Maximizing Equine Forage Utilization through the Reduction of Hay Waste and Grazing Alternative Pasture Species

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Table of Contents

Acknowledgements i

Table of Contents ii

List of Tables iii

List of Figures iv

Chapter 1: Review of Literature

Forages and Horses 1
Equine Management 2
Costs Associated with Feeding Hay 3
Utilizing Feeders to Reduce Hay Costs 9
Feeding Horses on Pasture 13
Utilizing Alternative Grasses to Reduce Feeding Costs 15
Literature Cited 32

Chapter 2: The Effect of Small Square-Bale Feeder Design on Hay Waste and Economics during Outdoor Feeding of Adult Horses

Chapter Summary 41
Introduction 42
Materials and Methods 43
Results and Discussion 46
Conclusion 51
Acknowledgements 51
Literature Cited 55

Chapter 3: Yield, Forage Nutritive Value, and Preference of Annual Grasses under Horse Grazing

Chapter Summary 57
Introduction 58
Materials and Methods 61
Results and Discussion 65
Conclusion 81
Literature Cited 92

Bibliography 97

List of Tables

Table 2.1. Forage nutritive value (means ± SE) of grass hay fed to adult horses at maintenance. 52

Table 2.2. Hay waste, estimated hay intake, herd bodyweight (BW) change, and payback of three small square-bale feeders and a no-feeder control used to feed adult horses. 53

Table 3.1. Gender, bodyweight (BW), age, and body condition score (BCS) of four groups of horses used for grazing experiments. 86

Table 3.2. Stages of maturity for cool-season annual grasses planted in spring and fall and grazed at two different maturities in St. Paul, MN. 87

Table 3.3. Yield, horse preference, crude protein (CP), neutral detergent fiber (NDF), nonstructural carbohydrate (NSC), and equine digestible energy (DE) of spring-planted annual cool-season grasses grazed by horses at an immature growth stage in St. Paul, MN. 88

Table 3.4. Yield, horse preference, crude protein (CP), neutral detergent fiber (NDF), nonstructural carbohydrate (NSC), and equine digestible energy (DE) of spring-planted annual cool-season grasses grazed by horses at a mature growth stage in St. Paul, MN. 89

Table 3.5. Yield, horse preference, crude protein (CP), neutral detergent fiber (NDF), nonstructural carbohydrate (NSC), and equine digestible energy (DE) of fall-planted annual cool-season grasses grazed by horses at an immature growth stage in St. Paul, MN. 90

Table 3.6. Yield, horse preference, crude protein (CP), neutral detergent fiber (NDF), nonstructural carbohydrate (NSC), and equine digestible energy (DE) of fall-planted annual cool-season grasses grazed by horses at a mature growth stage in St. Paul, MN. 91

List of Figures

Figure 2.1. Small square-bale feeder designs evaluated when feeding adult horses, including (A) basket, (B) hayrack, (C) slat, and (D) all three photographed together. 54

Figure 3.1. Monthly air temperature (°C), precipitation (cm), and 30-year historical average for St. Paul, MN during the 2013 and 2013 growing season. Weather data obtained from http://www.dnr.state.mn.us/climate/historical/ index.html. 83

Figure 3.2. Distribution of yield (t ha^{-1}) across multiple grazing events for (A) immature spring-planted annual grasses, (B) mature spring-planted annual grasses, (C) immature fall-planted annual grasses, and (D) mature fall-planted annual grasses. 84

Chapter 1

Review of Literature

Forages and Horses

Horses are herbivores, with a digestive system that has developed to be able to consume a large quantity of forages, such as vegetative grasses, legumes, herbs, and shrubs. Horses are uniquely designed in that they have foregut enzymatic digestion similar to non-ruminants such as pigs, but they also have an enlarged hindgut for post-gastric fermentation. This specialized digestive system enables the equine to successfully subsist on a forage-based diet. Forages are typically characterized by a high dietary fiber content, which is comprised of both structural carbohydrates (SC) and nonstructural carbohydrates (NSC). Structural carbohydrates consist of the plant cell wall and varying amounts of lignin, while NSC originate from the cell contents, including the simple sugars glucose, fructose, and sucrose, as well as storage carbohydrates such as starch or fructan (NRC, 2007). Together, the SC and NSC constitute the main energy-yielding fractions of forage. The starch portion of forages can be digested to glucose by endogenous enzymes in the horse's small intestine, and together with the free sugars, be absorbed across the small intestine of the horse and metabolized to yield adenosine triphosphate (ATP) and provide energy (NRC, 2007). However, the SC and fructans in forages cannot be digested by mammalian enzymes in the foregut (Janis, 1976; Åman and Graham, 1990). Instead, these SC and fructans are fermented by the gut microflora in the hindgut, yielding volatile fatty acids (VFAs) which can be absorbed and metabolized to yield ATP (Janis, 1976; NRC, 2007).

It is generally assumed that on average, horses need to consume about 2% of their body weight (BW) in feed on a dry matter (DM) basis per day (Dulphy et al., 1997a; b; NRC, 2007). Forages, in the form of either hay or pasture, represent a significant portion of the diet for all classes of post-weaned horses, and some adult horses can receive their entire dietary requirement from forages alone (NRC, 2007). Forages consist of the leaf, sheath, and stem of the plant and, depending on the stage of growth, may also include flowers and seed-heads. All portions of the plant differ in chemical composition, and their relative proportions may change substantially depending on the stage of growth, time of year, climate, and soil type and fertility (NRC, 2007). For adult horses, forages should never comprise less than 50% of the total diet, as the fiber content in forages plays an essential role in maintaining normal microbial function necessary for fiber fermentation and VFA production in the hindgut (NRC, 2007).

Equine Management

The equine population is a rapidly growing sector of the livestock industry. As of 2005, the American Horse Council (AHC) estimated that there were approximately 9.2 million horses in the United States (AHC, 2005). The 2012 USDA Census of Agriculture reported 9,537 horse and pony farms in Minnesota, and 66,384 horses and ponies (USDA/NASS, 2012). A statewide survey of Minnesota horse owners indicated that a majority of horses in Minnesota spend a significant amount of time being housed on pasture where free grazing is available (Martinson et al., 2006). However, according to the same survey, only 24% of horses were reported to receive their entire nutritional requirement from pasture during the summer months, and 45% of horse owners who keep their horses on their own residential property buy between 81 and 100% of their hay (Martinson et al., 2006).

As the equine population continues to grow, there is increasing demand for good quality forages, either in the form of harvested forage or land able to be grazed as pasture. Feed costs are one of the greatest expenditures of horse ownership, a concept well known within other livestock industries as well. Feed remains the largest single cost item for meat and milk production, accounting for 60-70% of the total cost in most years (Lawrence et al., 2010; Rosser et al., 2013) and having large impacts on farm profitability (Buskirk et al., 2003). Across recent years, forage, grain, and land prices have increased significantly, resulting in increased feed costs for livestock producers as well as horse owners (Lawrence et al., 2010). With feed prices on the rise, horse owners generally look for a way to reduce feeding costs. Forages such as hay and pasture are typically the largest dietary components included in horse rations; therefore, reducing the expense of either of these feedstuffs will likely result in an overall reduction of feed costs for horses.

Costs Associated with Feeding Hay

Hay is commonly fed to horses and is often one of the largest and most expensive dietary components for adult horses (Martinson et al., 2012b). Few horses can escape the need to consume hay at some point during the year, especially in areas where pasture availability is limited during winter months due to freezing temperatures and snowfall coverage (NRC, 2007). In recent years, the price of hay in the US has been increasing due to a number of factors, including fuel costs, increasing land prices, and lack of supply due to drought, winterkill, and other weather related conditions (Gibbs, 2007; McMillan et al., 2009; Lawrence et al., 2010). Although horse owners have little control over hay prices, previous research has shown that hay storage and feeding practices also contribute to large annual economic losses by influencing the amount of hay wasted as well as the quality of hay fed to the animal (Gibbs, 2007; McMillan et al., 2009). Therefore, there is potential for horse owners to reduce their hay costs by limiting the amount of hay wasted during both storage and feeding.

Hay storage methods have been shown to have a large impact on the amount of hay lost during storage, and may be greater than appearance would suggest. Much of the research investigating hay storage methods has focused on the storage of large round bales, as their large size and decreased stacking capability more often leads to outdoor storage compared to the conventional small square bales. Losses during outdoor storage are often a result of weathering and moisture movement from the ground into the bale (Collins et al., 1997). Previous research examining storage losses of hay stored outside has demonstrated that rain penetration leads to substantial deterioration and loss of feed value during storage (Verma et al., 1978; Verma and Von Bargen, 1979). Compressed and non-compressed hay stacks stored outside differed in the way rain penetrated the stack; when compressed, moisture moved laterally toward the stack sides rather than penetrating the interior, whereas non-compressed stacks had moisture penetration moving downward towards the center of the stack (Verma and Von Bargen, 1979). In a comparison of large round bales, small round bales, and compressed hay stacks stored outside, Lechtenberg et al. (1974) estimated that hay stored in large round bales or compressed stacks from June until November lost 13 to 22% of the hay due to weather deterioration, accounting for an 8-13% loss in total digestible DM, while small round bales had 21% deterioration, or a 17% loss in total digestible DM.

When comparing multiple storage methods, many researchers have found higher storage losses for large round bales stored outside and uncovered compared to bales stored either inside or outside but covered. For example, Anderson et al. (1981) showed storage DM losses averaging 3% of the harvested DM weight for bales stored indoors and 14% for bales stored outdoors. Verma and Nelson (1983) found DM losses up to 40% for bales stored on the ground and unprotected, while Nelson et al. (1983) reported storage losses of 23 to 26% for large round bales stored outside uncovered, 13% for bales stored outside and covered, and only 4% for bales stored in a barn. Storage losses of alfalfa, bermudagrass, and sorghum-sudan gasses in round bales were evaluated by Rider et al. (1979), who reported that inside storage or protection by circumferential wrapping on bales minimized dry matter losses for all three hays. Russell and Buxton (1985) also found covering hay bales to be beneficial, noting that plastic covers reduced the proportion of hay which was weathered, allowing for a higher recovery of unweathered DM after storage. In Oklahoma, Belyea et al. (1985) found that loss of DM during storage was least for large round bales stored inside (2.5%), moderate for large round bales stored outside but covered (6%), and greatest for large round bales stored outside, uncovered (15%). A study completed in Wisconsin found DM losses ranging from 5% for barn storage to 11% for uncovered bales with direct ground contact (Collins et al., 1987). In the same study, weathered material constituted 16% of the final bale weight for bales stored outside on the ground and 12% for bales stored outside and elevated, but was negligible for bales stored inside; therefore, combining DM loss and weathering together, total losses exceeded 26% of the initial DM for bales stored outside compared to only 5% for bales stored inside (Collins et al., 1987). Huhnke (1987) found DM losses ranging from 2% for bales stored either in the barn or on pallets with a cover to 13% for bales stored on the ground with no cover. In Michigan, Harrigan and Rotz (1994) studied the effects of different large round bale wrapping options and found DM losses to be less for plastic wrapped bales (10%), compared to net wrapped and twine wrapped bales (16-17%); however, DM loss for bales stored inside was still lower (6%) than for any bales stored outside. Large round bales are cylindrical, with a considerable portion of the volume and weight occurring in the outer layers. Penetration by water into these outer layers and subsequent weathering and deterioration during storage can lead to a significant loss of total DM. The amount of weathered or deteriorated hay varies, but can account for 24 to 56% of dry bale weights (Belyea et al., 1985; Baxter et al., 1986). Due to the large potential for loss during hay storage, it is recommended that hay be stored inside or be covered and elevated to prevent weather deterioration.

Hay storage methods are not only significant when considering the amount of hay lost, but also when considering changes in the quality of the hay after storage, which ultimately affects the value of the hay. Protection of hay packages from weather during storage has resulted in higher quality hay as compared to unprotected hay (Bledsoe et al.,1973), and nutritive losses during winter storage were found to be significantly greater for hay bales stored outdoors (Anderson et al., 1981). Verma and Nelson (1983) evaluated the difference in quantitative and qualitative losses for large round alfalfa bales under three storage methods: on racks without cover, on rack with cover, and inside a barn. After seven months, all bales showed slight increases in crude protein (CP) and neutral detergent fiber (NDF), although protected bales retained the most protein. Unprotected bales also showed decreases in the in vitro digestible DM (IVDDM). Russell and Buxton (1985) also found benefits to covering hay bales, noting reduced NDF concentrations and higher IVDDM from plastic-covered bales compared to unprotected bales. Changes in quality parameters were also evaluated by Collins et al. (1987), who found that all storage methods resulted in increased acid detergent fiber (ADF) and NDF concentrations, but that bales stored inside lost less IVDDM. The same study also completed a separate analysis of the outer, weathered layer from uncovered bales stored outside, finding a drastic reduction in the quality of the weathered hay compared to the rest of the hay bale. Huhnke (1987) also examined hay quality differences before and after storage, reporting a significant increase in bale moisture content of more than 50% for exposed bales after storage compared to less than 3% for covered bales. Huhnke (1987) also concluded that CP content increased for all bales except uncovered bales with ground contact; concentrations of ADF and NDF were lowest for covered or barn-stored bales compared to uncovered bales; and in vitro dry matter disappearance increased for bales protected from precipitation but decreased for uncovered bales, with the greatest change occurring in the outer 10 cm of unprotected bales. In Michigan, Harrigan and Rotz (1994) found similar results, noting higher moisture concentrations and decreasing hay quality for uncovered hay bales after six to nine months of storage. Again, much of the difference in loss between storage methods occurred in the outer 10 cm of the bale, where large increases in fiber concentration indicated large losses of NSC in unprotected bales, likely due to increased respiration by microorganisms in the moist hay and leaching of soluble plant constituents by precipitation on the outer surface (Harrigan and Rotz, 1994).

Changes in hay quality based on storage method are important to consider, as weathered hay suffers substantial losses not only in yield but also in forage quality, often being much less palatable to livestock than undamaged hay (Collins et al., 1997). These effects may then be significant when translating to changes into animal production. Baxter et al. (1986) found significantly higher milk production and BW gains for dairy cows fed hay stored inside compared to cows fed hay stored outside, attributing the difference to the effects of weather on the outside stored hay.

Unfortunately, substantial hay waste has not only become a concern during hay storage, but also when feeding animals. Belyea et al. (1985) found that feeding losses ranged from 12-15% when cattle were fed large round bales that were either stored inside or outside and covered, with losses increasing to 25% for cattle fed large round bales that were stored outside and uncovered. Similarly, Nelson et al. (1983) reported feeding losses between 13 and 20% for large round bales stored uncovered outside compared to 1% for bales stored outside and covered or in a barn. Baxter et al. (1986) noted that weather deteriorated hay also had increased hay refusal by cows, with apparent consumption by milking cows averaging 67% for bales stored on the ground and 74% for bales stored on tires, compared to 93% for bales stored inside. In addition, ten cows were able to eat hay from unweathered round bales for 7 days, while weathered round bales only lasted 5 days. Thus, when considering combined storage and feeding losses, it is apparent that hay bales stored outside can lose 15 to 25% of DM during storage and an additional 15 to 25% during feeding, accounting for a combined loss of up to 50%.

Utilizing Feeders to Reduce Hay Costs

In order to compensate for these large feeding losses, some researchers have shown that hay waste during feeding can be minimized by utilizing a hay feeder to prevent animals from trampling and contaminating the hay. Lechtenberg et al. (1974) found that the average DM needed per cow per day was 23 to 39% greater when large hay packages were fed to beef cows without a hayrack. Renoll et al. (1971) reported 35 to 46% wastage with cattle fed on hay stacks compared to 6% when baled hay was fed in a feeder. In a comparison of multiple feeder types, Buskirk et al. (2003) found hay waste ranging from 3 to 15% for cone, ring, trailer, and cradle type feeders, with significantly less hay being wasted with the cone and ring feeders. This reduction in hay waste for the cone and ring feeders was attributed to the observation that cattle eating from these feeders ate with their heads down, more closely mimicking a natural grazing position than cattle eating from the trailer and cradle feeders. Feed wastage was also thought to be reduced by increasing the constrictiveness of the feeder, which prevents cows from tossing their feed over their backs or along their sides, and by decreasing the bale diameter to feeder diameter ratio and keeping the hay centered within the feeder, causing cows to reach for their feed (Buskirk et al., 2003). Other research studies involving hay feeders have found similar results, noting that hay feeders which limit access to the forage and encourage the cattle to reach for their hay often have improved utilization (Schultheis and Hires, 1982; Petchey and Abdulkader, 1991).

Previous research evaluating hay waste when feeding horses has demonstrated similar results. Much of the research investigating hay waste for horses has involved the feeding of large round bales. Round bales are often used as a means to provide forage to horses housed in poor pastures, in dry-lots, or during winter months, as they often provide a convenient and reduced cost option compared to traditional small square bales (McMillan et al., 2009, 2010; Martinson et al., 2012b). However, stall feeding is also common and generally includes the use of more conventional small square bales (McMillan et al., 2009). Research examining hay waste for horses fed large round bales of alfalfa with or without a hay ring feed concluded that mean DM hay waste was higher when horses were fed without a hay ring, averaging 32% waste, compared to 9% waste when a hay ring was used (McMillan et al., 2009). Due to the increased amount of waste, all unspoiled hay had been consumed after 7 days when hay was fed without a hay ring versus 9 days when a hay ring was used. In the same study, stalled horses were fed small square bales of alfalfa hay either in a hay feeder or off the stall floor. Mean hay waste for alfalfa fed on the ground was 7% compared to 1% when hay was fed in a feeder (McMillan et al., 2009). A second study completed by McMillan et al. (2010) had similar conclusions. In this experiment, horses were fed coastal bermudagrass hay or alfalfa hay both with and without a hay ring. On average, the mean DM wastage for hay fed without a hay ring was 35% versus 6% when a hay ring was used. When looking at the two types of hay separately, the mean hay waste for alfalfa hay was 9% and the mean waste for coastal bermudagrass hay was 2% when a hay ring was used. Conversely, mean waste for alfalfa was 32% and mean waste for coastal bermudagrass was 38% when fed without a hay ring. When no hay ring was used, all unspoiled coastal bermudagrass hay was consumed by day 6 versus day 8-9 when a hay ring was used. When alfalfa was fed, all unspoiled hay had been consumed by day 7 when fed without a hay ring and by day 9 when a hay ring was used. When making observations regarding both of their studies, McMillan et al. (2009; 2010) noted that for both the large round bales and the small square bales, the decrease in waste from using a hay feeder was likely due to a reduction in the amount of trampled and contaminated hay. Horses fed without a feeder tended to spread hay around on the ground, trampling it and soiling it with urine and fecal matter, but when hay was contained in a feeder, these effects were limited, therefore reducing the overall amount of hay waste.

In a comparison of nine different large round bale feeders, Martinson et al. (2012b) found that all feeders reduced waste (5-33%) compared to the no-feeder control (57%), thus limiting waste from trampling and manure and urine contamination. Differences in hay waste between feeders was also confirmed, with feeders designed to provide greater physical restrictions resulting in less hay waste compared to feeders that provided easier access to hay. The feeders that were most successful at reducing hay waste did not allow horses to immerse their heads into the bale, but instead horses were frequently observed pulling small mouthfuls from the bale with little waste. On the other hand, feeders that were least successful at reducing hay waste provided easy access to the hay, and horses were frequently observed immersing their entire head into the bale, pulling hay out of the feeder, and dropping hay on the ground (Martinson et al., 2012b). To further demonstrate the effects of reduced hay waste on cost savings, Martinson et al. (2012b) performed an economic analysis on the amount of time it took each feeder to pay for itself based on the reduction in hay waste. Payback for hay feeders was affected by initial feeder price, amount of hay waste, and the current price of hay at the time of the study. Martinson et al. (2012b) reported that using a hay price of $110/ton, all large round bale feeders paid for themselves within 2 – 20 months; with feeders lasting indefinitely, this demonstrates not only a significant reduction in hay waste compared to no hay feeder, but also a significant cost savings with long-term use of hay feeders.

In addition to reducing the amount of hay waste, using hay feeders has also been shown to offer other advantages such as increasing hay utilization and maintaining hay quality. Martinson et al. (2012b) found hay intakes between 2.0 to 2.4% of BW when a hay feeder was used compared to 1.3% BW for the no-feeder control. Hay feeder intakes were considered within the normal range, as other researchers have documented similar voluntary intake levels (Dulphy et al., 1997a; Buskirk et al., 2003; McMillan et al., 2010). A reduction in intake when horses were fed without a feeder was also previously observed (McMillan et al., 2010) and resulted in greater pen BW losses, indicative of a reduced DE intake below the requirement (NRC, 2007; Martinson et al., 2012b). Researchers noted that the reduced intake and BW losses were likely due to non-uniform hay intakes over the 4 day period, with bale quality declining as increasing amounts of hay became spoiled from horse defecation, urination, and trampling (Martinson et al., 2012b). Increased hay spoilage when a feeder was not used has been previously reported by others as well (Lechtenberg et al., 1974; McMillan et al., 2010), demonstrating that the use of a hay feeder is beneficial not only in reducing the amount of hay waste, but in reducing the amount of spoiled hay as well. A decrease in the amount spoiled hay allows for increased utilization of the forage by the animal, reducing long-term costs by allowing horse owners to feed less hay while still maintaining higher levels of intake. Additionally, feeding horses hay in a feeder may be advantageous compared to ground feeding by reducing the incidence of sand colic and internal parasites resulting from the ingestion of sand, dirt, and fecal matter (McMillan et al., 2009).

Although much of the research investigating hay waste for horses has involved the feeding of large round bales or small square bales in a stall, many horses are also fed small square bales in a dry-lot setting. Horse owners with small numbers of horses or concerns regarding excessive waste and hay spoilage during feeding may choose to feed small square bales, as mold formation and hay spoilage is likely when round bales are exposed to the elements for extended periods of time during feeding (Lawrence and Coleman, 2000). Additionally, horse owners who are concerned about increases in disorders such as recurrent airway obstruction may choose to avoid large round bales, as they are thought to be associated with increased dust exposure and risk for these types of diseases (Robinson et al., 2006). Lastly, feeding small square bales provides horse owners with an easier way to control horse intakes and BW gain compared to ad-libitum forage when horses are fed large round bales. Currently, no research exists to characterize the hay waste or utilization of small square bales fed in outdoor paddocks. Therefore, one of the objectives of my research was to determine hay waste, herd BW change, hay intake, and the economics of small square bale feeders when used for the outdoor feeding of adult horses.

Feeding Horses on Pasture

Stored and purchased feeds such as hay are utilized extensively in both equine and livestock grazing operations to fill the forage deficit during winter months when pasture production is low. However, the cost of purchased and stored feed is high relative to the cost of feeding livestock on pasture (McCormick et al., 2006). Previous economic analyses have shown that beef production from high-quality pastures costs one-half to one-fourth as much as the same production using stored forages (Bishop-Hurley and Kallenbach, 2001). For example, placing beef cows on stockpiled orchardgrass reduced winter feeding costs 10-48% over feeding hay, depending on the cows physiological stage of production (Schoonmaker et al., 2003). Pastures can also supply inexpensive forage to lactating dairy cows, reducing feed costs 30 to 50% over conventional stored-forage systems (Parker et al., 1992).

If properly managed and stocked, pastures can provide a valuable source of forage which has the capability to meet or exceed the overall dietary requirements for many types of horses (NRC, 2007). This represents a more affordable feed option for many horse owners, especially if pasture productivity can be maximized. Across much of the northern United States, cool-season perennial grasses are the foundation of productive horse pastures (Allen et al., 2012). Cool-season grasses commonly used for horse pastures include orchardgrass, tall fescue, Kentucky bluegrass, perennial ryegrass, timothy, meadow fescue, smooth bromegrass, meadow bromegrass, and reed canarygrass (NRC, 2007). Previous research has reported perennial cool-season grass yields ranging from 5 to 14 t ha^{-1} (Jung et al., 1974; Marten and Hovin, 1980; Allen et al., 2012). University trials have found similar results, reporting that varieties of perennial cool season grasses typically have yields ranging from 8 to 16 t ha^{-1} (Olson et al., 2014b; Undersander, 2014). Most perennial cool-season grasses also have a high forage nutritive value, with CP concentrations $\geq$ 10% DM, NDF concentrations $\leq$ 63% DM, and equine DE content $\geq$ 1.91 Mcal kg^{-1} (Cherney et al., 1993; Hoffman et al., 1993; Hockensmith et al., 1997; Hoskin and Gee, 2004; Dowler et al., 2012; Allen et al., 2013). Cool-season perennial grasses typically begin to grow when temperatures reach 7°C, with optimal growth occurring between 16 and 24°C. Although growth depends on soil temperature, moisture, fertility, and management practices, cool-season grasses are typically most productive during the spring and fall seasons, experiencing a reduction in production during the warmer and drier summer months commonly referred to as the "summer slump" (Engel et al., 1987; Moser and Hoveland, 1996; Riesterer et al., 2000; Allen et al., 2012).

Contrary to the cool-season grasses, warm-season grasses grow best during the warm summer months, beginning to grow when temperatures reach 15°C and reaching maximum productivity at temperatures between 32 and 35°C. The difference in growth patterns of the warm-season grasses can be used to offset the decrease in cool-season grass production during the summer months, maximizing pasture production through a rotational grazing system. Therefore, in areas of the country where a range of temperatures allows for the growth of both warm- and cool-season pasture grasses, utilizing both of these grass types can greatly extend the grazing season, providing a good source of forage throughout the spring, summer, and fall seasons.

Utilizing Alternative Grasses to Reduce Feeding Costs

While pasture systems can offer an inexpensive source of high quality forage, pasture production is often unreliable, with growth fluctuating throughout the year due to variable growing conditions (Fales et al., 1993; Matches and Burns, 1995). Typically, cool-season perennial grass pastures are able to provide forage for grazing during the spring, summer, and fall months. However, there may be opportunities to utilize other forages such as annual cool-season grasses and small grains to extend the grazing season beyond the time when perennial species are either not yet growing or are no longer productive. Numerous research studies have suggested that utilizing small grains to extend the grazing season could cut back on production animal feeding costs by reducing the use of harvested forages (Sprague, 1954; Lawrence and Strohbehn, 1999; Orloff and Drake, 2001; Kallenbach et al., 2003; McCormick et al., 2006; Gunsaulis et al., 2008; Coblentz and Walgenbach, 2010; Coblentz et al., 2011). Based on these findings, it could be expected that these same concepts should hold true for horse ownership as well. Therefore, there is increasing interest in including small grains and annual crops into a rotational grazing system to provide supplemental forage and additional grazing opportunities beyond the use of traditional pasture species.

In addition to extending the grazing season, annual grasses and small grains could also be used as a means to provide forage in emergency grazing situations, as they can offer good yields of high quality forage in a relatively short amount of time (Rankin, 2003; Gunsaulis et al., 2008; Coblentz and Walgenbach, 2010; Coblentz et al., 2011). In 2013, approximately two million acres of legume and grass hay fields and pastures in the upper-Midwest were affected by winterkill, resulting in a significant problem for many livestock and horse owners (Wells et al., 2014). Emergency grazing situations can also occur after poor spring growing conditions, summer floods, drought, and/or an early fall frost. Global changes in climate and weather patterns make these scenarios both frequent and hard to predict across many areas of the US and Canada, and unfortunately, there is limited information available regarding emergency grazing options for horses.

When selecting the ideal forage for emergency or alternative grazing, important factors to consider include the forage yield potential, dependability and seasonal distribution of forage, and forage quality characteristics (Bruckner and Raymer, 1990). Although not always considered, plant maturity is also an important consideration to make when assessing the appropriate time to graze or harvest a pasture, as it will have an impact on both forage yield and forage nutritive value. Typically, as a plant develops from the vegetative through reproductive stages of growth, yield will continue to increase but will often be accompanied by subsequent decreases in forage quality and leafiness due to increased cell wall accumulation (Cherney and Marten, 1982; Walker et al., 1990; Juskiw et al., 2000). However, the rate at which this occurs will vary depending on species and environmental conditions. For example, previous research involving forage-type oat cultivars has demonstrated a much slower maturation rate for these varieties compared to grain-type oat cultivars planted at the same time (Coblentz and Walgenbach, 2010; Coblentz and Bertram, 2012a; b). Additionally, young, immature plants are often preferred by animals over older, more fibrous plants of the same species, making forage maturity an important factor when considering the acceptability of various forages to grazing animals (Burton et al., 1956; McCann and Hoveland, 1991).

Cereal grains and annual grasses vary in growth characteristics that will affect both their total yield potential and their seasonal yield distribution. Yields from annual cool-season grasses has previously been found to be variable and highly dependent on numerous factors, including species, variety, adaptation to the environment, soil type and fertility, weather, harvest management, and seeding/harvest dates (Helsel and Thomas, 1987; Coblentz and Bertram, 2012a). When comparing yields for annual cool-season grasses, Edmisten et al. (1998a) found spring yields of 2.9 to 3.9 t ha^{-1} for barley, 2.7 to 2.9 t ha^{-1} for oat, 2.5 to 3.9 t ha^{-1} for rye, and 3.0 to 3.9 t ha^{-1} for wheat when harvested at the vegetative stage, and 5.9 to 9.2 t ha^{-1} for barley, 4.3 to 5.2 t ha^{-1} for oat, 5.6 to 5.9 t ha^{-1} for rye, and 6.1 to 8.5 t ha^{-1} for wheat when harvested at the boot stage. Averaged across six stages of maturity, Cherney and Marten (1982) reported yields for spring wheat between 4.6 to 7.3 t ha^{-1}, for spring oat between 5.4 and 7.8 t ha^{-1}, and for spring barley between 5.9 and 8.0 t ha^{-1}. Maloney et al. (1999) reported yields of 3.6, 3.1, 1.6, and 0.9 t ha^{-1} for spring oat, spring barley, winter wheat, and winter rye, respectively, and Griggs (2006) reported yields between 1.9 and 4.1 t ha^{-1} for winter barley and winter rye. Rosser et al. (2013) found average yields of 6.9, 4.6, 7.0, and 5.6 t ha^{-1} for barley, millet, oat, and wheat, respectively, when planted in June and harvested at the head elongation stage of maturity. When harvested at the boot to early head stage, fall-planted spring cereals have been shown to be capable of providing 3.7 to 6.2 t ha^{-1} (Rankin, 2003). Coblentz and Walgenbach (2010) reported yields for oat cultivars ranging from 2.9 to 7.4 t ha^{-1}, and Hossain et al. (2003) found an expected fall forage yield of 3.6 t ha^{-1} for wheat when planted late-August. Others have found slightly lower yields for autumn-planted annuals, ranging from 0.2 to 3.2 t ha^{-1} for winter wheat, winter rye, oat, barley, and annual ryegrass (Sprague, 1954; Qualset and Stanley, 1968; McCormick et al., 2006); this is likely due in part to a later planting date, as well as variations in plant varieties, temperature, precipitation, and other environmental factors.

Research has consistently shown that forage yield of small grains will increase with increasing plant maturities (Stuthman and Marten, 1972; Burgess et al., 1972; Cherney and Marten, 1982; Helsel and Thomas, 1987; Walker et al., 1990; Juskiw et al., 2000; Orloff and Drake, 2001; Coblentz and Walgenbach, 2010; Rosser et al., 2013). Edmisten et al. (1998a) found average DM yields for barley, oat, rye, and wheat to be between 0.68 and 2.3 t ha^{-1} when harvested at the vegetative stage, compared to 7.8 to 12.8 t ha^{-1} when harvested at the milk stage. Rankin (2003) found DM yields ranging from 3.7 to 6.2 t ha^{-1} at the late-boot stage compared to 7.4 to 9.9 t ha^{-1} at the milk and dough stages. Helsel and Thomas (1987) reported increasing DM yields for barley, oat, wheat, and rye as grasses matured, averaging 5.3, 8.2, and 8.4 t ha^{-1}, respectively, at three successive harvest dates. In a study evaluating the influence of planting date on wheat forage yield, Hossain et al. (2003) concluded that a 20-d delay in planting date from 10 to 30 September resulted in a 68% decrease in expected forage yield. Between winter varieties, McCormick et al. (2006) noted that 'Winter King' rye had the highest forage yield over 'VNS' rye, winter triticale, and winter wheat, attributing the higher yield to its more advanced maturity. Coblentz and Walgenbach (2010) found that more rapidly-maturing, grain-type oat cultivars consistently demonstrated significant yield advantages over forage-type oat cultivars; however, Coblentz et al. (2011) found that yields were highly dependent on planting and harvest dates, with forage-type, late-maturing oat cultivars yielding more than grain-type oat cultivars if planted in mid-July but less when planted after the first week in August.

Previous research has also found that spring varieties often had higher yields than winter varieties. The vernalization requirement for winter varieties means these grasses will remain vegetative until the following spring, while spring varieties will joint, elongate, and produce a seedhead during the fall, allowing for higher yields (Coblentz et al., 2013). McCormick et al. (2006) noted that spring oat and spring triticale had greater autumn yields compared to winter triticale, winter wheat, and winter rye. Gunsaulis et al. (2008) found a 50% increase in DM yield for cultivars that underwent stem elongation compared to cultivars that remained vegetative throughout the fall, with average yields of 0.9 to 1.9 t ha^{-1} for cultivars that remained vegetative compared to 2.4 to 4.5 t ha^{-1} for cultivars that underwent stem elongation. In Wisconsin, Maloney et al. (1999) also reported significantly higher yields for August-planted spring grains over winter hardy species, and an Arkansas study found forage yield in autumn to be negatively correlated with winter hardiness of small grain species (West et al., 1988). Other more recent studies have made similar conclusions, reporting that cereal grains which undergo stem elongation following fall establishment will likely exhibit a 2:1 DM yield advantage over winter cereals that remain vegetative until spring (Gunsaulis et al., 2008; Coblentz and Walgenbach, 2010; Coblentz et al., 2013). However, one previous study did find opposite results, reporting higher yields from winter wheat and winter rye compared to spring oat (Sprague, 1954). Additionally, Qualset and Stanley (1968) reported higher fall yields from barley, wheat, and rye (1.0 – 1.4 t ha^{-1}) over oat (0.3 – 1.0 t ha^{-1}), demonstrating that yield potential is variable and dependent on other factors in addition to plant species.

Yields for annual cool-season grasses have typically been shown to be higher when grasses are planted in the spring than when planted in the fall. Spring cereal grains have a long-day photoperiod requirement for flowering that is thought to be somewhat disrupted by a late-summer planting date, resulting in a slower maturation rate for all cultivars and therefore lower yields when planted in the fall (Coblentz and Bertram, 2012a; b). In Wisconsin, researchers found that oat cultivars produced 8.5 t ha^{-1} of forage 77 days after spring planting compared to 7.4 t ha^{-1} of forage 77 days after fall planting (Contreras-Govea and Albrecht, 2006).

Although total yield potential is important, knowing the seasonal distribution of forage is also essential, especially when considering plant species for grazing. The ideal forage will have a more uniform seasonal distribution with consistent regrowth potential, allowing rotational grazing to continue throughout the growing season. Previous results have shown limited or no regrowth potential for spring cereals such as oat, suggesting that the most complete utilization of these species would be accomplished by a one-time removal of standing forage (Gunsaulis et al., 2008; Coblentz and Walgenbach, 2010; Coblentz et al., 2013). In contrast, winter rye and winter wheat cultivars have exhibited regrowth potential, accumulating an average of 0.6 and 1.0 t ha^{-1}, respectively, in regrowth over a 45 day window (Gunsaulis et al., 2008). Plant maturity at the time of grazing also will have an impact on forage regrowth potential. Edmisten et al. (1998a) reported a variable number of regrowth harvests for fall-planted small grains harvested at varying maturities, with more regrowth occurring when grasses were harvested at the vegetative and boot stages and limited or no regrowth occurring when grasses were harvested at the heading stage or later.

Differences in growth characteristics also affect the forage nutritive value of cool-season annual grasses. When harvested at a vegetative stage, Edmisten et al. (1998b) found NDF concentrations ranging from 31 to 41% and CP concentrations ranging from 18 to 30% for barley, oat, rye, and wheat. Between species, the CP content for oats was lower (18 to 21%) compared to barley, rye, and wheat (20 to 30%). Cherney and Marten (1982) also found small differences in the CP content of spring-planted cereal grains, with spring barley having an additional 1.6% CP compared to spring oats. However, Helsel and Thomas (1987) found slightly different results, observing greater CP concentrations for oat compared to rye, barley, and wheat. When harvested at a more mature stage, Edmisten et al. (1998b) reported NDF concentrations between 41 and 50% and CP values between 11 and 26% for barley, oat, rye, and wheat. Rosser et al. (2013) found average NDF concentrations to be 60, 52, 56, and 57% and CP concentrations to be 19, 22, 16, and 19% for barley, millet, oat, and wheat, respectively, and Contreras-Govea and Albrecht (2006) found NDF concentrations ≥ 57% and CP concentrations ≥ 12% for mature spring-planted oat. For fall-planted grasses, Maloney et al. (1999) reported NDF contents of 43, 41, 32, and 34% and CP contents of 12, 16, 18, and 19%, respectively, for spring oat, spring barley, winter rye, and winter wheat. McCormick et al. (2006) found that oat, spring triticale, and annual ryegrass had CP levels ≥ 27% and NDF values that ranged from 26 to 34% in late autumn. Contreras-Govea and Albrecht (2006) reported an average of 18% CP and 52% NDF for mature oat varieties. In Utah, Griggs (2006) found slightly lower NDF concentrations, with average NDF ranging from 23 to 37% and CP ranging from 16 to 22% for winter wheat and winter barley. Coblentz and Walgenbach (2010) reported NDF concentrations ≤ 63% for oat, triticale, and winter wheat across three fall harvests but found somewhat higher CP concentrations, with initial CP being ≥ 31% for fall-planted oat, triticale, and winter wheat. Sprague (1954) also found high fall protein concentrations, with total protein content for wheat and rye being higher than 28%.

It has been well-documented that NDF increases and CP content declines as a plant matures and becomes more fibrous (Smith, 1960; Stuthman and Marten, 1972; Belyea et al., 1978; Cherney and Marten, 1982; Helsel and Thomas, 1987; Edmisten et al., 1998b; Orloff and Drake, 2001; Coblentz and Bertram, 2012b; Rosser et al., 2013).

Smith (1960) found increasing crude fiber concentrations and decreasing CP concentrations in oat forage as maturity advanced from the four-leaf stage to the ripe stage. Rankin (2003) noted that the concentration of NDF from oats harvested at the boot stage averaged 52-54%, increasing to 59-61% at the milk stage, while CP averaged 16-18% at the boot stage and decreased to 12-14% at the milk stage. Studies in Wisconsin and Michigan found increasing concentrations of NDF for oat and other cereal grain cultivars across multiple harvest dates (Helsel and Thomas, 1987; Coblentz and Walgenbach, 2010; Coblentz et al., 2012). Cherney and Marten (1982) found that NDF increased from about 40% at the boot stage to about 53% at heading for spring barley, oats, and wheat grown in Minnesota, with little changes occurring after heading. At the same time, Coblentz and Walgenbach (2010) reported that concentrations of CP for fall-planted oat, triticale, and winter wheat decreased from ≥ 31% down to 13-19% across multiple harvests, and Coblentz et al. (2012) found that concentrations of CP declined from 22% to 12% for August-planted oat cultivars across five harvest dates. Belyea et al. (1978) noted a consistent decrease in CP content from 31% to 7% for wheat harvested across ten cutting dates. In a comparison of fall seeding dates, Griggs (2006) noted decreasing NDF levels and increasing CP levels from cultivars harvested with later seeding dates compared to earlier seeding dates. In Ohio, a higher concentration of NDF and a lower concentration of CP for ‘Winter King’ rye compared to other winter varieties was attributed to its advanced maturity at harvest (McCormick et al., 2006), and in Wisconsin, the late-maturing ‘Forage Plus’ spring oat had lower stem NDF accumulations and a higher CP content than other, more mature varieties of spring oat (Contreras-Govea and Albrecht, 2006; Coblentz and Walgenbach, 2010).

Previous research comparing the forage nutritive values for annual cool-season grasses has found higher levels of CP and lower levels of NDF for winter species compared to spring species. Coblentz and Walgenbach (2010) reported that vegetative wheat cultivars maintained greater CP concentrations (23%) compared to oat and triticale cultivars (19%), but that oat and triticale had greater NDF concentrations compared to winter wheat. McCormick et al. (2006) and Maloney et al. (1999) also found that winter hardy species such as winter rye, triticale, and wheat had higher CP and lower NDF compared to winter-sensitive cereal grains such as spring oat, triticale, barley, and annual ryegrass. Additionally, mixtures containing one spring variety and one winter variety contained higher NDF content than winter varieties planted in monoculture (McCormick et al., 2006). These differences are likely due to a suppression of plant maturity for winter-hardy species, as the vernalization requirement for winter varieties keeps these grasses in vegetative growth until they are exposed to an extended cold period (Coblentz et al., 2013).

Growth characteristics and nutritive values may also be affected by season and temperature. Several researchers have reported improved forage nutritive values when small grains were grown under cooler conditions (Smith, 1975; Maloney et al., 1999; Contreras-Govea and Albrecht, 2006). In both Wisconsin and New Jersey, CP concentrations for rye, wheat, and oat were found to be higher in autumn than in spring or early summer (Sprague, 1954; Contreras-Govea and Albrecht, 2006). McCormick et al. (2006) also reported high CP levels in fall-planted grasses, with spring oat, spring triticale, and annual ryegrass all containing $\geq 20\%$ CP. Previous research studies have also demonstrated lower NDF concentrations for fall-planted grasses compared to spring-planted grasses (Contreras-Govea and Albrecht, 2006; McCormick et al., 2006; Coblentz and Walgenbach, 2010). The differences between fall- and spring-planted grasses are thought to be associated with a more advanced maturity for summer-harvested forages compared to autumn-harvested forages, as increasing maturity has been previously associated with increasing NDF and decreasing CP concentrations (Smith, 1960; Belyea et al., 1978; Cherney and Marten, 1982; Edmisten et al., 1998b; Coblentz and Walgenbach, 2010; Coblentz and Bertram, 2012b). A late-summer planting disrupts the long-day photoperiod requirement for flowering, suppressing maturation rate and therefore limiting NDF accumulation (Coblentz and Bertram, 2012a; b; Coblentz et al., 2013). In addition, a change in temperature from warm to cold has been shown to increase stem proportion while delaying plant maturity (Smith, 1974). Therefore, as temperature decreases moving into the fall season, plant growth slows and plant maturities tend to be lower, resulting in a lower NDF concentration and a higher CP concentration.

Nonstructural carbohydrate fractions in forage are also an important nutritive quality to evaluate, especially in the equine population, as they have been found to play a role in equine diseases that involve carbohydrate intolerance (Chatterton et al., 2006; Longland and Byrd, 2006). Nonstructural carbohydrate contents will affect horses diagnosed with obesity, laminitis, equine metabolic syndrome, insulin-resistance (Frank, 2009), and polysaccharide storage myopathy (Borgia et al., 2009). Although horses diagnosed with the above diseases should have their total diet restricted to ≤12% NSC (Frank, 2009; Borgia et al., 2009), there are no NSC restrictions for healthy horses.

Nonstructural carbohydrate concentrations are typically estimated as the sum of the simple sugars, fructan, and starch portion of a plant (Longland and Byrd, 2006). The storage carbohydrate concentrations in plants are constantly changing as a result of production from photosynthesis and utilization for growth and development, resulting in diurnal variations that tend to rise during the morning, reach a maximum peak in the afternoon, and decline in the overnight hours, as well as seasonal variations that tend to be highest in late spring, lowest in mid-season, and intermediate in the fall (Waite and Boyd, 1953; Holt and Hilst, 1969; Longland and Byrd, 2006). However, numerous other factors are also known to influence NSC concentrations in forages, including plant species, maturity, and environmental conditions such as temperature, light, and nutrient and water availability, making it difficult to accurately predict NSC content (Chatterton et al., 2006; Longland and Byrd, 2006).

Much of the research done evaluating the forage nutritive value of annual cool-season grasses has been focused on the nutritive value of these forages for cattle, and NSC concentrations are not often reported. When evaluating the NSC content of oat hay across seven maturities and two seeding dates (April or June), Chatterton et al. (2006) found that NSC concentrations demonstrated a disjoint relation with plant maturity. Oat hay from spring-planted oats was found to have a greater NSC concentration in immature hay compared to mature hay; however, oat hay from summer-planted oats had similar NSC concentrations in both immature and mature hay (Chatterton et al., 2006). Previous research has also documented NSC content for a variety of perennial cool-season grasses. In a comparison of 11 perennial cool-season grasses evaluated for horse pasture, Allen et al. (2013) observed NSC concentrations ranging from 6 to 17%. Similarly, Pelletier et al.

(2010) observed total nonstructural carbohydrate (TNSC) concentrations of 6 perennial cool-season grasses ranging from 4 to 12%.

When examining WSC content, previous research has reported greater WSC concentrations for less mature oat cultivars compared to more mature oat cultivars (Coblentz et al., 2012) and for fall-planted grasses compared to spring-planted grasses (Smith, 1975; Contreras-Govea and Albrecht, 2006). Winter-annual cereals are known to undergo a process called hardening at temperatures just above freezing. Generally, these plants accumulate various solutes within the individual plant cells during cooler conditions, which serves to increase osmotic pressure and provide protection against freezing or winterkill; however, one of the principle compounds accumulating in these plants is sugar, and as a result, these plants typically exhibit increased concentrations of sugars during late fall when temperatures are low (Livingston and Premakumar, 2002; Coblentz and Walgenbach, 2010; Coblentz and Bertram, 2012b). Contreras-Govea and Albrecht (2006) found that leaf and stem WSC concentrations were 1.5 to 3.3 times greater in fall-grown oat than in identical cultivars established in the spring, and Smith (1975) reported increasing WSC concentrations in oat as temperature shifted from warm to cool as a natural response to cold adaptation. Coblentz et al. (2012) reported that July-planted oat cultivars had a linear decrease in WSC concentration across fall harvest dates, consistent with previous data indicating decreasing WSC content with increasing plant maturity; however, in the same study, August-planted oat cultivars had a linear increase in WSC concentrations across fall harvest dates, indicating an accumulation of sugars during late fall that is capable of offsetting the natural deposition of structural fiber associated with morphological development.

Similar to NSC concentrations, equine DE content of annual cool-season grasses is not often reported. However, equine DE concentrations have been reported for perennial grass pastures and hay. Dowler et al. (2012) found an average DE content for tall fescue pastures ranging from 2.10 to 2.25 Mcal kg^{-1}, and Hoskin and Gee (2004) reported average DE concentrations between 1.91 and 2.87 Mcal kg^{-1} for pastures containing a mix of perennial ryegrass and white clover. Martinson et al. (2012a) reported that orchardgrass hay at the vegetative and flowering growth stage contained 2.18 and 2.14 Mcal kg^{-1}, respectively, of equine DE, and Grev et al. (2014) found the DE content of mixed grass hay to be 2.07 Mcal kg^{-1}. Equine DE of the annual grasses from the current study are also comparable to the DE content of grass hay and pasture reported by the NRC (2007), which range from 2.04 to 2.39 Mcal kg^{-1}.

When selecting forages for horses in particular, additional consideration should be given to horse preference. It has long been understood that horses are selective grazers, especially when compared to other livestock, often showing strong preferences for certain grass species over others (Archer, 1973, 1978b; Hunt and Hay, 1990). When horses are allowed to graze freely, they quickly establish patterns within a pasture, selecting some areas to use for grazing and other areas to use for excretion (Taylor, 1954; Ödberg and Francis-Smith, 1976; Archer, 1978a). These highly selective differences in preference will have an influence not only pasture utilization, but also on forage persistence and stability over time if preferred pasture species are continually being grazed (Hunt and Hay, 1990; Allen et al., 2013). Much of the previous equine palatability research has focused on understanding horse preferences of cool-season perennial grasses (Archer, 1973, 1978b; Hunt and Hay, 1990; Allen et al., 2013; Olson et al., 2014a), with very few researchers investigating the preference of annual cool-season grasses and small grains under horse grazing. McCann and Hoveland (1991) found that annual ryegrass was preferred by grazing horses, averaging 75% apparent consumption of the dry forage. Oats and wheat were second in preference with 47 and 41% consumption, respectively, and rye and triticale were least preferred, averaging only 35 and 32% apparent consumption. Although other livestock tend to be less selective than horses, differences in preference between small grains have been found to be significant in other species as well. Research investigating the preferences of sheep found that when given a choice, sheep preferred oat to other small grains, both in the fall and spring, with barley being their second choice in both seasons (Washko, 1947).

Palatability is a complex phenomenon that can be influenced by several variables, including animal species, plant characteristics, and environmental factors (Marten, 1978; Marten et al., 1987; Allen et al., 2013). Although the term palatability has been defined in many ways, it is generally thought to be "a plant characteristic(s) eliciting a proportional choice among two or more forages conditioned by plant, animal, and environmental factors which stimulate a selective intake response by the animal" (Marten, 1978). Plant qualities that may influence animal preference include not only the species, but the morphology, chemical composition, maturation, availability, and intraspecific variation as well (Marten, 1978). Additionally, differences in animal species, physiological condition, previous experiences, senses, and individual animal variation can all affect preference, along with environmental factors such as plant diseases, soil fertility, presence of animal waste, changes in climate, and seasonal or diurnal plant variations (Marten, 1978). With so many confounding variables, it is often hard to determine the true factors influencing animal preference. However, previous research has shown that plant maturity is often associated with animal palatability. Burton et al. (1956) found forage maturity to be a factor of acceptability in determining cattle preference, noting that cattle tended to select less mature vegetation over older, more fibrous plants of the same species. Dairy heifers who grazed oat forage preferentially grazed the leaf tissue over the stems, and utilization of standing forage was found to be improved when plants were shorter and less mature (78 to 90%) compared to taller, more mature forage (42 to 65%; Coblentz et al., 2013). Other researchers have also reported a negative relationship between the amount of forage fiber or cell wall constituents and animal intake, with intake typically decreasing as plant maturity and fiber content increase (Van Soest, 1965; Fisher and Fowler, 1975; Cherney and Marten, 1982). Therefore, plant maturity at the time of grazing and its effects on horse preference should be considered when evaluating and selecting alternative forages.

These results show that small grains and annual grasses can serve as productive and high quality pasture forages. However, few studies have done comparisons of yield and forage nutritive value on multiple species of small grains and annual grasses across multiple seasons, and no research has been done to evaluate small grains and annual grasses under horse grazing at multiple target maturities. Hoof traffic and frequent forage removal to variable heights by grazing livestock creates unique and stressful situations for forage grasses, yet the effect of livestock grazing on pasture yield and quality is not commonly investigated (Deak et al., 2009; Allen et al., 2012). Therefore, the objectives of this study were to evaluate the yield, forage nutritive value, and preference of small grains and annual grasses under horse grazing at two separate maturities in both spring and fall seasons.

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Chapter 2

The Effect of Small Square-Bale Feeder Design on Hay Waste and Economics During Outdoor Feeding of Adult Horses

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Chapter Summary

Hay waste during feeding represents a costly expense for horse owners. The objectives of this study were to determine hay waste, herd bodyweight (BW) change, hay intake, and economics of small square-bale feeders used in outdoor feeding of adult horses. Feeder designs included a hayrack, slat feeder, basket feeder, and a no-feeder control. Feeders were placed in separate outdoor dirt paddocks. Twelve adult horses were divided into four groups and rotated through the paddocks in a Latin square design. Horses were weighed immediately before and after each rotation. Horses were fed grass hay at 2.5% of the herd BW split evenly at 0800 and 1600 hours. Waste hay and orts were collected daily before each feeding. The number of months to repay the feeder cost (payback) was calculated using hay valued at $250/ton, and improved efficiency over the no-feeder control. Mean hay waste was 13, 5, 3, and 1%, for the no-feeder control, hayrack, basket feeder, and slat feeder, respectively. The hayrack, basket feeder, and slat feeder paid for themselves in 12, 11, and 9 months, respectively. Herds gained 10 and 7 kg when feeding from the basket feeder and hayrack, and lost 3 and 11 kg when feeding from the slat feeder and no-feeder control ($P \leq 0.0015$). Estimated hay intake was 2.4% BW for the basket feeder and hayrack and 2.2% BW for the slat feeder and no-feeder control ($P < 0.0001$). Small square-bale feeder design affected hay waste, hay intake, herd BW change, and payback.

Introduction

Hay is commonly fed to horses and is usually the largest and most expensive dietary component for adult horses (Martinson et al., 2012). Hay waste can occur during both storage and feeding. For example, storage losses of large round-bales can range from 2 to 16% dry matter (DM), depending on forage type, storage method, environment, and storage length (Belyea et al., 1985; Huhnke, 1987; Harrigan and Rotz, 1994). Combined, storage and feeding losses can add up to ≥ 40% (Belyea et al., 1985). Researchers determined that hay waste associated with feeding small square-bales of hay in individual stalls was higher when hay was fed on the stall floor (7%) compared to inside a feeder (1%) (McMillan et al., 2009). Two additional research studies found that hay waste during feeding of large round-bales in outdoor paddocks was less when a feeder was used compared to a no-feeder control (McMillan et al., 2010; Martinson et al., 2012).

Martinson et al. (2012) also determined that hay waste differed between round-bale feeders, with average waste ranging from 5 to 33% DM.

It is common knowledge that many horses are fed small square-bales in outdoor paddocks. Although hay waste has been determined for feeding small square-bales inside individual stalls and for feeding large round-bales in outdoor paddocks, no research exists to characterize hay waste of small square-bales fed in outdoor paddocks. The objectives of this study were to determine hay waste, herd bodyweight (BW) change, hay intake, and economics of three small square-bale feeders and a no-feeder control when used for outdoor feeding of adult horses.

Materials and Methods

Hay

Each day of data collection, 3 small square-bales of mixed cool-season grass hay were cored (2 x 51 cm) multiple times to determine forage nutritive value. Daily samples were combined by week (n=5) and analyzed for forage nutritive value by a commercial forage testing laboratory (Equi-Analytical, Ithaca, NY) using the following methods. Dry matter was determined by placing samples in a 60°C forced air oven for 24 hours (method 991.01; AOAC, 2010). Crude protein (CP) was calculated as the percentage of nitrogen multiplied by 6.25 (method 990.03; AOAC, 2010). Neutral and acid detergent fibers were measured using filter bag techniques (Ankom Technology, 2013a; b; c). Starch and water and ethanol soluble carbohydrates were measured using techniques described by Hall et al. (1999). Mineral concentrations were determined (Thermo Jarrell Ash IRIS Advantage HX Inductively Coupled Plasma Radial Spectrometer, Thermo

Instrument Systems Inc., Waltham, MA) after microwave digestion (Microwave Accelerated Reaction System, CEM, Mathews, NC). Equine digestible energy (DE) was calculated using an equation developed by Pagan (1998).

Animals

All experimental procedures were conducted according to those approved by the University of Minnesota Committee on Animal Use and Care. Twelve mature, stock-type mares (mean ± SD: 12.3 ± 3.3 years; 503 ± 36 kg BW) at maintenance were used to form 4 similar herds of 3 horses each. Prior to the start of the trial, horses were acclimated to their herd and paddock and were fed grass hay on the ground at 2.5% of the herd BW split evenly between two feedings at 0800 and 1600 hours. Herds remained together for the duration of the trial which started on July 26, 2013 and concluded on August 23, 2013. The trial was conducted in St. Paul, MN.

Treatments

Three small square-bale feeders (Figure 1) specifically manufactured for and marketed to the equine industry were tested, including a basket feeder ($372; Equine Hay Basket, Tarter Farm and Ranch Equipment, Dunnville, KY), hayrack ($280; Horse Bunk Feeder and Hay Rack, Priefert Manufacturing, Mount Pleasant, TX), and slat feeder ($349; The Natural Feeder, Story City, IA). Feeders were compared to a no-feeder control where hay was fed off the paddock ground. Prices listed reflect the purchase price in July 2013. The slat feeder came with three different sized grates. The medium grate was used which included 18 oblong shaped openings that measured 7.5 x 18 cm arranged in two rows of 9 openings each.

Two feeders of each type were placed in separate, outdoor, dirt paddocks of similar size. Horse groups were rotated through the 4 paddocks in a Latin Square design. Herds remained in each paddock for a period of 7 days, including 2 days of acclimation and 5 days of data collection. Horses had *ad libitum* access to shelter, water, and a salt block, and were fed approximately 0.5 kg of a ration balancer (Empower Balance^{TM} Grass Formula Supplement, Nutrena) at 1600 hours each day to ensure all vitamin and mineral requirements were met for adult horses at maintenance (NRC, 2007). Horses were individually weighed immediately before and after the 5 day data collection period on a portable livestock scale (Weigh-Tronix, Fairmount, MN; model PS2000). The sum of differences within a herd is herd BW change.

Horses were fed grass hay at 2.5% of the herd BW split evenly between two feedings at 0800 and 1600 hours. Waste hay on the ground and orts remaining inside the hay feeder were collected twice daily before each feeding. Waste hay was any hay on the ground outside of the feeder that was not consumed by the horses, while orts were considered any hay left inside the feeder that was not consumed by the horses. Care was taken to avoid contamination with manure and dirt during collection, although some contamination was unavoidable. The area around each feeder was raked clean of manure after collection to minimize contamination for the following feeding. All waste hay and orts were dried in a 140°C oven for 48 hours and then weighed before being discarded.

Hay disappearance was calculated as the amount of hay delivered to each paddock minus orts. Percent hay waste was calculated as the amount of hay waste divided by hay disappearance. Hay dry matter intake (DMI) was estimated as hay disappearance minus hay waste and was expressed as percentage of BW by dividing hay DMI by average horse BW upon entering the paddock. The number of months for waste reduction to payback feeder cost (payback; Rice et al., 2001; Martinson et al., 2012) was calculated using hay valued at \$250/t. Hay value was established at the time of purchase in June 2013. Temperature and rainfall data were collected daily from a weather station located near the paddocks. Climate data was obtained from http://climate.umn.edu/doc/historical.htm.

Statistical Analysis

Feeders were compared using a mixed effects linear model in which groups of horses were considered a random effect and pen was the experimental unit. Analysis was performed using the mixed procedure of SAS (SAS Inst. Inc., Cary, NC; version 9.3) with statistical significance set at $P \leq 0.05$. Variables analyzed included hay waste, estimated hay intake, herd BW change, and payback. Means are the least square means of the procedures ± SE and mean separations were determined using the Tukey test.

Results and Discussion

Weather

Ideal weather conditions were observed during the trial period. Mean daily air temperature during the trial period was 19°C, similar to the 30-year air temperature mean of 21 and 19°C for July and August, respectively. It is unlikely that air temperature impacted hay intake or horse BW during the trial period. Rainfall during the trial period totaled 2.8 cm, which was less than the 30-year rainfall average of approximately 10 cm each for July and August. Twice daily collection and oven drying of waste hay and orts limited any effect of rainfall on hay waste. Outside of a controlled research setting, rainfall will likely impact hay waste, but the extent is unknown.

Horse Safety

No injuries were observed from any of the small square-bale feeders during the data collection period. Experiments utilizing different age groups of horses and for longer durations are necessary to further examine the safety of each feeder.

Hay Nutritive Value

Forage nutritive values for the grass hay used in the study are listed in Table 1.1. When compared to a national hay nutritive value database (Common Feed Profiles), the hay was within or near normal ranges for all nutrients tested for grass hay. The hay met or exceeded the horses' nutritional requirements for DE, CP, calcium, and phosphorous at the 2.0% feed intake for mature horses at maintenance (NRC, 2007).

Hay Waste and Payback

Hay waste was different between small square-bale feeder designs ($P < 0.001$). Mean hay waste was 1, 3, 5 and 13% for the slat, basket, hayrack and no-feeder control, respectively (Table 1.2). All feeders resulted in less hay waste compared with the no-feeder control ($P \leq 0.0001$), and a difference was observed between the hayrack and slat feeder ($P = 0.0203$). All feeders provided a physical barrier between the horses and the forage, helping to contain the hay and limit hay waste associated with trampling and contamination from manure and urine. Similar results have been observed with both horses (McMillan et al., 2009, 2010; Martinson et al., 2012) and beef cattle (Buskirk et al., 2003). Horses fed small-square bales of hay in individual stalls had greater hay waste when hay was fed on the stall floor (7%) compared to in a feeder (1%) (McMillan et al., 2009). McMillan et al. (2009; 2010) found that hay waste from horses fed large round-bales with a ring bale feeder was ≤ 9% compared to ≥ 31% when fed without a feeder. Martinson et al. (2012) found that feeding large round-bales without a feeder resulted in 57% hay waste compared to ≤ 33% hay waste when a feeder was used.

Other researchers have also observed differences in hay waste between feeders. Martinson et al. (2012) determined that hay waste ranged from 5 to 33% when horses were fed from nine different large round-bale feeders, while Buskirk et al. (2003) determined that hay waste when beef cattle were fed from different hay feeders ranged from 3 to 15%. Researchers agree that less hay waste is observed when a feeder provides more of a physical barrier between the livestock and the forage (Buskirk et al., 2003; Martinson et al., 2012). In the current study, the slat feeder did not allow the horses to immerse their nose into the forage or grab large mouthfuls at a time. Horses were frequently observed pulling small mouthfuls of hay from inside the feeder with little waste. In comparison, feeders that provided easier access to hay resulted in more hay waste. When feeding from the hayrack, horses were observed pulling large mouthfuls of hay out of the feeder and dropping some on the ground. Although the basket feeder appeared to provide easier access to the hay, horses consuming hay out of the basket feeder tended to chew over the basket, therefore limiting hay that fell to the ground.

Feeder design affected payback ($P = 0.0049$). The hayrack, basket, and slat feeders paid for themselves in 12, 11, and 9 months, respectively, with the slat feeder resulting in the shortest payback period ($P \leq 0.0239$) compared to the other feeders (Table 1.2). The low amount of hay waste and moderate price resulted in the quickest payback for the slat feeder. In comparison, the hayrack was the most affordable feeder but it had the greatest amount of hay waste observed among the feeders, resulting in a longer payback time. Although the basket feeder was the most expensive feeder evaluated, the moderate amount of waste resulted in a similar payback compared to the hayrack. Martinson et al. (2012) also determined that round-bale feeder design affected payback. Payback from round-bale feeders ranged from 0.4 to 10 months with hay valued at $200/ton. In the current study, all feeders claim to last indefinitely; however, feeder longevity was not measured nor accounted for in payback. Payback is impacted by hay price, and hay prices are affected by location (Livestock Hay and Grain Reports, 2014), weather conditions, and local supply and demand. Payback is an important consideration when determining hay feeder needs.

Estimated Hay Intake and Pen BW Change

Hay intakes differed between feeder designs ($P < 0.0001$), with the basket feeder and hayrack resulting in an increased hay intake compared with the slat feeder and no-feeder control (Table 1.2). Average herd hay intakes were 2.4, 2.4, 2.2, and 2.2% BW for the hayrack, basket, slat, and no-feeder control, respectively. Hay intakes were comparable to results found in other studies where horses were fed from feeders. In these studies, hay intake ranged from 2.0 to 2.4% BW (Dulphy et al., 1997; McMillan et al., 2010; Martinson et al., 2012).

The lower hay intakes observed for the slat feeder and no-feeder control were affected by orts and hay waste. The slat feeder had a greater amount of orts collected each day ($P < 0.0001$) compared to the other hay feeders, with a daily mean of 4.8 kg/day. However, most orts were collected prior to the evening feeding. Horses were fed twice daily at 0800 and 1600 hours; therefore, herds had 8 hours to consume their hay meal in the morning and 16 hours to consume their hay meal in the afternoon. Since the slat feeder presented the greatest barrier to consuming hay compared to the other feeders evaluated, the horses may not have had sufficient time to consume their hay meal in the morning. Other researchers have also documented that barriers can slow hay, pasture, and grain consumption. Glunk et al. (2014a) determined that horses feeding from slow feed hay nets had reduced dry matter intake rates (DMIR), resulting in extended foraging time compared to feeding hay off the stall floor. Glunk et al. (2014b) and Longland et al. (2011) observed reduced pasture DMIR when horses and ponies were fitted with a grazing muzzle. Kutzner-Milligan et al. (2013) and Carter et al. (2012) determined that the use of obstacles in a feed bucket increased time to feed consumption by 20 to 80%. These results show that horse owners can utilize various methods to slow consumption of hay, pasture, and grain when feeding adult horses. Time to hay consumption and the ability of horses to acclimate to the slat feeder over time should be further investigated. For the basket and hayrack feeders, the lack of differences between feeder DMI indicates that feeder design did not cause restricted hay intake.

The lower hay intake rate observed for the no-feeder control was affected by hay waste. Due to the greater amount of hay waste, horses feeding from the no-feeder control had less available forage. Martinson et al. (2012) also found a reduced intake of 1.3% BW when horses were fed large round-bales using a no-feeder control versus hay intakes of 2.0 to 2.4% BW when horses were fed large round-bales inside a feeder.

Herd BW change differed with feeder design ($P \leq 0.0015$). Herds gained small amounts of BW when feeding from the basket feeder and hayrack, and lost small amounts of BW when feeding from the slat feeder and no-feeder control (Table 1.2).

Changes in herd BW reflect hay intake for each feeder and the no-feeder control. Longer term monitoring of BW changes resulting from small square-bale feeder designs is warranted.

Conclusion

No injuries were observed when horses were fed from the small-square bale feeders. Small square-bale feeder design affected hay waste, estimated hay intake, herd BW change, and payback when adult horses were fed in outdoor paddocks. The use of a small square-bale feeder reduced hay waste compared to not utilizing a feeder, and all feeders paid for themselves in ≤ 12 months. Estimated hay intake ranged from 2.2 to 2.4% herd BW, and small changes in herd BW were observed when horses were fed from the feeders. Future research should focus on feeder longevity, horse safety, time to consumption of hay fed from more restrictive feeders, and the horses' ability to adapt to the feeders over longer periods of time. This information will aid horse owners and professionals when purchasing small square-bale feeders and estimating hay needs.

Acknowledgements

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Table 2.1. Forage nutritive value (means ± SE) of grass hay fed to adult horses at maintenance.

Nutrient[1]	Content
	% DM
DM	95 ± 0.56
CP	9 ± 0.27
ADF	40 ± 0.27
NDF	64 ± 0.47
Starch	0.7 ± 0.34
WSC	11 ± 0.43
ESC	6 ± 0.30
Ca	0.5 ± 0.01
P	0.2 ± 0.01
	Mcal kg^{-1}
Equine DE	2.07 ± 0.01

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

Table 2.2. Hay waste, estimated hay intake, herd bodyweight (BW) change, and payback of three small square-bale feeders and a no-feeder control used to feed adult horses.

	Hay Waste		Estimated Hay Intake		Herd BW Change		Payback	
Feeder	%	± SE	% BW	± SE	kg	± SE	Months	± SE
Basket[1]	3^{ab}	0.21	2.4^{b}	0.02	10^{b}	6.70	11^{b}	0.23
Hayrack[2]	5^{b}	0.51	2.4^{b}	0.02	7^{b}	5.02	12^{b}	1.01
Slat[3]	1^{a}	0.10	2.2^{a}	0.03	-3^{a}	3.80	9^{a}	0.08
No Feeder	13^{c}	2.11	2.2^{a}	0.05	-11^{a}	4.83	-	-

$^{a\text{-}b}$Within a column, means without a common superscript differ ($P \leq 0.05$)

[1] Equine Hay Basket, Tarter Farm and Ranch Equipment, Dunnville, KY.

[2] Horse Bunk Feeder and Hay Rack, Priefert Manufacturing, Mount Pleasant, TX.

[3] The Natural Feeder, Story City, IA.

Figure 2.1. Small square-bale feeder designs evaluated when feeding adult horses, including (A) basket[1], (B) hayrack[2], (C) slat[3], and (D) all three photographed together.

[1] Equine Hay Basket, Tarter Farm and Ranch Equipment, Dunnville, KY.

[2] Horse Bunk Feeder and Hay Rack, Priefert Manufacturing, Mount Pleasant, TX.

[3] The Natural Feeder, Story City, IA. Slat placed on top of feeder for demonstration purposes only. Normally, the slat sits on top of the hay inside the feeder.

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Chapter 3

Yield, Forage Nutritive Value, and Preference of Annual Grasses under Horse Grazing

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Chapter Summary

Annual grasses can serve as emergency forage but have not been evaluated under horse grazing. The objectives of this study were to evaluate annual grasses for yield, forage nutritive value, and preference under horse (*Equus caballus* L.) grazing at two maturities during the spring and fall. Spring grasses were planted on May 8, 2013 and April 22, 2014 in a randomized complete block (RCB) with eight replicates. Fall grasses were planted on August 1, 2013 and August 5, 2014 in a RCB with six replicates. Beginning in June and September of each year, adult horses grazed half of the replicates for four hours at an immature stage. Approximately one week later, horses grazed the remaining plots at a mature stage. Plots were mowed and grazing was repeated when annual grasses regrew to the target maturities. Although spring and forage oat (*Avena sativa L.*) and winter barley (*Hordeum vulgare* L.) often had the highest yields (≥ 3.9 t ha^{-}

^{1}; $P \leq 0.0455$) across seasons and maturities, they were among the least preferred annual grasses ($\leq 28\%$; $P \leq 0.0498$). Across seasons and maturities, annual ryegrass (*Lolium multiflorum* L.) and winter and spring wheat (*Tricum aestivum* L.) were the most preferred annual grasses with $\geq 45\%$ removal ($P \leq 0.0370$). Among these highly preferred grasses, annual ryegrass was typically higher yielding (≥ 4.7 t ha^{-1}), while winter and spring wheat were among the lowest yielding species (≤ 6.4 t ha^{-1}; $P \leq 0.0455$). Although differences were observed, all annual grasses resulted in $\geq 15\%$ crude protein (CP), $\leq 59\%$ neutral detergent fiber (NDF), $\leq 17\%$ nonstructural carbohydrates (NSC), and ≥ 2.05 Mcal kg^{-1} equine digestible energy (DE). Annual ryegrass appears to be a viable option for horse owners looking to extend the grazing season or provide emergency pasture forage.

Introduction

The American Horse Council (AHC) estimates there are 9.2 million horses in the United States (AHC, 2005). One of the greatest expenditures of horse ownership is feed costs (NRC, 2007), and owners tend to look for ways to decrease these costs. The cost of purchased and stored feed is high relative to the cost of feeding livestock on pasture (McCormick et al., 2006). Therefore, one method of reducing feed costs is to maximize pasture production. In the upper-Midwest, cool-season perennial grasses are the foundation of productive horse pastures (Allen et al., 2012). However, there may be opportunities to utilize alternative forages to extend the grazing season either earlier in the spring when perennial species are not yet growing or later into the fall when perennial species are no longer productive. Numerous research studies have suggested utilizing small grains to extend the grazing season (Sprague, 1954; Kallenbach et al., 2003; McCormick et al., 2006; Gunsaulis et al., 2008; Coblentz and Walgenbach, 2010), yet they are rarely evaluated under horse grazing. In addition to extending the grazing season, annual grasses can be used to provide forage in emergency grazing situations (Rankin, 2003; Gunsaulis et al., 2008; Coblentz and Walgenbach, 2010; Coblentz et al., 2011). In 2013, approximately two million acres of legume and grass hay fields and pastures in the upper-Midwest were affected by winterkill (Wells et al., 2014). Emergency grazing situations can also occur after poor spring growing conditions, summer floods, drought, and/or an early fall frost. Global changes in climate and weather patterns make these scenarios both frequent and hard to predict across many areas of the U.S., and there is limited information available regarding emergency grazing options for horse pastures.

When selecting emergency or alternative forage options, it is important to consider a variety of qualities, including yield, yield distribution, forage nutritive value, and livestock preference. Annual grasses vary in growth characteristics, which affect their seasonal yield distribution. Contreras-Govea and Albrecht (2006) found that oat cultivars produced 8.5 t ha^{-1} of forage 77 days after spring planting compared to 7.4 t ha^{-1} of forage 77 days after fall planting. McCormick et al. (2006) found that oat and spring triticale (*Triticale hexaploide* L.) had greater fall yields compared to rape (*Brassica napus* L.), annual ryegrass, winter triticale, winter wheat, and winter rye (*Secale cereale* L.). In Wisconsin, fall planted spring cereals had greater forage yield compared to winter-hardy species such as winter wheat or rye (Maloney et al., 1999). Other studies have also found that cereal grains which undergo stem elongation following late-summer establishment have shown a 2:1 DM yield advantage over cereal forages that remain vegetative until spring (Gunsaulis et al., 2008; Coblentz and Walgenbach, 2010; Coblentz et al., 2013).

Differences in growth characteristics also affect forage nutritive value. Maloney et al. (1999) and Coblentz and Walgenbach (2010) reported that winter-sensitive cereal grains grew more actively and had greater NDF and lower CP concentrations in the fall compared to winter-hardy cereal species. McCormick et al. (2006) found that oat, spring triticale, and annual ryegrass had CP levels ≥ 27% and NDF values that ranged from 26 to 34% in late fall. As plants develop from the vegetative through reproductive stages, increases in yield are often accompanied by decreases in forage nutritive value due to increased cell wall accumulation (Cherney and Marten, 1982; Walker et al., 1990). Slower-maturing, forage-type cultivars such as 'Forage Plus' spring oat have been found to have lower NDF and higher CP accumulations than other, grain-type oat cultivars when planted at the same time (Contreras-Govea and Albrecht, 2006; Coblentz and Walgenbach, 2010). Forage nutritive values are also affected by season and temperature, with several researchers have reporting improved forage nutritive values when small grains were grown under cooler conditions (Smith, 1975; Maloney et al., 1999; Contreras-Govea and Albrecht, 2006).

It is common knowledge that horses are selective grazers, especially compared to other livestock, and they often prefer certain species over others (Archer, 1973, 1978; Hunt and Hay, 1990). Preference is important to consider when selecting forages for horse pasture, as it will influence pasture utilization and stability over time (Hunt and Hay, 1990). Much of the previous equine palatability research has focused on understanding horse preferences of cool-season perennial grasses (Archer, 1973, 1978; Hunt and Hay, 1990; Allen et al., 2013; Olson et al., 2014), with few researchers investigating the preference of annual cool-season grasses under horse grazing. McCann and Hoveland (1991) found that annual ryegrass was preferred over wheat, oat, rye, and triticale by grazing horses. Research investigating the preferences of other species found that sheep preferred oat to other small grains (Washko, 1947). Maturity is a factor many researchers often associate with preference. Burton et al. (1956) found forage maturity to be a factor of acceptability in determining cattle preference, noting that cattle tended to select less mature vegetation over older, more fibrous plants of the same species. Dairy heifers who grazed oat forage preferentially grazed the leaf tissue over the stems, and utilization of standing forage was found to be improved when plants were shorter and less mature compared to taller, more mature forage (Coblentz et al., 2013).

Annual grasses have potential as productive and high quality pasture forages. However, few studies have investigated the yield, forage nutritive value, and preference of annual grasses planted at different times of the year and grazed by horses at multiple maturities. Therefore, the objectives of this study were to evaluate the yield, forage nutritive value, and preference of annual grasses under horse grazing at two maturities during the spring and fall.

Materials and Methods

Research was conducted in St. Paul, MN (44°59’14” N, 93°10’37” W) in 2013 and 2014. A seedbed was prepared each year using multiple disking and field cultivation passes prior to planting. On May 8, 2013 and April 22, 2014, spring experiments were planted in monoculture in a randomized complete block (RCB) with eight replicates. Spring-planted grasses included 'Badger' spring oat, 'RB07' spring wheat, 'VNS' (2013) or 'Expedition' (2014) winter wheat, 'Morex' spring barley, and 'Gulf' (2013) or 'Jumbo' (2014) annual ryegrass and were planted at 90, 134, 101 (2013) or 106 (2014), 95, and 39 kg/ha, respectively. On August 1, 2013 and August 5, 2014, fall experiments were planted in monoculture in a RCB with six replicates. Fall-planted grasses included the same five species plus 'VNS' winter rye, 'Charles' (2013) or 'MacGregor' (2014) winter barley, and 'Forage Plus' spring oat and were planted at 67, 95 (2013) or 101 (2014), and 90 kg/ha, respectively. Plot size for all individual plots was 1.8 x 6.1 m. The soil was a Waukegan silt loam (fine-silty over skeletal, mixed, superactive, mesic Typic Hapludoll) with a soil pH of 6.6, 18 ppm P, and 85 ppm K; no additional soil amendments were required based on Minnesota fertility guidelines. No fertilizer was applied in the spring of 2013. In the spring of 2014, 28 kg N ha^{-1} was applied prior to planting. In the fall of both years, 56 kg N ha^{-1} was applied two weeks after planting. Weeds were controlled by hand pulling.

One day prior to the initiation of grazing, yield and forage nutritive values were determined by hand-harvesting random duplicate 0.46 x 0.51 m areas to a height of 8 cm. Samples were dried for 24 h at 60ºC and weighed to determine dry matter (DM). After drying, samples were ground through a 6-mm screen in a Wiley mill (Thomas Scientific) followed by a 1-mm screen in a Cyclotec (Foss). Samples were mixed thoroughly and subsamples were analyzed for forage nutritive value by a commercial forage testing laboratory (Equi-Analytical, Ithica, NY) using the following methods. Crude protein was calculated as the percentage of nitrogen multiplied by 6.25 (method 990.03; AOAC, 2010). Neutral detergent fiber was measured using filter bag techniques (Ankom Technology, 2013). Starch and water soluble carbohydrates were measured using techniques described by Hall et al (1999). Non-structural carbohydrates were estimated as the sum of water-soluble carbohydrates and starch (Longland and Byrd, 2006). Equine DE was calculated using an equation developed by Pagan (1998).

To evaluate the effect of grass maturity, half of the replicates within each year and season were grazed at a more immature stage (onset of stem elongation), while the remaining replicates were grazed at a more mature stage (boot stage). Grass maturity of the main stem was evaluated before grazing using a scale developed by Moore et al. (1991), where emergence of first leaf was equal to 1.0, onset of stem elongation was equal to 2.0, and boot stage was equal to 3.0. In the spring of 2013, three adult stock-type horses grazed for four hours at the onset of stem elongation (immature) on June 18 and at the boot stage (mature) on June 25. Horse group descriptions for each season and year are available in table 3.1. The four hour grazing length was selected based on estimated available herbage mass, estimated horse intake (Glunk and Siciliano, 2011), and to allow for determination of horse preference while achieving a minimum average residual height of 8 cm to avoid over-grazing. In the fall of 2013, three adult stock-type horses grazed at the onset of stem elongation on September 17 at the boot stage on October 1. In 2014, favorable growing conditions required the addition of a fourth horse to maintain an appropriate and similar stocking density. In the spring of 2014, four adult stock-type horses grazed at the onset of stem elongation on June 4 and at the boot stage on June 12. In the fall of 2014, four adult stock-type horses grazed at the onset of stem elongation on September 9 and at the boot stage on September 23.

Immediately after grazing, horse preference was determined by visually assessing percentage of available forage removal on a scale of 0 (no grazing activity) to 100 (100% of the existing vegetation grazed down to 8 cm; Marten et al., 1987; Ehlke et al., 2003; Allen et al., 2013). Upon completion of grazing, manure was removed and plots were mowed to a height of 8 cm and allowed to regrow. Grazing was repeated when spring forages regrew to the onset of stem elongation on July 9, 2013; June 24 and July 18, 2014; and to the boot stage on July 11, 2013; June 26 and July 29, 2014. Grazing was repeated when fall forages regrew to the onset of stem elongation on October 15, 2013; October 7 and November 4, 2014; and to the boot stage on October 29, 2013 and October 21, 2014. All horses had *ad libitum* access to water throughout the study. When not grazing, horses were housed in a dry lot and fed a mixed cool-season perennial grass hay. All experimental procedures used in this study were conducted according to those approved by the University of Minnesota Committee on Animal Use and Care.

Data was analyzed using the Proc Mixed procedure of SAS (version 9.4; SAS Institute Inc., Cary, NC). Individual plots were the experimental unit, and statistical significance was set at $P \leq 0.05$. The inclusion of additional grass species in the fall seasons compared to spring seasons created an unbalanced data set, so spring and fall seasons were analyzed separately. Initial analysis also demonstrated an interaction between annual grass species and stage of maturity within both spring and fall seasons ($P \leq 0.0209$); therefore, immature and mature grazing experiments were analyzed separately. Within each season and maturity, weighted means were used to average preference and forage nutritive values across grazing events and yield was totaled for all grazing events. Replicate and year were considered a random effect and grass species was designated as a fixed effect. Means are the least square means of the Mixed procedure (± SE), and mean separations were determined using Tukey's test. Variables analyzed included maturity, yield, percent removal (preference), CP, NDF, NSC, and DE. To assess the relationship between preference and plant characteristics, a linear model using post-grazing herbage removal was fit with plant maturity, height, and forage nutritive value components (CP, NDF, and NSC) as predictors.

Results and Discussion

Weather

Mean daily air temperature for both the 2013 and 2014 grazing seasons were similar to the 30-year average, except for April and May which were cooler than normal (Figure 3.1). Total rainfall during the 2013 and 2014 grazing seasons (May – October) was 63 and 56 cm, respectively, similar to the 30-year average of 60 cm (Figure 3.1). However, the rainfall was not evenly distributed. More rainfall was recorded in April, May, and June compared to late summer and fall months, which were drier compared to the 30-year average.

Maturity

Table 3.2 shows that target maturities were reached during both seasons and that annual grass maturity differed between species ($P \leq 0.0001$). At both target maturities during the spring, winter wheat remained within the vegetative or leaf development phase (≤ 1.6; Moore et al., 1991) and was less mature compared to the other annual grasses (≥ 2.2; $P \leq 0.0012$). Similar results were observed at both maturities in the fall, with winter wheat, barley, and rye remaining in a more vegetative stage (≤ 1.6) compared to all spring species except for annual ryegrass ($P \leq 0.0131$). This was expected, as winter species require a vernalization period to progress in maturity and have been shown to have extensive tiller growth but very little intermodal elongation prior to overwintering (Sprague, 1954; Griggs, 2006; Coblentz and Walgenbach, 2010; Coblentz et al., 2013). In the fall, spring forage oat was less mature at both target growth stages compared to spring oat ($P \leq 0.0029$). The slower maturation rate of spring forage oat was also expected, as previous research demonstrated a slower maturation rate for this variety compared to grain-type oat cultivars planted at the same time (Coblentz and Walgenbach, 2010; Coblentz and Bertram, 2012a; b).

Maturity is an important consideration to make when assessing the appropriate time to graze, as it affects not only forage yield, but also nutritive value and preference (Cherney and Marten, 1982; Juskiw et al., 2000; Rosser et al., 2013). As a plant develops and matures, yield will continue to increase but will be accompanied by subsequent decreases in forage nutritive value, although the rate at which this occurs will vary depending on species and environmental conditions (Cherney and Marten, 1982; Walker et al., 1990; Juskiw et al., 2000). Young, immature plants are often preferred over older, more fibrous plants of the same species, making forage maturity an important factor when considering the acceptability of various forages to grazing animals (Burton et al., 1956; McCann and Hoveland, 1991).

Yield

Annual grasses differed in total seasonal yield ($P \leq 0.0085$; Table 3.3-3.6). Within the immature spring-planted grasses, annual ryegrass had a greater yield (4.7 t ha^{-1}) compared to spring barley, spring wheat, and winter wheat, which had average yields ≤

3.6 t ha^{-1} ($P \leq 0.0185$). Within the mature spring-planted grasses, spring oat was the highest yielding grass (8.0 t ha^{-1}), while winter wheat was the lowest yielding with an average yield of 3.9 t ha^{-1} ($P \leq 0.0455$). Within the immature fall-planted grasses, winter barley, annual ryegrass, and spring forage oat were among the highest yielding species with yields $\geq$ 4.7 t ha^{-1}, while spring barley and spring wheat were among the species with the lowest yields, with yields $\leq$ 3.4 t ha^{-1} ($P \leq 0.0218$). Yields from the mature fall-planted grasses ranged from 3.9 to 6.5 t ha^{-1}, with spring forage oat having a higher yield (6.5 t ha^{-1}) than spring wheat, winter wheat, and winter rye ($\leq$ 4.2 t ha^{-1}; $P \leq 0.0357$).

Although no direct comparisons were made between the seasons and target maturities, general trends were observed across all experiments. Spring oat, annual ryegrass, spring forage oat, and winter barley tended to yield the most, with yields ranging from 3.9 to 8.0 t ha^{-1}, while spring wheat, spring barley, winter rye, and winter wheat typically produced lower yields, ranging from 3.4 to 6.4 t ha^{-1}. Grasses grazed at the onset of stem elongation had lower yields than grasses grazed at the boot stage. Spring varieties of annual grasses tended to result in greater yields compared to winter varieties, and yields were generally higher when annual grasses were planted in the spring compared to the fall.

The range of yields observed in the current study are similar to yields reported by others. For spring planted annual grasses, Edmisten et al. (1998a) found yields of 2.5 to 3.9 t ha^{-1} for barley, oat, rye, and wheat when harvested at the vegetative stage and 4.3 to 9.2 t ha^{-1} when harvested at the boot stage. Cherney and Marten (1982) observed yields between 4.6 and 8.0 t ha^{-1} for spring wheat, oat, and barley when averaged across six stages of maturity, and Rosser et al. (2013) found yields average yields of 6.9, 4.6, 7.0, and 5.6 t ha^{-1} for barley, millet, oat, and wheat, respectively, when planted in June and harvested at the head elongation stage of maturity. Contreras-Govea and Albrecht (2006) also reported high yields for spring-planted oat, with 8.5 t ha^{-1} of forage produced 77 days after sowing. For fall-planted annual grasses, Maloney et al. (1999) and Griggs (2006) reported yields between 0.9 and 4.1 t ha^{-1} for spring oat, spring barley, winter wheat, winter barley, and winter rye. When harvested at the boot to early head stage, yields for fall-planted grasses ranged from 3.7 to 6.2 t ha^{-1} (Rankin, 2003). Coblentz and Walgenbach (2010) reported yields from oat cultivars ranging from 2.9 to 7.4 t ha^{-1}, and Hossain et al. (2003) found yields averaging 3.6 t ha^{-1} for wheat when planted in late-August. Contreras-Govea and Albrecht (2006) reported an average yield of 7.4 t ha^{-1} when oat was harvested 77 days after planting. This is slightly higher than fall oat yields in this study; however, oats were grazed after 49 to 61 days in the current study.

In the current study, grasses grazed at an immature stage had lower yields compared to grasses grazed at a more mature stage. Although yield potential is variable and dependent on species, variety, environmental conditions, and management practices, increased yields with increasing plant maturity is well documented (Cherney and Marten, 1982; Helsel and Thomas, 1987; Walker et al., 1990; Coblentz and Walgenbach, 2010; Rosser et al., 2013). For example, Edmisten et al. (1998a) found average DM yields for barley, oat, rye, and wheat to be 0.68 to 2.3 t ha^{-1} when harvested at the vegetative stage compared to 7.8 to 12.8 t ha^{-1} when harvested at the milk stage. Helsel and Thomas (1987) also reported increasing DM yields for barley, oat, wheat, rye, and wheat as grasses matured, averaging 5.3, 8.2, and 8.4 t ha^{-1}, respectively, at three successive harvest dates. In a study evaluating the influence of planting date on wheat forage yield, Hossain et al. (2003) concluded that a 20-d delay in planting date from 10 to 30 September resulted in a 68% decrease in expected forage yield.

Spring varieties tended to yield more compared to winter varieties in the current study. The vernalization requirement for winter varieties keeps these grasses in vegetative growth until they are exposed to an extended cold period, resulting in lower yields when planted and grazed during the same growing season (Coblentz et al., 2013). Maloney et al. (1999) reported higher yields for fall planted spring grains over winter hardy species, with average yields of 0.7 to 1.6 t ha^{-1} for cultivars that remained vegetative compared to 2.5 to 3.6 t ha^{-1} for cultivars that underwent stem elongation. McCormick et al. (2006) had similar findings, noting that spring oat, spring barley, and spring triticale had greater yields compared to winter triticale, winter wheat, and winter rye. Several other researchers agree, determining that cereal grains which undergo stem elongation following fall establishment will likely exhibit a 2:1 DM yield advantage over winter cereals that remain vegetative until spring (Gunsaulis et al., 2008; Coblentz and Walgenbach, 2010; Coblentz et al., 2013).

In the current study, yields were typically higher when annual grasses were planted in the spring compared to the fall. This agrees with Contreras-Govea and Albrecht (2006), who found that oat forage yields were 1.1 t ha^{-1} less for fall-planted cultivars compared to spring-planted cultivars. Oat and other cereal grains have a long-day photoperiod requirement for flowering that can be disrupted by a late-summer planting date, resulting in a slower maturation rate and lower yields compared to spring plantings (Coblentz and Bertram, 2012a; b).

Yield Distribution

Along with total yield, yield distribution should be considered when selecting annual grasses for forage. Yield distribution was variable across species, seasons, and maturities (Figure 3.2). For spring-planted annual grasses, annual ryegrass and winter wheat had the most consistent regrowth potential and continued to produce forage after each grazing event. In contrast, spring barley, spring oat, and spring wheat produced over half of their yield during the first grazing, with minimal yields available for a third grazing. For fall-planted annual grasses, annual ryegrass, winter barley, winter wheat, and winter rye had the most consistent regrowth potential, with continual regrowth after each grazing event. Spring barley and spring oat had the least potential for regrowth, with a large majority of yield occurring during the first grazing and little to no regrowth being available for a second or third grazing. The current research agrees with others who have evaluated multiple harvests for small grains. Edmisten et al. (1998a) found that regrowth potential was highly dependent on plant maturity at harvest, with more regrowth occurring after vegetative and boot stage harvests compared to harvests initiated at the heading stage or later. Winter rye and winter wheat cultivars have previously exhibited multiple-harvest potential, accumulating an average of 0.6 and 1.0 t ha^{-1}, respectively, in regrowth over a 45 day window (Gunsaulis et al., 2008), while oat cultivars have shown limited or no regrowth potential, suggesting that the best utilization of oat might be accomplished by a one-time removal of standing forage (Gunsaulis et al., 2008; Coblentz and Walgenbach, 2010; Coblentz et al., 2013).

Forage Nutritive Value: Crude Protein

The CP concentration differed between grasses ($P \leq 0.0001$; Table 3.3-3.6). For both the immature and mature spring-planted grasses, winter wheat had the greatest amount of CP (≥ 23%), while annual ryegrass and spring oat were among the species with the least amount of CP, containing ≤ 22% ($P \leq 0.0184$). For both the immature and mature fall-planted grasses, winter rye had the greatest CP with ≥ 32% and spring oat had the least CP with ≤ 21% ($P \leq 0.0444$). However, all grasses contained ≥ 15% CP, exceeding that required by a 500-kg mature horse in moderate exercise with an intake of 2.5% of BW (NRC, 2007). When considering general trends between species, winter varieties tended to contain higher levels of CP compared to spring species, and immature grasses typically contained a higher amount of CP compared to mature grasses. When comparing seasons, fall planted grasses often had greater CP concentrations compared to spring.

These results agree with findings from previous studies examining the forage nutritive value of annual grasses. Edmisten et al. (1998b) found that CP values for oats at the vegetative stage were lower (18-21%) compared to barley, rye, and wheat (20-30%). When grasses were harvested at a more mature growth stage, Edmisten et al. (1998b) observed CP values ranging from 11 to 26% for the same annual grasses. Rosser et al. (2013) found average CP contents of June-planted grasses to be 19, 22, 16, and 19% for barley, millet, oat, and wheat, respectively, when harvested at the head elongation stage of maturity. Contreras-Govea and Albrecht (2006) found similar CP concentrations for fall-planted spring oat (16-18%) and ‘Forage Plus’ oat (21% CP). Coblentz and

Walgenbach (2010) and Sprague (1954) also reported high CP concentrations (≥ 28%) for fall-planted annual grasses.

In the current study, winter, immature, and fall planted species tended to contain higher levels of CP. When comparing winter and spring varieties of annual grasses, Coblentz and Walgenbach (2010) reported that vegetative wheat cultivars maintained greater CP concentrations (23%) than oat and triticale cultivars (19%). McCormick et al. (2006) and Maloney et al. (1999) determined that winter hardy species such as winter rye, winter triticale, and winter wheat had higher CP compared to spring oat, barley, triticale, and annual ryegrass. It is also well-documented that CP content declines as plants mature (Cherney and Marten, 1982; Helsel and Thomas, 1987; Edmisten et al., 1998b; Rosser et al., 2013). Smith (1960) and Rankin (2003) both determined that CP of oat forage decreased as maturity advanced from the boot to milk stage, and Belyea et al. (1978) noted a consistent decrease in CP content from 31% to 7% for wheat harvested across ten cutting dates. Similarly, Coblentz and Walgenbach (2010) reported that concentrations of CP for fall-planted annual grasses decreased from ≥ 31% to ≤ 19% as the grasses matured. Lower concentrations of CP for 'Winter King' rye was attributed to its advanced maturity at harvest (McCormick et al., 2006), and late-maturing 'Forage Plus' spring oat had a higher CP concentrations compared to more mature varieties of spring oat (Contreras-Govea and Albrecht, 2006). Previous research has also documented higher CP content for fall-planted grasses. In both Wisconsin and New Jersey, CP concentrations for rye, wheat, and oat were found to be higher in autumn than in spring or early summer (Sprague, 1954; Contreras-Govea and Albrecht, 2006), and McCormick et al. (2006) also reported high CP levels in fall-planted grasses. The higher CP concentrations observed in fall-planted grasses are thought to be a result of plant maturity and suppression of physiological development by cooler temperatures and the lack of a long-day photoperiod required for flowering (Contreras-Govea and Albrecht, 2006; Coblentz and Walgenbach, 2010; Coblentz and Bertram, 2012a; b; Coblentz et al., 2013).

Forage Nutritive Value: Neutral Detergent Fiber

Concentrations of NDF varied among the grasses ($P \leq 0.001$; Table 3.3-3.6). For both the immature and mature spring-planted grasses, spring wheat and spring oat contained the highest levels of NDF with ≥ 52% and winter wheat contained the lowest levels of NDF with ≤ 48 ($P \leq 0.0340$). Within the immature fall-planted grasses, spring oat had the greatest NDF concentration (56%), while spring forage oat, annual ryegrass, and winter rye were among those with the lowest NDF concentration (≤ 44%; $P \leq 0.0057$). Within the mature fall-planted grasses, spring oat, spring barley, spring wheat, and spring forage oat all had higher NDF concentrations (≥ 55%) compared to the three winter varieties and annual ryegrass (≤ 46%; $P \leq 0.0187$). Across all seasons and target maturities, similar trends were observed. More mature grasses were higher in NDF compared immature grasses, spring varieties typically contained higher levels of NDF compared to winter varieties, and spring-planted annual grasses were often higher in NDF compared to fall-planted grasses.

Neutral detergent fiber values observed in the current study are similar to those previously reported. Edmisten et al. (1998b) found NDF concentrations of 31 to 41% for vegetative annual grasses and 41 to 50% for grasses harvested at the boot stage. Contreras-Govea and Albrecht (2006) and Rosser et al. (2013) observed NDF concentrations ≥ 52% for mature spring-planted annual grasses, and Coblentz and Walgenbach (2010) examined NDF concentrations for oat, triticale, and winter wheat across three fall harvests and found concentrations of NDF ≤ 63% for all varieties on all harvest dates. However, the results from the current study are slightly higher than those reported by Maloney et al. (1999) and Griggs (2006), who observed NDF concentrations between 23 and 43% for fall-planted annual grasses.

It is well documented that the fibrous content of grasses increases as plants mature (Smith, 1960; Belyea et al., 1978; Edmisten et al., 1998b; Coblentz and Bertram, 2012b). Rankin (2003) noted that the concentration of NDF from oats harvested at the boot stage averaged 52 to 54%, increasing to 59 to 61% at the milk stage. Cherney and Marten (1982) found that NDF increased from about 40% at the boot stage to about 53% at heading for spring barley, oats, and wheat grown in Minnesota, and studies in Wisconsin and Michigan reported increasing concentrations of NDF for cereal grain cultivars across multiple harvest dates (Helsel and Thomas, 1987; Coblentz and Walgenbach, 2010; Coblentz et al., 2012). Results of the present study also agree with previous research documenting higher NDF contents for spring varieties compared to winter varieties (Maloney et al., 1999; Coblentz and Walgenbach, 2010) and for spring planted grasses compared to fall planted grasses (Contreras-Govea and Albrecht, 2006; McCormick et al., 2006; Coblentz and Walgenbach, 2010). The higher NDF concentration in spring planted grasses is thought to be associated with a more advanced maturity in summer-harvested forages compared to autumn-harvested forages. A late-summer planting disrupts the long-day photoperiod requirement for flowering, suppressing maturation rate and therefore limiting NDF accumulation (Coblentz and

Bertram, 2012b). In addition, a change in temperature from warm to cold has been shown to increase stem proportion while delaying plant maturity (Smith, 1974). Therefore, as temperatures decrease moving into the fall season, plant growth slows and plant maturities tend to be lower, resulting in a lower NDF concentration.

Forage Nutritive Value: Non-Structural Carbohydrates

Non-structural carbohydrate concentrations differed between the grasses ($P \leq 0.0001$; Table 3.3-3.6). Within the immature spring-planted grasses, all varieties had levels of NSC between 14-16% except for spring wheat, which had the lowest level at 11% ($P \leq 0.0011$). Within the mature spring-planted grasses, annual ryegrass, spring oat, and spring barley were among those with the highest NSC concentration (≥ 16%), while spring wheat contained the least NSC at 11% ($P \leq 0.0202$). Within the immature fall-planted grasses, annual ryegrass contained the highest levels of NSC with 16%, while all other varieties had similar NSC concentrations between 12 and 13% ($P \leq 0.0175$). Within the mature fall-planted grasses, winter wheat, annual ryegrass, spring oat, and winter rye all contained NSC ≥ 14%, which was higher compared to spring wheat, spring barley, and spring forage oat (≤ 9%; $P \leq 0.0024$). No general trends were observed between winter and spring varieties or between mature and immature grasses, but spring planted grasses typically had higher concentrations of NSC compared to fall planted grasses.

Numerous factors are known to influence NSC concentrations in forages, including plant species, maturity, and environmental conditions such as temperature, light, and nutrient and water availability (Chatterton et al., 2006; Longland and Byrd, 2006). Although NSC concentrations are known to vary, the NSC content of annual grasses in this study are similar to concentrations previously reported for perennial cool-season grasses. Allen et al. (2013) observed NSC concentrations of 11 perennial cool season grasses ranging from 6 to 17%, and Pelletier et al. (2010) observed total nonstructural carbohydrate (TNSC) concentrations of 6 perennial cool-season grasses ranging from 4 to 12%. Previous research has also demonstrated a disjoint relationship between NSC content and plant maturity. Oat hay from spring-planted oats was found to have a greater NSC concentration in immature hay compared to mature hay; however, oat hay from summer-planted oats had similar NSC concentrations in both immature and mature hay (Chatterton et al., 2006).

In the current study, NSC concentrations were often higher for spring-planted grasses compared to fall-planted grasses. This is somewhat contrary to previous research. Winter-annual cereals are known to undergo a process called hardening at temperatures just above freezing. Generally, these plants accumulate various solutes within the individual plant cells during cooler conditions, which serves to increase osmotic pressure and provide protection against freezing or winterkill; however, one of the principle compounds accumulating in these plants is sugar, and as a result, these plants typically exhibit increased concentrations of sugars during late fall when temperatures are low (Livingston and Premakumar, 2002; Coblentz and Walgenbach, 2010; Coblentz and Bertram, 2012b). Contreras-Govea and Albrecht (2006) found that leaf and stem WSC concentrations were 1.5 to 3.3 times greater in fall-grown oat than in identical cultivars established in the spring, and Smith (1975) reported increasing WSC concentrations in oat as temperature shifted from warm to cool as a natural response to cold adaptation. Coblentz et al. (2012) reported that July-planted oat cultivars had a linear decrease in

WSC concentration across fall harvest dates; however, August-planted oat cultivars had a linear increase in WSC concentrations across fall harvest dates, indicating an accumulation of sugars during late fall that is capable of offsetting the natural deposition of structural fiber associated with morphological development.

Nonstructural carbohydrates are important to evaluate when feeding horses, as they affect horses diagnosed with obesity, laminitis, equine metabolic syndrome, insulin-resistance (Frank, 2009) and polysaccharide storage myopathy (Borgia et al., 2009). Although horses diagnosed with the above diseases should have their total diet restricted to $\leq$12% NSC (Frank, 2009; Borgia et al., 2009), there are no NSC restrictions for healthy horses.

Forage Nutritive Value: Digestible Energy

Digestible energy content of the annual grasses varied ($P \leq 0.0001$; Table 3.3-3.6). Within the immature spring-planted grasses, winter wheat and annual ryegrass had a higher DE content ($\geq$ 2.33 Mcal kg^{-1}) compared to spring wheat (2.16 Mcal kg^{-1}; $P \leq 0.0004$). Similar results were seen within the mature spring-planted grasses. Winter wheat and annual ryegrass had a greater DE ($\geq$ 2.24 Mcal kg^{-1}) compared to spring oat and spring wheat ($\leq$ 2.16 Mcal kg^{-1}; $P \leq 0.0098$). Within the immature fall-planted grasses, winter rye, annual ryegrass, and spring forage oat were among those with the highest DE content ($\geq$ 2.38 Mcal kg^{-1}), while spring oat contained the least DE at 2.11 Mcal kg^{-1} ($P \leq 0.0412$). Within the mature fall-planted grasses, winter rye, annual ryegrass, winter wheat, and winter barley had a greater DE with $\geq$ 2.29 Mcal kg^{-1}, while spring forage oat, spring wheat, spring barley, and spring oat contained the least DE with $\leq$ 2.11 Mcal kg^{-1} ($P \leq 0.0207$). Although no direct comparisons were made between seasons and target maturities, general trends were observed. Winter varieties tended to have higher DE compared to spring varieties, and vegetative annual grasses contained higher amounts of DE compared to mature grasses.

Equine DE of the annual grasses observed in this study are comparable to previously reported DE content for perennial grass pastures and hay. Dowler et al. (2012) found an average DE content for tall fescue (*Festuca arundinacea* L.) pastures ranging from 2.10 to 2.25 Mcal kg^{-1}, and Hoskin and Gee (2004) reported average DE concentrations between 1.91 and 2.87 Mcal kg^{-1} for pastures containing a mix of perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.). Martinson et al. (2012) reported that orchardgrass (*Dactylis glomerata* L.) hay at the vegetative and flowering growth stage contained 2.18 and 2.14 Mcal kg^{-1}, respectively, of equine DE, and Grev et al. (2014) found the DE content of mixed grass hay to be 2.07 Mcal kg^{-1}. Equine DE of the annual grasses from the current study are also comparable to the DE content of grass hay and pasture reported by the NRC (2007), which range from 2.04 to 2.39 Mcal kg^{-1}.

In the current study, DE for the vegetative annual grasses tended to be higher than for the mature grasses. Although there are limited studies reporting the equine DE content for pasture grasses, the NRC (2007) reports increasing DE content for grass hay with increasing maturity, with immature grass hay containing more equine DE (2.36 Mcal kg^{-1}) compared to mid-maturity (2.18 Mcal kg^{-1}) and mature grass hay (2.04 Mcal kg^{-1}).

Preference

Horses showed distinct preferences among the grasses ($P \leq 0.0001$; Table 3.3-3.6). Within the immature spring-planted grasses, winter wheat and spring wheat were among the most preferred grasses with ≥ 73% removal, while spring oat was the least preferred species with an average percent removal of 15% ($P \leq 0.0367$). Similar preferences were seen within the mature spring-planted grasses. Winter wheat and spring barley were the most preferred species, with ≥ 61% removal, while spring oat was the least preferred species, averaging 15% removal ($P \leq 0.0071$). Within the immature fall-planted grasses, spring wheat and annual ryegrass were highly preferred (≥ 69%), while spring oat, winter barley, spring forage oat, and winter rye were among the least preferred species (≤ 23%; $P \leq 0.0370$). Within the mature fall-planted grasses, spring wheat, annual ryegrass, and winter wheat were the most preferred species with ≥ 62% removal, while winter barley, spring forage oat, and winter rye were among the least preferred species with ≤ 20% removal ($P \leq 0.0498$).

Preference is a complex phenomenon that is not entirely understood, but thought to be determined by several variables, including animal species, plant characteristics, and environmental factors (Marten, 1978; Marten et al., 1987; Allen et al., 2013). However, it is common knowledge that horses are selective grazers, especially when compared to other livestock (Archer, 1973, 1978; Hunt and Hay, 1990). Horse preference is therefore an important consideration when selecting forage species, as it will influence pasture utilization and stability over time (Hunt and Hay, 1990). Results from the current study are similar to previously documented results. McCann and Hoveland (1991) found annual ryegrass to be the most preferred annual grass species, averaging 75% removal;

oats and wheat were moderately preferred, with 47 and 41% removal, respectively, and rye and triticale were least preferred, averaging only 35 and 32% removal. Horses have also shown distinct preferences between perennial cool season grasses, with percent removals ranging from 28 to 96% (Allen et al., 2013).

Variation in forage acceptability to horses is not well understood (McCann and Hoveland, 1991). In the current study, correlations between preference and plant maturity, height, CP, NDF, and NSC were analyzed. Small correlations were found within each of the spring grazing experiments ($P \leq 0.0142$), but not in either of the fall grazing experiments ($P \geq 0.0934$). In the spring, horse preference had a small positive correlation to annual grass CP content ($P \leq 0.0004$) and a small negative correlation to annual grass maturity, plant height, and NDF content ($P \leq 0.0142$). Horse preference was not correlated to annual grass NSC content ($P \geq 0.1833$). These results are similar to those of others who found a positive relationship between preference and protein content (Fontenot and Blaser, 1965) and a negative relationship between preference and fiber concentrations (Fontenot and Blaser, 1965; Allen et al., 2013) and between preference and plant maturity (Burton et al., 1956; McCann and Hoveland, 1991). However, others have also reported a positive relationship between preference and carbohydrate content (Reid et al., 1967; Longland and Byrd, 2006; Allen et al., 2013), which was not seen in the current study. Additionally, the lack of correlation between plant characteristics and horse preference in the fall highlights the fact that horse preference is a complicated issue that is impacted by several confounding factors, including available species, agronomic management, geographic location, and weather conditions.

Conclusions

Differences were observed between annual grass species when evaluating maturity, yield, forage nutritive value, and horse preference. Winter wheat, barley, and rye remained in a more vegetative stage compared to spring species. Yield increased with increasing plant maturity and was higher for spring varieties and when annual grasses were planted in the spring. Spring oat, annual ryegrass, spring forage oat, and winter barley were among the higher yielding species, while spring wheat, winter wheat, and winter rye were among the lower yielding species. Yield was more evenly distributed for annual ryegrass, winter barley, winter wheat, and winter rye compared to spring oat, spring barley, and spring wheat, which often had little or no regrowth potential. Immature grasses and fall planted grasses often had greater CP concentrations, and the winter varieties of wheat, barley, and rye tended to contain higher levels of CP compared to spring species such as annual ryegrass, spring oat, and spring wheat. Typically, winter wheat had lower amounts of NDF in the spring, while annual ryegrass, winter wheat, and winter rye had lower NDF in the fall. Neutral detergent fiber concentrations were generally greater for spring varieties compared to winter varieties, with spring wheat, spring oat, and spring barley being among those with the highest fiber content. More mature grasses and spring planted grasses also were usually higher in NDF. Annual ryegrass and spring oat generally had the greatest amount of NSC, while spring wheat and spring forage oat tended to have lower amounts. Winter wheat, annual ryegrass, and winter rye typically contained the greatest DE, while spring wheat and spring oat had the lowest DE. Winter varieties tended to have higher DE compared to spring varieties, and vegetative annual grasses resulted in higher DE compared to mature grasses. Horses tended to prefer winter wheat, annual ryegrass, and spring wheat and showed less preference for spring oat, spring forage oat, winter barley and winter rye. In the spring, horse preference was found to be positively correlated with CP content and negatively correlated with plant maturity, plant height, and NDF content. When making forage pasture decisions, it is important to consider yield, forage nutritive value, and horse preference. Based on a combination of these factors, annual ryegrass appears to be a good option for horse owners looking to extend the grazing season or in need of emergency forage during both the spring and fall seasons.

Figure 3.1. Monthly air temperature (°C), precipitation (cm), and 30-year historical average for St. Paul, MN during the 2013 and 2013 growing season. Weather data obtained from http://www.dnr.state.mn.us/climate/historical/index.html.

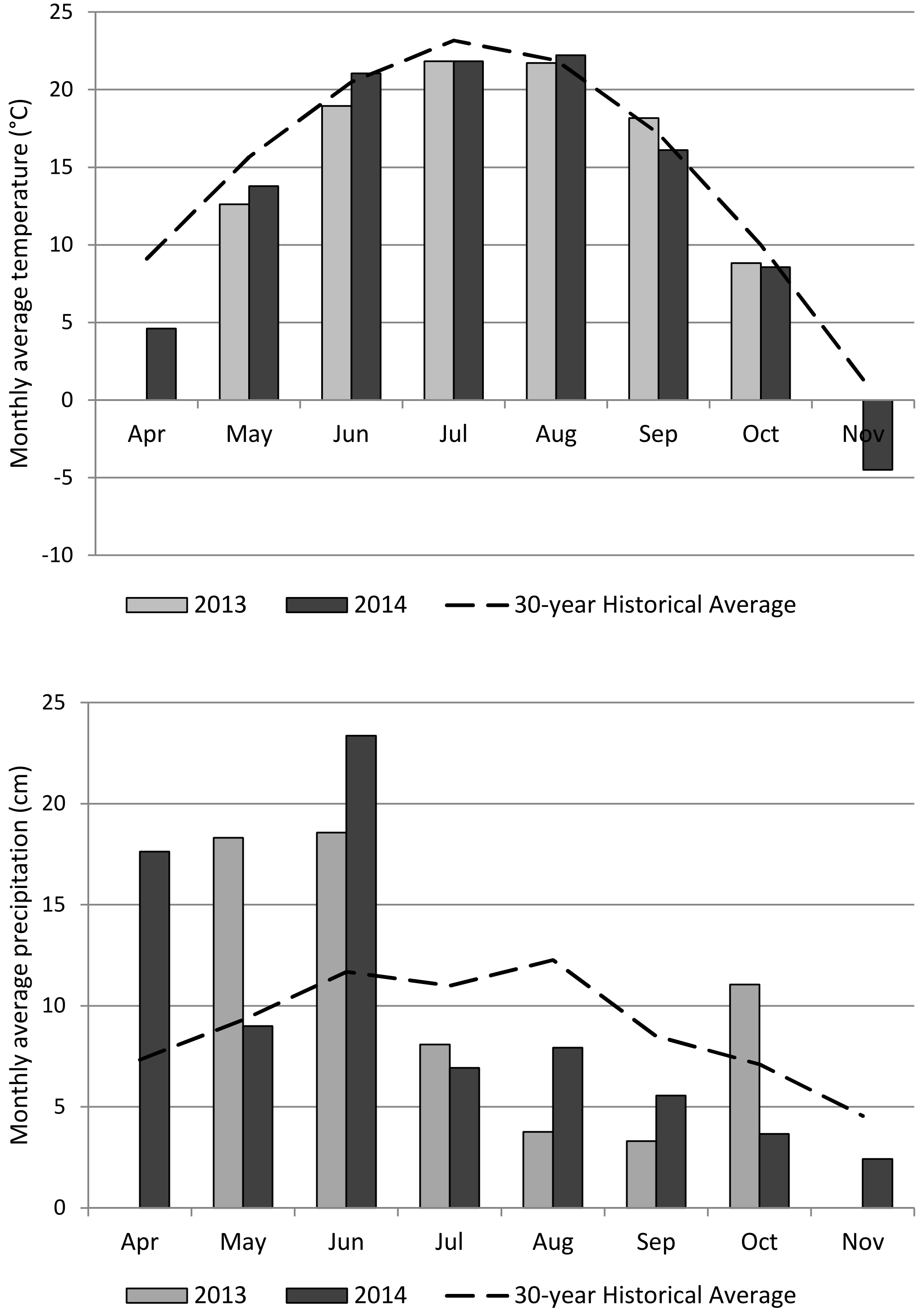
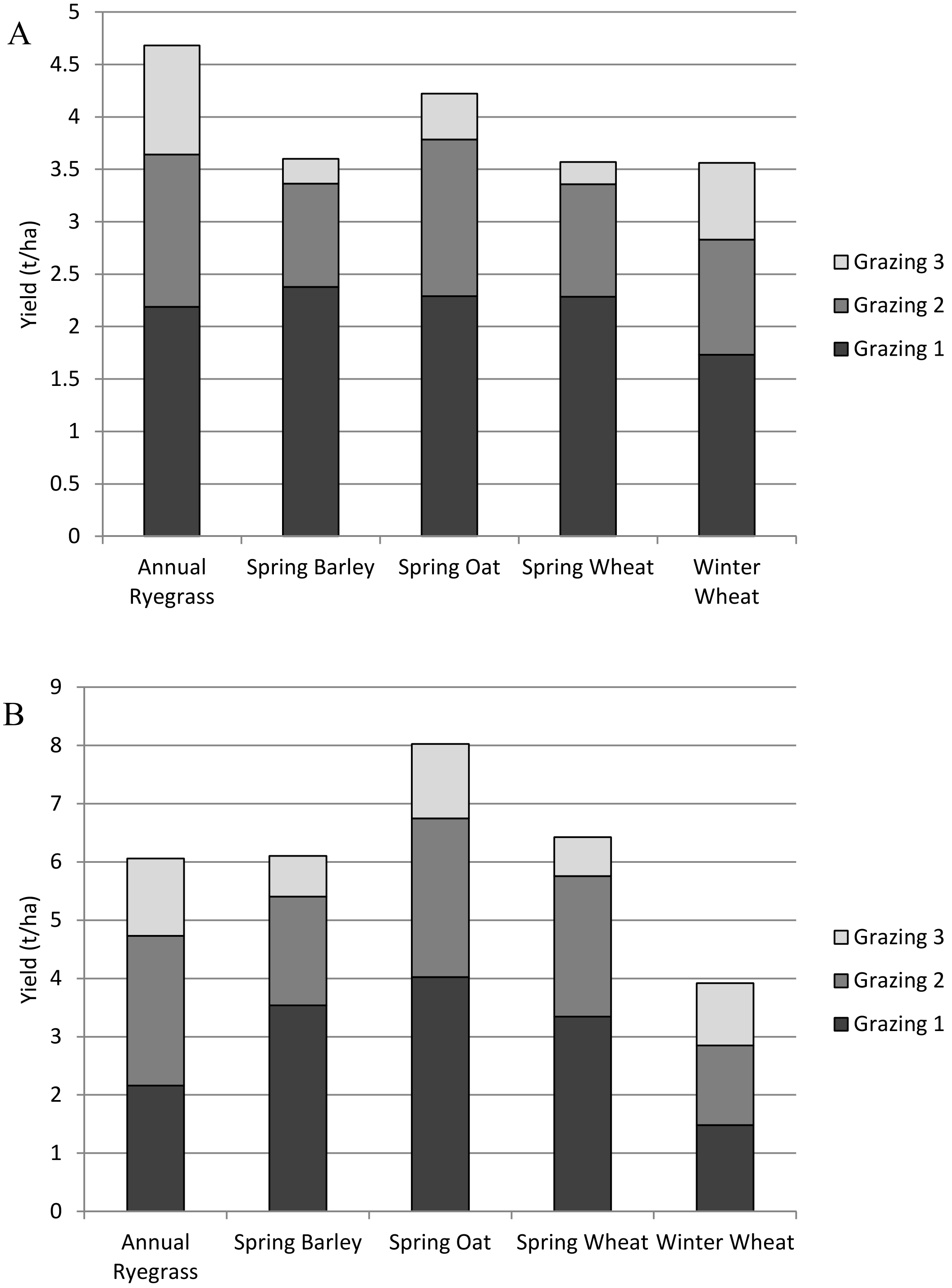
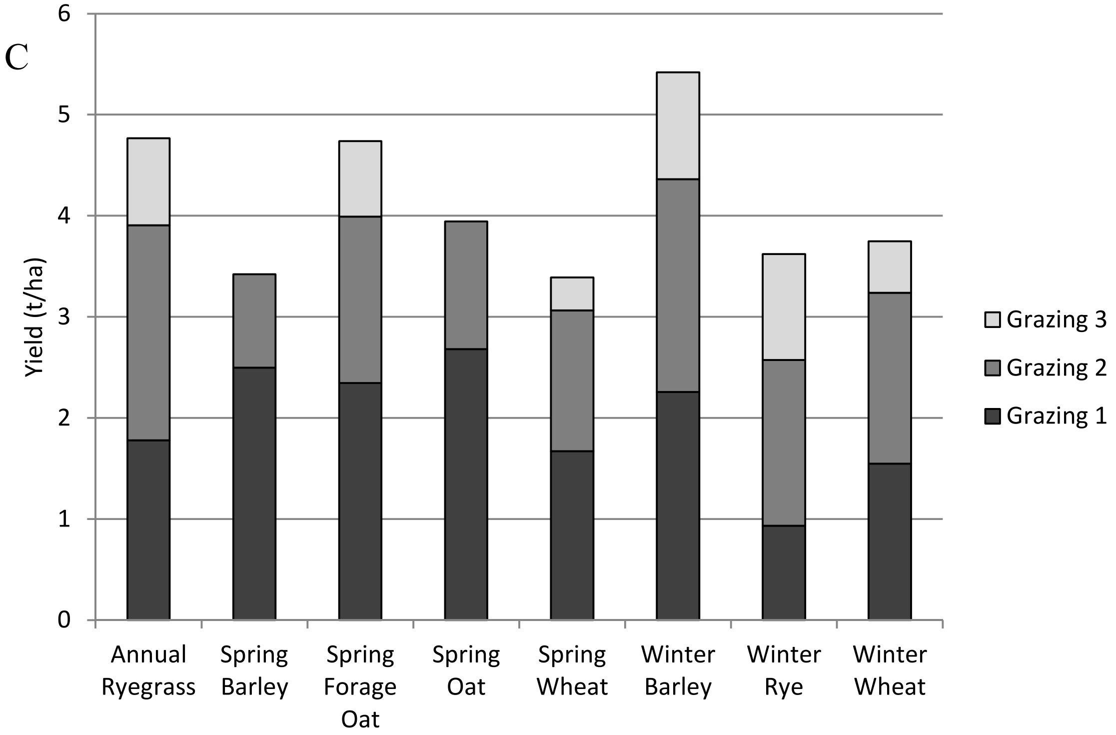


Figure 3.2. Distribution of yield (t ha^{-1}) across multiple grazing events for (A) immature spring-planted annual grasses, (B) mature spring-planted annual grasses, (C) immature fall-planted annual grasses, and (D) mature fall-planted annual grasses.




C
Yield (t/ha)
0
1
2
3
4
5
6
Annual Ryegrass
Spring Barley
Spring Forage Oat
Spring Oat
Spring Wheat
Winter Barley
Winter Rye
Winter Wheat
Grazing 3
Grazing 2
Grazing 1

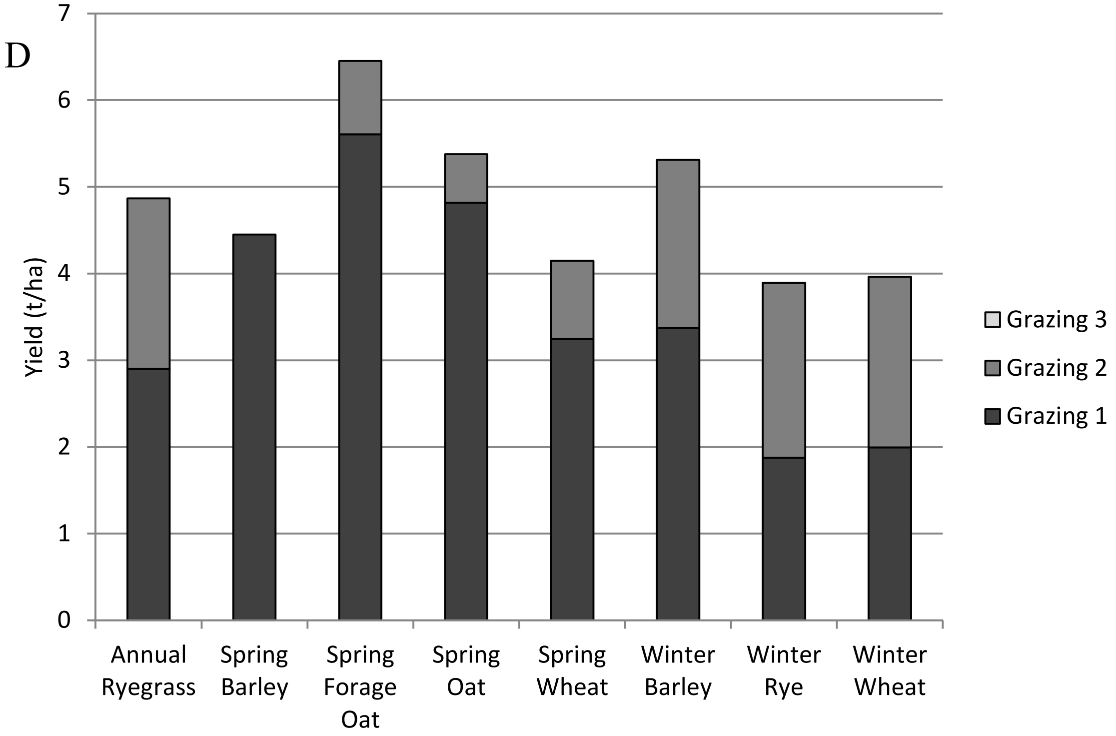

D
Yield (t/ha)
0
1
2
3
4
5
6
7
Annual Ryegrass
Spring Barley
Spring Forage Oat
Spring Oat
Spring Wheat
Winter Barley
Winter Rye
Winter Wheat
Grazing 3
Grazing 2
Grazing 1

Table 3.1. Gender, bodyweight (BW), age, and body condition score (BCS) of four groups of horses used for grazing experiments.

Horse Group	**Gender**		**Mean beginning horse BW**	**Mean group age**	**Mean group BCS**
	Mare	Gelding	kg ± SD	year ± SD	BCS ± SD
Spring 2013	1	2	479 ± 45	10 ± 3	5.0 ± 0.9
Fall 2013	2	1	484 ± 52	10 ± 3	5.5 ± 0.0
Spring 2014	3	1	556 ± 75	13 ± 5	6.4 ± 0.5
Fall 2014	2	2	519 ± 24	15 ± 3	5.4 ± 0.5

Table 3.2. Stages of maturity for cool-season annual grasses planted in spring and fall and grazed at two different maturities in St. Paul, MN.

Species	Spring		Fall	
	Immature	**Mature**	**Immature**	**Mature**
	——— Indexǂ ———			
Annual Ryegrass	2.2^{a}	3.4^{a}	1.6^{d}	2.1^{c}
Spring Barley	2.2^{a}	3.1^{b}	2.9^{ab}	3.1^{ab}
Spring Oat	2.3^{a}	3.3^{ab}	3.0^{a}	3.5^{a}
Spring Wheat	2.3^{a}	3.2^{ab}	2.7^{b}	3.1^{ab}
Winter Wheat	1.4^{b}	1.6^{c}	1.6^{d}	1.5^{d}
Spring Forage Oat			2.0^{c}	2.8^{b}
Winter Barley			1.6^{d}	1.6^{cd}
Winter Rye			1.5^{d}	1.5^{d}

$^{a\text{-}b}$Within a column, means without a common superscript differ ($P \leq 0.05$)

ǂ Numerical index referring to stage of grass development (Moore et al., 1991). Emergence of first leaf is equal to 1.0, onset of stem elongation is equal to 2.0, and boot stage is equal to 3.0.

Table 3.3. Yield, horse preference, crude protein (CP), neutral detergent fiber (NDF), nonstructural carbohydrate (NSC), and equine digestible energy (DE) of spring-planted annual cool-season grasses grazed by horses at an immature growth stage in St. Paul, MN.

Species	Yield	Preference	CP	NDF	NSC	DE
	— t ha^{-1} —	— % Removalǂ —	——— % DM ———			— Mcal kg^{-1} —
Annual Ryegrass	4.7^{a}	68^{b}	22^{cd}	48^{b}	16^{a}	2.33^{ab}
Spring Barley	3.6^{b}	64^{b}	25^{b}	47^{b}	14^{a}	2.31^{b}
Spring Oat	4.2^{ab}	15^{c}	20^{d}	52^{a}	16^{a}	2.24^{bc}
Spring Wheat	3.6^{b}	73^{ab}	24^{bc}	53^{a}	11^{b}	2.16^{c}
Winter Wheat	3.6^{b}	84^{a}	28^{a}	43^{c}	15^{a}	2.40^{a}

$^{a\text{-}b}$Within a column, means without a common superscript differ ($P \leq 0.05$)

ǂ Preference assessed as visual removal of available forage after 4 h of horse grazing, ranging from 0 (no evidence of grazing) to 100 (100% of vegetation grazed to a height of 8 cm).

Table 3.4. Yield, horse preference, crude protein (CP), neutral detergent fiber (NDF), nonstructural carbohydrate (NSC), and equine digestible energy (DE) of spring-planted annual cool-season grasses grazed by horses at mature growth stage in St. Paul, MN.

Species	Yield	Preference	CP	NDF	NSC	DE
	— t ha^{-1} —	— % Removalǂ —	——— % DM ———			— Mcal kg^{-1} —
Annual Ryegrass	6.1^{b}	45^{b}	17^{bc}	52^{b}	17^{a}	2.24^{ab}
Spring Barley	6.1^{b}	61^{ab}	19^{b}	53^{b}	16^{ab}	2.22^{bc}
Spring Oat	8.0^{a}	15^{c}	15^{c}	56^{a}	16^{ab}	2.16^{cd}
Spring Wheat	6.4^{b}	52^{b}	18^{b}	57^{a}	11^{c}	2.11^{d}
Winter Wheat	3.9^{c}	74^{a}	23^{a}	48^{c}	15^{b}	2.31^{a}

$^{a\text{-}b}$Within a column, means without a common superscript differ ($P \leq 0.05$)

ǂ Preference assessed as visual removal of available forage after 4 h of horse grazing, ranging from 0 (no evidence of grazing) to 100 (100% of vegetation grazed to a height of 8 cm).

Table 3.5. Yield, horse preference, crude protein (CP), neutral detergent fiber (NDF), nonstructural carbohydrate (NSC), and equine digestible energy (DE) of fall-planted annual cool-season grasses grazed by horses at an immature growth stage in St. Paul, MN.

Species	Yield	Preference	CP	NDF	NSC	DE
	— t ha^{-1} —	— % Removal‡ —	——— % DM ———			— Mcal kg^{-1} —
Annual Ryegrass	4.8^{ab}	69^{ab}	30^{bc}	42^{cd}	16^{a}	2.40^{ab}
Spring Barley	3.4^{c}	50^{bc}	30^{bc}	46^{c}	13^{b}	2.33^{b}
Spring Forage Oat	4.7^{ab}	12^{d}	32^{b}	45^{c}	13^{b}	2.38^{ab}
Spring Oat	3.9^{bc}	23^{cd}	31^{bc}	44^{cd}	12^{b}	2.11^{d}
Spring Wheat	3.4^{c}	79^{a}	21^{d}	56^{a}	13^{b}	2.20^{c}
Winter Barley	5.4^{a}	19^{d}	35^{a}	40^{d}	13^{b}	2.33^{b}
Winter Rye	3.6^{bc}	12^{d}	31^{bc}	45^{c}	13^{b}	2.44^{a}
Winter Wheat	3.8^{bc}	51^{b}	29^{c}	51^{b}	12^{b}	2.35^{b}

$^{a-b}$Within a column, means without a common superscript differ ($P \leq 0.05$)

‡ Preference assessed as visual removal of available forage after 4 h of horse grazing, ranging from 0 (no evidence of grazing) to 100 (100% of vegetation grazed to a height of 8 cm).

Table 3.6. Yield, horse preference, crude protein (CP), neutral detergent fiber (NDF), nonstructural carbohydrate (NSC), and equine digestible energy (DE) of fall-planted annual cool-season grasses grazed by horses at a mature growth stage in St. Paul, MN.

Species	Yield	Preference	CP	NDF	NSC	DE
	— $t\ ha^{-1}$ —	— % Removalǂ —	——— % DM ———			— $Mcal\ kg^{-1}$ —
Annual Ryegrass	4.9^{ab}	63^{a}	27^{bcd}	45^{bc}	14^{a}	2.38^{ab}
Spring Barley	4.5^{ab}	36^{b}	25^{cd}	56^{a}	9^{b}	2.07^{c}
Spring Forage Oat	6.5^{a}	16^{cd}	29^{b}	48^{b}	12^{ab}	2.11^{c}
Spring Oat	5.4^{ab}	28^{bc}	24^{d}	55^{a}	9^{b}	2.05^{c}
Spring Wheat	4.2^{b}	70^{a}	17^{e}	59^{a}	14^{a}	2.09^{c}
Winter Barley	5.3^{ab}	20^{bcd}	32^{a}	42^{c}	14^{a}	2.29^{b}
Winter Rye	3.4^{b}	10^{d}	28^{bc}	46^{bc}	15^{a}	2.42^{a}
Winter Wheat	4.0^{b}	62^{a}	24^{d}	56^{a}	9^{b}	2.33^{ab}

$^{a\text{-}b}$Within a column, means without a common superscript differ ($P \leq 0.05$)

ǂ Preference assessed as visual removal of available forage after 4 h of horse grazing, ranging from 0 (no evidence of grazing) to 100 (100% of vegetation grazed to a height of 8 cm).

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