ABSTRACT

GLUNK, EMILY CLARE. Effect of Restricted Grazing on Dietary Energy Intakes, Dry Matter Intake Rates, and Fecal pH. (Under the direction of Dr. Paul Siciliano and Dr. Shannon Pratt-Phillips.)

Eight mature idle horses (549 ± 40.73 kg) were used in a 4x4 Latin square design to determine the effect of restricted pasture access on pasture DM intake (DMI), DMI rate (DMIR), caloric intake and hindgut pH. Horses were randomly assigned to one of four groups, each containing two horses per group. Groups were randomly assigned to one of the four treatments, 3, 6, 9, and 24 h of pasture access, for a period of 7 d. Treatments were switched every 7 d so that each horse group received all treatments. Grazing began at 0700 each day for all treatments. Horses were maintained in individual partially covered pens while not grazing. The 3 and 6-h groups were fed free choice grass hay while not grazing. Hay intake was measured daily. Both initial herbage mass (IHM) prior to grazing and residual HM (RHM) following 7 d of grazing were measured within each horse group's grazing cell using a falling plate meter. Daily pasture DMI was estimated by calculating the difference between IHM and RHM, and expressed as g DM/ kg BW/ d. Dry matter intake rate (DMIR) was obtained by dividing the daily pasture DMI by hours at pasture. Total DMI (totDMI) was calculated as the sum of pasture and hay intake. Pasture samples were collected to reflect actual grazing height of horses on d 1 of each period, and then analyzed for chemical composition. Body weights and fecal pH samples were collected on d 7 of each period at approximately 0700 and pH was measured in triplicate. The response variables (Dry matter intake rate (DMIR), DMI, totDMI (hay intake + pasture), and IHM) were analyzed using ANOVA for Latin square design. The model included horse group (HGRP),
period, and treatment. Mean pasture DMI was 5.88, 9.1, 10.1, and 13.6 ± 1.12 g DM/kg BW for 3, 6, 9 and 24-h treatments respectively. Mean totDMI was 10.6 and 12.4 ± 1 g DM/kg BW for the 3 and 6-h treatments, respectively, and was not different among all treatments ($P = .16$). Mean pasture DMIR was 1.96, 1.52, 1.12, and .57 ± .207 g DM · kg BW$^{-1}$ · h$^{-1}$ for the 3, 6, 9 and 24 h treatments, respectively. This showed a significant increase in DMIR when horses were subjected to restricted turnout times ($P < .02$). Mean digestible energy (DE) intake was 13.4, 21.9, 22.3, and 31.4 kcal/ kg BW for the 3, 6, 9, and 24 h treatments, respectively ($P = .02$). Mean fecal pH values were 7.23, 7.30, 7.32, and 7.61 (± 0.11) for the 3, 6, 9 and 24-h groups, respectively and was not affected by treatment ($P= 0.17$). Restricting pasture access increases DMIR and subsequent energy intake from pasture, but does not appear to affect hindgut pH as indicated by fecal pH.
Effect of Restricted Grazing on Dietary Energy Intake, Dry Matter Intake Rates, and Fecal pH

by
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A thesis submitted to the Graduate Faculty of North Carolina State University in partial fulfillment of the requirements for the degree of Master of Science Animal Science

Raleigh, NC

2012

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DEDICATION

This thesis is dedicated to my family members, because without them it wouldn’t have been possible to get this far. To my mom and dad especially, thank you for always believing in me and pushing me to pursue my dreams. Words cannot express how much I appreciate everything that you have done for me, and without you I know it would not have been possible to be at this point today. Thank you for instilling in me a sense of responsibility and passion for always doing my best. To my brothers, thank you for always giving me something to laugh at. For my grandparents Clara Mae, Bob and Gram, thank you for always showing your support and confidence in me. I love you all.
BIOGRAPHY

Emily Clare Glunk grew up on a small farm in central Pennsylvania. Exposed to animals at an early age instilled in her a passion for both animals and agriculture. Almost all of her childhood memories included horses, whether it was early morning breakfast trail rides with her mom, or being up at the crack of dawn to get her ponies ready for shows, she spent most of her time around the barn. Graduating from Jersey Shore Area High School in 2006, she attended The Pennsylvania State University majoring in Animal Bioscience. After graduating with her Bachelor of Science degree in 2010, she moved to Raleigh, North Carolina to attend North Carolina State University to pursue her Master’s degree in Animal Science and Nutrition under the guidance of Dr. Paul Siciliano.
ACKNOWLEDGEMENTS

There are many that I have to thank for helping me complete this project:

Dr. Siciliano, thank you for all of your guidance, support, and patience, I could not have asked for a better PI.

Dr. Pratt-Phillips, thank you not only for your guidance and advice, but also for opening up new opportunities and travels along the way.

Cassie Wycoff, Josie Drayton, Chris Sykes and Jenna Kutzner-Mulligan, thanks for all of your hard work on all of the projects, and for being there to talk to when things got stressful. I will always be appreciative of the friendships that I have created. It’s great to have such amazing people to de-stress with after a long day at ERU…

Marian Correll, thank you for always being there to solve all of the endless problems, you have really helped to make things a lot easier.

Brittany Pagliaro, Ali Thomas-Hollands, and all the other graduate and undergraduate students who have assisted on the projects, thank you so much, we could not have done it without you!
# TABLE OF CONTENTS

**LIST OF TABLES**........................................................................................................................................viii
**LIST OF FIGURES**........................................................................................................................................ix
**INTRODUCTION**..........................................................................................................................................1

**CHAPTER I: LITERATURE REVIEW** ........................................................................................................2
   Grazing Behaviors and Pasture Dry Matter Intake................................................................. 2
   Nutritive Values of Pastures.................................................................................................................. 9
   Ability of Pasture to meet Horses’ Requirements................................................................. 15
   Current Methods to Decrease Pasture Intake................................................................. 20
   Methods to Estimate Forage Intake and its Effects.......................................................... 21
   Fecal pH estimation......................................................................................................................... 22

**CHAPTER II: MATERIALS AND METHODS** .........................................................................................24
   Animals and Treatments................................................................................................................. 24
   Animal Sample Collection and Analysis.................................................................................... 25
   Pasture Sample Collection and Analysis.................................................................................... 25
   Statistical Analysis......................................................................................................................... 27

**CHAPTER III: RESULTS** .....................................................................................................................28
   Pasture Plant Composition........................................................................................................... 28
   Initial Herbage Mass.................................................................................................................... 28
   Dry Matter Intake.......................................................................................................................... 28
   Dry Matter Intake Rates................................................................................................................ 29
   Total Dry Matter Intake................................................................................................................ 29
   Dietary Energy Intake.................................................................................................................... 30
   Fecal pH......................................................................................................................................... 30
   Body Weight.................................................................................................................................. 30
LIST OF TABLES

Table 1. Pasture Plant Composition…………………………………………………………28
LIST OF FIGURES

Fig 1. Utilization of different forage heights by horses.............................................7
Fig 2. Relationship between body weight and energy requirements.............................17
Fig 3. Diagram of plant composition............................................................................19
Fig 4. Diagram of pasture layout..................................................................................44
Fig 5. Initial herbage mass............................................................................................45
Fig 6. Pasture dry matter intake....................................................................................46
Fig 7. Pasture dry matter intake rate............................................................................47
Fig 8. Total dry matter intake.......................................................................................48
Fig 9. Pasture digestible energy intake.........................................................................49
Fig 10. Total digestible energy intake...........................................................................50
Fig 11. Fecal pH values................................................................................................51
Fig 12. Body weight.......................................................................................................52
Fig 13. SAS input of total pasture intake......................................................................53
Fig 14. SAS input of total dry matter intake.................................................................54
Fig 15. SAS input of pasture digestible energy..............................................................55
Fig 16. SAS input of total digestible energy.................................................................56
Fig 17. SAS input of pH.................................................................................................57
Fig 18. SAS input of body weight..................................................................................58
INTRODUCTION

Excessive caloric intake in grazing horses is associated with problems such as obesity, insulin resistance and laminitis. A commonly used strategy to decrease caloric intake is to restrict time spent grazing. However, this strategy assumes that horses’ forage intake rate remains constant during the entire time they are grazing at pasture.

Dowler et al [1] reported that the dry matter intake rate (DMIR) does not remain constant, with DMIR accelerating in the first 4 hr of grazing versus the second 4 hr of grazing. This initial accelerated DMIR allowed horses to consume approximately 55% of their daily maintenance dietary energy (DE) requirements in the first 4 hr of grazing. This data suggests that restricting time allowed for grazing may not be an effective means of decreasing the overall dry matter or calories consumed while at pasture. The accelerated pasture intake may decrease hindgut pH, as it has been shown in previous studies that increased intakes of large grain-based meals can decrease hindgut pH, altering the hindgut microbial environment [2].

An understanding of how DMIR and subsequent dry matter intake (DMI) and caloric intake change in response to restricted grazing is necessary to accurately regulate caloric intake of grazing horses. Therefore, an experiment was designed to determine if pasture DMIR and subsequent caloric intake is accelerated when time allowed for grazing is restricted, and if a change in DMIR can then alter hindgut fermentation. The objective of this study was to determine DE, DMIR, fecal pH, and DMI in horses having access to pasture for four different time periods: 3, 6, 9, and 24 hr.
CHAPTER I- LITERATURE REVIEW

Grazing behavior and strategies

Pasture forages serve as a significant source of nutrients for horses. Depending on the daily activity of the horse, many are able to be maintained on pasture alone, without the addition of concentrates to their daily diet. The horse’s digestive system has evolved to be able to consume a large quantity of forages, and extract their daily requirements via digestion and absorption in the foregut and intestines, and microbial fermentation in their hindgut. Horses are uniquely designed in that they have enzymatic digestion and post-gastric fermentation like non-ruminants such as pigs, but the post-gastric fermentative capacity of horses’ digestive systems are much more developed. Other types of non-ruminant herbivores have the capacity to ferment fiber, but not to the extent of horses.

Evolution of the equine hindgut to include an enlarged cecum for fermentation was necessary in order for the equine to subsist on a forage-based diet. Mammals do not possess cellulolytic enzymes necessary to digest the plant walls and utilize the nutrients that are contained within. Cellulose is an important source of fiber, along with the many digestible cell wall contents that are bound by the cellulose. If horses did not have the ability to utilize the cellulose, they would be missing out on an important nutrient source, as cellulolytic fermentation results in formation of volatile fatty acids (VFAs), short chain fatty acids that provide a large part of the horse’s energy requirement, up to 40% of their daily energy requirements [3].
Because horses, along with other species such as cattle and sheep, are able to utilize the nutrient capabilities of cellulose, they are often chosen to graze together, as their grazing preferences can be complementary to one another. It was observed that grazing wildebeests (*Connochaetes taurinus*), representative of the ruminant species, chose to consume the leafy part of the plant, while the zebra (*Equus Hippotigris* or *Equus Dolichohippus*), representative of the non-ruminant herbivore, chose to graze on the stem part of the plant. They are able to satisfy both of their metabolic needs while efficiently using the herbage mass available [4].

In the same study, the zebra selected not only the most fibrous part of the plant, the stem, but also chose the tallest parts, which are generally higher in fiber and less soluble nutrients. This is evidence to the argument that horses are able to subsist on larger amounts of low-quality grass, compared to other ruminants that mainly subsist on smaller quantities of high-quality grasses [4].

Digestion by ruminant species and horses has also been studied; comparing how each animal is able to metabolize various nutrients. In a study comparing horses and cattle, the animals grazed six different hays and digestibility was compared between the species and among hays. The hays utilized were Altai wildrye, smooth bromegrass, crested wheatgrass, Kentucky bluegrass, oat hay, and reed canarygrass. Digestibility of all forage nutrients (P< 0.001) except for crude protein (CP) were affected by the plant species. Cattle were able to digest more dry matter (DM), gross energy (GE), acid detergent fiber (ADF), neutral detergent fiber (NDF), and P (P< 0.001), but less Ca than horses. However, horses were able to digest the DM, NDF and CP from alfalfa similarly to cattle (P< 0.05), differing only in their use of GE, ADF, Ca, and P [5]. This lower digestibility of some hays may be due to the
lower number and cellulolytic activity of the microflora in the horses’ cecal-colic hindgut. Also, horses have a more rapid rate of passage of feed in their gastrointestinal tract than ruminants typically do [5].

For horses, eating is a default behavior, and they will eat until prohibited, either by stalling them or placing a restrictive device on them while at pasture. Horses are also social animals, and if they see a horse eating next to them, they will be more inclined to begin to eat [6]. One of the mechanisms that cause horses to voluntarily stop eating is gut fill. Once they have consumed enough that their stomach cannot expand to fit any more food, they will be forced to stop eating or else they will become uncomfortable, potentially even leading to gastric rupture. Along with gut fill, several hormonal mechanisms have also been investigated that may influence satiety, such as leptin and cholecystokinin (CCK). Although these mechanisms have been studied intensively in humans, there still has yet to be a definite link established to confirm this same process in horses [7].

Horses on pasture are estimated to spend about 75% of the time during the day grazing, and 50% of the night grazing, totaling about 60% of each day [8]. The rest of their time at pasture is spent standing, walking, lying, drinking and scratching. Horses will tear a mouthful of grass, chew it several times and then tear off subsequent mouthfuls, continuing in this pattern over the entirety of their grazing period. This behavior pattern is modified by forage palatability, the amount of forage available, and the type of forage available, as horses are selective grazers. Horses will generally select grasses over other types of available forages, in particular rye grass and timothy, and they also prefer legumes such as white clover and dandelions. They will spend a short period of time ingesting one species, and then
move on to the next, ingesting a wide variety of forage throughout the entirety of their turnout [6]. In a study by Naujeck (2005), horses were found to graze a patch of grass and then moved onto a patch of different height, never staying on a patch of grass longer than a few minutes [9]. They also found that the horses visited the patches of varying height equally, although the height differences observed were over a much smaller range than other studies focusing on the same effects [9]. Naujeck attributed this behavior to the marginal value theorem introduced by Charnov [10]. Charnov proposed that “when the intake rate in any patch drops to the average rate for the habitat, the animal should move on to another patch.” This movement may decrease the actual amount of forage that is being ingested, but will help to increase the efficiency of their foraging activity by allowing them to spend less time ingesting higher quality forage [10].

Horses also have a preference to graze lawns instead of rough patches of grass of varying heights. Horses were found in one study to preferentially graze grass at heights around 5-6 cm [11]. When offered grasses of varying heights that was classified as the mixed pasture, they selected the shortest grass and avoided the tallest grass, with a mean consumption height of 6.4 ± 0.2 cm in the first year of the study and 7.3 ± 0.2 cm in the second year of the study. The height of the grasses in the mixed pasture varied from 1 to 56 cm. They found that the horses fed on the two shortest class heights, 1-4 cm and 5-8 cm, three times more than the other grass class heights, 9-16 cm, 17-24 cm, 25-32 cm, 25-32 cm, 33-40 cm, 41-48 cm, 49-56 cm, 57-64 cm, 65-72 cm, and greater than 72 cm. They completely tried to avoid grass heights greater than 17 cm. In the short height pasture, horses ate at an average height of 5.2 ± 0.3 cm in the first year of the study and 4.0 ± 0.1 cm in the
second year. The average grass height of this pasture was found to be less than 8 cm high. In the final treatment pasture, classified as tall pasture, horses consumed at an average daily feeding height of 22.9 ± 0.5 cm in the first year and 22.1 ± 0.5 cm in the second year. The range of heights for the tall pasture was 9 to 40 cm, showing that the horses tried to consume at a fairly short level, even though there was plenty of tall forage available.

There has also been a trend shown for horses to graze longer on shorter pastures compared to pastures containing taller forage [11]. As shown in Figure 1, in the second year of the trial horses grazed about 60.2 ± 5% in the short pasture, compared to 54.9 ± 0.6% in the mixed height pasture and 51.2 ± 1% in the tall pasture. However, in the first year they found no significant difference among grazing times (short= 53.6 ± 5.9%, mixed= 55.6 ± 6.7%, tall= 56.1 ± 1.2%). If this trend were true and horses ingested more short grass than tall grass, this could have implications on the daily caloric intake of their diets, as it has been found that while grass biomass increases with increasing grass height, quality declines. In the short grass, crude protein (CP) was about 50% higher than other heights, and neutral detergent fiber (NDF) was about 20% more in the taller grasses. They also found organic matter digestibility (OMD) to be about 20-30% lower in the tall pasture compared to the mixed and short pastures. And so if horses are choosing to graze short grass heights and for a longer time, they will be consuming a much larger amount of nutrients compared to horses that only have tall grasses available. Also, if average chemical analysis values are used to calculate a ration for a horse on pasture, actual intake may be underestimated as they will be selecting shorter grasses at the higher end of the nutrient range more so than taller grasses at the lower end of the nutrient range.
Horses may also graze based on chemical composition of the plant species. When given the choice of 6 cool-season grasses in the fall of 2005, it was found that the horses preferred timothy and perennial rye grass over other species [12]. The species offered included bluegrass, orchardgrass, perennial ryegrass, timothy, festulolium and tall fescue. Perennial ryegrass, festulolium and annual ryegrass were the intermediate grazing choice of the horses (the annual ryegrass was not originally included in the study, but had infected one of the festulolium cultivars), while orchardgrass and tall fescue were usually not chosen by the horses. Tall fescue was the least preferred out of all of the species. This data suggested horses chose forages with higher levels of copper, zinc and potassium, and lower levels of
magnesium ($P<0.05$), as shown by the higher levels of timothy and perennial ryegrass that were consumed. They also found that the horses did not necessarily base their grazing preferences off of crude protein, non-structural carbohydrates (NSC), water-soluble carbohydrates, ethanol-soluble carbohydrates, or starch content [12].

When daily pasture intake of horses was studied, several different variables were looked at. In yearling horses, exercise and its effects on dry matter intake, bite size and bite rate were investigated. It was found that daily pasture intake is dependent on numerous factors, including bite rate, bite size and time spent foraging [13]. The yearlings without exercise ate at a rate of about .63 kg · h$^{-1}$, while yearlings with exercise ate at a rate of about 1.75 kg · h$^{-1}$ (no significant difference between the two treatments being observed). Cantillon et al estimated pasture dry matter intake (DMI) rates to be between 1.5 and 1.65 kg · h$^{-1}$ while grazing fescue and alfalfa in adult horses [14,14]. Duren estimated that exercised yearling horses had an intake rate of about 3.2 kg DM over a 3-hr grazing session, which he extrapolated to be a rate of about 1.07 kg DM · h$^{-1}$ in a 24-h grazing period [15,15]. However, in both of these studies the horses were tethered and not allowed free range of a pasture, which is uncharacteristic of many management systems in effect today. In effect this may not be representative of horses’ actual pasture intake rates as these horses would not have the same behavior as free-ranging horses at pasture, such as walking around throughout the pasture. Tethered horses also have the tendency to perceive that they are supposed to be tied instead of free to graze, decreasing the amount of time that they actually spend grazing [16,16]. Several studies have been done to estimate daily pasture intake of horses over longer periods, such as Moffitt et al [17] who estimated mean DMI for a group of 2-year-old
horses to be about 10.3 and 12.7 kg/day. These studies show a lack of not only DMI rates over an extended period of time, but also a lack of research of DMI rates in a realistic setting.

In a preliminary study by Dowler, it was found that horses will consume about 55% of their daily DE requirements in the first four hours of grazing [18]. It is common for owners to restrict grazing to about eight hours of turnout a day or less, the length of a typical workday. If the horses need further caloric or nutrient restriction, grazing time is decreased even further under the assumption that horses’ intake is being effectively decreased. But Dowler’s data shows that the horses are still consuming a large portion of their total calories for the day, over half of their daily needs, in just four hours, which may lead to an underestimation of their actual caloric intake. This suggests that restricting time allowed for grazing may not be an effective means of decreasing the overall amount of calories consumed while grazing on pasture. In the second four hours of turnout during the same study, horses’ intake levels were halved, along with their caloric consumption. This effectively showed that decreased turnout times may not be the proper means of decreasing caloric consumption, but rather other means should be explored that could more effectively decrease their intakes from pasture.

Nutritive value of pasture

Forages make up the major portion of most horses’ diets, with horses generally consuming an average of 1.5-3% of their body weight in dry matter. High-quality fresh forages have the ability to meet the maintenance requirements of horses when fed in adequate amounts [19]. Forages, especially fresh forages, play an essential role in maintenance of the
normal microbial function of the hindgut, which is in turn needed for maximal fiber fermentation and volatile fatty acid (VFA) production.

The quality of the fresh forage varies among the different pasture species. Tall fescue \textit{(festuca arundinacea)}, a common pasture plant for horses, has a high in-vitro dry matter disappearance (IVDMD), an estimate of how digestible the plant material is by microbes. IVDMD has a positive correlation to average daily gain (ADG) in growing animals, meaning that it has higher amounts of calories available for use by the animal, including higher VFA production. Corresponding to IVDMD is particle size of the plant digesta, with particle size also positively correlated to ADG. Large particles are consistent with the leafy part of the plant, so the more leafy the plant, the more calories it contains. In tall fescue, most of the plant is the leaf fraction, which is why it has a high IVDMD and also could potentially be a problem for those trying to promote weight loss in their horses. Pastures that contain mixed groups of species such as crabgrass will have a lower ADF and NDF, meaning higher energy content and higher intake levels. While this type of pasture may be suitable for horses that require high energy intakes, it is not suitable when caloric intake levels are trying to be limited.

Crabgrass, a warm-season grass present during our study, has been used by farmers and horse-owners as a pasture forage since the early 20\textsuperscript{th} century \cite{20}. It is a hardy grass that has an affinity for hot, dry conditions. It has been found to be a particularly nutritious grass when used as a pasture or hay. It has been shown to be a high-yield grass, producing 9.0 to 11.0 kg DM ha\textsuperscript{-1} in a study in Oklahoma \cite{20}. It has also been found that crabgrass is fairly
digestible compared to other perennial warm-season grasses, marking it as a more desirable high-energy pasture forage for horse and livestock grazing [21].

Another perennial warm-season grass present during this study was dalisgrass (*Paspalum dilatatum*). Dalisgrass is also high-quality forage, utilized as pastures grass mainly in the southeastern US. It generally has a longer grazing season than other warm-season perennials, being available earlier in the spring and later into the fall [22]. However, dalisgrass usually has a lower forage yield than its warm-season counterparts, with little research available on the productivity of this plant [23]. Grasses like bermuda grass, switch grass and flaccid grass may be better options for overweight horses to graze on, as they have much lower IVDMD, with higher ADF and NDF, providing smaller amounts of calories to horses [24].

Several studies have compared the chemical compositions of different forage species that were harvested at the same time. Fonnesbeck et al [25] compared smooth bromegrass (*Bromus inermis*), tall fescue (*Festuca arundinacea*), canarygrass (*Phalaris canariensis*), and timothy (*Phleum pretense*) all harvested at the pre-bloom stage. It was found that the concentrations of CP varied (13.8, 9.5, 11.2, and 8.3% respectively), along with ether extract (2.1, 1.9, 3.3, and 2.5% respectively) and ash (6.5, 7.1, 8.0, and 6.1% respectively), while crude fiber (CF; average 38.2%) and nitrogen-free extract (NFE; average 41.9%) were similar among all species. In another study by Crozier et al, they had similar findings when looking at alfalfa (*Medicago sativa*), tall fescue (*Festuca arundinacea*) and caucasian bluestem (*Bothriochloa caucasia*) [26]. Crude protein concentrations varied (19, 11, 7% respectively) along with NDF (55, 72, and 73% respectively), hemicellulose (12, 32, and
34%), total NSC (4, 8, and 7% respectively), Ca (0.94, 0.26, and 0.27% respectively) and several other minerals. However, ADF (average 40.6%), Mg (average 0.23%) and cellulose (average 3.17%) were similar [26]. The changing chemical composition of these forages could play a role in the selection of forages for grazing by horses.

Another study found that the changes in chemical composition did not lead to a difference in grazing preference and DMI in geldings, but did lead to differences in digestibility due to the variations in plant chemical composition [27]. The geldings consumed all three of the grass species offered, orchard grass, tall fescue and ryegrass, at an average of 2.2% BW. The orchard grass had higher DM, OM, CP and NDF (58.4, 62.5, 71.0, and 51.6% respectively) than the other two forages offered (average 49.4, 53.4, 62.9 and 43.7% respectively) [27]. Showing that even if the horses do not have a grazing preference for a particular plant species, they could still be getting a larger amount of nutrients and calories from one grass versus another, due to the differing digestibilities of those plants.

Changes in chemical composition within forage species also can have an effect on the amount of nutrients consumed by horses. As a plant matures, lignin will begin to accumulate in the cell wall, decreasing digestibility of the plant material. As the lignin accumulates the plant’s digestibility decreases along with the caloric content of the grasses. Immature grasses will have a higher percentage of non-structural carbohydrates (NSC), which are sugars, starches and fructan components of plants, and a lower percentage of fiber, thereby being more nutritionally valuable to the equine [19]. As a result of green plants “fixing” carbon dioxide in the presence of sunlight the plant produces NSC’s [28]. Sugars may be produced
in excess of the plant’s requirements for maintenance, growth and development, where they are then converted into storage carbohydrates. Plant respiration is the process by which the plants utilize these stored carbohydrates when light is no longer available like during the night [29]. The NSC content of forages is higher in spring and fall, due to minimal growth and respiration of sugars because of large fluctuations in diurnal temperatures. In a study by Geor, a positive association was found between hours of sunshine and laminitis, seemingly due to increased consumption of forage carbohydrates because the sunshine promotes photosynthesis and carbohydrate accumulation [29]. Several studies have also found that plant carbohydrates will be highest during the afternoon and into the evening hours, peaking at about 4 pm, due to carbohydrates being stored throughout the day from photosynthesis. The lowest plant carbohydrate concentrations are found in the early morning into late morning hours, around 3 am, after the plant has been consuming the stored carbohydrates. Also, when plants are stressed or are present in conditions suboptimal for plant growth such as freezing temperatures or drought, there will be an increase in the NSC content of the forage [28,30].

Darlington found that as a plant matured, there will be changes in the chemical composition of the plant. In a study investigating nutrient content of alfalfa, timothy and orchard grasses, it was found that the percentage of CP and ash declined, while ether extract (EE), NFE, and gross energy remained the same, and the crude fiber increased [31]. All three forage species were cut on June 3 (first cut), June 13 (second cut), and June 23 (third cut). In the digestion portion of the trial, they found that in exception to the EE and CF of orchard grass, all other plant components decreased significantly with maturity. They also
found that in all the forages, but most markedly in alfalfa, the DE content of the plant decreased significantly with increasing maturity. They found that this was the least pronounced in timothy, but hypothesized that it was due to the reasonably high DE coupled with the relatively low rate of decrease of DE. They also thought that this could be the reason why timothy has been the choice of many horses for grazing [31].

The DE of the plant can be estimated using the crude protein (CP), acid-detergent fiber (ADF), hemicellulose, fat, NSC, and ash percentages of the plant, similar to estimating the amount of calories consumed by the horse. As the ADF, ash and hemicellulose percentages of the plant increases with the increasing maturity, the DE will decrease and the horse will obtain fewer calories from each mouthful of grass. In turn, as the fat, protein, and NSC portions of the plant increase, the DE will increase as well, providing more calories per mouthful [32]. Also important in the chemical analysis is the NDF portion. As ADF correlates with energy provided in the plant, NDF correlates with the animal’s voluntary intake of the plant. As NDF increases, intake levels will decrease [19]. All of these factors also leads to the conclusion that pasture DE content is extremely variable, and can only be determined and properly estimated through continuous and regular chemical analysis.

Another factor affecting the caloric content of each individual plant is the location of the carbohydrate storage organs. Some species store carbohydrates in their bases instead of their apices, while others collect them in their stems, and still others store them in their leaves. Ryegrass, timothy, fescue, and orchard grass all have increased amounts of fructan in their leaves, sometimes in amounts that are 1.5- to 10-fold greater than that in their stems [19]. This means that the stem: leaf ratio becomes very important, and can be a factor in
selection of species for horses to graze, as they will be consuming the carbohydrate storage organs, a more concentrated source of calories. For those plant species who store their carbohydrates in their base, it is harder for horses to ingest these carbohydrate storage compartments as they usually do not graze that close to the ground, and they will not be consume as large amounts of carbohydrates from these plants. Also affecting carbohydrate storage is light availability, fertilization, and environmental conditions. When light is reduced or when fertilizer containing high amounts of nitrogen is applied NSC will decrease, whereas it will increase in plants during droughts or poor environmental growing conditions [19].

**Ability of pasture to meet horses’ requirements**

Forages can offer adequate amounts of the important nutrients that horses need, and many horse owners do not realize that the amounts of nutrients available in pastures can usually meet or exceed their horses’ requirements when consumed in proper amounts. For turnout times up to 8 hours, a general estimation of 1.5 g DM · kg BW⁻¹ · h grazing⁻¹ can be used to predict how much a horse will eat. The problem with this prediction equation is that it can only be used up to 8 hr of turnout, and it assumes a constant intake rate [19].

When owners underestimate the nutritional value of pasture, concentrates are added to the ration, leading to even higher caloric intakes, often in excess of the horses’ requirements. Except in certain areas of the country where soils may be deficient in various minerals thereby causing the forages growing in them to be deficient as well, most good to fair-quality forages have acceptable levels of nutrients like crude protein, fat, Ca, P, K, and
Owners feel the need to supplement their horses’ rations with concentrates, allowing their horses to consume excess calories causing them to develop metabolic problems. A study by Gallagher and McMeniman investigating pregnant mares at pasture found that even though the pasture nutrient content fluctuated throughout the year, it was always sufficient to meet the mares’ protein and energy requirements, as these mares were seen to gain weight [33]. Because these horses were pregnant, their nutritional requirements were increased significantly and are much higher than most horses even in work. This shows that pasture should be more than sufficient to meet most horses’ needs, as gestating mares represent a sub-group of horses that have some of the highest metabolic requirements. They are exceeded, in this regard, by horses engaged in intense exercise routines such as racehorses and high-level three day eventers, or mares in early lactation.

It has proven difficult to estimate pasture DMI, as it is hard to accurately estimate how much grass is present before horses graze a pasture, and also how much is present after grazing is finished. Several studies have attempted to estimate pasture intakes by subtracting residual herbage mass from initial herbages mass, utilization of fecal markers, or measuring fecal outputs of known organic matter. These studies have reported that intake levels are generally in the range of 1.5-3.1% BW [34,6]. However, there are still conflicting reports as to whether intake will increase or decrease when horses are placed on high-quality pasture. Nash et al found that in Thoroughbred fillies there was a decreased intake of the higher-quality pastures, while other studies have found that intakes increased on high-quality forages [6,35]. This suggests that pasture DMI may not be entirely dependent on pasture quality, but rather on the amount of DE that the horses ingest from the plants.
Studies on different species such as cattle, have found that they are able to consume extremely large quantities of forage in relatively short amounts of time. In one study observing grazing behavior of cows, they found that they were able to consume 90% of their daily needs in only 2 hours [36]. If horse owners extrapolated this data and used it as a model for horses’ grazing behavior, they would find that limiting horses to such small amounts of turnout time may still not decrease their caloric intake to a desired range. When decreasing turnout, it is usually limited to 3 or 4 hours at the minimum, with most horses being turned out 8-10 hours, as it is convenient for the owners. This presents a difficult problem for owners trying to limit horses’ caloric intakes. A possibility would be to alter the types of grasses available to their horses at pasture, as there are differences in the caloric content of different forage species.

**DE Maintenance Requirements by BW**

![Graph showing DE Maintenance Requirements by Body Weight](image)

*Fig 2. Relationship between BW and energy requirements in horses [37].*
Digestible Energy (DE) is the amount of energy available to the horse to use for maintenance, growth, production, lactation and performance. As noted in Figure 2, the DE requirements increase with increasing BW. The general equation used to determine a horse’s DE requirements is [19]:

\[ \text{DE} = 0.033 \times \text{BW of the horse (kg)} \]

To determine DE of a feed, the amount of energy that is undigested and lost in feces is subtracted from the gross energy (GE) of that feed and can be estimated from the following equation:

\[ \text{DE (Mcal/kg DM)} = 2118 + 12.18 \times \text{(CP\%)} - 9.37 \times \text{(ADF\%)} - 3.83 \times \text{(hemicellulose \%)} + 47.18 \times \text{(fat \%)} + \frac{20}{35} \times \text{(NFC\%)} - 26.3 \times \text{(ash\%)} \]

Fiber and ash have low digestibility, and so both of them were included as decreasing the total DE. Protein, ADF and NSC all are highly digestible, and so when their concentrations increase, so does DE. The multiplication factor for each variable is the estimated heat of combustion for each chemical constituent [37].

This equation accounts for the input of calories from various chemical sources of the plant, including the crude protein (CP), hemicellulose, fat, and non-NDF carbohydrates (NFC), while subtracting the amount of ash or minerals that is in the plant. Non-NDF carbohydrates are often used interchangeably with non-structural carbohydrate (NSC) content, which is not correct. While both NFC and NSC are important sources of energy in a horse’s diet, NSC’s refer to the sugar, starch and other cell contents of the plant, while NFC is a calculated value. NFC is estimated using the equation [38]:
The four general categories of NFC are organic acids, mono- and oligosaccharides, starch, and neutral detergent fiber (NDF), as shown in Figure 3. Although organic acids are not true carbohydrates, they are fermentation products that are found in silage, and more importantly for horses they are plant organic acids that are found in fresh forage and hay. The predominant sugars that are found in plant sources are glucose, fructose and sucrose. The majority of the sugars are able to be digested by mammalian enzymes, and so can be absorbed by the horse prior to fermentation. Starch, on the other hand, is able to be digested by both mammalian and microbial enzymes, and so will either be absorbed prior to...
fermentation, or will reach the fermentative hindgut, all depending on the processing, storage method and source of the starch. The final category, NDF, contains pectins, B-glucans, fructans, and other non-starch polysaccharides. Sources of NDF are unable to be digested by mammalian enzymes, and therefore must be fermented by the microbes in the hindgut of the horse [38].

**Current methods to decrease pasture intake**

There are several methods implemented by horse owners to decrease nutrient intake, especially caloric and non-structural carbohydrate (NSC) intakes. One of the common methods utilized is muzzling during turnout, so that “problem” horses can still be turned out with the rest of the herd, but will have a decreased forage intake. Grazing muzzles allow for a reduction in bite size and allow the animals to graze larger areas of pasture for longer periods of time [39]. Longland looked at differences in pasture intakes over a three hour period comparing ponies’ DMI with and without grazing muzzles. They measured the intakes by calculating the ponies Insensible Weight Loss (ISWL) and excretory outputs, subtracting both from their live weight. What they found was that pasture intakes were significantly reduced when the ponies were fitted with a grazing muzzle. Pasture DMI of the muzzled ponies was an average of .14% live weight in three hours, comparing this to their counterparts who had an estimated intake of 0.8% of their live weight in three hours without the grazing muzzles. These findings show a decrease in intake of about 83% when the grazing muzzles were used. Also highlighted in these findings was the fact that the unmuzzled horses were able to consume about one half to two-thirds of their daily total DMI in
only three hours, leading to a potential for owners to underestimate pasture intakes at pasture [39].

Another method that was investigated by Dowler et al was restriction of turnout time on pasture to decrease DMI, thereby decreasing caloric intake. The horses were turned out for 4 and 8 hours, and DMI and dry matter intake rates (DMIR) were calculated. They found that horses had the ability to consume about 55% of their daily DE requirement in the first 4 hours alone. The DMIR of the first 4 hours was almost double that of the second 4 hours (0.9 g DM · kg BW\(^{-1}\) · h\(^{-1}\)). This data shows that horses may be ingesting more than we would predict when turned out for limited time, which would mean a possible consumption of calories over their requirements [1].

**Methods to estimate forage intake and its effects**

Rayburn et al devised a method of herbage mass estimation using a plate meter device to estimate sward height and density so that intakes can be estimated using loss of herbage mass (Rayburn EB; Rayburn EB and Lozier J; Johnson PJ, CE Wiedmeyer, and VK Ganjam 163-74). Multiple measurements are made in random order covering the entire pasture both before and after grazing, and these measurements were able to predict the initial and residual herbage mass. By measuring the sward height at each of the measurements and then cutting a known area of grass representing low, medium and tall heights of grasses found in the pasture, an approximation can be made of herbage mass present. The weight of the cut grass of the small known area is extrapolated to the entire pasture and according to Rayburn gives a fairly accurate estimate of forage availability (P<0.01) [40].
The step-point forage estimation, taken from Evans et al [41], was used to estimate the plant species that were present during the trial. For the step-point, a specific point is noted on the observer’s boot, and a predetermined number of steps are taken between each measurement. Whatever plant the point of the boot lands on is the species that is recorded. It is generally done in a diagonal or serpentine pattern across each pasture, with 50 measurements taken from each. Then the numbers are multiplied by two in order to get a percentage of each species present.

**Fecal pH Estimation**

Fecal pH has been shown to be a fairly accurate assessment of colonic health in other species such as rats, pigs [42,43]. In a study by Berg et al, they used fecal pH to determine the effects of fructooligosaccharide (FOS) supplementation in yearlings, and how it can exert different effects on the hindgut [44]. They found that pH at baseline to be 6.48, decreasing to 6.44 after 8 g of FOS was added, and further decreasing to 6.38 after 24 g of FOS was added to the diet. This is due to the fermentation of the β 2-1 bonds of the FOS in the equine hindgut, leading to an increase in the production of both lactic acid and volatile fatty acids (VFAs), decreasing the pH of the hindgut and feces [44].

It has not been validated whether a correlation exists between fecal pH values and cecal pH values in horses, and so whether or not the fecal pH is entirely definitive of what is going on in the cecum is still to be discovered. This correlation has been investigated in rats, where they found that fecal pH was consistently higher than cecal pH [45]. But even if there
is not a direct correlation numerically, the trend of decreasing and increasing fecal pH values may still reflect fermentative processes that are occurring in the hindgut of the horse.

Fermentation of carbohydrates to VFA’s are a very important energy source for the equine, as they are produced at fairly high levels in the cecum and ventral and dorsal colon of the equine, and then rapidly absorbed [46]. The fermentation of carbohydrates to form VFA’s can alter the fecal pH of the horse, with increasing VFA production leading to decreased pH, although there have been very few studies on how different forage types influence the hindgut microbial community and fermentation patterns. Silage and haylage both contain more lactic acids and lead to higher production of VFA’s, which leads to lower pH when compared to traditional hay sources [47]. However, in a study by Muller et al (2008), they found that hay consumption produced a lower fecal pH measurement of 6.07 ($P \leq 0.05$) compared to the silage and haylage pH values (6.23 and 6.36, respectively), with a moderate right ventral colon pH measurement [48].
CHAPTER II - MATERIALS AND METHODS

Animals and Treatments

The following experimental protocol was approved by the North Carolina State University Animal Care and Use committee. The following experimental protocol was approved by the North Carolina State University Animal Care and Use committee. This study took place during September 2010 at the North Carolina State University Equine Research Unit near Raleigh, NC. Eight mature idle geldings (549 ± 41 kg) were used in a 4x4 Latin square design. Horses were randomly assigned to one of four groups, with two horses per group. Horse groups (HGRP) were randomly assigned to one of four treatments consisting of 3, 6, 9, or 24-h of pasture access for a period of 7 d. Horse groups within grazing cells were reassigned to a new treatment every 7 d so each HGRP received all treatments. A 3.2 ha pasture was divided equally into 16 grazing cells, each 0.2 ha in size. Grazing began at 0700 h each day for all treatments, and ended at 1000, 1300, and 1600 h for the 3 h, 6 h, and 9 h groups respectively. Horses were housed individually in partially covered dry lot pens (3.6 m x 12 m) while not at pasture. All horses had continuous access to water and salt. The 3 and 6 h groups were individually fed free choice grass hay (92.87% DM, 1.78 Mcal DE/kg, 5.91% CP, 66.38% NDF, 41.33% ADF). Individual hay intake was determined daily for horses in the 3 and 6 h groups every morning after the horses were returned to their grazing cells as the difference between the amount of hay offered, and the orts.
Animal Sample Collection and analysis

Body weights were measured immediately prior to and following each 7-d grazing period using an electronic scale (precision = ± 1 kg; Smart Scale 200, Gallagher Animal Management, USA). Fresh fecal samples were collected from each horse via rectal grab-sample on d 7 at 0700 before turnout, or if horses defecated prior to rectal collection the feces were picked up off of the ground using care to avoid contamination. Immediately after collection 50 g of feces were mixed with 50 g of distilled water and vortexed for 30 seconds using a vortex and then left to equilibrate for 5 minutes. Duplicate measures of pH and temperature of the samples were taken immediately after using a Symphony pH portable meter (VWR International, Batavia, IL). The pH meter was calibrated using a two-point calibration (pH 4.01 and 7) in order to ensure accurate measurements.

Pasture Sample Collection and Analysis

Pasture plant composition was estimated using the point-step method, with 11 steps taken between each recording and moving in a serpentine pattern from opposing corners of each 0.2 Ha grazing cell. Fifty measurements were taken from each grazing cell for each period. Initial Herbage Mass (IHM) and residual HM (RHM) were measured using a plate meter estimation, according to Rayburn [49]. The plate meter consisted of a circular polyvinyl disc, 0.25 m diameter, attached to a plastic sheath that was placed over a metal pole which was labeled up to 50.8 cm in height. For each measurement, the sheath was held to a predetermined height of 50.8 cm and then dropped onto the canopy and the compressed canopy height was then recorded. Twenty plate meter measures were taken in a serpentine pattern on
with 20 steps between each measurement. Initial herbage mass (IHM) measurements were taken the day prior to the beginning of each period, before horses were allowed to graze the new pastures. Residual herbage mass (RHM) measurements were taken the day after the horses were removed from the pasture, again using the plate meter method. Nine of the twenty plate meter measurements made on both d-1 and d-7 that represented the three shortest, three average, and three tallest heights were used to calibrate the plate meter for a total of eighteen measures. Calibration was accomplished by recording the compressed canopy height and then harvesting the plants within the compressed canopy’s boundaries to 5.2 cm in height. A .25 x .25 m PVC square outline was used to define the boundary of the compressed canopy. The harvested calibration samples were placed in plastic bags and initial weight was recorded. They were then placed in a freezer at 20 °C until analyzed for percent dry matter. Dry matter concentration was determined by placing individual samples in brown paper bags within a drying oven set at 60° C, along with three empty paper bags that were dried as controls. The weights of the samples and empty paper bags were recorded daily until two consecutive readings were obtained that were of the same weight (± .2 g). These dry weights were then divided by the weights of the samples immediately after clipping in order to obtain the percent dry matter. The grams of dry matter harvested from the .25 x .25 m area under the plate meter were regressed against the compressed plate height and the resulting prediction equation was used to determine IHM and RHM based on the mean of the twenty compressed canopy heights obtained from individual grazing cells prior to and following grazing. Daily pasture DMI was expressed as a g · kg BW\(^{-1}\) · d\(^{-1}\). Total DMI (totDMI) was calculated as the sum of daily pasture and hay intake and also expressed as g · kg BW\(^{-1}\) · d\(^{-1}\).
Pasture DMIR was calculated by dividing the pasture DMI by the number of hours of pasture access, and expressed as g DM · kg BW\(^{-1}\) · h\(^{-1}\). DE was determined using the equation DE (Mcal/kg DM) = 2.118 + 0.01218 CP - 0.00937 ADF - 0.00383 (NDF - ADF) + 0.04718 EE + 0.02035 NFC - 0.0262 Ash \[37\]. DE was expressed as Mcal/ d.

An additional sample was collected from the immediate grazing area of the horses on d 1 of each period to reflect the actual grazing height and forage preferences of the horses in each period and placed in plastic bags. These samples were sent for chemical composition analysis of DM, ADF, NDF, CP, NFC, and fat by North Carolina Department of Agriculture Forage Testing Lab. Forage DE was calculated using the equation DE = ((4.22-0.11(\% ADF))+(0.0332(\% CP))+(0.00112(\%ADF)\(^2\)) \[37\].

Statistical Analysis

Response variables (pasture DMI, DMIR, totDMI (pasture + hay intake), pasture DE, total DE, IHM, and fecal pH) were analyzed as a Latin square design using the PROC GLM procedure of SAS (version 8, SAS Inst. Inc., Cary, NC), according to Walker \[50\]. Horse group was considered the experimental unit. The model included HGRP, period and treatment. Results were considered significant at \(P< .05\), with a trend being considered at \(P< .10\). Results are expressed as least squares means (± SE). Pasture plant composition was calculated by determining the proportion of each individual plant forage specie (i.e. crabgrass, tall fescue), weed or bare ground measurements relative to the total number of measurements (i.e. 50) for each pasture.
CHAPTER III- RESULTS

Pasture Plant Composition

Pasture composition shown in Table 1. Pasture consisted of 54.7% *Digitaria ischaemum*, 28.3% *Festuca arundinacea*, with the remaining forage available being comprised of *Alopecurus myosuroides*, *Paspalum dilatatum*, weeds, and bare ground.

Table 1. Pasture Plant Composition

<table>
<thead>
<tr>
<th>Species</th>
<th>Pasture Composition (% of Pasture)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crabgrass (<em>Digitaria ischaemum</em>)</td>
<td>54.7</td>
</tr>
<tr>
<td>Tall Fescue (<em>Festuca arundinacea</em>)</td>
<td>28.3</td>
</tr>
<tr>
<td>Fox Tail (<em>Alopecurus myosuroides</em>)</td>
<td>8.4</td>
</tr>
<tr>
<td>Dalisgrass (<em>Paspalum dilatatum</em>)</td>
<td>1.14</td>
</tr>
<tr>
<td>Weeds</td>
<td>0.86</td>
</tr>
<tr>
<td>Bare Ground</td>
<td>6.6</td>
</tr>
</tbody>
</table>

*a determined using the step-point method  
*b measurements were taken every 5 steps

Initial Herbage Mass (IHM)

Mean IHM was 38.11, 36.52, 33.67 and 31.5 ± 2.58 kg DM/d for 3, 6, 9 and 24-h treatment groups respectively. Mean IHM was not significantly different among the treatments (*P* = .35, Fig. 5), but was numerically lower in periods 2 and 3 (29.43 and 31.24 ± 2.58 kg DM/d, respectively) versus 1 and 4 (37.52 and 41.57 ± 2.58 kg DM/d, respectively).

Pasture Dry Matter Intake

Mean pasture DMI was 5.88, 9.1, 10.1, and 13.6 ± 1.12 g DM/ kg BW for 3, 6, 9 and 24-h treatments respectively (*Fig. 6*). Mean pasture DMI for the 3-h treatment was less (*P* < .05)
than both the 9 and 24-h treatments, and the 6-h treatment was less \((P = .03)\) than the 24-h treatment.

Mean pasture DMI was 13.53, 7.1, 5.85, 12.15 ± 1.12 g DM/ kg BW for periods 1, 2, 3 and 4.

Periods 1 and 4 were higher than periods 2 and 3 \((P < .001)\). Mean total DMI (totDMI), also shown in Table 1, was not different among treatments \((P = .16)\), however, there was a period effect observed \((P = .01)\). Mean totDMI was 15.3, 8.92, 7.88, and 14.6 ± 1.04 g DM/ kg BW for the 1, 2, 3 and 4 periods, respectively, with periods 2 and 3 being significantly lower than periods 1 and 4 \((P = .01)\).

**Pasture Dry Matter Intake Rate**

Mean DMIR was 1.96, 1.52, 1.12, and .57 ± .207 g DM · kg BW⁻¹ · h⁻¹ for horses having access to pasture for 3, 6, 9 and 24 h, respectively \((Fig. 7)\). Mean DMIR for the 3-h treatment was greater \((P < .05)\) than both the 9 and 24-h treatments, and the 6-h treatment was greater \((P = .02)\) than the 24-h treatment. Mean pasture DMIR was 1.645, .89, .79, and 1.84 ± .21 g DM · kg BW⁻¹ · h⁻¹. Mean pasture DMIR and DMI for periods 1 and 4 were greater \((P < .05)\) than periods 2 and 3.

**Total DMI**

Mean total DMI (totDMI) was 10.6, 12.4, 10.0 and 13.6 ± 1 kg DM/ kg BW for the 3, 6, 9 and 24 hour treatments, respectively \((Fig. 8)\). The means did not differ among treatments \((P = 0.16)\), with only a small numerical difference being observed. However, there was a period effect observed \((P = 0.005)\). TotDMI by period were 15.3, 8.92, 7.88, and 14.6 ± 1.04 kg DM/ kg BW for the 1, 2, 3 and 4 periods respectively.
**Digestible Energy Intake**

Mean pasture digestible energy (DE) shown in Figure 9 was 14.87, 24.09, 23.59, and 34.34 ± 3.07 Mcal/d for the 3, 6, 9 and 24 h treatments, respectively (Fig. 9). Mean pasture DE was greater when horses were on the 24 h treatment ($P < .0001$) as compared to all other treatments. A period effect was also observed for the pasture DE measurements, with periods 1 and 4 being significantly higher than periods 2 and 3 ($P < .01$). Mean total DE (hay + pasture) intake as was not affected by horse group or treatment, but was affected by period ($P = .01$, Fig. 6), with periods 2 ($P < .01$) and 3 ($P < .01$) being significantly lower than periods 1 and 4.

**Fecal pH**

Mean pH values were 7.23, 7.30, 7.32, and 7.61 (± 0.1090) for the 3, 6, 9 and 24-h groups respectively (Fig. 11). Mean fecal pH values were not affected by treatment ($P = .17$), but did experience a period effect. Mean fecal pH values observed in period 1 were significantly higher ($P < .01$) than for the other three periods.

**Body Weight**

There was a significant difference in mean body weight (BW) observed among treatments, periods and horses (Fig 12.). The horses in the 3- and 24-h treatments had higher BW’s than horses in the 6- and 9-h treatments ($P < 0.0001$). Horses’ BW in the 6- and 9-h treatments were not statistically different from one another ($P = 0.71$), and the BW’s in the 3- and 24-h treatments were not statistically different from one another ($P = 0.0136$). Among periods, period 1 horses had the highest observed BW’s (an average of 554.40 kg), and were statistically similar to the
BW’s from period 2 (an average of 551.62 kg). Periods 3 and 4 BW were statistically similar to one another, and was the lowest of all of the periods (an average of 546.63 and 543.59 kg, respectively). The average BW declined between each consecutive period, with average BW being 554.40 kg for period 1, 551.62 kg for period 2, 546.63 kg for period 3 and 543.59 kg for period 4. Among horses, there were only similarities observed between horses 4 and 5 \( (P = 0.4949) \) with average BW’s of 595.20 and 597.33 kg, respectively, and horses 6 and 7 \( (P = 0.8910) \), with average BW’s of 530.20 and 529.78 kg, respectively. There was a tendency for a similarity between horses 3 and 8 \( (P = 0.0808) \), with their BW’s averaging 501.14 and 495.48 kg, respectively.
CHAPTER IV - DISCUSSION & CONCLUSION

The results of the present study support the hypothesis that restricting pasture access increases pasture dry matter intake rate. These results agree with a previous report showing DMIR during the first 4 h of grazing was 67% greater than that of the following consecutive 4-h grazing period [1]. The 3- and 6-h DMIR values in the present study are slightly higher than the 4- and 8-h DMIR of 1.2 and 1.5 g DM \cdot kg BW^{-1} \cdot h^{-1}, respectively, reported by Dowler et al. This difference may be a function of accelerated DMIR caused by the shorter grazing period (3- and 6-h) in the present study as compared to 4- and 8-h used by Dowler et al. Other reports of DMIR over a 3-h period in yearlings [15,15] and ponies [51] range from .9 to 2.7 g DM \cdot kg BW^{-1} \cdot h^{-1}, and have a mean of 1.8 ± .76 g DM \cdot kg BW^{-1} \cdot h^{-1}, which is similar to the present DMIR measured over a 3-h period. Cantillon reported DMIR values obtained over 7-h grazing period ranging from 1.3 to 1.5 g DM \cdot kg BW^{-1} \cdot h^{-1} for mature idle horses [14,14], which is similar to the mean DMIR measured for the 6- and 9-h treatments. The similarities between the present study findings and previous reports add support to the validity of these DMIR measurements.

The reported totDMI from this study are lower than expected, as previous reports reported average intakes of about 2-3% BW (Grace et al. 182-85;Dulphy et al. 49-56;Marlow et al. 155-57). The 24-h treatment in this study had the highest totDMI intake, equating to about 1.4% BW. This could potentially be due to the limiting IHM for the 24 h treatment, as it had numerically the lowest amount of herbage mass available. Assuming horses could consume 50-70% of the available pasture, at
maximum the horses in this treatment had the ability to consume 2.2% of BW if everything in the cell was consumed except for trampled grass and spots of defecation. However, the totDMI for the other three treatments did not exceed that of the 24-h treatment and were consistent among treatments, suggesting either errors in DMI estimation, or other factors leading to a totDMI that was lower than expected.

Increased forage maturity and associated high NDF and ADF values can decrease pasture DMI [52]. However, there are studies that disagree with these findings, and conclude that NDF has no effect on voluntary DMI [53]. The present study supports the former hypothesis, as intakes were depressed while using mature pasture forage high in NDF, potentially leading to a lower DMI. This is further supported by data reported by Frape, in which they found coarse, poorly digested long-fibrous feeds to be retained longer in the large intestine, decreasing DMI [54].

The totDMI in periods 2 and 3 were lower than periods 1 and 4, potentially due to lower available IHM and environmental conditions. Overall, mean IHM was lower in periods 2 and 3 as compared to periods 1 and 4, which could have been contributing factor. The lower totDMI in period 2 can also be attributed to the highest environmental temperatures occurring in this period. Cymbaluk and Christison found higher environmental temperatures led to significantly decreased DMI in horses, up to 15-20% [55]. Period 3 experienced the lowest environmental temperatures, with temperatures staying mostly around 75°F compared to temperatures in the 80-95°F range for the other periods. Theoretically this would lead to an increase in DMI, however, the only precipitation of the study occurred during period 3 which could have directly led to a decrease in DMI, or indirectly caused an error in DMI estimates.
The rainfall could have led to re-growth of the pasture forages after IHM was estimated, leading to a higher RHM estimate due to an increase in forage present after the first IHM estimate, equating to a smaller difference between the IHM and RHM measurements, making the DMI estimate appear much smaller than it actually was.

Pasture DE intakes were significantly affected by both treatment and period. The trend observed is intuitively obvious, with DMI increasing from the 3 to 6 up to the 24-h treatment, and so a larger amount of calories were consumed. However, in the 3 h treatment, horses were able to increase their DMIR to consume about 50% of their daily caloric requirements. This is in agreement with caloric intake values published by Dowler et al, in which horses were able to consume about 55% of their daily caloric requirements in the first 4 h [1]. After caloric intake from hay was added to the 3- and 6-h treatments, no significant difference was observed among treatments. All treatments were able to consume close to their recommended daily caloric intakes, even with the low-quality hay that was provided. The hay provided on average about 1.78 Mcal/kg, compared to an average fresh pasture caloric value of about 2.24 Mcal/kg. For the 3-h treatment, the horses consumed 45% of their caloric intake from hay in the remaining 21 h, while the majority of their calories came from their brief time at pasture. Even though it was thought that DMI was low for the 24 h, horses were still able to consume 100% of their daily recommended caloric intake. Suggesting that even when horses are thought to have an inadequate DMI, they can still meet almost if not all of their nutrient requirements, and additional supplementation may be unnecessary.
Fecal pH values are a useful tool for describing the effects of diet on hindgut fermentation processes. Although fecal pH is consistently lower in many studies than both cecal or right ventral colon pH, it is still reflective of the changes occurring in the hindgut [48]. Fecal pH is influenced by the fermentable substrates present in the diet, and addition of these substrates will cause a decrease in fecal pH [56]. Pagan et al. found that increasing the amount of substrate being delivered to the hindgut will affect rate of passage, altering hindgut fermentation [57]. However, it has been found that a decrease from 24 h to 12 h of grazing allowance does not have a similar effect, even though it has been hypothesized that a decrease in forage access should force horses to consume larger amounts in a shorter period of time, increasing delivery of the fermentable substrates to the hindgut. Fecal pH was not different between horses allowed to graze continuously for 24 h, and those whose access was restricted to 12 h only [2], suggesting that horses may have the ability to maintain a homeostatic range in pH, even with what appears to be a significant external change in feeding patterns.

The results of the present study further support the finding of no effect of grazing restriction on fecal pH. This may be a function of the poor quality of forage provided, increasing gut retention time and rate of passage, or not enough difference in totDMI among treatments. However, there was a period effect observed with period 1 fecal values being higher than the other three treatments. This may be explained by the higher pasture DMI and totDMI observed in period 1 versus the other periods, and also a residual effect of the horses being moved from previous maintenance pasture to experimental pastures without a wash-out period.
Mean BW differed among periods, treatments and horses. It is unlikely that the changes seen in BW were due to any actual changes in BW, as the time period was too short to see any significant differences, and rather was likely a function of sampling time. The 24-h probably had a fairly constant gut fill, leading to a higher overall live weight at sampling. The 3-h had been stalled for about 21 h, and so by the time of BW sampling, one hour before turnout, the horses were most likely starting to anticipate pasture access, and started to consume some of the preserved forage provided. The 9-h treatment on the other hand had been stalled about 15 h without any other forage or feed being provided, and so had the smallest amount of gut fill, leading to the lowest BW being observed.

The higher observed period 1 BW could be explained by a residual effect from a lack of a wash-out period before the beginning of our trial, where horses had unrestricted access to pasture. There was a continuous decline in BW’s from period 1 to period 4, with each period having a slightly lower average BW than the period before, suggesting that the horses were losing weight throughout the trial. Again, this could be due to the high environmental temperatures which have been shown to decrease horses’ DMI in an attempt to decrease heat production and try to keep cool [6], thereby potentially decreasing their BW. It is less surprising to see a difference in BW among individual horses, as horses vary from one to another. There were a few horses in the trial that were of lighter breeding than the others, which accounts for some of the lower average BW that were observed.
The results of this study support our hypothesis that DMIR increases with restricted grazing. This is important for horse owners and managers because the assumption that horses maintain a steady rate of intake may not be valid, and extrapolation of 24-hr intakes to shorter turnout periods may under estimate the actual pasture caloric intake levels of horses. This can then lead to improper ration balancing, further exacerbating metabolic problems in horses. This study also suggests that decreased turnout time does not have an effect on the pH of the feces, and most likely of the hindgut as well. This is in agreement with previous studies published, presenting the same results. This could imply that horses’ hindgut have the ability to maintain a homeostatic range in pH, even with what appears to be significant external change in feeding patterns.
REFERENCES


[34] Friend M. A. and Nash D. Pasture intake by grazing horses. RIDRC. 2000;


[51] Ince JC, Longland AC, Newbold CJ, and Harris PA. Changes in proportions of dry matter intakes by ponies with access to pasture and haylage for 3 and 20 hours per day respectively, for six weeks. Journal of Equine Veterinary Science. 2011;31:283.


APPENDIX
Pasture Layout

<table>
<thead>
<tr>
<th>Period</th>
<th>Period</th>
<th>Period</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>HGRP 1</td>
<td>3 h</td>
<td>24 h</td>
<td>9 h</td>
</tr>
<tr>
<td>HGRP 2</td>
<td>6 h</td>
<td>3 h</td>
<td>24 h</td>
</tr>
<tr>
<td>HGRP 3</td>
<td>9 h</td>
<td>6 h</td>
<td>3 h</td>
</tr>
<tr>
<td>HGRP 4</td>
<td>24 h</td>
<td>9 h</td>
<td>6 h</td>
</tr>
</tbody>
</table>

*Figure 4. Diagram of treatment layout and location of horse groups.*
Initial Herbage Mass (IHM)

Fig 5. Graph of results of initial herbage mass estimation. There was no significant difference observed in the amount of herbage mass available to the horses among treatments. Available herbage mass ranged from 31.5-38.11 kg DM/d.

Treatment $P=0.3526$
Period $P=0.0503$
Pasture DMI by treatment

Fig 6. Graph of estimation of Pasture dry matter intake by treatment represented in g DM/ kg BW. The 3-h treatment had similar intakes to the 6-treatment group, while the 6- and 9-h groups were similar, along with the 9- and 24-h groups being statistically similar. 24-h intakes were slightly lower than expected, representing an intake of about 1.42% BW which may be due to limited herbage mass availability.
Pasture DMIR by treatment

Fig 7. Graph of pasture dry matter intake rate in g DM · kg BW$^{-1}$ · h$^{-1}$. Results are comparable to results obtained by Dowler et al., with the 3-h treatment consuming at a rate of 1.96 g DM · kg BW$^{-1}$ · h$^{-1}$, similar to Dowler’s 4 h DMIR of 2.2 g DM · kg BW$^{-1}$ · h$^{-1}$. The 9-h treatment had a DMIR of about 1.12 g DM · kg BW$^{-1}$ · h$^{-1}$, compared to 0.09 g DM · kg BW$^{-1}$ · h$^{-1}$ for their 8-h treatment.
Fig 8. Estimation of total dry matter intake in g DM/ kg BW, including both pasture forage and hay intakes. The black bars represent pasture dry matter intake, while the checkered bars represent dry matter intake after hay intakes were added. No statistically significant differences were observed among any of the treatments, even after hay was added into the ration. The 3- and 6-h treatments were numerically similar to one another, along with the 6- and 24-h treatments being similar to one another.
Daily Pasture DE Intake

Model $P = 0.04$
Period $P = 0.02$
Treatment $P = 0.04$

![Graph of daily pasture digestible energy intake by horse group, represented in Mcal/day. The 24-h treatment was the only treatment that was statistically different from any of the other treatments, while the 6- and 9-h treatments were numerically similar to one another.](image-url)
Fig 10. Graph of total daily digestible energy intake per horse group, including both daily hay and forage intakes, represented in Mcal · kg DM⁻¹ · d⁻¹. All treatments were able to consume at a level close to their recommended daily caloric intakes, with the 3- and 9-h treatments consuming the lowest at 70%, while the 6-h treatment was able to consume about 90% and the 24-h treatment was able to consume about 100% of their daily requirements.
Average fecal pH values by treatment

Model $P = 0.07$
Treatment $P = 0.17$
Period $P = 0.02$
Pooled SEM = 0.109

Fig 11. Graph of average fecal pH values by treatment. There was no significant difference observed among any of the treatments, as the pH did not appear to be affected by turnout length.
Average BW by Treatment

\[ R^2 = 0.99; \text{Model } P < 0.0001 \]
\[ \text{Horse Group } P < 0.0001 \]
\[ \text{Period } P = 0.0004 \]
\[ \text{Treatment } P < 0.0001 \]

Pooled SEM = 1.53

Fig 12. Graph of average body weight, in kg, by treatment. There was a significant effect of horse group, period, and treatment on body weight seen in the results.
Title1 'PS2010_03 Total pasture intake (g/kgBW/d)';
Title2 'Using d1+d7 calibration for each pasture w/in periods';
Data pasture; input horsegrp period time pasture;
cards;
 1 1 3 4.39
 1 2 6 5.88
 1 3 9 5.19
 1 4 24 4.52
 2 3 3 3.96
 2 4 6 11.69
 2 1 9 10.69
 2 2 24 9.58
 3 4 3 9.01
 3 1 6 11.89
 3 2 9 10.62
 3 3 24 9.36
 4 2 3 3.78
 4 3 6 7.17
 4 4 9 7.17
 4 1 24 3.73
;
proc glm;
class horsegrp period time;
model pasture = horsegrp period time;
lsmeans time period horsegrp /stderr pdiff;
run;

Fig 13. SAS input for determining effects of variables on total pasture DMI.
Title1 'PS2010_03 tot DMI ';

Data pasture; input horsegrp period time totDMI;
cards;
  1 1 3 9.858750319
  2 1 6 9.105989411
  3 1 9 5.192264094
  4 1 24 4.515012256
  1 2 3 7.942885968
  2 2 6 15.8370982
  3 2 9 10.68833486
  4 2 24 9.577360982
  1 3 3 14.67465962
  2 3 6 14.64476319
  3 3 9 10.61754896
  4 3 24 9.362917957
  1 4 3 7.779407005
  2 4 6 11.49071892
  3 4 9 7.172216813
  4 4 24 6.728158361
;
proc glm;
class horsegrp period time;
model totDMI = horsegrp period time ;
lsmeans time period horsegrp / stderr pdiff;
run;

Fig 14. SAS input for determining differences in totDMI among variables.
Title1 'PS2010_03 pasture DE Mcal/d';

Data pasture;
input horsegrp period time pastDE;
cards;
1 1 3 13.78
3 1 6 33.30
2 1 9 42.64
4 1 24 42.60
1 2 3 8.78
3 2 6 17.10
2 2 9 14.11
4 2 24 29.81
2 3 3 10.55
4 3 6 16.20
1 3 9 14.75
3 3 24 22.95
3 4 3 26.35
2 4 6 29.75
4 4 9 22.84
1 4 24 42.01

;  
proc glm;
  class horsegrp period time;
  model pastDE = horsegrp period time ;
  lsmeans time period horsegrp /stderr pdiff;
  run;

Fig 15. SAS input for determining pasture DE differences among variables.
Title1 'PS2010_03 Total DE Intake (Mcal/d)';
Title2 'Using d1+d7 calibration for each pasture w/in periods';
Data pasture; input horsegrp period time totDE;
cards;
1  1  3  24.95
1  2  6  38.81
1  3  9  42.6
1  4 24  42.6
2  3  3  16.14
2  4  6  23.67
2  1  9  14.1
2  2 24  29.21
3  4  3  18.38
3  1  6  23.9
3  2  9  14.75
3  3 24  22.95
4  2  3  37.74
4  3  6  37.6
4  4  9  22.84
4  1 24  42.01
;
proc glm;
class horsegrp period time;
model totDE = horsegrp period time;
lsmeans time period horsegrp /stderr pdiff;
run;

Fig 16. SAS input for determining differences in total DE intake among horsegroups.
Title1 'PS2010_03 pH data by HGRP';

Data pasture; input horsegrp period time pH;
cards;
1 1 3 7.69
1 2 6 7.10
1 3 9 7.10
1 4 24 7.18
2 3 3 6.90
2 4 6 7.53
2 1 9 7.60
2 2 24 7.55
3 4 3 7.15
3 1 6 7.65
3 2 9 7.29
3 3 24 7.46
4 2 3 7.16
4 3 6 6.93
4 4 9 7.28
4 1 24 8.23:

proc glm;
class horsegrp period time;
model pH = horsegrp period time;
lsmeans time period horsegrp / stderr pdiff;
run;

Fig 17. SAS input for determining differences in pH among horsegroups.
Title1 'PS2010_03 change in BW by horse';

Data pasture;
input horse period time BW;
cards;
1 1 3 561.93
2 1 3 586.93
3 1 9 501.14
4 1 9 593.18
5 1 6 595.45
6 1 6 530.68
7 1 24 550.57
8 1 24 515.34
1 2 6 559.55
2 2 6 583.07
3 2 24 509.77
4 2 24 606.36
5 2 9 592.95
6 2 9 527.05
7 2 3 535.00
8 2 3 499.20
1 3 9 555.91
2 3 9 575.76
3 3 3 504.55
4 3 3 601.48
5 3 24 601.59
6 3 24 532.39
7 3 6 517.39
8 3 6 483.98
1 4 24 561.25
2 4 24 589.09
3 4 6 489.09
4 4 6 579.77
5 4 3 599.32
6 4 3 530.68
7 4 9 516.14
8 4 9 483.41;

proc glm;
class horse period time;
model BW = horse period time;
lsmeans time period horse / stderr pdiff;
run;

Fig 18. SAS input for determining change in BW throughout trial by each individual horse.