inlet tube (a rigid straw) which is set below the surface of the water. When the reservoir tower is open to the disc and has its air inlet closed, the only way to allow water to drain is to replace the air in the head space. The pressure generated in the head space pulls air from the air inlet tube in the bubble tower. The rate at which air can be pulled from the bubble tower depends on how many cm the air inlet tube is set below the water surface.

The result of this system is that water will only flow into the soil if the pressure potential in the soil is lower than the pressure potential of the water in contact with the soil through the infiltrometer membrane. It also restricts water infiltration to smaller pores at the most negative tension, allowing water to flow into larger pores as the tension is reduced; the maximum pore diameter through water can flow is inversely proportional to the absolute value of the potential applied to the soil surface (Perroux and White, 1988). Water will infiltrate slowly at more negative tensions and faster as the tension approaches 0.

By taking infiltration measurements at several tensions, the K_{sat} of a soil may be approximated (Logsdon and Jaynes, 1993). Wooding (1968) developed a method to estimate steady-state unconfined infiltration rates from a circular source:

$$Q = \pi r_0^2 K \left[1 + \frac{4}{\pi r_0 \alpha} \right] \qquad [1]$$

Where Q is infiltration rate (V/T), r_0 is the radius of the infiltrometer disc, K is hydraulic conductivity (L/T), and α is a constant describing the soil's pore size distribution (Reynolds and Elrick, 1991). Gardner (1958) identified a relationship between unsaturated hydraulic conductivity and the pressure potential (or tension) of the soil:

$$K(h) = K_{Sat} \exp(\alpha h) \qquad [2]$$

Where $K(h)$ is unsaturated hydraulic conductivity (V/T) at pressure potential h, K_{sat} is saturated hydraulic conductivity (L/T), and α and h are the same as in Equation [1]. Equation [2] can be substituted into Equation [1] to estimate the expected infiltration rate given a certain h and when α and K_{sat} [$K(0)$] are known:

$$\frac{Q(h)}{\pi r_0^{\,2}} = K(0)\exp(\alpha h) + \frac{4K(0)\exp(\alpha h)}{\pi r_0 \alpha} \qquad [3]$$

When actual infiltration rates at several pressure potentials are known, a nonlinear least squared regression of the actual rates and the rates predicted by Equation [3] can be performed to estimate α and K_{sat} for all tensions (Logsdon and Jaynes, 1993).

To the author's knowledge, no previous studies have compared soil properties in rotational (ROT) vs. continuously (CONT) grazed pastures using horses, which have different physiology and grazing habits than other livestock species (Archer, 1973; Singer et al., 1999).

Research Objective and Hypothesis

Objective: To compare the effects of rotational and continuous grazing on soil properties.

Hypothesis: Rotational grazing will result in lower bulk density, higher hydraulic conductivity, and optimal soil fertility.

Materials and Methods

General Grazing System. The Rutgers University Institutional Animal Care and Use Review Board approved all methods and procedures used in this experiment (Protocol # 04-005). The study site was the Ryders Lane Best Management Practice Demonstration Horse Farm at Rutgers University, Cook Campus (Figure 1). Areas 2 and 3 (3.19 and 3.06 ha, respectively) were used, totaling 6.25 ha. These areas were previously used for grazing horses, and were chemically treated to eliminate the existing vegetation, plowed to a depth of approximately 18 cm, disced, and vegetation was reestablished starting in 2012. Soil fertility was adjusted to optimum with lime and fertilizer and pastures were seeded with Jesup MaxQ endophyte-free tall fescue (*Festuca arundinacea*; Pennington

Seed, Madison, GA) at 7.9 kg per ha, Camas Kentucky bluegrass (*Poa pratensis*) at 12.9 kg per ha, and Potomac orchardgrass (*Dactylis glomerata*) at 8.2 kg per ha (both from Chamberlin & Barclay, Cranbury, NJ). The following year, due to poor growth of the grasses, pastures were overseeded with the same species at 3.6 kg per ha, 14.5 kg per ha, and 7.3 kg per ha of the same seed, respectively, to establish a better stand. Pastures were maintained without grazing until August 2014 using mowing, chemical weed control, and nitrogen fertilizer as needed. Four grazing areas (two replicates of each grazing system) were established with fencing to be as equal in size as possible (Table 1). The ROT pastures are referred to as 2R and 3R, and the CONT pastures are referred to as 2C and 3C (Fig. 1). The CONT fields contained temporary run-in shelters, water sources, and hay feeders. The ROT fields contained 0.17 and 0.16 ha (2R and 3R, respectively) stress lots with permanent shelters, water sources, and hay feeders; and 4 pastures sectioned off using temporary horse-friendly fencing (electric tape).

The fields are primarily composed of FapA (Fallsington loams, 0 to 2 percent slopes, Northern Coastal Plain) with NknB (Nixon loam, 2 to 5 percent slopes) and NkrA (Nixon moderately well drained variant loam, 0 to 2 percent slopes). Fields 2R, 2C, and 3R are silty clay loams, and field 3C is a loam.

Baseline samples of soil fertility and bulk density were collected in July 2014 and horses were turned out in August 2014 at a stocking rate of 0.52 ha per horse as recommended by Singer et al. (2002) and Burk et al. (2011). Twelve Standardbred mares were used, aged 14 ± 2 yr, and 544 ± 47 kg body weight (mean ± SD); they were paired by body weight and body condition and randomly assigned to either the ROT or CONT grazing system.

Throughout the project, recommended pasture management practices were followed as they relate to each system (Foulk et al., 2004; Burk et al., 2011). Specifically, for the ROT system, horses were grazed when forage was taller than 15.2 cm and removed from pasture when reached 7.6 cm. The average length of grazing bouts was 10 days. Immediately after grazing (prior to the rest period), each pasture was dragged (to disperse manure) and mowed to a height of 10 cm. Continuously grazed pastures were mowed and dragged as needed to help control weeds and manure build up (approximately twice per growing season).

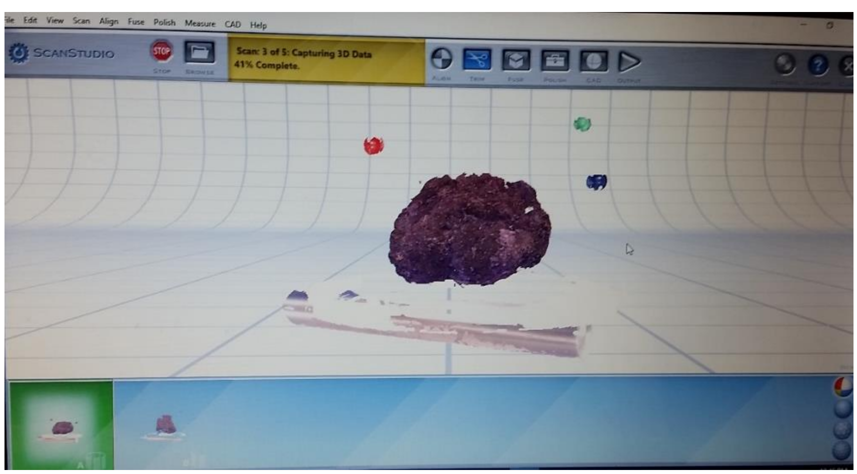
When ROT horses did not have adequate grass due to poor weather conditions (i.e. drought, snow, plant senescence), they were confined to a stress lot and fed hay to meet nutritional requirements (NRC, 2007). Continuous horses were offered hay when forage was low. During times of no pasture availability, hay was fed at 2% BW. Over the winter, horse condition decreased enough that supplemental concentrate was fed at the rate of 1.8 kg per horse (EQUI-PRO *E-TEC*, Poulin Grain, Newport, VT).

Soil fertility. Soil fertility was measured at the beginning and end of the study period. Twenty to 25 core samples of each field were collected using a soil sampling probe (Oakfield Apparatus Company, Oakfield, WI), mixed together to form 1 representative sample for each of the 4 fields, and analyzed by the Rutgers University Soil Testing Laboratory (New Brunswick, NJ) for pH, P, K, Mg, and Ca by Mehlich-3 extraction; cation exchange capacity (CEC) by the Ammonium Acetate (pH 7.0) method; soil textural class by hydrometer; and organic matter (OM), and organic C (OC) by dichromate oxidation (Gee and Or, 2002; NEC 10-12, 2011).

Collecting soil peds.

Bulk density. Bulk density was measured seasonally during the study period, in July 2014, October 2014, April 2015, and August 2015. Due to the rocky nature of the fields, core samples could not be extracted. Four holes were dug in each pasture using shovels, and then a slice of soil 15 to 20 cm wide was made parallel to the hole. Intact peds were collected from the 0 to 10 cm (plow layer) and the 35 to 40 cm (subsoil) layer of the slices, wrapped in aluminum foil, sealed in a plastic bag, and refrigerated until analysis.

Bulk density was calculated using an automated three dimensional laser scanner (NextEngine Desktop 3D Scanner Model 2020i, NextEngine, Inc., Santa Monica, CA) according to the method of Rossi et al. (2008).



3-D scan of a soil ped.

Ped volumes (Table 2) were calculated using MeshLab (open-source software developed at the Visual Computing Lab of the Institute of Information Science and Technologies [ISTI], an institute of the Italian National Research Council [CNR], Pisa, Italy). Peds were oven dried at 100 ºC for at least 24 hours and weighed, then all gravel (> 2 mm) was separated by grinding with mortar and pestle and sieving, and weighed. Bulk density was calculating using the equation from Rossi et al. (2008):

$$BD = \frac{W_p - W_g}{V_p - (W_g / 2.65)} \qquad [4]$$

Where W_p is the weight of the ped, W_g is the weight of the gravel, and V_p is the volume of the ped.

Hydraulic conductivity. Hydraulic conductivity was measured at the conclusion of the study using tension infiltrometers. It was intended to be measured at the beginning as well, but technical difficulties with sensors prevented getting this measurement. Eight readings were taken from each pasture system (2R, 3R, 2C, 3C). Four infiltrometers were run simultaneously on two different days, and temporary fencing was erected to keep CONT horses from disturbing the equipment.

Setting up 4 infiltrometers in a CONT pasture.

Tension infiltrometers with 20-cm stainless steel mesh discs (Soil Measurement Systems, Tuscon, AZ) were first calibrated to determine air entry tube settings. Normally the air entry tube should be adjusted 4 cm lower than the desired tension because the bottom of the water reservoir is 4 cm higher than the bottom of the disc when they are on a level surface. However, after setting up a manometer out of flexible tubing and an air vacuum, it was determined that the adjustment factor for each infiltrometer should be 3 cm instead of 4 (Appendix 1).

Next, differential pressure transducers (26PCAFA6D, Honeywell, Morris Plains, NJ) were calibrated to the infiltrometers (Appendix 2). Field measurements were taken by running 4 infiltrometers at once, twice per pasture. All infiltrometers were connected to a CR-1000 data logger (Campbell Scientific, Logan, UT), which was powered by a 10 Watt solar panel (410M, Ameresco Solar, Middle River, MD) and took readings every 30 seconds. The data logger was housed inside a container to keep it safe from the elements.

Vegetation was clipped to ground level and the ground was leveled by scraping. A 20 cm ring was placed on the level ground and nearby soil was sieved, placed in the ring, and leveled again to ensure even contact with the disc. The ring was removed, and the prepared soil surface was lightly sprayed with water. The infiltrometer disc, which had been soaked in water overnight to saturate the stainless steel mesh, was connected to the infiltrometer water reservoir and placed on the prepared soil surface. Tension at the disc surface was set to -15 cm by adjusting the bottom of the air entry tube in the bubble tower to 18 cm below the water surface (15 cm plus the 3 cm adjustment determined by calibration). Discs and infiltrometers were leveled. Making the bottom of the infiltrometers level with the bottom of the discs was too difficult; therefore photographs were taken of the difference in height between the two in order to adjust actual pressure potential for calculations. The infiltrometers were run for 1 h at -15 cm, -10 cm, and -5 cm and 30 min at -3.5 cm and -1 cm. The values for the -1 cm tension had to be dropped because the stronger water flow at the last two tensions deteriorated the sharp edges of the prepared soil surface and even contact was lost, resulting in inconsistent water flow rates. The data logger recorded the panel temperature, and water temperature within the water reservoirs was measured with an analogue thermometer between each tension. However, thermometer temperature was not measured during all runs of the infiltrometers, so a polynomial regression of thermometer temperature versus panel temperature was plotted to generate a calibration equation used to estimate actual water temperature based on panel temperature. The calibration equation was $y = -0.1186x^2 + 8.4999x - 113.04$ with an R^2 of 0.6658.

Infiltrometer data analysis. Volume output from the CR-1000 was read using and LoggerNet software (Campbell Scientific, Logan, UT) and separated by infiltrometer and tension. The volume was standardized to the area through which it infiltrated by dividing by the area of the disc, giving infiltration in cm. The insensitivity of the transducers resulted in stepwise data when plotted against time, so the infiltration data was subjected to a moving average to smooth out the line. Adjusted infiltration was then plotted against time to give a linear equation for infiltration rate for each tension and infiltrometer. The slope of the line was considered to be the infiltration rate in cm/hr. Next, the infiltration rate was standardized to a water temperature of 35º C, which was the average temperature observed during measurements, because temperature can affect the rate of water flow. Either the actual temperatures recorded with a thermometer or the temperatures estimated using the panel temperature (see above calibration equation) were used as x in the equation (Iwata et al., 1988):

$$K_{35} = K_x \left(\frac{v_x / d_x}{v_{35} / d_{35}} \right) \qquad [5]$$

Where K_{35} is the adjusted infiltration rate with 35 ºC water, K_x is measured infiltration rate, v_x is viscosity of water at xº C, d_x is density of water at xº C, v_{35} is viscosity of water at 35º C, and d_{35} is density of water at 35º C.

A nonlinear least squared regression of the standardized infiltration rates and the rates estimated by Equation [3] was performed to estimate α and K_{sat} for all tensions (Logsdon and Jaynes, 1993). The Solver function in Microsoft Excel (Microsoft Corp., Redmond, WA) was used to estimate α and K_{sat} for each infiltrometer by minimizing the sum of the squared residuals.

Statistical analysis. All statistics were analyzed in R (R Foundation for Statistical Computing, Vienna, Austria). Soil fertility data was analyzed for differences between treatment, year, and treatment by year interaction using ANOVA. Bulk density, K_{sat}, and α data had major outliers removed (3 times the interquartile difference) and were tested for normality using PP Plots in R (Appendix 3). Saturated hydraulic conductivity was not normal, but was normal when log-transformed, so log(K_{sat}) was used for analysis by ANOVA. Bulk density was analyzed for differences between treatments, depths, months, and interactions, and hydraulic conductivity and α were analyzed for differences between treatments.

Results

Soil fertility. There were no treatment or treatment by year differences, but some yearly differences were observed among the soil chemical composition. Magnesium, Ca, OM, and OC were significantly different before and after grazing (P < 0.05; Table 2).

Bulk density. There was no difference between treatments (P = 0.739) or months (P = 0.737) for BD (Figure 2). Mean BD in CONT pastures was 1.44 ± 0.03 g/cm^3 and mean BD in ROT pastures was 1.45 ± 0.02 g/cm^3. There were significant differences in BD by depth (P < 0.0001), but no treatment by depth effect (P = 0.337). Mean BD at 0 to 10 cm was 1.34 ± 0.02 g/cm^3 and mean BD at 35 to 40 cm was 1.56 ± 0.02 g/cm^3 (Figure 3).

Saturated hydraulic conductivity. There were no significant differences between treatments for log(K_{sat}) (P = 0.070) or α (P = 0.166). Mean K_{sat} in CONT fields was 0.52 ± 0.09 and mean K_{sat} in ROT fields was 1.29 ± 0.39. Mean α in CONT fields was 0.071 ± 0.011 and mean α in ROT fields was 0.105 ± 0.023 (Table 3).

Discussion

Soil fertility. The lack of overall treatment difference in chemical composition could reflect the fact that pre (2014) and post (2015) grazing samples were combined. However, the lack of treatment by year interaction also indicates that each chemical component did not differ by treatment even when years were compared. It is important to note that there were only 2 representative sample values per treatment, so this test is not robust. More relevant results may have been seen if several soil samples were taken from each field rather than one representative sample. The literature suggests some more reasons why differences may not have been observed and a suggestion for why differences may be observed in future years.

Teague et al. (2005) found higher CEC and OC in “multi-paddock” (ROT) grazing of sheep compared to light and heavy CONT grazing. However, this study compared farms that have historically used these grazing systems. Perhaps additional years of sampling will be necessary to see changes by treatment in the present study. Singer et al. (2001) compared soil chemical properties by stocking rate in NJ horse pastures, also comparing farms that have historically been managed at a certain stocking rate. They found that P was above optimum (70 ppm) in all stocking densities. While there was not a statistically significant difference in P between years in the present study, the mean P value in year 2 had risen to this optimum value (71 ± 5 ppm), likely due to the addition of P in horse manure. According to Singer et al. (2001), soil pH means across stocking rates ranged from 5.88 ± 0.05 to 6.16 ± 0.06. The pH range observed in the present study was similar (5.96 to 6.61), although Singer et al. (2001) presented means, therefore the actual range of values would be wider. It is unclear whether means were calculated on the log-transformed pH values or if they were backtransformed prior to calculating the means. Interestingly, OM reported by Singer et al. (2001) was lowest in the high stocking density pastures (0.16 to 0.24 ha/animal), which likely had a large quantity of manure deposited. Organic matter values in year 2 of the present study (6.16%) were similar to the highest value observed by Singer et al. (2001) (6.56%). Lastly, Airaksinen et al. (2007) suggests a mechanism for why differences in grazing system may be expected. They found that horses tend to defecate in feeding areas of paddocks. In the rotational systems of the present study, the feeding areas were within stress lots, therefore much of this manure was not deposited in the pasture areas that were sampled.

The elevated Mg, Ca, OM, and OC in post-grazing samples are likely due to the addition of horse manure to the soil over the year of grazing. Horse manure is an excellent source of OM that is often used as a soil amendment to improve agricultural soils, and OC makes up a fraction of OM. Despite the raised levels of OM, Mg, and Ca, CEC did not increase between years. This could be due to the fact that other cations which contribute to CEC were not reported on a standard soil test and may not have changed over the year.

Bulk density. Increases in BD have been observed with increasing stocking rate (Willat and Pullar, 1984; Holt et al. 1996), trampling levels (Pietola et al., 2005), and by grazing system (Proffitt et al., 1995) and season (Abdel-Magid et al., 1987; Bormann and Klaasen, 2008). Abdel-Magid et al. (1987) suggest that sandy soils are less prone to compaction than clay soils. In the present study, no differences were seen between treatments for BD, similar to work by Teague et al. (2005) who compared "multi-paddock" (ROT) grazing with light and heavy stocked CONT grazing of sheep. Abdel-Magid et al. (1987) also found that BD was not affected by grazing system or stocking rate in 2 years of study. However, BD was lower in the spring than the fall during year 2, which may be explained by freeze-thaw cycles remediating the soil compaction. While freeze-thaw cycles may have played a role in soil compaction in the present study, it is more likely that the stocking rate was not heavy enough to cause significant compaction. At the time of the first sampling, pastures had been ungrazed for 2 years. Greenwood et al. (1998) determined that soil recovery from sheep grazing may be rapid, as similar BD was found in pastures that had not been grazed in 2.5 year and 27 years. Additionally, the soils in the present study had been plowed to approximately 18 cm 2 years before grazing began, destroying any long-term effects of grazing in the topsoil layer. The fact that there were no monthly differences suggests that the stocking rate was indeed too low to compact the soil above baseline values. A meta-study by Beylich et al. (2010) determined that BD above 1.7 g/cm^3 is detrimental to soil microbial biomass and C mineralization. Mean monthly BD in the present study ranged from 1.36 ± 0.05 to 1.52 ± 0.04 g/cm^3, suggesting that the stocking rate did not have harmful consequences on soil biota.

Bulk density has been shown to differ significantly by depth, though not consistently. Pietola et al. (2005) found that in a clay soil trampled by cattle, BD was lower in the surface layer of soil, while a trampled sandy loam had higher BD at the surface. Once again, the pastures in the present study were plowed to a depth of 18 cm before grazing, which breaks up soil structure. This may account for the lower BD observed in the surface layer. However, two other factors that were observed were the presence of plant roots and a dark, crumbly appearance to most of the plow layer samples, and a sticky, clay texture in most of the subsoil samples. This suggests that OM content and soil texture may also have influenced the BD values. Duplicate peds taken for BD analysis have been sent for texture analysis, but results were not ready at the time of writing.

Saturdated hydraulic conductivity and α. The average K_{sat} values (0.52 ± 0.09 cm/h for CONT and 1.29 ± 0.39 cm/h for ROT) are higher than the range reported by Hillel (2008) for a clay soil, 0.0036 to 0.36 cm/h, and lower than the range for a sandy soil, 3.6 to 36 cm/h. Because the soils in the present study are loams and silty clay loams, these values appear to be within ranges found in the literature. The K_{sat} values reported by Web Soil Survey (2015) for FapA, NknB, and NkrA are 216, 3.3, and 3.3 cm/h, respectively. These values are higher than those observed in the present study and correspond more closely to the sandy soil values suggested by Hillel (2008). However, it does suggest that the dominant soil type and minor soil types present in the pastures may have influenced the K_{sat} values. Saturated hydraulic conductivity ranged from 1 to 5 cm/h in silty loam soils measured by Zhang et al. (2006).

Alpha values appear to increase numerically as K_{sat} values increase, which is appropriate as α should increase with increased macropore flow. According to Reynolds et al. (1995), tensions ranging from 0 to -15 cm represent the range at which water will flow through macropores. These macropores transport water at a faster rate than micropores using capillary flow, which would be measured at lower tensions. No treatment differences were observed in α, which suggests that both continuous and rotational pastures had similar pore sizes and numbers.

The lack of significant differences seen in log(K_{sat}) and α are likely linked to the lack of differences in BD. Zhang et al. (2006) measured K_{sat} in the laboratory on soil cores mechanically compacted to different bulk densities, and found that K_{sat} was reduced by the highest compaction level in 1 soil type and by all levels in another soil type, indicating that compaction can have a strong influence on hydraulic conductivity. Field studies have resulted in similar conclusions (Bormann and Klaasen, 2008; Zhou et al., 2008). Other researchers measured water infiltration rates, which should be compared only within studies due to the various factors affecting the rates, which are minimized by calculating K_{sat}. However, Abdel-Magid et al (1987) and Pietola et al. (2005) did observe changes in infiltration rates by grazing systems and years. In contrast, Proffitt et al. (1995) did not find any difference in infiltration rate by grazing system despite observing changes in BD. However, infiltration rate was calculated using only 1 tension on a disc permeameter, and other studies have found that significant differences in infiltration can exist using some tensions but not others (Zhou et al., 2008). This is why the present study calculated overall K_{sat} instead of evaluating the infiltration rate of each tension individually.

Hydraulic conductivity was difficult to measure in the field using the tension infiltrometer. A level soil surface was carefully prepared, but often lost its integrity during tension adjustments. After the tension was adjusted and the valve allowing water from the reservoir into the disc was reopened, water would rush out until the desired tension was reached in the head space of the reservoir. This rapid water flow may have eroded the sharp edges of the prepared soil surface, altering contact between the disc and soil surface and potentially affecting infiltration rates. Additionally, during several measurements, the infiltration rate of a single infiltrometer did not follow the expected pattern of increased infiltration with decreased tension. In cases where rates at -15 cm and -10 cm tensions were similar, it could be due to the pressure potential of the soil being somewhere between those two values. Additionally, Bormann and Klaasen (2008) and Zhou et al. (2008) reported that K_{sat} has high small-scale spatial variation, which can contribute to less significant differences when means are compared. If K_{sat} values are to be compared across time periods, care should be used to measure the same locations; however Bormann and Klaasen (2008) also reported significant seasonal changes in K_{sat} in some soils.

Conclusion

Overall, this study did not detect differences in soil physical properties between grazing systems. One possible explanation for the lack of change could be that the stocking rate (ha per animal) was not high enough to produce notable effects on the soil. Another possibility is that one year is not enough time for grazing to have significant effects, and studies should track pastures for longer periods of time. The results of this 1 year study do not support the recommendation to practice rotational grazing to protect soil quality.

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Tables

Table 1. Sizes of continuous and rotational fields at the Ryders Lane Best Management Practices Horse Farm in New Brunswick, NJ, used for a grazing trial. Continuous fields are denoted “C” and rotational fields are denoted “R.” Values in the “Rotational Fields” column are the size of each of the four grazing units in that system; all four are equally sized.

Field	Total Size, ha	Rotational Fields, ha
2C	1.61	
2R	1.59	0.40
3C	1.58	
3R	1.50	0.37

Table 2. Soil chemical composition before and after one year of rotational and continuous grazing by horses in New Brunswick, NJ. All components had no differences by grazing system treatment, so treatments were combined. Data are presented as the means ± SEM and pH is presented as a range of values.

Component[1]	**2014**	**2015**	**P-value**
pH	5.96 to 6.61	6.17 to 6.48	0.72
P, ppm	53 ± 8	71 ± 5	0.146
K, ppm	107 ± 11	171 ± 23	0.0635
Mg, ppm	214 ± 10	256 ± 6	0.003
Ca, ppm	1140 ± 61	1425 ± 60	0.023
CEC, %	15.0 ± 0.6	15.3 ± 0.7	0.759
OM, %	4.4 ± 0.5	6.2 ± 0.4	0.0395
OC, %	2.6 ± 0.3	3.6 ± 0.3	0.0477

[1] P, phosphorus; K, potassium; Mg, magnesium; Ca, calcium; CEC; cation exchange capacity; OM, organic matter; OC, organic carbon.

Table 3. **S**aturated hydraulic conductivity (K_{sat}) and α means by treatment in horse pastures in New Brunswick, NJ at the conclusion of a one year grazing trial. Treatment CONT is continuous grazing and treatment ROT is rotational grazing. Data are presented as the means ± SEM.

Treatment	**K_{sat} (cm/hr)**	**α**
CONT	0.52 ± 0.09	0.071 ± 0.011
ROT	1.29 ± 0.39	0.105 ± 0.023

Figure Captions

Figure 1. Map of pasture layout at the Ryders Lane Best Management Practices Horse Farm in New Brunswick, NJ. Black lines indicate permanent fencing and white lines indicate temporary electric tape fencing separating rotational fields. The 3R stress lot connects to a laneway with openings into each rotational field. The 2R stress lot has gates opening into each rotational field. Continuous fields are denoted “C” and rotational fields are denoted “R.”

Figure 2. Bulk density of soil in horse pastures used in a grazing trial in New Brunswick, NJ by treatment and month. August and October measurements were in 2014 and April and July measurements were in 2015. Treatment CONT is continuous grazing and treatment ROT is rotational grazing. Data are presented as the means ± SEM.

Figure 3. Bulk density of soil in horse pastures used in a grazing trial in New Brunswick, NJ by treatment and depth. Treatment CONT is continuous grazing and treatment ROT is rotational grazing. Data are presented as the means ± SEM. Bars with different letters differ at $P < 0.05$.

Figures

Figure 1.

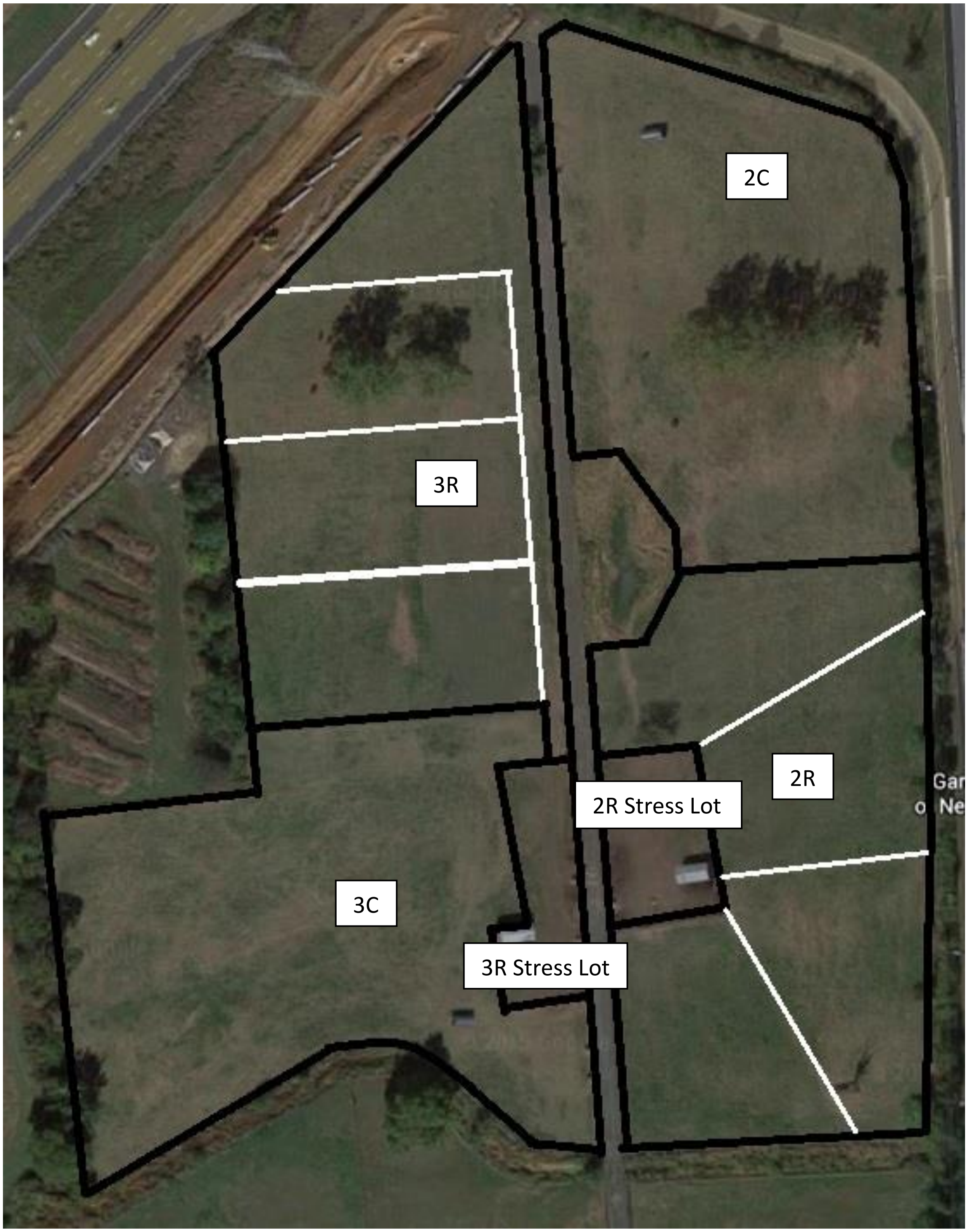


Figure 2.

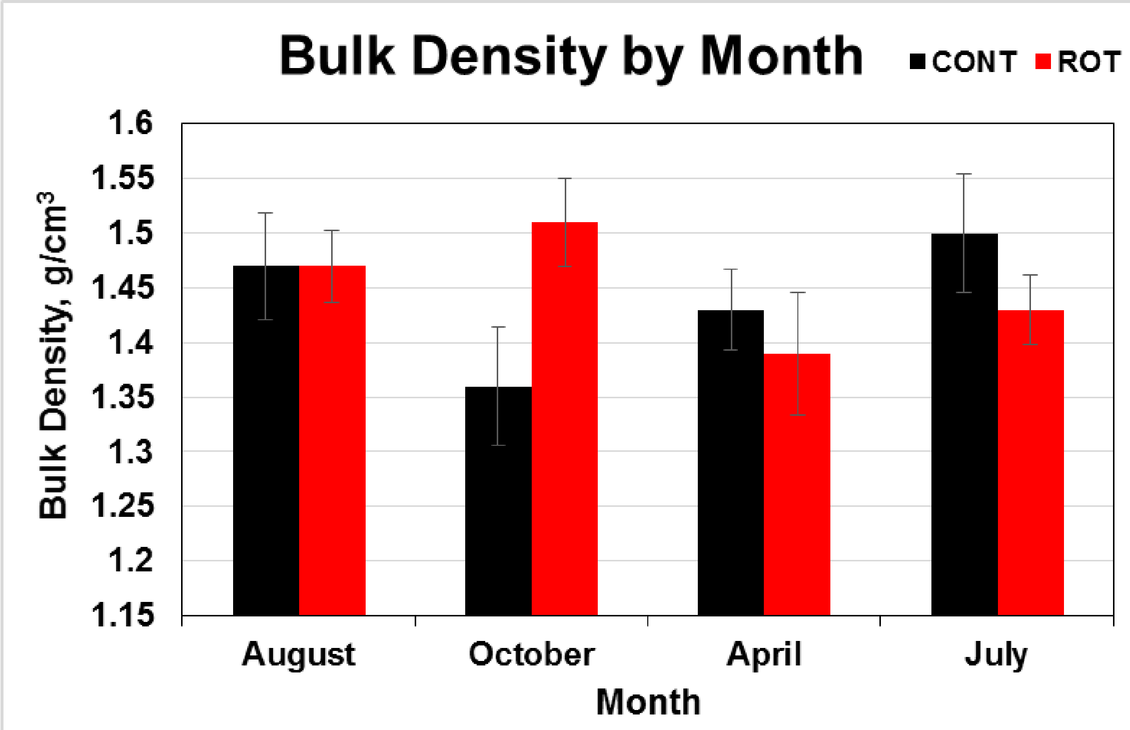
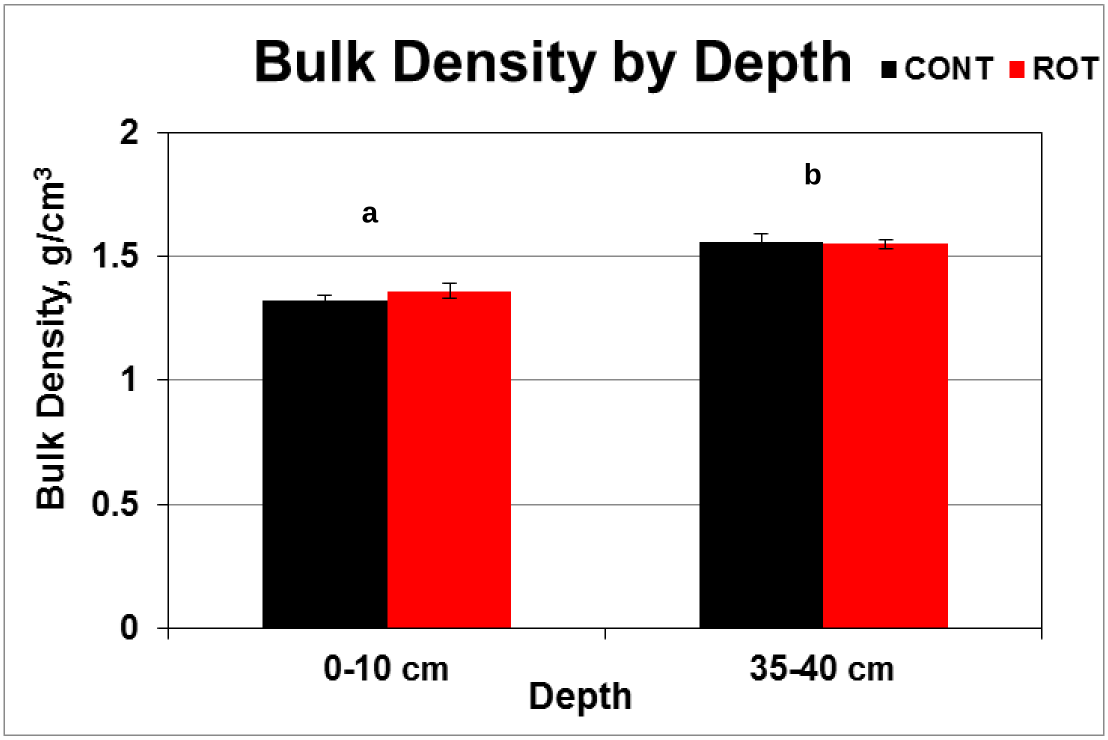

Bulk Density by Month
CONT
ROT
Bulk Density, g/cm3
1.6
1.55
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
August
October
April
July
Month

Figure 3.


Bulk Density by Depth
CONT
ROT
Bulk Density, g/cm3
2
1.5
1
0.5
0
a
b
0-10 cm
35-40 cm
Depth

OVERALL DISCUSSION AND SUMMARY

This series of experiments represents the first study to comprehensively examine the effects of rotational (ROT) and continuous (CONT) grazing on horse, pasture, and soil in controlled, replicated treatments. The first step was selecting methodology for each variable measured, which was straightforward except for species composition. Three possible methods had been identified and determined as feasible. Each had been compared to other methods in the literature, but never all 3 against one another. Thus, the first step was to evaluate the methods for estimating species composition. Statistical analysis of overall and mean bias in species prevalence detection showed that the 3 methods (one method was practiced using 2 different techniques) agreed well enough to be used interchangeably in a lush, improved cool-season horse pasture. Therefore, the method with the greatest ease of use, Step Point, was selected.

One year of sampling revealed that horse condition was not affected by grazing system. Body weight, body condition score, and body fat percentage did not differ by treatment, but quarterly effects were observed as all horses showed a general increase in condition in the grazing months, likely due to the seasonal fluctuations in pasture nutrient content and limited hay intake during the winter. However, during the winter months, horse condition was ideal, meaning that grazing high-quality pasture in either system caused them to be overweight during the grazing season. Global positioning system (GPS) tracking of horses showed no difference in voluntary movement between the two grazing systems, and ROT horses appeared to spend less time in grazing areas, although this may be due to poorly defined loafing areas in CONT pastures.

Pasture condition was significantly impacted by grazing system. Sward height, herbage mass, vegetative cover, and total cover were higher in ROT pastures. This effect was expected since ROT grazing is managed to maximize pasture productivity. However, the differences observed in pasture productivity did not translate into higher pasture feed quality or increased horse condition. There were no treatment differences in nutritional content despite higher swards and increased herbage mass. This could be due the fact that higher, more mature swards that were sometimes offered to ROT horses generally have lower quality than shorter, vegetative swards. Seasonal fluctuations were seen in pasture variables, as would be expected.

Total cover and vegetative cover were both higher in ROT pastures, representing the proportion of bare soil that is covered by anything and by green foliage, respectively. These values remained above the recommended 70% level for all pastures except for vegetative cover in the early winter, when most plants had become senescent and were no longer green. When treatment by quarter effects were examined, the final grazing season showed that sward height, herbage mass, vegetative cover, and total cover was significantly higher in ROT fields. This suggests that the pasture variables were not affected by horse grazing immediately; rather, the process of pasture deterioration is slow when all fields begin in excellent condition. Some forage species differed by treatment, including the tall grass tall fescue, which was higher in ROT pastures, and the sod grass creeping bentgrass, which was higher in CONT pastures. Other desirable grass species orchardgrass and Kentucky bluegrass did not differ by treatment, yet there was a higher proportion of weeds in ROT pastures. The higher proportion of weeds does not reflect a lower proportion of desirable grasses, so it may reflect a lower proportion of grass weeds, plant residue, bare ground, and other combined.

Pasture production cost also did not vary by treatment, with similar amounts of hay fed and similar costs of mowing and dragging work. It is possible that the CONT horses did not require as much hay as expected because those pastures remained lush into the early winter as a result of little pasture damage over the first grazing season. The accumulated damage to the pastures over several more grazing seasons could cause the CONT horses to require hay supplementation earlier in the fall season in coming years.

Soil measurements also showed no effect of grazing system. Soil fertility showed some differences between pre and post grazing, which likely represent manure additions to the soil over a year of horse turnout. Soil bulk density and hydraulic conductivity were expected to show effects of increased soil compaction, but that did not occur. It is possible that the recommended stocking rate used on these pastures was not high enough to cause compaction. This would lend credibility to the stocking rate recommendation used for this study. However, other possibilities include soil remediation by freeze-thaw and wetting-drying cycles or the year of sampling not being long enough to see compaction effects.

Considering all of the data together, it is clear that damage to soil properties did not cause the vegetation effects observed. Therefore, the vegetation differences must be due to effects inherent to the grazing systems, such as the rest and regrowth period allowed to ROT pastures or the continual overgrazing and trampling of plants in the CONT pastures. Horse grazing appeared to have an overall positive impact on soil fertility, as it increased levels of organic matter and organic C in the soil, which increases soil water-holding capacity and adsorbs ions, holding nutrients in the root zone for plants. Despite the promising differences observed in pasture condition, they did not translate into differences in horse condition. Because horses were supplemented with hay and feed to maintain body condition, the only way a treatment effect would manifest is in increased condition during the grazing seasons. During the first grazing season, all pastures were very high quality and few differences were seen between them, suggesting that no differences would be observed in horse condition. During the second grazing season, a decline in CONT pasture condition started to become apparent, though there was still enough forage to provide adequate nutrition for horse condition to increase. It is likely that a second year of sampling would further elucidate the trends that are just beginning to develop at the end of the first year. If CONT pasture condition continues to decline while ROT pastures remain productive, it could mean more hay supplemented to CONT horses to maintain body weight and a lower scale body condition increase during grazing seasons. Further decreased vegetative and ground cover in CONT pastures could decrease the presence of plant roots and increase erosion, which could result in effects on soil properties. Overall, this study sheds light on important horse-vegetation-pasture interactions, but requires a second and possibly third year of observation to truly understand the potential effects of ROT and CONT grazing systems.

Appendix 1

Method used to calibrate infiltrometer air inlet tube adjustment factor.

The position of the air entry tube in the bubble tower sets the tension to be applied to the soil-water interface on the disc. However, the bottom of the bubble tower is located 4 cm above the soil-disc interface, assuming they are placed level with one another. Normally, a 4 cm adjustment factor would be used to ensure the correct tension, but it is good practice to calibrate the adjustment factor in the laboratory.

A manometer was set up to perform this calibration. The disc was detached from the infiltrometer and a long piece of flexible tubing was attached in its place. The infiltrometer was placed on a countertop and the tubing was looped through cabinet handles such that it was oriented downward, then made a 180° turn and returned to the level of the counter surface, forming the manometer. A meter stick was placed parallel to the upward tubing, oriented with 0 at the height of the benchtop. The water reservoir and bubble tower were filled and the valve to the tubing was opened to push all air out of the tubing, then closed again. A regulated vacuum source was attached to the air inlet on the water reservoir and adjusted until a slow flow of bubbles were drawn from the bubble tower. The valve to the tubing was reopened, and the water level in the upward side of the loop settled at a certain height, which represents actual surface tension at the soil-disc interface. The air entry tube in the bubble tower was adjusted until the manometer read the desired tension (i.e. -5 cm of tension equates to 5 cm below the countertop). Then the distance of the air entry tube below the water surface was recorded and the difference between the two distances was calculated. This was repeated for tensions of -10 and -15 cm for each infiltrometer. The results of the manometer calibrations indicated that the difference between actual surface tension at the soil-disc interface and tension set in the bubble tower averaged 3 cm for each tension on each infiltrometer.

Appendix 2

Calibration of the infiltrometers to the pressure transducers

Transducers were installed via flexible tubing with one end attached to an outlet at the bottom of the water reservoir column and the other end attached to the head space at the top of the water reservoir column to read the differential voltage. Infiltrometers were filled with water, and water height was recorded with corresponding voltage reading from a CR-1000 data logger (Campbell Scientific, Logan, UT) and LoggerNet software (Campbell Scientific, Logan, UT). Some water was drained and another set of readings were recorded. Twenty to 26 readings were taken per infiltrometer and plotted against one another to yield a linear equation. This equation was then programmed into LoggerNet to produce water height and volume output readings for each infiltrometer. It was found that the transducers were not as sensitive as desired, with several centimeters of water draining between voltage changes.

Appendix 3

Probability-probability (PP) plots for bulk density, saturated hydraulic conductivity, log-transformed saturated hydraulic conductivity, and α data

Figure Captions

Figure A.1. PP plot indicating normality of bulk density data (with major outliers removed) for soils in pastures grazed by horses.

Figure A.2. PP plot indicating lack of normality for K_{sat} data (with major outliers removed) for soils in pastures grazed by horses.

Figure A.3. PP plot indicating normality of log(K_{sat}) data (with major outliers removed) for soils in pastures grazed by horses.

Figure A.4. PP plot indicating normality of α data (with major outliers removed) for soils in pastures grazed by horses.

Figure A.1.

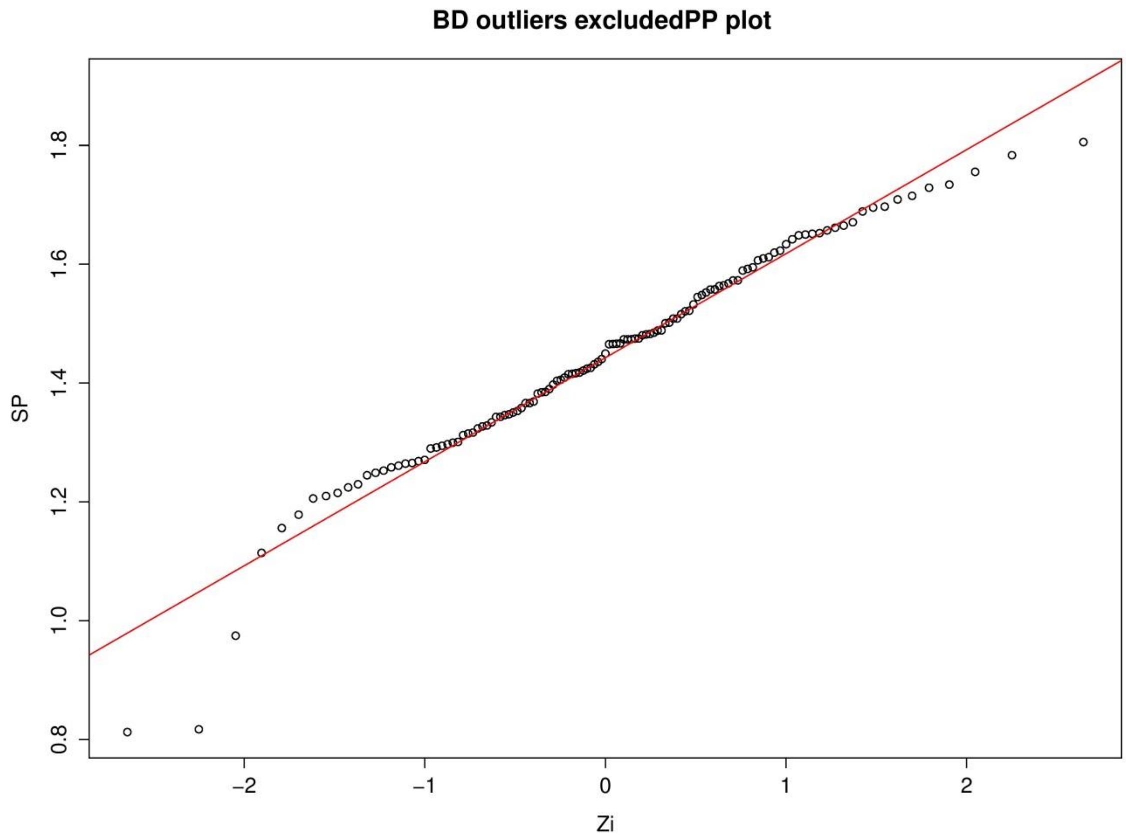


Figure A.2.

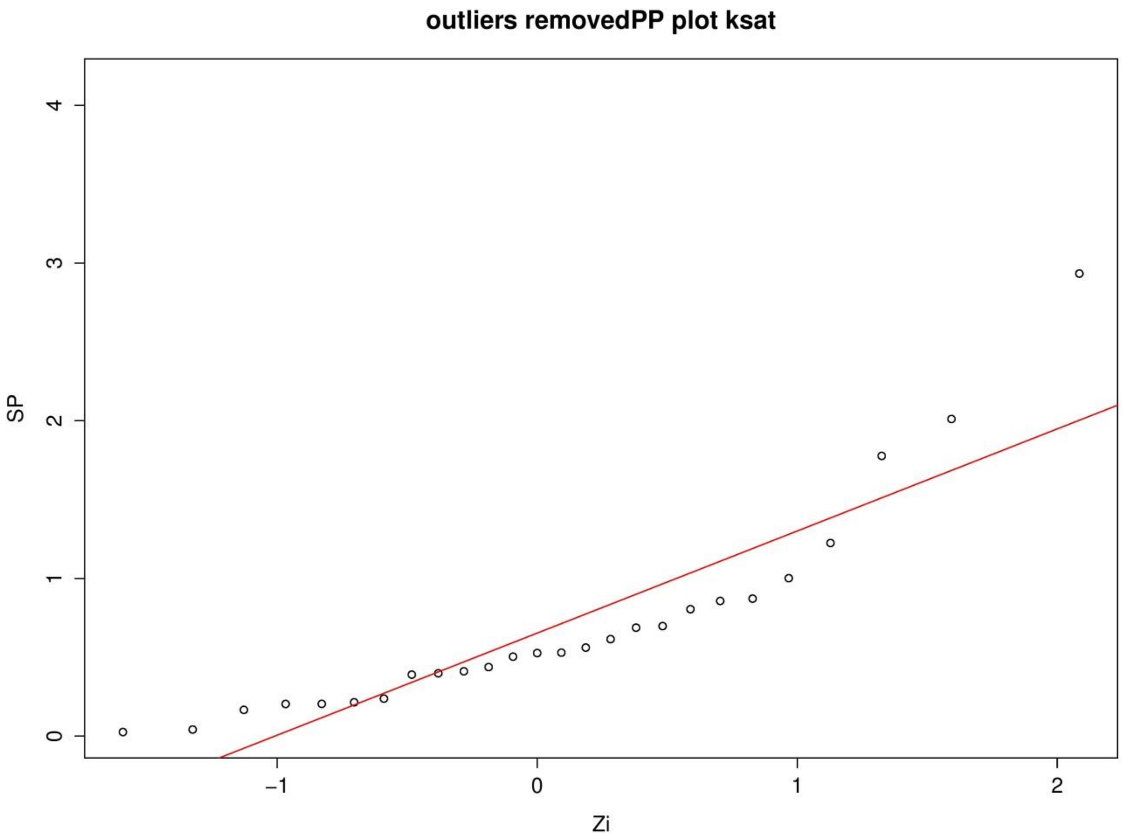


Figure A.3.

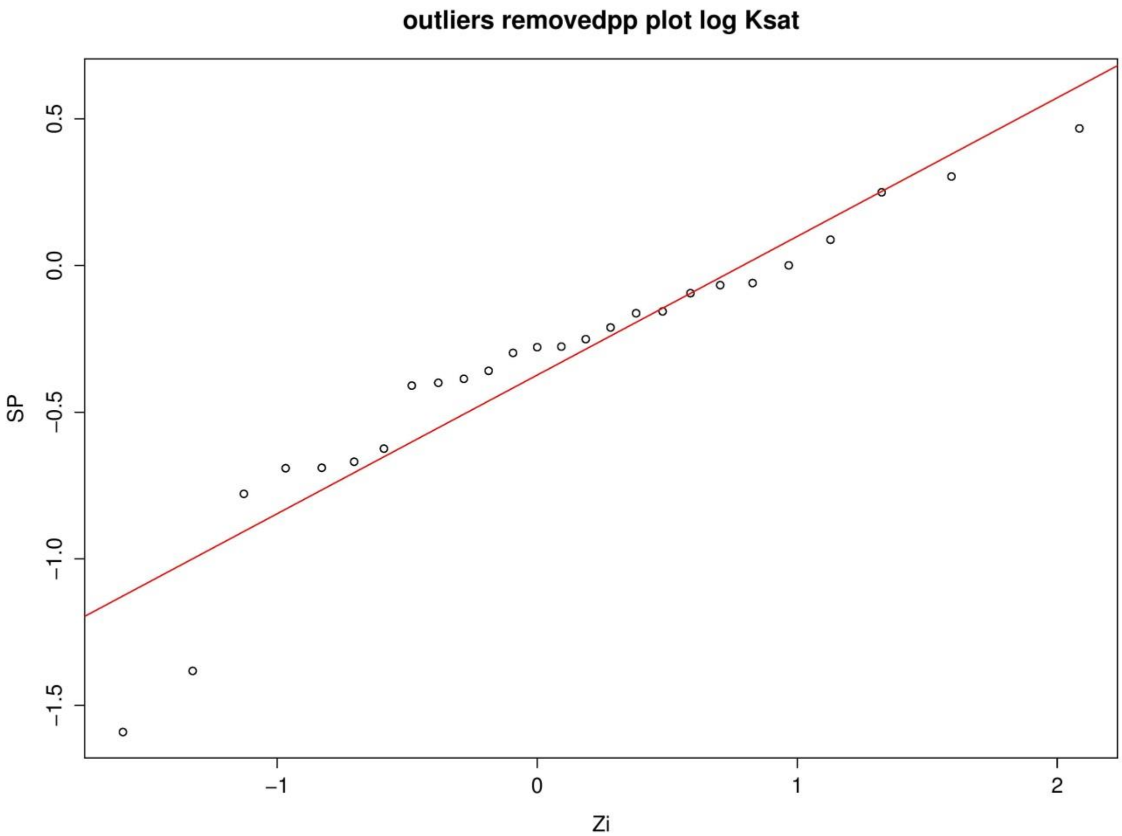
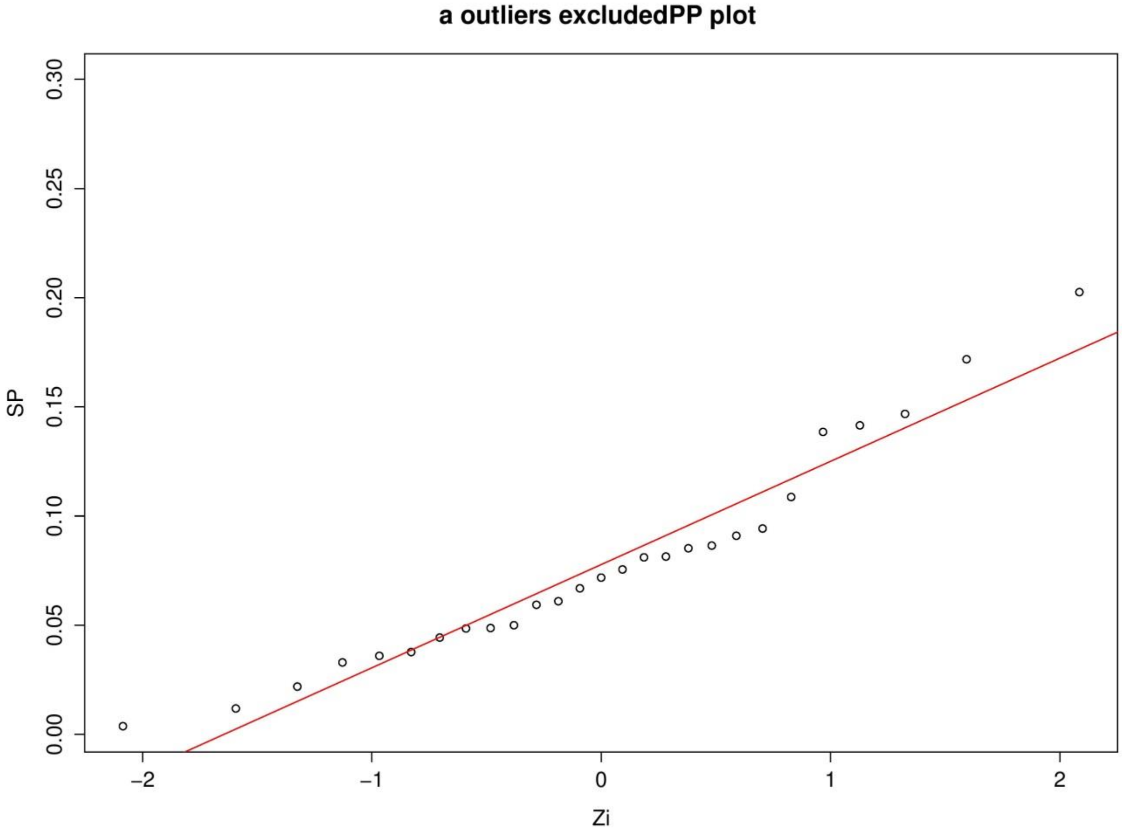


Figure A.4.


a outliers excludedPP plot
SP
Zi
0.00
0.05
0.10
0.15
0.20
0.25
0.30
−2
−1
0
1
2

BIOGRAPHY

Laura Beth Kenny (formerly Laura Beth Gladney) grew up in Cherry Hill, New Jersey where her hobbies included horseback riding, acting, singing, and even miming. She attended Cook College at Rutgers University from 2005 to 2008, majoring in Animal Science with an Equine focus. While at Rutgers, Laura participated in Alpha Zeta, RU Equestrian Team, Equine Science Club, Animal Science Club, Northeast Student Affiliate animal science competition, and completed a George H. Cook Honors thesis. After graduation, she worked as a Program Assistant in the Salem County Rutgers Cooperative Extension office in Woodstown, NJ, traveling the state and teaching farmers about crop insurance. In 2011, she was hired in the Rutgers Department of Animal Sciences in New Brunswick, NJ as Program Associate to the state Equine Extension Specialist, Dr. Carey Williams. There, she enjoyed working with the equine industry while working on her graduate education part-time in the Department of Plant Biology and Pathology.