Potential of Stockpiled Annual and Perennial Forage Species for Fall and Winter Grazing in the Canadian Great Plains Region

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ABSTRACT

The practice of stockpiling forage for the fall and winter has become a popular feeding strategy used to extend the grazing season and maintain profitability of beef operation in the Canadian Great Plains Region. This thesis research was conducted in the field to determine the potential of perennial and annual species with the major focus on stockpiled forage dry matter yield and late fall forage quality. Five cultivars from four grass species and three cultivars from two legume species were seeded using grass-legume binary mixture or monocultures for the perennial forage trial, and managed under two different stockpile initiation treatments. Five cool-season and two warm-season species were selected for an annual forage stockpiling trial. Cool-season perennial stands yielded higher but had lower quality in a relatively dry and cool growing season compared with the stands that experienced a warm and wet summer. Early stockpile initiation resulted in longer accumulation period and significantly higher ($P <$ 0.05) regrowth yield compared with late stockpile initiation. Stockpiled dry matter yield ranged from 1.5 to 3.6 Mg ha^{-1} with meadow brome [(*Bromus riparius Rehm.*) cv. Fleet], mixed with alfalfa [(*Medicago sativa* L.) cv. Algonquin] having the highest production. Meadow brome and tall fescue (*Festuca arundinacea* Schreb.) in mixed stands with legumes had significantly higher production than pure stands of cicer milkvetch (*Astragalus Cicer* L.) and orchardgrass (*Dactylis glomerata* L.) as well as mixed stands of hybrid brome [(*Bromus inermis* Leyss. x *Bromus riparius* Rehm.) cv. Success (S)] and cicer milkvetch (*Astragalus Cicer* L.). The latter three together with both pure alfalfa stands failed to meet the minimum stockpiled yield requirement for winter stockpiling of forage species. Tall fescue stands had the highest stockpiled yield among all pure stands. Late stockpile initiation provided more nutritious forage than the earlier initiation, however, the nutritive value of all species was adequate for a variety of grazing animals in different production stages regardless of the stockpile initiation date. Warm-season annuals generally exhibited higher stockpiled dry matter production than cool-season annuals. The

overall results showed that many of the tested perennial and annual forage species provided adequate forage production and nutritive value for stockpiled grazing in the Great Plains region of western Canada.

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DEDICATION

I would like to dedicate this work to my parents (Gongjia Peng and Shuanlan Zhang) who not only taught me how to be a proper student but also a good human being. I appreciate their patience and tolerance for all these years when I am studing abroad. They gave me precious suggestions. I would also like to delicate this work to my grandparents (Weishen Peng and Wenlan Wang) who fortunately are well despite their age. Their love and supporting are very important in my life.

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LIST OF ABBREVIATIONS

ADF	Acid detergent fiber
CP	Crude protein
cv.	Cultivar
DMJ	Dry matter yield in June
HSD	Honest significant difference
NDF	Neutral detergent fiber
SDM	Stockpiled dry matter yield
TDM	Total dry matter yield
TDN	Total digestible nutrients

1.0 Introduction

Winter climatic conditions are challenging for cow-calf producers in western Canada and the prairie regions in United States due to the lack of actively growing feeding materials (McCartney et al., 2004; Kelln et al., 2011). Winter feeding costs accounts for 60% to 68% of the total production cost of beef-cow systems in western Canada (Kaliel and Kotowich, 2002) and the United States (Karn et al., 2005). Supplemental feed is required for 150 to 200 days on the Canadian prairies (Mathison, 1993; Entz et al., 2002). The expense of this feed has encouraged western beef producers to seek alternate methods to replace conventional drylot feeding programs using stored hay.

Stockpiling is one of several grazing techniques that has the potential to extend the grazing season and reduce winter feeding costs (Barnhart, 2014). Forage under an extensive grazing system is left growing to accumulate dry matter in the summer and fall, which can be used after the growing season or during a period of forage deficit (Hitz and Russell, 1998; Riesterer et al., 2000). Extending the grazing season by using stockpiled forage in late fall and during the winter months has been shown to be an economical and practical way to increase profitability of livestock operation (Johnson and Wand, 1999; Riesterer et al., 2000). Savings occur from less harvesting, transportation and labour input (Hitz and Russell, 1998; Johnson and Wand, 1999; Volesky et al., 2002; Nayigihugu et al., 2007). Livestock grazing stockpiled pasture remain on the fields and spread their manure back onto the pasture saving the cost of hauling manure from confined feeding areas and spreading on fields (Johnson and Wand, 1999; Riesterer et al., 2000). Nutrients released from manure can also be spread out more efficiently under extensive winter grazing systems (Jungnitsch et al., 2011; Kelln et al., 2011). In general, for each week that the grazing season is extended, total annual feed costs for a forage-fed animal (i.e., ewes or beef cows) are reduced by about 1% (Willms et al., 1993). Even an extra three to four weeks added to the grazing season is beneficial (McCartney et al., 2004). Volesky et al. (2002) claimed that using swath/standing stockpiled forage grazing cost only US \$0.16 cow^{-1} d^{-1} while conventional drylot pens would cost \$0.30 cow^{-1} d^{-1}. Enhanced pasture growth and soil fertility were also reported due to deposition of the in-field manure and urine. Enhanced pasture growth and soil fertility were also reported due to deposition of the in-field manure and urine. However, stockpiling of forage for grazing is a relatively new concept for most livestock producers since they are more familiar with the practice of harvesting and storing forage as hay or silage (McCartney et al., 2008). Most of the recenr studies have been concentrated on stockpiled pure perennial species, for instance, crested wheatgrass [*Agropyron cristatum* (L.) Gaertn.], tall fescue [*Festuca arundinaceum* (Schreb.) Darbysh.], and meadow bromegrass (*Bromus riparius* Rehm.), few studies have examined the stockpiling of grass-legume mixed stands (Kulathunga et al., 2016). Contributions of N from legume species enhance the productivity of many grasses species in perennial forage mixtures. More information is needed on the nutritive value of perennial grass-legume mixtures under stockpiling systems. In addition, annual forage species have some agronomic advantages over perennial forages, thus, could be considered as forage supplements whenever perennial forages are in short supply or fail to establish. It is known that cool season annual species and warm season annuals like corn (*Zea mays subsp. mays* L.) and millet (*Pennisetum glaucum*) are generally well adapted to the growing conditions in the prairie regions of western Canada (Manitoba Government, 2004). However, there is little information available on nutritive value and performance of cool and warm season annuals under stockpiled system.

A growing interest in managing tame pastures for extended grazing necessitates targeted evaluation studies to generate performance information on forage species in fall and winter stockpiled perennial and annual forage systems in the great plains region of western Canada. Our study focused on evaluating the production and nutritive value of annual and perennial forage species for stockpiled fall grazing to determine whether they produce adequate yield and nutritive value to support fall and winter grazing beef cattle. We hypothesized that: 1) Perennial forage species stockpiled following a single cut in June would have higher productivity, but lower nutritive value, than those stockpiled following a second cut in July or early August; 2) Stockpiled perennial forage grasses would have higher nutritive value than stockpiled perennial forage legumes, while stockpiled grass legume mixtures would be intermediate in nutritive value and; 3) Cool-season annuals will show higher productivity and nutritive value than warm-season annuals when stockpiled. The objective of this study was to evaluate the production and nutritive value of annual and perennial forage species for late fall and winter grazing, with emphasis on stockpiled production in October.

2.0 Literature review

2.1 Winter feeding strategies

Forage growth accumulated from spring growth (green up) or forage regrowth accumulated after early season grazing or hay harvests could be utilized as stockpiled forage (Entz et al., 2002). Producers consider stockpiled grazing to be an alternative to drylot pen hay feeding strategies. Standing stockpiled forages are usually mature with considerable leaf senescence, which often results in poor nutritive quality (Matches and Burns, 1995). However, stockpiled forage often meets the nutritive requirements of dry cows in early to mid-gestation, which are much less compared with lactating cows (Poore and Drewnoski, 2010). With stockpiled forage, grazing can occur from October to December, or until weather conditions (e.g. snow covering) prevent grazing. Pastures could also be saved till early spring to be grazed before new pasture growth (Baron et al., 2005).

2.2 Species selection

Species are selected based on their adaptation to climatic conditions and the stockpiling systems used. Within stockpiling systems, species can be selected for yield, quality, or both. Stockpiling systems should be adjusted to the local environment (Alberta Agriculture Food and Rural Development, 2008).

2.2.1 Stockpiled perennial species

For drier prairie regions, where rainfall is a major limitation, a single-graze system with native species would be suitable where grasses are utilized once due to reduced regrowth and species that retain high nutrients levels are considered first (Alberta Agriculture and Forestry, 1998). In the parkland or prairie areas of western Canada, where there is more moisture, a multi-pass system, involving two seasonal grazings or cuttings prior to stockpiling is possible. The regrowth of perennial forages following a later stockpiling initiation has higher quality and can be grazed in late fall or winter which enables more efficient land use (Alberta Agriculture Food and Rural Development, 2008). In the Midwestern USA, stockpiling with rotational grazing efficiently utilizes pasture forage throughout the year (Bartholomew, personal communication, 1998), which is known to play an important role in reducing costs associated with traditional winter management programs (Van Keuren, 1970).

2.2.1.1 Cool-season perennial grasses

Cool-season perennial grasses are commonly preferred in stockpiling systems due to their ability to store nutrients in roots and crown parts after maturing. Studies done in Central Parkland and Northern Fescue Natural Sub-regions pointed out that Creeping red fescue (*Festuca rubra* L.) and Kentucky bluegrass (*Poa pratensis* L.), for example, maintain green basal leaves and stems at more mature growth stages. Spear grass [*Heteropogon contortus* (L.)] and rough fescue (*Festuca scabrella* L.) have good standability even in snow. However, these species tend to have relatively low yields and sometime suffer winter kill, so are recommended to be stockpiled under a single-graze system (Alberta Agriculture Food and Rural Development, 2008; Desserud, 2016).

In western Canada, winter stockpiling has been practiced on native rangeland of the southern and western prairies (Willms et al., 1993) and dryland grass grazing is still possible even with snow cover (Lawrence and Heinrichs, 1974). Crested wheatgrass is a persistent, winter hardy, drought tolerant grass (Smith et al., 1986), that can be useful in complementary in grazing systems (McKendrick and Sharp, 1970). However, this species reaches maturity rapidly and tends to have lower nutritive values in late fall (McKendrick and Sharp, 1970). Smooth bromegrass (*Bromus inermis* Leyss.) is an upright, winter hardy rhizomatous sod forming species and tends to be drought and heat tolerant as well (Smith et al., 1986; Tzvelev, 1976; Miller, 1984). Recently in western Canada, meadow bromegrass (*Bromus* *riparius* Rehm.) and hybrid bromegrass (*B. riparius* × *B. inermis*) have become more popular. Meadow brome has been reported to generate consistent biomass over the growing season regardless of environmental conditions and other factors (Baron et al., 2005) and regrows faster than smooth bromegrass which makes it more suitable for grazing than hay production. Meadow bromegrass has often been studied in mixtures with alfalfa (*Medicago sativa* L.) (Knowles et al., 1993), and more information has been available in pure stands recently. Hybrid brome has been recently developed through crossing between smooth and meadow bromegrass. It tends to be intermediate in characteristics to the two parental lines (Coulman, 2004; Biligetu and Coulman, 2010). Hybrid brome was found to be suitable for pasture grazing and hay production (Knowles and Baron, 1990).

Under higher moisture conditions in some parkland regions of western Canada (Black soil zone), a multi-pass system (i.e. more than one cutting or grazing during the spring/summer) is possible using tame species which regrow faster and are higher yielding than native species (Alberta Agriculture Food and Rural Development, 2008). Orchardgrass (*Dactylis glomerata* L.) and quackgrass [*Elytrigia repens* (L.) Nevski.] have superior biomass production but orchardgrass has lower cold tolerance. Crested wheatgrass and timothy (*Phleum pratense* L.) yield higher than other species during years of above-average rainfall, while meadow brome grass shows high potential for stockpiling with good yield, adequate forage quality and lower winter dry matter loss regardless of moisture conditions (Baron et al., 2004). Short growing species like Kentucky bluegrass and Creeping red fescue had the lowest production.

Some cool-season grasses, such as tall fescue are well adapted to temperate and higher rainfall areas, particularly in the eastern United States and parts of eastern Canada (Smith et al., 1986). Previous studies showed that tall fescue produces enough summer and autumn biomass which can be used as fall-saved pasture in winter feeding programs (Matches, 1979; Rayburn et al., 1979; Fribourg and Bell, 1984). However, studies done in Southern Great Plains showed that tall fescue cultivars infected with a fungal endophyte [*Neotyphodium coenophialum* (Morgan-Jones & W. Gams) Glenn, Bacon, & Hanlin] often possess a summer dormant strategy that avoid severe drought stress (Rogers et al., 2014).

In the Mid-western USA, pasture is available for rotational grazing from late April to late October, thus forages with rapid growth and high production are required. The nutritive value of stockpiled forage species evaluated is adequate to meet the requirements of livestock such as beef cattle or dry dairy cows if enough forage is available. Studies carried out in the intermountain west region of the USA further confirmed these results (Ambrosek et al., 2014).

2.2.1.2 Perennial legume species

Legumes are usually not recommended for stockpiling systems since leaves of many legumes tend to be lost due to frost or maturity which results in dramatic declines in nutritive value (Matches and Burns, 1995). In early fall, however, legumes species have been found to have much higher crude protein (CP) concentrations and relative feeding value (RFV) than grasses. These traits make legume species attractive for many producers (Ambrosek et al., 2014).

Adapted legumes like alfalfa performs well in drier conditions and is known to produce more biomass than cicer milkvetch (*Astragalus cicer* L.) or the clovers (*Trifolium* spp.) but its leaves tend to fall from the plant with advancing maturity or after hard frosts. Because of the leaf loss following frosts, alfalfa is better utilized in September (Alberta Agriculture Food and Rural Development, 2008). Alfalfa-grass mixed stands had a high dry matter loss during winter, thus were only found to be suitable for grazing in September and October (Baron et al., 2004). Cicer milkvetch can be grazed longer in the fall since it retains it leaves and quality following fall frosts. Birdsfoot trefoil (*Lotus corniculatus* L.) was suggested to be useful for stockpiling due to its non-bloating characteristic (Ambrosek et al., 2014). No stockpiled legume species was found to be suitable for spring grazing due to poor nutritive value. Swathing before leaf loss is a possible alternative to reduce leaf loss and maintain high quality (Alberta Agriculture Food and Rural Development, 2008).

2.2.1.3 Warm-season perennial grasses

Studies done in Mississippi showed that stockpiling perennial warm-season grasses such as bermudagrass [*Cynodon dactylon* (L.) Pers.] and bahiagrass (*Paspalum notatum*) as either monocultures or mixed with legumes like white (*Trifolium repens* L.) or red (*Trifolium pratense* L.) clovers showed great potential. Grazing can occur from late October to early January when some of the annual cool-season grasses such as annual ryegrass (*Lolium multiflorum* Lam.) and small grains are in short supply. However, warm-season grass has a relatively shorter availability compared with tall fescue which could be utilized from late November to late February (Lemus, 2007).

In Arkansas, the late summer yields of warm season grasses such as bermudagrass are found to be high enough for utilization during late fall instead of hay feeding. With proper rainfall during late summer and an early August stockpile initiation date, forage yield can be significantly high, which enabled the late fall grazing instead of hay utilization (Scarbrough et al., 2002). From earlier extension demonstrations, average yield of bermudagrass would range from 533 kg ha^{-1} to 1102 kg ha^{-1} (Scarbrough et al., 2001; Scarbrough et al., 2002). Forage quality was noticed to be very good with high CP and TDN in the samples taken from extension farms (University of Arkansas research & extension http://www.uaex.edu).

Productivity of warm-season forages may be limited for Northern Great Plains locations compared to results from the Southern Great Plains. In a 7-yr study done in Swift Current, SK, Canada, warm-season grasses produced the lowest DM yields and were not adequate for late-season grazing

(Biligetu et al., 2014).

2.2.2 Stockpiling annual forage species

Annual species cost more per unit of production compared with perennial pastures because of the annual costs for tillage, seeding, weed control and fertilizer (Alberta Agriculture Food and Rural Development, 2008). Annuals, however, give producers the flexibility to add pastures quickly when needed. Highly productive annual species could serve as a supplemental feed when perennials are in short supply (Alberta Agriculture Food and Rural Development, 2008).

2.2.2.1 Potential annual forage species

When perennial pasture growth has slowed in late fall, oats (*Avena sativa* L.) and barley (*Hordeum vulgare* L.) can provide production (Aasen et al, 2004). Spring seeded oat can provide pasture 6 to 8 weeks after planting, and can be included into the forage system to provide extra pasture anytime from May to fall frost. When pastured early, oats can be the best annual emergency hay crop (Government of Manitoba, 2016).

Barley generates higher dry matter yields than oats but is not as palatable and is more often used for silage than for pasture. Few studies have been done which focused on standing stockpiled barley (Alberta Agriculture Food and Rural Development, 2008).

Ryegrass (*Lolium multiflorum* Lam.) is another popular annual used for grazing. Ryegrass grows rapidly, maintains good forage quality late into the fall, and tends to be highly productive under intensive management (Keatinge et al., 1980; Hill and Pearson, 1985; Hoveland et al., 1991). However, ryegrass is not drought tolerant and its productivity will be low in areas with low moistures. Although some ryegrasses are perennial in milder climates, ryegrass species are used as annuals in Canada, due to poor winter hardiness (Alberta Agriculture Food and Rural Development, 2008; Government of Manitoba, 2016).

Winter cereals mixed with spring cereals are also promising in extending the grazing season in the fall as they offer producers the flexibility to focus on the first cut or regrowth (Alberta Agriculture Food and Rural Development, 2008).

Millets can be productive as a grazing crop but are not highly adapted for this purpose because of poor regrowth ability and they are subject to grazing injury. Siberian millet (*Setaria italica* (L.) P. Beauvois), commonly known as foxtail millet, yields the highest among all millet species in Manitoba and have a better leaf to stem ratio (Government of Manitoba, 2016) than other millets.

Corn (*Zea mays* subsp. *mays* L.) is a C_4 annual crop used for grazing, but is more often used as a grain or silage crop. Corn requires sufficient heat, measured by ‘corn heat units (CHU). When the grain is not sufficiently filled, yield is decreased dramatically. In most of the prairie regions of Canada, there are not sufficient "corn heat units" (CHU) to grow corn as a grain crop (Alberta Agriculture Food and Rural Development, 2008). Without sufficient heat units, corn yields are suppressed and generally not higher than spring cereals such as barley and oats. The higher cost associated with growing corn may make it less attractive. However, the high quality of corn leaves and stalks adds value when being stockpiled (Alberta Agriculture Food and Rural Development, 2008).

Annual legume crops can be another option for winter stockpiling due to the nitrogen (N) fixation contribution, which would lower the N fertilizer costs. However, frost damage and subsequent loss of leaves may make annual legumes such as soybean less desirable or be avoided by grazing livestock (Blout et al., 2015).

2.3 Management of stands for stockpiling

2.3.1 Perennial forage management

2.3.1.1 Accumulation period

The amount of forage available for producers to use in the fall and winter time is a major concern. Adequate yield is desirable since grazing efficiency is reduced with biomass production lower than 2.0 Mg ha^{-1} (Alberta Agriculture Food and Rural Development, 2008). The most important factor for forage production is the 'summer resting period', commonly known as the 'accumulation period'. It refers to the summer period that animals are removed from the pasture to let it grow and recover for utilization in the fall and winter. The longer the pasture is allowed to grow, the more yield is accumulated but the quality decreases simultaneously. Studies done in New Liskeard, Ontario, Canada showed that pasture with an earlier start of the accumulation period (mid-July) generated 4.55 Mg ha^{-1} with 103g kg^{-1} crude protein (CP) and 585 g kg^{-1} total digestible nutrients (TDN) in the fall (October/November) while similar pasture with a later start of the accumulation period (mid-August) yielded 2.6 Mg ha^{-1} with 147 g kg^{-1} CP and 634 g kg^{-1} TDN tested in fall. Correctly estimating the right quality and quantity of forage required late in the fall is essential (Ministry of Agriculture, food and rural affairs, Ontario, 2016). Producers often benefit from this yield/quality relationship when designing management programs according to the individual situation. Weaned calves would require higher quality forages while beef cows are usually satisfied with pastures of average nutritive value, however, the amount needed is much higher (Ministry of Agriculture, Food and Rural Affairs Ontario, 2016).

Research conducted in Lacombe, Alberta Canada (Alberta Agriculture Food and Rural Development, 2008) compared the stockpiled production of cool-season perennial species under different cutting management. Meadow brome grass ranked the highest in biomass production consistently exceeding 2.0 Mg ha^{-1} over years as long the first cutting is applied before August. When the resting period started on July 15, production of all species reached the required amount, however, once the rest date was delayed until August 1, only alfalfa achieved this goal. Smooth bromegrass, orchardgrass and Kentucky bluegrass achieved this level of production two-thirds of the time while Creeping red fescue achieved it one-third of the time, indicating that these species need earlier rest starting time, probably at the beginning of July, to consistently generate enough biomass. The results further confirmed that the longer the accumulation period, a greater amount of biomass is produced from pastures (Alberta Agriculture Food and Rural Development, 2008). A study done near North Platte, NE, US (Volesky et al., 2008) examined the effect of stockpile initiation date on the quality of irrigated cool-season grasses in the central plains of USA. The nutritive value was much higher from the late initiation stockpiling than the earlier due to less mature herbage; however, no difference in nutritive value was noticed at the end of stockpiling season in January or February. Similar finding were found for species evaluated like Smooth bromegrass (Cuomo et al., 2005), tall fescue (Collins and Balasko, 1981), orchardgrass and meadow bromegrass (Baron et al., 2005). Tall fescue and *Festulolium* (*Festuca* X *Lolium*) ranked high in nutritive value due to stable and high *in-vitro* digestibility which is known to impact animal performance. The overall magnitude of the decline in nutritive value through the winter is less than expected, meeting the needs of CP for gestating beef cows (71g kg^{-1}) even in February (NASEM, 2016). In addition, soil fertility and precipitation affected the length of the accumulation period needed in a certain area (Volesky et al., 2008).

2.3.1.2 Soil fertility requirements

Perennial grass species need more nitrogen to ensure their optimum productivity while legumes, which fix their own nitrogen, generally require higher amounts of phosphorus, potassium and sulphur than grasses. Stockpiling systems can affect fertility levels in the soil since more cutting removes more nutrients; A soil test is recommended to determine the nutrient status and how much fertilizer is required based on the environmental conditions. (Alberta Agriculture Food and Rural Development, 2008).

Researchers in Ontario evaluated forage quality and yield under two different nitrogen rates. Pastures receiving an additional 50 kg ha^{-1} of nitrogen fertilizer at the beginning of the stockpiling period showed increased yield in the last two of three years of the study compared with those fields which received no additional nitrogen fertilizer. Nitrogen application was found to have only slight benefit for the total digestible nutrient (TDN) concentration in the first year; however, there were no difference in the last two years. Variable response of pastures to nitrogen fertilizer further confirmed the necessity of doing a soil test before any fertilizer application (Ministry of Agriculture, Food and Rural Affairs, Ontario, 2016).

Grass tetany has bbeen reported for animals grazing cool-season pastures. Tetany happens on soils that are low in available magnesium and high in available potassium. Any forages that are high in potassium and nitrogen with lower than 0.25% DM magnesium should be tested for tetany ratios. Animals get grass tetany most often during cool and rainy weather, especially when the cool weather is followed by a warm period. Grass tetany can lead quickly to death if not treated. It has been reported that tetany occurred on perennial ryegrass and crested wheatgrass when stockpiled, but is not common on legume pastures (Harris and Shearer, 2003).

2.3.1.3 Time of grazing

In much of the prairie region of western Canada, it is better to graze stockpiled forage in the fall rather than in the winter since quality decreases under freezing conditions due to leaf loss and/or dormancy with remaining biomass containing lower protein and higher fiber. Many grass species maintain adequate nutritive value between mid-September and mid-October with protein being well above maintenance level for dry beef cows in the second or third trimester of gestation. Significant yield and quality loss occurs after mid-October. Grazing stockpiled forage in the following spring is not recommended for stocker cattle; both energy and protein supplementation are required (Alberta Agriculture Food and Rural Development, 2008). In Ontario, however, under proper management, pastures can be grazed until December, or until the snow is too deep. Several livestock have the ability to graze in 10-15cm of snow if there is sufficient forage and the snow cover is relatively loose (Ministry of Agriculture, food and rural affairs, Ontario 2016). Grazing can occur anytime during the winter in the Midwestern USA for stockpiled tall fescue, early-maturing orchardgrass and reed canarygrass. Timothy and late-maturing orchardgrass are suggested to be grazed by December because of the rapid decline of forage biomass throughout the winter (Riesterer et al., 2000).

Legume species may be more susceptible to winter kill when grazed or cut in late August or in September as this results in lower carbohydrate storage in the roots. In the prairie region of western Canada alfalfa can be cut as hay in July and the regrowth grazed in October and November. (Alberta Agriculture Food and Rural Development, 2008).

Quality of warm-season species like bermudagrass, bahiagrass and dallisgrass (*Paspalum dilatatum* Poir.) dropped dramatically after a killing frost due to leaf loss in Arkansas. It is recommended that warm-season species are used during mid- to late- fall before January to ensure adequate quality (Scarborough et al., 2002).

2.3.2 Annual forage management

2.3.2.1 Time of seeding

In the Canadian prairies, winter cereals can be seeded in early to mid-May to provide early grazing with the regrowth being stockpiled. If silage or greenfeed is required, mixtures of spring and winter cereals can be seeded at the same time to enable a harvest before stockpiling regrowth. Winter cereals growing as a fall pasture alone to extend the grazing season should be seeded by August 1 to provide sufficient yields. Some species like winter wheat, however, might lose winter hardiness. Spring cereals seeded late (July or early August) can be used as fall pastures but are not recommended for stockpiling because of its low production with fewer grazing days available (Alberta Agriculture Food and Rural Development, 2008).

Annual ryegrass is small seeded like most perennial grasses. When seeded early in spring, its growth rate is slow until it becomes established. In prairies, annual ryegrass seeded in mixture with spring cereals provided rapid regrowth for stockpiling when seeding occurs earlier than August 21 (Alberta Agriculture Food and Rural Development, 2008).

Millet seeding in Manitoba should be delayed until the soil temperature is 10 degrees or warmer to enable the germination and establishment (Government of Manitoba, 2016). Millet stockpiled in the northern parts of New South Wales, Australia are suggested to be seeded in early October when the required temperature reached (Collett, 2004). Generally, corn used in Alberta, Canada for pasture should be seeded when soil temperature is above 10°C for successful germination. It is also crucial to seed two weeks after the last spring frost to guarantee sufficient heating units for maximum yield (Alberta Agriculture Food and Rural Development, 2008).

2.3.2.2 Soil fertility requirements

Soil test should be done before seeding to determine he adequate fertilizer rate. Annual grasses require large amount of nitrogen and phosphorous to develop a deep and extensive rooting system necessary for the plant to establish well and have high production. It is recommended to drill in as much nitrogen and phosphorous with the seed as the crop will tolerate which would help developing a extensive rooting system under dry conditions, unless certain species are known to be incompatible with fertilizer in contact with seed (Alberta Agriculture Food and Rural Development, 2008; Government of Manitoba, 2016).

2.3.2.3 Time of grazing

Annual species are not able to survive through winter in prairies, thus forage yield and nutritive value decline drastically later in the fall. Senescing plants and significant leaf loss in winter can make annual grasses unsuitable for livestock in winter. However, winter hardy annual ryegrass can maintain excellent production for 6-8 weeks under intensive management; millet can be grazed 65 to 70 days after seeding with proper management. Even with these excellent traits, no single annual species is fully reliable for livestock winter surviving due to the possibility of management failure and climate fluctuations. It is better to either graze stockpiled annuals in fall or use annuals as supplemental feeds when perennials are lacking biomass production or nutrient level before late winter (Alberta Agriculture Food and Rural Development, 2008).

In Louisiana where cool-season annuals can be successfully established and utilized even in warm-season perennial pastures, grazing can continue till February when seeding occurs in late November or early December with high crop density (Alison, 2011).

2.4 Other considerations

With the presence of snow, strip or rotational grazing is usually recommended with the use of temporary electric fences. It’s better to use smaller paddock sizes and move animals more often to prevent excessive trampling (Alberta Agriculture Food and Rural Development, 2008).

Water provision is another major concern in freezing temperature. A common practice is hauling water or pumping from a stream especially for beef cows that required at least five gallons of water per day in cold weather (Alberta Agriculture Food and Rural Development, 2008). As producers become more experienced with stockpile grazing management more are training their cattle to utilize snow to meet daily water requirements.

2.5 Performance of animals grazing stockpiled forage

2.5.1 Animals grazing perennial forage species

Animal performance is a function of diet and energy input (Volesky et al., 2002). Based on a study conducted at the Western Beef Development Center, Saskatchewan, Canada (Kulathunga et al., 2016), body weight changes under stockpiling and drylot hay feeding were similar and positive, with 23.6 and 32 kg , respectively, at the end of winter feeding period. Spring-calving cows were found to maintain body weight, and body reserves at an adequate level when using extensive feeding systems. In this study, cows had always good access to high-quality stockpiled forage that was similar to baled hay quality examined by Coleman (1992) and Baron et al. (2005) in addition to adequate energy supplementation to adjust to cold temperature conditions when grazing outside in field paddocks. Animals without proper protection experience greater heat loss and require more feed to overcome energy losses; however, Hitz and Russell (1998) found that non-supplemented cows in Iowa winter feeding trials gained equal or greater body weight when relied on high quality stockpiled tall fescue-alfalfa forage compared with drylot hay feeding. It is crucial to maintain adequate body weight and body condition score (2.5-3.0 in a 5-point scale) to guarantee livestock reproductive performance (Selk et al., 1988; Osoro and Wright, 1992). Previous studies confirmed that any BCS below 2.5 is will have negative effects on cow reproductive efficiency (McCartney et al., 2004; Kelln et al., 2011; Krause et al., 2013). With proper management, stockpiled forage quality can reach the requirements of maintenance (National Research Council, 2000) with no net loss of body tissue.

A study done in Ohio, eastern United States showed that beef cows could gain 0.8 kg head^{-1} day^{-1} with an increase of 0.3-0.9 points in body condition through December when grazing a mixture of stockpiled orchardgrass, tall fescue, Kentucky bluegrass and white clover (Turner et al., 1998). Earlier research showed that beef cattle in the same region gained more when grazing orchardgrass (0.4-1.3 kg head^{-1} day^{-1}) than grazing tall fescue alone (-0.1-1.0 kg head^{-1} day^{-1}) (Baker et al., 1965).

Research at New Liskeard, Ontario with weaned lambs indicated that stockpiled pasture managed for high quality and moderate yield provided average gains of 126 g head^{-1} day^{-1}. This pasture had a carrying capacity of 1,100 lamb days per hectare (meaning 1,100 lambs would require 1 hectare of stockpiled pasture per day). Lamb gains were highest in October and lowest in late November and December. When stockpiled pasture was managed to provide maximum yield (but lower quality), lambs gained an average of 86 g head^{-1} day^{-1}, but the carrying capacity of the stockpiled pasture was much higher, averaging about 1,750 lamb days per hectare (Ministry of Agriculture, Food and Rural Affairs, Ontario, 2016). Research with dry beef cows indicated that a high volume, moderate quality (mid-July rest date) stockpile allowed significant increases in fat cover, body condition score, and body weight. This pasture provided 150 cow days per hectare (60 cow days per acre). Pastured dry cows in snow free conditions gained significantly better than hay-fed housed cows. In moderate snow and winter exposure, performance was similar between pastured and housed cows. Some pastured cows lost body condition during severe weather. In this trial, cows with at least 50% British breeding performed better in winter grazing conditions (Coleman, 1992 & National Research Council, 1996).

In western North America, livestock depending on fescue prairies (Willms et al., 1993) or mixed grass prairies (Cochran et al., 1986a) during the fall and winter ended up with much lower body condition scores and body fat, indicating that supplementation with protein concentrates would be required (Waldron et al., 2006).

2.5.2 Animals grazing annual forage species

Stocker cattle grazing stockpiled winter annual or ryegrass performed well with gains approaching 1.35 kg head $^{-1}$ day^{-1}, which makes it feasible to fatten feeder cattle on this quality of pasture alone. Lactating cows relying on stockpiled high energy-ryegrass produced well and weaned calves or dry cows could be expected to gain more than 1 kg head $^{-1}$ day^{-1} (Alberta Agriculture Food and Rural Development, 2008).

Body weight of heifers were measured when using stockpiled fall-grown oat as an emergency crop. Heifers on these pastures gained slightly more weight daily (0.85 kg) than those fed in a confined area (0.74 kg) (Coblentz, 2014).

2.6 Economics of stockpiling forage

In western Canada and United States prairie regions, winter feeding costs make up to 60-68% of the total production input in a cow-calf operation system (Kaliel and Kotowich, 2002). Stockpiled pasture can be a low-cost option for livestock producers in winter time. A multi-pass system may be more economical than a single-graze system as costs would be spread over several growing periods. Previous study done in western Canada showed that grazing stockpiling pasture costs were from \$0.80 to \$0.96 day^{-1} cow^{-1} while the cost of a conventional winter feeding program of a beef cow under confined drylot ranges from \$1.08 to \$1.42 day^{-1} cow^{-1} [Saskatchewan Forage Council (SFC), 2009]. It is further noticed that swathed stockpiled forage was found to be slightly costlier compared with standing stockpiled forage due to the additional cost of swathing. The quality of swathed versus standing forages was not significantly affected by leaf-loss during handling. No difference in management time was found between the two treatments for all three sites [Saskatchewan Forage Council (SFC), 2009]. Lang (2006a) also mentioned that traditional winter feed costs ranged from \$0.99 to \$1.28 day^{-1} cow^{-1}, much higher than utilizing stockpiled forage. Another three-year study (Alberta Agriculture Food and Rural Development, 2008) found that if hay was harvested and sold after the first cut, extra profit could be made. When livestock relied on stockpiled alfalfa, the actual value of hay overweighed the cost of the pasture: the net cost of forage per animal unit month was \$-0.58, which provide a beneficial situation. Among all the species evaluated in a three-year period, a meadow bromegrass-alfalfa pasture consistently provided high biomass production thus high carrying capacity with a low cost (Alberta Agriculture Food and Rural Development, 2008).

Another three-year study done at the Western Beef Development Center, Saskatchewan, Canada evaluated the system costs associated with both stockpiling and drylot hay feeding (Kulathunga et al, 2015). Though more energy supplement was provided to livestock grazing stockpiled perennial forage, the total feed costs were still 46% less compared with drylot feeding hay bales. This was mostly because of the high hay price (\$0.97 day^{-1} cow^{-1} compared with the low price of stockpiled forage (\$0.25 day^{-1} cow^{-1}). Paddock establishment fielding requires labour and machinery including fence establishment, moving cattle and water supplementation; however, it was estimated that the stockpiling system was still 14% lower in total costs compared with hay feeding system, which was in accordance with previous studies (Kaliel and Kotowich, 2002; Kelln et al., 2011). It was considered viable to use a stockpiling system to extend grazing into December; further grazing into January or February might increase the supplementation cost, especially with heavy snow coverage.

More studies are needed to further confirm the economic benefits of mixed grass-legume stockpiled pasture. Compared with conventional winter feeding in which conserved feeds such as hay and silage accounted for approximately 65% of the maintenance of a livestock, utilization of stockpiled perennial forages provides the opportunity of reducing the winter feeding cost of beef production.

Stockpiling forage species can be considered as a viable option for many beef cow producers; however, several questions remained to be answered. It is difficult to estimate the actual forage utilization of either swathed or standing stockpiled forage due to different environmental conditions, forage types, site locations and grazing methods chosen. It is also not clear whether the leaf loss of standing alfalfa would be less if buried by heavy and timely snow. Meanwhile variable requirements for additional supplements like barley makes it more difficult to have a distinct comparison between diet qualities. Another question is whether the added cost for swathing stockpiled forage is justified as the benefits have been found to be variable. (Saskatchewan Forage Council 2009 & Saskatchewan Ministry of Agriculture, 2013).

3.0 Evaluating the forage production and nutritive value of stockpiled perennial forage species

3.1 Introduction

Perennial species are commonly utilized in North American prairie regions for winter stockpiling. The overall quality of stockpiled pasture forage species can fulfill the nutrient requirements for a range of classes of animals like beef cattle, dry dairy cows and sheep (Hedtcke et al., 2002). Both stockpiled grass and legume species were found to have adequate crude protein concentrations to support the grazing animals under the proper stocking rate. The relative feeding value (RFV) value remained above 100, indicating an overall good quality for forage grasses to ensure the basic intake of livestock. RFV was higher in legumes than grasses, however, it declined throughout the fall and early winter each year. While grasses initially had lower RFV, it declined less rapidly than legumes. It was a viable option to incorporate legume crops into grass to enhance the N concentration (Ambrosek et al., 2014).

Overall nutrient concentrations of stockpiled forage stands in October were within the range (National Research Council, 2000) to meet the daily nutrient requirements of dry beef cows. however, nutritive values of stockpiled perennials declined due to plant respiration, leaf loss, frost damage, or leaching of soluble cellular compounds (Ocumpaugh and Matches, 1977; Matches and Burns, 1995; Baron et al., 2004). It was suggested that additional winter supplements should be provided when the daily mean temperature decreases from 0°C to -15°C, especially when nutrient deficiencies in forages occur over an extended period (Alberta Agriculture Food and Rural Development, 2008).

Tame forage species are widely adapted but their potential for winter stockpiling system varies, indicating that the best species needed to be selected for specific conditions and goals. Grass species can be high in yield and nutritive values: species with stable yields like meadow brome grass and creeping red fescue ranked highest in quality with high *in vitro* digestible organic matter (IVDOM) and lower neutral detergent fiber (NDF) concentrations, even when left for spring grazing (Alberta Agriculture Food and Rural Development, 2008). High yielding species like timothy and smooth bromegrass failed to meet the minimum protein requirement of 70 g kg^{-1} (National Research Council, 1996) for brood cows, indicating nitrogen fertilization might be needed to enhance the protein level (Burns and Chamblee, 2000a, 2000b) or a protein supplement would have to be added. Though crested wheatgrass produced well in the spring (Smith et al., 1986), late fall quality was not adequate for livestock (Burns and Chamblee, 2000a, 2000b). Legume species often lose leaves due to frost or maturity, resulting in dramatic declines in nutritive value (Matches and Burns, 1995). High neutral detergent fiber (NDF) concentration and low in vitro digestible organic matter (IVDOM) made legumes unsuitable for animals during the winter period especially when they are in mid/late pregnancy stage. It was recommended that grazing of legumes should take place before heavy leaf loss occurred (Baron et al., 2004).

Stockpiling winter feeding systems are often compared to conventional drylot hay feeding. All current studies have found no significant difference in major forage quality parameters between these two feeding system (Kulathunga et al., 2016). The energy content of both systems in October and December (520g kg^{-1}) successfully met the requirement of a 635 kg dry pregnant beef cow (490 g kg^{-1}) during mid-gestation (National Research Council, 2000). Stockpiled perennial forage had slightly higher organic matter and NDF compared with drylot hay but no changes were noticed in nutritive values in this study once temperature dropped below -15°C. This was in accordance with Aasen et al., (2004) who found that only minimal changes in nutritive value would occur when temperatures were low (-15°C).

Nitrate toxicity may occur in conditions with plant stress such as drought or frost combined with heavy N fertilization, when species slow down the speed of growth and the nitrates have not yet been converted to protein, which may occur in fall prior to grazing (Harris and Shearer, 2003). Nitrate concentration of each pure and mixed stand was recorded and compared with the guidelines of nitrate levels in relation to cattle health by Yaremcio (1991) (Table 3.1). Due to the varying climate conditions and the changing of soil nutrients, it is highly recommended to test the forage nitrate level of stockpiled forage before feeding animals.

Table 3.1 Guidelines of nitrate levels in relation to cattle health.

Category	% NO_3	% NO3-N	% KNO_3	Remarks
1	0.5	0.12	0.81	Generally safe
2	0.5-1.0	0.12-0.23	0.81-1.63	Caution – some subclinical symptoms may appear
3	1.0	0.23	1.63	High nitrate – death losses and abortions occur

Producers in western Canada are becoming more interested in stockpiled forage because of its economic benefits. Much of the previous research in this area has focused on stockpiling pure stand of perennial forage species except meadow brome mixed with alfalfa for stockpiling (Lardner et al., 2013). The present study will test the stockpiling potential of six species (four grass and two legumes) in both pure and mixed stands. Yield and nutritive value, including concentrations of important minerals were determined. One of our objectives was to determine whether grass-legume mixed stands were a better choice for stockpiling compared with pure stands. We also compared the effects of different lengths of the summer stockpiling period on forage regrowth production and nutritive value.

3.2 Materials and Methods

3.2.1 Plant materials

The species and cultivars used in this study were as follows: Meadow brome (*Bromus riparius Rehm.*) cv. Fleet (F), meadow brome cv. Armada (AR), tall fescue (*Festuca arundinacea* Schreb.) cv. Courtenay (C), orchardgrass (*Dactylis glomerata* L.) cv. Killarney (K), hybrid brome (*Bromus inermis*

Leyss. x *Bromus riparius* Rehm.) cv. Success (S), alfalfa (*Medicago sativa* L.) cv. Yellowhead (Y), alfalfa cv. Algonquin (A), and cicer milkvetch (*Astragalus Cicer* L.) cv. Oxley II (O). Three legumes (two species) and five grasses (four species) were seeded in pure stands and in two species grass-legume mixtures (Table 3.2). Seeding rates were based on recommended cropping practices and were adjusted for germination percentages.

Table 3.2 Species, mixtures and seeding rates in the perennial forage field experiment.

Species	Cultivar	Legume in mixtures	Seeding rate (kg ha^{-1})
Meadow brome	Armada	------------	12
	Armada	Algonquin	6+4
	Armada	Yellowhead	6+4
	Armada	Oxley II	6+7
	Fleet	------------	12
	Fleet	Algonquin	6+4
	Fleet	Yellowhead	6+4
	Fleet	Oxley II	6+7
Hybrid brome	Success	-----------	10
	Success	Algonquin	5+4
	Success	Yellowhead	5+4
	Success	Oxley II	5+7
Tall fescue	Courtenay	------------	9
	Courtenay	Algonquin	4.5+4
	Courtenay	Yellowhead	4.5+4
	Courtenay	Oxley II	4.5+7
Orchardgrass	Killarney	-------------	10
	Killarney	Algonquin	5+4
	Killarney	Yellowhead	5+4
	Killarney	Oxley II	5+7
Alfalfa	Algonquin	------------	8
	Yellowhead	------------	8
Cicer milkvetch	Oxley II	------------	14

Note: seeding rates for mixed stands are expressed as (grass seeding rates + legume seeding rates).

3.2.2 Experimental design and location

Field experiments were conducted from 2014 to 2016 at the Agriculture and Agri-Food Research Center farm located in Saskatoon, SK, Canada (52°07′ lat, 106°38′ long). The soil type was a Sutherland Clay Loam (Typic Haploboroll).

All plots were seeded on July 21, 2014. Plot size was 1.2 × 6.0 m consisting of four rows, spaced 30 cm apart. The experiment was conducted as a split-plot randomized complete block with three replicates. The main plot treatments were early (ES) and late stockpile initiation (LS). The sub-plot treatments were species/mixtures (Figure 3.1). Soil samples were taken to determine nutrient levels and the experiment received fertilizer on October 22, 2015. For pure grass stands, 100 kg ha^{-1} N was applied and for pure legume stands, 20 kg ha^{-1} P_2O_5 was applied. For grass-legume mixture stands, 20 kg ha^{-1} N was applied. In 2015, all plots were cut first on June 16 while only the late stockpiled plots were cut for a second time on August 10. The final (stockpiled) harvest occurred on October 15, 2015 for all plots, and samples were taken for dry matter and nutritive value measurements. In 2016, plots were mowed on April 13 to remove dead growth from the previous years. The early stockpile was initiated on June 14 with all plots cut while the late stockpile was initiated on July 27. The final stockpiled harvest took place on October 19 with samples taken from each plot for both dry matter and quality analysis. All samples were dried at 60° C in a forced air oven.

Rep 3

code	18	13	23	19	5	3	14	6	20	15	16	22	7	12	11	8	9	1	2	10	21	4	17
plot	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115

code	17	23	18	22	12	20	21	1	5	7	6	10	4	15	3	19	11	13	8	14	2	16	9
plot	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138

5m

ES LS

Rep2

code	21	1	3	19	18	5	11	16	22	6	4	17	13	2	9	8	14	15	10	20	23	7	12
plot	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69

code	23	21	9	1	3	19	20	13	15	11	2	18	12	6	17	14	4	8	10	7	16	5	22
plot	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92

5m

LS ES

Rep 1

code	7	15	12	11	9	20	14	19	17	4	22	13	3	16	5	2	21	8	1	18	10	23	6
plot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23

code	12	21	3	23	6	22	14	19	11	2	13	4	18	17	10	5	9	7	16	15	20	1	8
plot	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46

ES LS

Code		Treatment
1		Killarney Orchardgrass
2		Courtenay Tall Fescue
3		Success Hybrid Brome
4		Fleet Meadowbrome
5		Armada Meadowbrome
6		Algonquin Alfalfa
7		Yellowhead Alfalfa
8		Oxley II Cicer Milkvetch
9		Killarney - Algonquin
10		Killarney - Yellowhead
11		Killarney - Oxley II
12		Courtenay - Algonquin
13		Courtenay - Yellowhead
14		Courtenay - Oxley II
15		Success - Algonquin
16		Success - Yellowhead
17		Success - Oxley II
18		Fleet - Algonquin
19		Fleet - Yellowhead
20		Fleet - Oxley II
21		Armada - Algonquin
22		Armada - Yellowhead
23		Armada – Oxley II

Fugure 3.1 Experimental design layout

3.2.3 Experimental procedures

3.2.3.1 Ground cover percentage estimation

Plants ground cover percentage provides a measure of the success of establishment. Ground cover percentage was firstly determined on October 2, 2014 (72 days post seeding). Data was expressed as the percentage of ground covered by plants per 0.25 m^2. Visual estimates were taken within each plot. For mixed stands, the ground cover percentage of each species was visually measured separately. Ground cover percentage was also determined on June 15 in 2015 and June 13 in 2016 to measure whether there had been any winter plant death. Data was expressed in the same way.

3.2.3.2 Botanical composition (grass/legume mixes)

Three subsamples (0.25m^2 each) were collected prior to the June and October harvest. Grasses and legumes were separated and individually weighed and dried in a forced-air oven at 60°C. Weights of dry material were used to determine the percent composition of the two components. Data are presented in appendix A, table A2.

3.2.3.3 Stage of maturity

Maturity was first determined at the June harvest, by randomly subsampling the harvested material or by taking subsamples prior to harvest (3×0.25 m^2). The methods of Kalu and Fick (1981) for legumes and Moore et al. (1991) for grasses were used to determine stage of maturity. Data are presented in appendix A, table A4.

Maturity was then measured prior to the October harvest by examining the percentage of heading, yellow colored and senesced plants for grass species and the percentage of flowering, ripe-pods, and senesced plants for legume species. Data are presented in appendix A, table A5.

3.2.3.4 Plant height measurement

For perennial forage species, plant height was measured prior to each June cut (June 15 in 2015 and June 13 in 2016). The height was measured in centimeters from the base of the plant (soil level) to the top of the highest stems of the plants using a measuring stick. Data are presented in appendix A, table A1.

3.2.3.5 Forage dry matter yield

For the perennial forage trial, stockpiled dry matter yield (SDM) was determined on October 15 and 19 in 2015 and 2016 separately by cutting entire plots to a height of 5 cm using a WinterSteiger-CiBus harvester (WinterSteiger, Salt lake City, UT) with an integrated digital scale. Yields were also determined from cuts taken during the growing season. Total dry matter yield (TDM) was calculated as the sum of all of the yields taken. At harvest, a random sample was taken from the cut material, weighed and dried at 60° in a forced air oven to determine percentage dry matter. The dry matter concentration was used to calculate forage DM yield.

3.2.3.6 Stockpiled forage composition (nutritive value) determination

Plots of each treatment were sampled at each October harvest. Samples were dried at 60°C in a forced air oven and then ground in a Wiley Mill to pass through a 1 mm screen. These ground samples were used for nutritive value determinations. All samples were analyzed by Central Testing Labs (Winnipeg, Manitoba) each year for the components listed in Table 3.3. Protein, fiber and mineral variables (Ca and P) were the focus of this thesis. Forage K and Mg concentrations were further used for forage tetany calculation. TDN is a more summative expression for energy so, other energy variable components are listed in appendix A but are not presented and discussed in the body of the thesis.

Table 3.3 Measurements of perennial forage composition.

Categories		
Protein and fiber	Energy variables	Mineral variables
Crude protein (CP)	Digestible energy (DE)	Potassium (K)
Total digestible nutrients (TDN)	Metabolizable energy (ME)	Calcium (Ca)
Acid detergent fiber (ADF)	Net energy of maintenance (NEM)	Magnesium (Mg)
Neutral detergent fiber (NDF)	Net energy of gain (NEG)	Nitrates (NO_3)
	Net energy of lactation (NEL)	Phosphorus (P)

Grass tetany ratios in milli-equivalents from % units of Mg, Ca and K were calculated using following equation: Ratio = (K * 255.74) / (Ca * 499 + Mg * 882.64).There is a greater susceptibility of the tetany symptoms to occur in cattle grazing the specific forage when the ratio is above 2.2 (Bohman et al., 1983; Horn, 1983; Littledike and Bohman, 1984).

3.2.4 Statistical Analysis

Data was subjected to analysis of variance (ANOVA) as a split plot with RCBD (Steel and Torrie, 1980) using the SAS mixed model procedure (SAS Institute, 2014).

Stockpile initiation date was the main-plot effect and forage species/mixtures was the sub-plot effect. Year was considered as a fixed effect in this initial analysis because of the difference in environmental conditions between the two experimental years (2015 and 2016). A random effect consisted of block nested within year. The three-way interaction, year × stockpile initiation date × species and the two-way interaction, year × species were used to determine if the years could be combined, except for plant density, which was presented separately by years. When any of the interactions were significant, data were presented for the individual factors separately by years; when no significant interaction was shown, year data were combined. Means separation was performed using Tukey's HSD at $P < 0.05$. The coefficient of variation was calculated to express the variability of the model.

3.3 Results

3.3.1 Climate data

Environmental conditions varied among the years. In 2014, the year of establishment, seeding was done in July into soils that were wet from heavy rains from April through June. Stands established well using this residual moisture as July through September was drier than normal. The year 2015 had a very dry spring and a hot summer. In 2016, there was an adequate amount of spring precipitation and cooler summer temperatures (Table 3.4).

Table 3.4 Monthly mean temperature and precipitation during 2014, 2015, and 2016, and long-term average monthly temperature and precipitation in Saskatoon.

	Monthly mean temperature				Monthly precipitation			
	2014	2015	2016	Avg.†	2014	2015	2016	Avg.†
Month	℃				mm			
January	-15.0	-11.8	-12.9	-14.8	6.1	5.8	17.3	15.0
February	-19.2	-17.4	-7.9	-11.0	2.1	16.5	7.0	11.0
March	-10.1	-1.2	-1.5	-4.3	5.8	5.7	13.9	12.0
April	1.7	6.2	5.5	5.3	74.2	41.1	3.0	24.0
May	10.1	11.3	13.7	12.2	61.1	6.3	41.6	52.0
June	14.1	18.1	17.4	16.6	94.8	20.2	49.7	60.0
July	18.3	20.1	18.7	19.1	44.5	85.1	58.6	63.0
August	17.9	18.6	16.9	18.0	18.5	58.2	70.2	43.0
September	12.4	12.9	11.8	12.2	10.7	50.8	24.1	33.0
October	6.7	7.9	2.1	5.5	14.1	32.7	40.8	17.0
November	-9.7	-1.8	1.9	-4.7	30.5	15.6	9.2	13.0
December	-9.4	-8.1	-13.7	-12.4	2.5	4.0	9.7	14.0
Total	NA‡	NA	NA	NA	364.9	342.0	345.1	357.0

† Average of 30 yr. in Saskatoon (1981-2010), obtained from Environment Canada (2017).
‡ NA, denotes not applicable.

3.3.2 Ground cover percentage

Ground cover percentage varied significantly ($P < 0.0001$) among cultivars/mixtures in all three years. No severe winter kill was noticed, all stands regrew well in the following years with the majority of the stands maintaining their original density with some fluctuations. Many stands showed lower density in year 2015 compared with the other two years (Table 3.5).

Among pure stands, cicer milkvetch had poor stand density to begin with and the density was very low in year 2015, with only 29.3% ground coverage (Table 3.5). In most of the grass-cicer mixed stands, grass cover percentage was much higher than the cicer milkvetch cover percentage. Meadow bromegrass appeared to be particularly competitive with cicer milkvetch. Success hybrid brome-cicer milkvetch mixtures, however, had a lower grass cover percentage than cicer milkvetch cover percentage in year 2014 and 2016. Meadow brome and alfalfa stands exhibited high plant density in either pure or mixed stands. Meadow brome appeared to be particularly competitive with cicer milkvetch. Alfalfa, especially cv. Algonquin had increased density each year and was dominant in third year mixture stands, except for those with Courtenay tall fescue. Orchardgrass, when mixed with Algonquin alfalfa, had considerably reduced ground cover percentage in third year stands (Table 3.5).

Table 3.5 Grass and legume ground cover percentage in 2014, 2015 and 2016.

Species	Cultivar	Grass cover percentage 2014	2015	2016	Legume in mixtures	Legume cover percentage 2014	2015	2016
			%				%	
Meadow brome	Armada	75.0	78.7	95.0	------------	0.0	0.0	0.0
	Armada	41.7	33.7	48.3	Algonquin	41.7	49.0	51.7
	Armada	40.0	54.7	81.7	Yellowhead	38.3	30.0	40.0
	Armada	50.0	71.0	60.0	Oxley II	35.0	4.0	10.0
	Fleet	66.7	83.0	98.0	------------	0.0	0.0	0.0
	Fleet	43.3	31.3	26.7	Algonquin	43.3	45.0	65.0
	Fleet	36.7	46.7	51.7	Yellowhead	33,3	28.3	48.3
	Fleet	31.7	61.7	80.0	Oxley II	40.0	7.0	11.7
Hybrid brome	Success	58.3	68.7	73.3	------------	0.0	0.0	0.0
	Success	35.0	26.7	25.0	Algonquin	48.3	53.0	70.0
	Success	28.3	33.0	16.7	Yellowhead	40.0	36.7	81.7
	Success	18.3	40.0	40.0	Oxley II	30.0	8.0	48.3
Tall fescue	Courtenay	76.7	62.3	78.3	------------	0.0	0.0	0.0
	Courtenay	50.0	21.7	78.3	Algonquin	46.7	52.3	21.7
	Courtenay	46.7	41.0	50.0	Yellowhead	41.7	27.7	50.0
	Courtenay	50.0	62.3	50.0	Oxley II	33.3	4.7	25.0
Orchardgrass	Killarney	65.0	61.0	73.3	-------------	0.0	0.0	0.0
	Killarney	43.3	32.7	20.0	Algonquin	45.7	41.7	71.7
	Killarney	53.3	47.3	53.3	Yellowhead	38.3	34.7	45.0
	Killarney	63.3	60.3	70.0	Oxley II	33.3	6.0	25.0
Alfalfa	Algonquin	0.0	0.0	0.0	------------	88.3	75.7	91.7
	Yellowhead	0.0	0.0	0.0	------------	86.7	64.7	91.7
Cicer milkvetch	Oxley II	0.0	0.0	0.0	------------	53.3	29.3	56.7
Mean		42.3	44.3	50.9		35.7	27.1	39.4
HSD†		28.2	27.9	40.6		23.0	21.1	41.8
CV§		21.2	20.2	25.5		20.7	26.3	33.9

Forage ground cover percentage

† HSD ($P < 0.05$), tests among means for grass and legume ground cover percentage within species.
§ CV, coefficient of variation.

3.3.3 Forage dry matter yield

3.3.3.1 Forage dry matter yields in June

Both early and late stockpile treatments were cut in the month of June in 2015 and 2016. The mean June yield (1st cut) for all species in 2015 (4.0 Mg ha^{-1}) was significantly lower compared with the mean yield of all species in 2016 (5.2 Mg ha^{-1}) (Table 3.7).

June forage yields showed a significant year by cultivar interaction ($P < 0.001$) (Table 3.6). In 2015, pure stands of the meadow brome cultivars, Armada and Fleet ranked highest in June yield with average production of 6.8 and 6.0 Mg ha^{-1} respectively. Among other pure stands, Algonquin alfalfa and Success hybrid bromegrass also had high yields with 4.2 and 4.4 Mg ha^{-1} (Table 3.7), respectively. Orchardgrass, tall fescue and cicer milkvetch were the lowest yielding with only 1.7, 1.7 and 0.5 Mg ha^{-1} dry matter produced, respectively. Mixtures which contained either Armada or Fleet meadow brome generally yielded higher than mixtures with other grasses. Armada meadow brome with both pure and mixed stands with cicer milkvetch had the highest yield (6.8 Mg ha^{-1}) which was numerically higher than the production from any other stands. Killarney orchardgrass and Courtenay tall fescue mixed with cicer milkvetch ranked lowest in June yield (Table 3.7).

In year 2016, alfalfa, Yellowhead or Algonquin, mixed with either Armada or Fleet meadow brome were found to have the top yields, with the Armada/Yellowhead mixture ranked the highest with 6.5 Mg ha^{-1} of dry matter. Mixtures with Success hybrid brome had intermediate yields, above 5.2 Mg ha^{-1}. Algonquin alfalfa was the highest yielding pure legume at 5.5 Mg ha^{-1}. Success hybrid brome and Fleet and Armada meadow bromes were the highest yielding pure grass stands, with greater than 5.5 Mg ha^{-1} production (Table 3.7).

The majority of pure stands or mixtures showed no significant differences in yield between 2015 and 2016. The two that did show significant differences were Killarney orchardgrass and Oxley II cicer milkvetch which yielded higher in 2016. Numerically, most pure stands and mixtures were higher yielding in 2016, with the exceptions being pure stands and mixtures with meadow bromegrass that were numerically higher in 2015 (Table 3.7).

Table 3.6 P-values for forage dry matter yields in June (DMJ), stockpiled dry matter yield (SDM) and total dry matter yield (TDM) in 2015 and 2016.

Source	DMJ	SDM	TDM
Cultivars/mixtures (C)	< 0.001***	< 0.001***	< 0.001***
Stockpile initiation (SI)	NA	< 0.001***	0.782
Year (Y)	< 0.001***	< 0.001***	< 0.001***
C × SI	NA	0.052	< 0.001***
C × Y	< 0.001***	0.133	< 0.001***
SI × Y	NA	0.455	0.043*
C × SI × Y	NA	0.088	0.080

*, **, ***, significant at the 0.05, 0.01 and 0.001 probability levels.
NA, denotes not applicable.

Table 3.7 June forage dry matter yields of pure stands and mixtures of perennial forage species in 2015 and 2016.

Species	Cultivar	Legume in mixtures	June Forage Yield 2015	June Forage Yield 2016
			Mg ha^{-1}	
Meadow brome	Armada	------------	6.8	5.7
	Armada	Algonquin	5.3	6.1
	Armada	Yellowhead	5.2	6.5
	Armada	Oxley II	6.8	5.1
	Fleet	------------	6.0	5.5
	Fleet	Algonquin	5.2	6.1
	Fleet	Yellowhead	6.0	6.4
	Fleet	Oxley II	5.4	5.2
Hybrid brome	Success	------------	4.4	5.7
	Success	Algonquin	4.7	6.3
	Success	Yellowhead	4.1	5.6
	Success	Oxley II	3.7	5.2
Tall fescue	Courtenay	------------	1.7	4.1
	Courtenay	Algonquin	3.5	5.4
	Courtenay	Yellowhead	3.0	5.3
	Courtenay	Oxley II	1.9	3.8
Orchardgrass	Killarney	-------------	1.7	4.3
	Killarney	Algonquin	3.4	5.4
	Killarney	Yellowhead	3.0	5.3
	Killarney	Oxley II	1.8	3.9
Alfalfa	Algonquin	------------	4.2	5.5
	Yellowhead	------------	3.6	5.1
Cicer milkvetch	Oxley II	------------	0.5	3.6
Mean			4.0	5.2
HSD1†			2.4	2.3
HSD2‡			1.6	
CV§			22.9	19.2

† HSD1 ($P < 0.05$), tests means for forage June yield among cultivars/mixtures.
‡ HSD2 ($P < 0.05$), tests among means for cultivars/mixtures between years. The interaction of cultivars/mixtures and year was significant ($P < 0.05$).
§ CV, coefficient of variation.

3.3.3.2 Stockpiled dry matter yields (SDM)

Interactions with year were non-significant for SDM (Table 3.6), thus the data combined over the two years and two stockpiling systems are shown in Table 3.8. The cultivars/mixtures by stockpile initiation interaction showed the trend to be significant (0.052) (Table 3.6). This was propabably due to the huge gap between early stockpile production and late stockpile production for certain species: Armada meadow brome mixed with cicer milkvetch had 4.3 Mg ha^{-1} production under early stockpile initiation, however, only 1.9 Mg ha^{-1} under late stockpile initiation, which was lower than most of the stands in the study (Data not shown). The same trend was also noticed for pure Armada meadow brome stands (Data not shown).

Stockpiled dry matter yield of cultivars/mixtures exhibited significant difference between years (P < 0.001) (Table 3.6). The year 2016 had significantly higher (P < 0.001) mean production (3.0 Mg ha^{-1}) compared with that in 2015 (2.4 Mg ha^{-1}). Stockpile initiation date affected SDM significantly (P < 0.001) (Table 3.6), the early stockpile initiation (June cut only) had 3.5 Mg ha^{-1} of SDM yield, which was significantly higher (P < 0.05) than the mean of the late initiation (June/August cut) which only yielded 1.9 Mg ha^{-1}.

Stockpiled yields were significantly different among cultivars/mixtures varying from 1.5 Mg ha^{-1} (cicer milkvetch) to 3.6 Mg ha^{-1} (meadow brome/alfalfa) with five treatments yielded less than 2.0 Mg ha^{-1}, including cicer milkvetch, orchardgrass, Yellowhead and Algonquin alfalfa and hybrid brome/cicer milkvetch. Although cicer milkvetch and Yellowhead and Algonquin alfalfa were low yielding in pure stands, they formed high yielding in mixtures with tall fescue and meadow bromegrass (Table 3.8). Six mixed stands were found to exceed their grass pure stand stockpiled DM yield: the highest yielding treatment was Fleet meadow brome/Algonquin alfalfa at 3.6 Mg ha^{-1} (Table 3.8) followed by: Courtenay tall fescue/Oxley cicer milkvetch, Success hybrid brome/Yellowhead alfalfa, Fleet meadowbrome/Yellowhead alfalfa, Armada meadowbrome/Oxley cicer milkvetch and Success hybrid brome/Algonquin Alfalfa. Courtenay tall fescue in both pure and mixed stands with alfalfa also had significantly higher yields than many of the other stands. In addition, Armada meadow brome yielded numerically higher when mixed with cicer milkvetch compared to mixtures with other legumes while Success hybrid brome yielded higher when mixed with Yellowhead alfalfa than when mixed with other legumes. All the mixtures of orchardgrass and legumes exceeded the pure stand orchardgrass stockpiled DM yield but were the lowest mixture yields observed. Pure legumes had the lowest yields among all the stands (Table 3.8).

Table 3.8 Stockpiled dry matter yields of pure stands and mixtures of perennial species.

Species	Cultivar	Legume in mixtures	SDM
			Mg ha^{-1}
Meadow brome	Armada	------------	2.9
	Armada	Algonquin	2.9
	Armada	Yellowhead	2.4
	Armada	Oxley II	3.1
	Fleet	------------	3.0
	Fleet	Algonquin	3.6
	Fleet	Yellowhead	3.3
	Fleet	Oxley II	2.6
Hybrid brome	Success	------------	2.1
	Success	Algonquin	2.8
	Success	Yellowhead	3.4
	Success	Oxley II	1.9
Tall fescue	Courtenay	------------	3.3
	Courtenay	Algonquin	2.9
	Courtenay	Yellowhead	3.2
	Courtenay	Oxley II	3.5
Orchardgrass	Killarney	-------------	1.9
	Killarney	Algonquin	2.5
	Killarney	Yellowhead	2.1
	Killarney	Oxley II	2.0
Alfalfa	Algonquin	------------	1.9
	Yellowhead	------------	1.5
Cicer milkvetch	Oxley II	------------	1.5
Mean			2.7
HSD†			0.5
CV‡			23.8

† HSD ($P < 0.05$), tests among means for forage forage stockpiled dry matter yield among cultivars/mixtures.
‡ CV, coefficient of variation.

3.3.3.3 Total dry matter yield (TDM)

Total dry matter yield was the sum of June, July/August harvests (in the late stockpile treatment) yield and October stockpiled yields. Since year 2016 had higher June forage yields and SDM yields, the TDM was higher than that of 2015 (Table 3.9). Interactions were found for TDM similar to

June forage yield, which is one of the components of TDM (Table 3.6). Most pure stands and mixtures were not significantly different in yield between the two years; however, tall fescue and hybrid brome mixed with Yellowhead alfalfa had significantly higher yields in 2016, almost double those of 2015. Cicer milkvetch did not show high yield potential though its production in 2016 was higher than the previous year (Table 3.9).

There was no significant difference in TDM between early (8.4 Mg ha^{-1}) and late (8.2 Mg ha^{-1}) (Table 3.9) stockpile treatments; however, TDM of forage stands showed a significant (P < 0.001) cultivar by stockpile initiation interaction (Table 3.6). Only Fleet meadow brome mixed with alfalfa stands had high TDM across years. Pure Armada meadow brome and Armada-cicer milkvetch mixed stands showed high yields under early stockpile initiation while Fleet meadow brome/alfalfa and Success hybrid brome/alfalfa mixed stands performed well under late stockpile initiation (Table 3.9).

Table 3.9 Total dry matter yields of pure stands and mixtures of perennial species in 2015 and 2016.

Species	Cultivars	Legume in mixtures	TDM 2015	TDM 2016	TDM ES	TDM LS
			Mg ha^{-1}			
Meadow brome	Armada	-----------	10.0	9.4	11.4	7.9
	Armada	Algonquin	9.7	10.5	9.4	10.7
	Armada	Yellowhead	8.2	10.4	9.9	10.7
	Armada	Oxley II	10.8	9.0	11.2	8.5
	Fleet	------------	10.0	8.9	10.5	8.4
	Fleet	Algonquin	10.0	11.5	11.0	10.5
	Fleet	Yellowhead	10.4	10.8	11.0	10.1
	Fleet	Oxley II	8.2	8.8	8.5	8.4
Hybrid brome	Success	------------	6.4	8.8	8.4	6.8
	Success	Algonquin	9.1	11.1	9.1	11.1
	Success	Yellowhead	6.6	12.2	8.3	10.5
	Success	Oxley II	5.9	8.3	7.3	6.8
Tall fescue	Courtenay	------------	4.7	9.4	7.0	7.1
	Courtenay	Algonquin	7.8	10.3	8.2	9.8
	Courtenay	Yellowhead	6.7	10.0	8.9	7.9
	Courtenay	Oxley II	5.4	8.7	7.6	6.5
Orchardgrass	Killarney	-------------	5.9	8.3	7.3	6.8
	Killarney	Algonquin	7.5	10.8	8.0	10.2
	Killarney	Yellowhead	5.0	8.1	7.3	5.9
	Killarney	Oxley II	4.0	6.8	6.2	4.6
Alfalfa	Algonquin	------------	8.0	9.9	8.6	9.3
	Yellowhead	------------	5.9	8.0	6.3	7.6
Cicer milkvetch	Oxley II	------------	2.0	6.0	3.7	4.2
Mean			7.2	9.4	8.4	8.2
HSD1†			4.2	5.0	4.9	5.7
HSD2‡			3.2		3.7	
CV§			32.0	18.2	23.1	24.2

† HSD1 ($P < 0.05$), tests means for TDM among cultivars/mixtures within a year or stockpile treatment (ES, early stockpile initiation; LS, late stockpile initiation).
‡ HSD2 ($P < 0.05$), tests among means for cultivars/mixtures between years. The interactions of cultivars/mixtures with year and stockpile initiation date were significant.
§ CV, coefficient of variation.

3.3.4 Forage nutritive value

Forage nutritive value variables did not show significant cultivar/mixture × stockpile initiation date × year interaction ($P > 0.05$) (Table 3.10). There were significant cultivar/mixture by year ($P < 0.001$) and cultivar/mixture by stockpile initiation date interactions ($P < 0.001$) for most variables (Table 3.10). Forage CP and P concentrations did not show significant cultivar/mixtures by year interaction while forage nitrate concentration was not affected by any factor significantly (Table 3.10). To show the consistency of species performance, data were presented separately by year and stockpile initiation date.

Table 3.10 P-values for crude protein (CP), total digestible nutrients (TDN), acid detergent fiber (ADF), neutral detergent fiber (NDF), calcium concentration (Ca), phosphorus concentration (P), nitrates concentration (NO_3) in 2015 and 2016.

Source	CP	TDN	ADF	NDF	Ca	P	NO_3
Cultivars/mixtures (C)	< 0.0001***	< 0.0001***	< 0.0001***	< 0.0001***	< 0.0001***	< 0.0001***	0.056
Stockpil/e initiation (SI)	< 0.0001***	< 0.0001***	< 0.0001***	< 0.0001***	< 0.0001***	< 0.0001***	0.224
Year (Y)	< 0.0001***	< 0.0001***	< 0.0001***	< 0.0001***	< 0.0001***	< 0.0001***	0.109
C × SI	< 0.0001***	< 0.0001***	< 0.0001***	< 0.0001***	< 0.0001***	0.085	0.058
C × Y	0.127	< 0.0001***	< 0.0001***	0.0007**	0.0002**	0.350	0.243
SI × Y	< 0.0001***	0.315	0.313	0.780	0.854	< 0.0001***	0.714
C × SI × Y	0.076	0.211	0.210	0.201	0.208	0.470	0.055

, *, significant at the 0.01, and 0.001 probability levels.

3.3.4.1 Forage protein and energy concentrations

Mean CP concentration was 142 g kg^{-1} in 2015 which was significantly higher than that of 2016 which was only 106 g kg^{-1} (Table 3.11). Late stockpile initiation had higher mean protein concentration compared with early stockpile initiation, the CP difference between the two stockpile initiations was significant (P < 0.001) in 2015 but not 2016 (Table 3.11).

Forage CP contentrations were significantly affected by cultivar/mixtures by stockpile initiation date effect (Table 3.11). Pure legume stands showed consistently high CP concentration in both years regardless of the stockpile initition. Cicer milkvetch had the highest CP under early initiation while Algonquin alfalfa showed highest CP under late initiation. In both years, grass stands, except for Killarney orchardgrass mixed with Algonquin alfalfa, exhibited consistently high CP under both initiation treatments. In addition, grass stands mixed with Algonquin alfalfa under late stockpile initiation consistently exhibited significantly higher CP concentrations than those under early stockpile initiation in both years. Success hybrid brome mixed with Algonquin alfalfa ranked the highest under late stockpile treatment in 2015 with 219 g kg^{-1} CP content. Hybrid brome also had high CP with Yellowhead alfalfa under both stockpile initiation. Pure grass stands ranked low in CP under both intitiation treatments, especially for Killarmey orchardgrass under early stockpile initiation. It was further noticed that most of the cultivars did not differ significantly in CP concentration under early initiation in 2016 (Table 3.11).

Table 3.11 Crude protein concentrations for perennial species under early and late stockpile initiation throughout year 2015 and 2016.

			Forage CP			
			2015		2016	
Species	Cultivars	Legume in mixtures	ES	LS	ES	LS
			g kg^{-1}			
Meadow brome	Armada	-----------	106	115	77	85
	Armada	Algonquin	130	175	110	118
	Armada	Yellowhead	116	139	104	100
	Armada	Oxley II	102	139	82	91
	Fleet	------------	106	120	86	81
	Fleet	Algonquin	137	189	110	130
	Fleet	Yellowhead	108	150	90	107
	Fleet	Oxley II	112	122	86	111
Hybrid brome	Success	------------	120	154	89	112
	Success	Algonquin	160	219	120	173
	Success	Yellowhead	139	202	121	135
	Success	Oxley II	155	181	103	128
Tall fescue	Courtenay	------------	104	118	87	83
	Courtenay	Algonquin	121	209	115	137
	Courtenay	Yellowhead	111	144	101	98
	Courtenay	Oxley II	115	125	96	81
Orchardgrass	Killarney	-------------	86	121	54	71
	Killarney	Algonquin	112	203	96	133
	Killarney	Yellowhead	113	140	79	109
	Killarney	Oxley II	112	116	70	71
Alfalfa	Algonquin	------------	145	212	133	179
	Yellowhead	------------	144	210	122	137
Cicer milkvetch	Oxley II	------------	175	204	139	121
Mean1			123	161	99	113
HSD1†			46.2	53.9	46.6	48.5
Mean2			142		106	
HSD2‡			34.5		32.6	
CV§			17.5	23.4	21.1	26.0

† HSD1 ($P < 0.05$), tests means for CP among cultivars/mixtures within stockpile initiation dates.
‡ HSD2 ($P < 0.05$), tests among means for cultivars/mixtures between stockpiled initiation dates. The interaction of cultivars/mixtures and stockpile initiation date was significant.
§ CV, coefficient of variation.

Stands showed significantly higher TDN concentrations in year 2015 (660 g kg^{-1}) than in year 2016 (573 g kg^{-1}) (Table 3.12). The mean TDN for late stockpile initiation was significantly higher (P < 0.05) than early stockpile initiation in both years (Table 3.13).

There was significant cultivars/mixtures by year interaction (P < 0.001) (Table 3.10). Success hybrid brome and Courtenay tall fescue had consistenly high TDN in both years when mixed with cicer milkvetch. Tall fescue was the only pure stand that had consistent high TDN in both years. Most of the cultivars/mixtures did not perform consistently in TDN contents across years. For example, cicer milkvetch ranked the highest in 2015 but was near the mean in 2016 (Table 3.12).

Total digestible nutrient concentrations were significantly affected by cultivars/mixtures by stockpile initiation interaction (P < 0.001) (Table 3.10). Late stockpiling resulted in increased TDN for Algonquin alfalfa-grass mixtures in 2015 and in four Algonquin alfalfa-grass mixtures in 2016. Late stockpiling resulted in increased TDN for Yellowhead alfalfa-grass mixtures in three cases in 2015 and four cases in 2016.Oxley cicer milkvetch-grass mixtures did not benefit from late stockpiling except when mixed with Fleet meadow brome in 2016. In 2016, cicer milkvetch pure stand exhibited a decline in TDN due to late stockpiling (Table 3.13).

Table 3.12 Forage TDN of pure stands and mixtures of perennial forage species by year and cultivars/mixtures.

			Forage TDN	
Species	Cultivar	Legume in mixtures	2015	2016
			$g\ kg^{-1}$	
Meadow brome	Armada	------------	628	554
	Armada	Algonquin	637	563
	Armada	Yellowhead	642	560
	Armada	Oxley II	640	565
	Fleet	------------	618	566
	Fleet	Algonquin	647	542
	Fleet	Yellowhead	619	552
	Fleet	Oxley II	643	581
Hybrid brome	Success	------------	669	594
	Success	Algonquin	673	554
	Success	Yellowhead	691	546
	Success	Oxley II	704	615
Tall fescue	Courtenay	------------	704	634
	Courtenay	Algonquin	679	595
	Courtenay	Yellowhead	691	585
	Courtenay	Oxley II	693	642
Orchardgrass	Killarney	-------------	636	558
	Killarney	Algonquin	653	549
	Killarney	Yellowhead	639	576
	Killarney	Oxley II	652	577
Alfalfa	Algonquin	------------	643	553
	Yellowhead	------------	641	524
Cicer milkvetch	Oxley II	------------	730	593
Mean			660	573
HSD1†			74.8	99.3
HSD2‡			61	
CV§			6.7	

† HSD1 ($P < 0.05$), tests means for TDN among cultivars/mixtures within eacxh year.

‡ HSD2 ($P < 0.05$), tests among means for cultivars/mixtures between years. The interaction of cultivars/mixtures and year was significant.

§ CV, coefficient of variation.

Table 3.13 Forage TDN of pure stands and mixtures of perennial forage species by cultivars/mixtures and stockpile initiation date.

			Forage TDN			
			2015		2016	
Species	Cultivars	Legume in mixtures	ES	LS	ES	LS
			g kg^{-1}			
Meadow brome	Armada	------------	612	643	522	587
	Armada	Algonquin	594	680	547	578
	Armada	Yellowhead	621	662	532	588
	Armada	Oxley II	627	653	543	586
	Fleet	------------	607	628	546	585
	Fleet	Algonquin	618	675	507	577
	Fleet	Yellowhead	590	648	514	589
	Fleet	Oxley II	638	647	551	610
Hybrid brome	Success	------------	642	696	572	615
	Success	Algonquin	633	713	501	606
	Success	Yellowhead	656	726	510	581
	Success	Oxley II	696	713	602	627
Tall fescue	Courtenay	------------	696	713	638	630
	Courtenay	Algonquin	646	713	551	639
	Courtenay	Yellowhead	668	713	529	642
	Courtenay	Oxley II	686	700	637	646
Orchardgrass	Killarney	-------------	625	647	541	575
	Killarney	Algonquin	593	713	503	595
	Killarney	Yellowhead	602	675	543	608
	Killarney	Oxley II	647	657	573	582
Alfalfa	Algonquin	------------	589	697	480	627
	Yellowhead	------------	615	668	500	547
Cicer milkvetch	Oxley II	------------	713	748	617	569
Mean1			635	684	546	600
HSD1†			47.3	63.9	42.1	51.5
Mean2			660		573	
HSD2‡			45.2		47.6	
CV§			5.7	4.7	8.0	4.4

† HSD1 (P < 0.05), tests means for TDN among cultivars/mixtures within stockpile initiation dates.
‡ HSD2 (P < 0.05), tests among means for cultivars/mixtures between stockpiled initiation dates. The interaction of cultivars/mixtures and stockpile initiation date was significant.
§ CV, coefficient of variation.

3.3.4.2 Forage fiber concentrations

Similar to forage CP and TDN concentration trends, forage stands were found to be significantly less fibrous in the first year with 307 g kg^{-1} ADF and 455 g kg^{-1} NDF concentrations compared with that in the second year which was 387 g kg^{-1} and 534 g kg^{-1}. Pure and mixed stands tended to have lower fiber concentration under late stockpile initiation in both years (Tables 3.15 & 3.16).

There was a significant cultivars by year interaction (P < 0.001) as several pure stands/mixtures ranked differently in each of the two years (Table 3.10). Cicer milkvetch had consistently low ADF and NDF fiber concentrations in both years. All of the fiber contentrations were the lowest for cicer milkvetch except for its ADF concentration in 2016. Among grasses, meadow brome was generally among the highest pure stands and mixtures in NDF in both years. Tall fescue had the lowest ADF concentration and mixtures with this species also tended to be the lower in ADF. Among mixed stands, Success hybrid brome with cicer milkvetch had the lowest NDF in 2015 while in 2016, the lowest ranking was tall fescue with cicer milkvetch (Table 3.14).

Mean ADF and NDF concentrations were significantly higher in the early stockpile than the late stockpile treatment (Tables 3.15 and 3.16). There was also a significant cultivar/mixture by stockpile initiation date interaction for both ADF and NDF (P < 0.001) (Table 3.10). Cicer milkvetch pure stands had the lowest ADF concentrations under both stockpiling treatments in 2015, while in 2016 cicer milkvetch and Courtenay tall fescue in pure stand were lowest in ADF in the early stockpile treatment and tall fescue mixed with cicer milkvetch was the lowest in late stockpiling. Alfalfa pure stands showed the highest ADF concentrations in the early stockpile treatments in both years (Table 3.15). Pure cicer milkvetch was also the lowest or among the lowest stands in NDF. Algonquin alfalfa had among the highest NDF concentrations in the early stockpile inititation and among the lowest in the late stockpile in both pure and mixed stands in year 2016. Meadow bromegrass pure and mixed stands (both Armada and Fleet) were generally the highest of the grasses in NDF regardless of stockpile initiation (Table 3.16).

Table 3.14 Forage fiber concentrations of pure stands and mixtures of perennial forage species by year and cultivars/mixtures.

Species	Cultivars	Legume in mixtures	ADF 2015	ADF 2016	NDF 2015	NDF 2016
			g kg^{-1}			
Meadow brome	Armada	------------	336	404	510	573
	Armada	Algonquin	327	397	465	545
	Armada	Yellowhead	323	399	486	548
	Armada	Oxley II	325	395	499	542
	Fleet	------------	345	394	520	562
	Fleet	Algonquin	318	416	508	546
	Fleet	Yellowhead	344	407	503	565
	Fleet	Oxley II	322	380	486	548
Hybrid brome	Success	------------	301	368	472	553
	Success	Algonquin	297	405	415	527
	Success	Yellowhead	277	413	427	538
	Success	Oxley II	273	348	425	492
Tall fescue	Courtenay	------------	269	330	451	524
	Courtenay	Algonquin	289	367	428	513
	Courtenay	Yellowhead	277	375	447	539
	Courtenay	Oxley II	275	323	440	516
Orchardgrass	Killarney	-------------	328	401	484	560
	Killarney	Algonquin	313	409	431	537
	Killarney	Yellowhead	326	385	454	518
	Killarney	Oxley II	314	383	474	544
Alfalfa	Algonquin	------------	321	405	415	502
	Yellowhead	------------	323	433	443	543
Cicer milkvetch	Oxley II	------------	242	368	290	457
Mean1			307	387	456	534
HSD1†			54.7	92.4	100.8	110.3
HSD2‡			57.3		77.2	
CV§			11.1		10.5	

† HSD1 ($P < 0.05$), tests among means for acid detergent fiber (ADF) and neutral detergent fiber (NDF) among cultivars/mixtures within each year.

‡ HSD2 ($P < 0.05$), tests among means for cultivars/mixtures between years. The interaction of cultivars/mixtures and year was significant.

§ CV, coefficient of variation.

Table 3.15 Acid detergent fiber (ADF) for perennial species under early and late stockpile initiation throughout year 2015 and 2016.

			ADF			
			2015		2016	
Species	Cultivars	Legume in mixtures	ES	LS	ES	LS
			g kg^{-1}			
Meadow brome	Armada	------------	350	321	435	374
	Armada	Algonquin	367	287	411	382
	Armada	Yellowhead	342	304	426	373
	Armada	Oxley II	336	313	415	375
	Fleet	------------	355	335	412	376
	Fleet	Algonquin	345	291	449	383
	Fleet	Yellowhead	372	317	442	372
	Fleet	Oxley II	326	318	407	352
Hybrid brome	Success	------------	322	280	388	347
	Success	Algonquin	331	263	454	356
	Success	Yellowhead	309	244	446	379
	Success	Oxley II	281	264	360	337
Tall fescue	Courtenay	------------	272	265	326	333
	Courtenay	Algonquin	319	259	407	326
	Courtenay	Yellowhead	298	256	428	323
	Courtenay	Oxley II	281	269	327	318
Orchardgrass	Killarney	-------------	339	318	417	385
	Killarney	Algonquin	369	257	452	367
	Killarney	Yellowhead	360	293	415	354
	Killarney	Oxley II	318	309	387	379
Alfalfa	Algonquin	------------	372	271	474	336
	Yellowhead	------------	348	298	456	411
Cicer milkvetch	Oxley II	------------	261	223	346	391
Mean1			328	285	412	362
HSD1†			54.8	54.5	99.7	80.4
Mean2			306.6		387.1	
HSD2‡			37.5		62.2	
CV§			10.0	10.2	9.9	6.8

† HSD1 ($P < 0.05$), tests means for ADF among cultivars/mixtures within stockpile initiation dates.
‡ HSD2 ($P < 0.05$), tests among means for cultivars/mixtures between stockpiled initiation dates. The interaction of cultivars/mixtures and stockpile initiation date was significant.
§ CV, coefficient of variation.

Table 3.16 Neutral detergent fiber (NDF) for perennial species under early and late stockpile initiation throughout year 2015 and 2016.

			NDF			
			2015		2016	
Species	Cultivars	Legume in mixtures	ES	LS	ES	LS
			g kg^{-1}			
Meadow brome	Armada	------------	531	488	591	556
	Armada	Algonquin	514	415	573	516
	Armada	Yellowhead	521	450	561	534
	Armada	Oxley II	513	485	561	524
	Fleet	------------	538	502	596	528
	Fleet	Algonquin	513	502	596	496
	Fleet	Yellowhead	529	477	600	530
	Fleet	Oxley II	521	400	591	555
Hybrid brome	Success	------------	504	440	576	530
	Success	Algonquin	474	355	603	451
	Success	Yellowhead	491	363	592	483
	Success	Oxley II	406	444	509	475
Tall fescue	Courtenay	------------	464	438	520	528
	Courtenay	Algonquin	483	372	564	461
	Courtenay	Yellowhead	466	428	592	487
	Courtenay	Oxley II	454	426	516	515
Orchardgrass	Killarney	-------------	501	467	572	547
	Killarney	Algonquin	514	347	600	473
	Killarney	Yellowhead	515	393	554	483
	Killarney	Oxley II	497	450	556	533
Alfalfa	Algonquin	------------	473	357	586	419
	Yellowhead	------------	464	421	573	513
Cicer milkvetch	Oxley II	------------	305	274	443	471
Mean1			486	425	565	503
HSD1†			70.7	119.7	92.6	117.5
Mean2			456		534	
HSD2‡			67.5		72.6	
CV§			10.3	13.6	6.7	7.1

† HSD1 ($P < 0.05$), tests means for NDF among cultivars/mixtures within stockpile initiation dates.
‡ HSD2 ($P < 0.05$), tests among means for cultivars/mixtures between stockpiled initiation dates. The interaction of cultivars/mixtures and stockpile initiation date was significant.
§ CV, coefficient of variation.

3.3.4.3 Calcium and phosphorus concentrations

Mean forage calcium (Ca) concentrations were significantly higher in the first year (11.3 g kg^{-1}) compared with those in the second year (9.7 g kg^{-1}) (Table 3.17). Both pure and mixed stands had higher concentrations under late stockpile initiation in both years (Table 3.18).

Calcium concentrations for forage stands were significantly affected by cultivar/mixtures by year interaction (P < 0.001) (Table 3.10). Pure legume species showed consistently high Ca concentrations with cicer milkvetch ranking the highest in both years. All legumes had significantly higher Ca in 2015 compared with that in 2016. All grass stands mixed with Algonquin alfalfa also were high in Ca concentration across years. Pure grass stands tended to have the lowest Ca concentrations in the two years (Table 3.17).

Forage Ca concentration also exhibited significant cultivar/mixture by stockpile initiation date interaction (P < 0.001) (Table 3.10). Legume stands consistently ranked the highest in Ca concentrations under both stockpile initiations in both years. Yellowhead alfalfa had significantly higher Ca under late initiation than it had under early initiation in 2015, stockpile initiation, however, did not affect its Ca in 2016. Algonquin alfalfa had the opposite performance with Ca under late stockpile initiation in 2016 significantly higher than that under early initiation. Cicer milkvetch showed a more consistent Ca concentration regardless of the stockpile initiation. All grass stands, except for meadow brome mixed with Algonquin alfalfa consistently showed high Ca concentrations in 2016. Other grass-legume stands had either numerically or significantly lower Ca concentrations compared with grass-Algonquin stands under both stockpile initiations (Table 3.18).

Table 3.17 Forage calcium (Ca) concentrations of pure stands and mixtures of perennial forage species by year and cultivars/mixtures.

			Ca concentration	
Species	Cultivar	Legume in mixtures	2015	2016
			$g\ kg^{-1}$	
Meadow brome	Armada	------------	5.7	7.1
	Armada	Algonquin	12.4	9.3
	Armada	Yellowhead	9.2	7.5
	Armada	Oxley II	6.3	7.8
	Fleet	------------	5.6	5.7
	Fleet	Algonquin	10.5	10.0
	Fleet	Yellowhead	8.3	8.1
	Fleet	Oxley II	6.2	7.4
Hybrid brome	Success	------------	6.6	5.9
	Success	Algonquin	17.5	13.7
	Success	Yellowhead	14.4	13.2
	Success	Oxley II	11.1	10.0
Tall fescue	Courtenay	------------	5.6	4.9
	Courtenay	Algonquin	14.4	11.3
	Courtenay	Yellowhead	7.8	7.7
	Courtenay	Oxley II	8.4	5.7
Orchardgrass	Killarney	-------------	6.9	6.5
	Killarney	Algonquin	16.3	11.9
	Killarney	Yellowhead	12.6	9.1
	Killarney	Oxley II	7.3	7.6
Alfalfa	Algonquin	------------	20.0	17.7
	Yellowhead	------------	22.4	16.6
Cicer milkvetch	Oxley II	------------	25.3	19.5
Mean			11.3	9.7
HSD1†			6.6	6.0
HSD2‡			4.4	
CV§			28.1	

† HSD1 ($P < 0.05$), tests among means for forage Ca concentration within each year.
‡ HSD2 ($P < 0.05$), tests among means for cultivars/mixtures between years. The interaction of cultivars/mixtures and year was significant.
§ CV, coefficient of variation.

Table 3.18 Calcium (Ca) concentrations for perennial species under early and late stockpile initiations throughout year 2015 and 2016.

			Ca concentration			
			2015		2016	
Species	Cultivars	Legume in mixtures	ES	LS	ES	LS
			g kg^{-1}			
Meadow brome	Armada	------------	5.4	6.0	5.9	8.2
	Armada	Algonquin	10.9	13.9	7.7	10.8
	Armada	Yellowhead	7.3	11.0	7.2	7.8
	Armada	Oxley II	6.8	5.7	7.7	7.8
	Fleet	------------	5.1	6.0	5.7	5.6
	Fleet	Algonquin	8.5	12.5	8.6	11.4
	Fleet	Yellowhead	7.8	8.8	7.1	9.0
	Fleet	Oxley II	5.9	6.5	6.5	8.2
Hybrid brome	Success	------------	6.0	7.1	5.4	6.3
	Success	Algonquin	15.2	19.7	9.6	17.8
	Success	Yellowhead	9.0	19.8	10.1	16.3
	Success	Oxley II	14.7	7.4	9.7	10.2
Tall fescue	Courtenay	------------	5.3	5.9	4.7	5.0
	Courtenay	Algonquin	12.7	16.1	8.5	14.1
	Courtenay	Yellowhead	7.6	8.0	8.3	7.0
	Courtenay	Oxley II	7.7	9.0	5.7	5.6
Orchardgrass	Killarney	-------------	6.3	7.4	6.4	6.5
	Killarney	Algonquin	11.5	21.0	9.1	14.7
	Killarney	Yellowhead	9.4	15.8	7.6	10.5
	Killarney	Oxley II	5.9	8.7	7.9	7.2
Alfalfa	Algonquin	------------	20.7	19.2	13.8	21.6
	Yellowhead	------------	19.4	25.3	14.7	18.4
Cicer milkvetch	Oxley II	------------	25.2	25.4	18.4	20.5
Mean1			10.2	12.4	8.5	10.9
HSD1†			7.6	6.5	6.2	7.9
Mean2			11.3		9.7	
HSD2‡			4.8		4.9	
CV§			53.8	52.3	38.0	46.5

† HSD1 ($P < 0.05$), tests means for Ca among cultivars/mixtures within stockpile initiation dates.
‡ HSD2 ($P < 0.05$), tests among means for cultivars/mixtures between stockpiled initiation dates. The interaction of cultivars/mixtures and stockpile initiation date was significant.
§ CV, coefficient of variation.

Year and stockpile initiation affected forage phosphorus concentrations in a similar manner to forage calcium concentrations with higher concentrations in 2016 and in the late stockpile treatment (data not shown). Cultivars/mixtures showed significant differences in phosphorus concentrations with a range of 1.5-1.9 g kg^{-1}. There were no consistent differences between grass and legume species/cultivars and mixed and pure stands, with the exception of those with Success hybrid brome which consistently had the highest concentrations (Table 3.19).

Table 3.19 Forage phosphorus (P) concentrations of pure stands and mixtures of perennial forage species by cultivars/mixtures.

Species	Cultivar	Legume in mixtures	P concentration
			g kg^{-1}
Meadow brome	Armada	------------	1.6
	Armada	Algonquin	1.7
	Armada	Yellowhead	1.6
	Armada	Oxley II	1.7
	Fleet	------------	1.6
	Fleet	Algonquin	1.6
	Fleet	Yellowhead	1.6
	Fleet	Oxley II	1.6
Hybrid brome	Success	------------	1.8
	Success	Algonquin	1.8
	Success	Yellowhead	1.8
	Success	Oxley II	1.9
Tall fescue	Courtenay	------------	1.5
	Courtenay	Algonquin	1.8
	Courtenay	Yellowhead	1.6
	Courtenay	Oxley II	1.6
Orchardgrass	Killarney	-------------	1.6
	Killarney	Algonquin	1.7
	Killarney	Yellowhead	1.8
	Killarney	Oxley II	1.7
Alfalfa	Algonquin	------------	1.6
	Yellowhead	------------	1.5
Cicer milkvetch	Oxley II	------------	1.7
Mean			1.7
HSD†			0.2
CV‡			11.17

† HSD ($P < 0.05$), tests among means for forage P concentration within cultivars/mixtures.
‡ CV, coefficient of variation.

3.3.5 Forage tetany ratio and nitrate concentrations

Based on the ratio calculations, pure and mixed stands of all species appear to be safe for fall/winter grazing (Tetany ratio < 2.2). Ratios tended to be higher in grasses than legumes, with meadow bromegarss showing the highest ratio (Table 3.20). Nitrate concentrations were also low generally ranging form 0.1-0.2 g kg^{-1}; however, pure Armada meadow bromegrass had a concentration of 0.6, which is above the recognized safe level of 0.5 g kg^{-1} (Table 3.21).

Table 3.20 Forage tetany ratios for perennial species under early and late stockpile initiation throughout year 2015 and 2016.

			Forage tetany ratios			
			2015		2016	
Species	Cultivars	Legume in mixtures	ES	LS	ES	LS
Meadow brome	Armada	------------	1.9	0.9	0.7	0.6
	Armada	Algonquin	0.9	0.2	0.7	0.6
	Armada	Yellowhead	1.2	0.4	0.7	0.7
	Armada	Oxley II	1.4	0.7	0.8	0.7
	Fleet	------------	1.7	0.8	1.4	0.9
	Fleet	Algonquin	1.1	0.3	0.6	0.5
	Fleet	Yellowhead	1.0	0.4	0.7	0.6
	Fleet	Oxley II	1.2	0.6	0.7	0.7
Hybrid brome	Success	------------	1.2	0.5	0.8	0.8
	Success	Algonquin	0.5	0.1	0.5	0.4
	Success	Yellowhead	0.9	0.2	0.4	0.3
	Success	Oxley II	0.8	0.3	0.6	0.6
Tall fescue	Courtenay	------------	0.7	0.3	0.8	0.2
	Courtenay	Algonquin	0.7	0.2	0.7	0.2
	Courtenay	Yellowhead	1.2	0.4	0.7	0.2
	Courtenay	Oxley II	1.2	0.4	0.8	0.2
Orchardgrass	Killarney	-------------	0.9	0.4	0.6	0.2
	Killarney	Algonquin	0.7	0.1	1.0	0.2
	Killarney	Yellowhead	0.8	0.2	0.7	0.2
	Killarney	Oxley II	1.2	0.4	0.6	0.2
Alfalfa	Algonquin	------------	0.4	0.1	0.3	0.2
	Yellowhead	------------	0.3	0.0	0.3	0.1
Cicer milkvetch	Oxley II	------------	0.7	0.1	0.4	0.2

Table 3.21 Forage nitrate concentrations of pure stands and mixtures of perennial forage species.

Species	Cultivar	Legume in mixtures	Forage NO_3
			g kg^{-1}
Meadow brome	Armada	------------	0.6
	Armada	Algonquin	0.1
	Armada	Yellowhead	0.1
	Armada	Oxley II	0.1
	Fleet	------------	0.1
	Fleet	Algonquin	0.2
	Fleet	Yellowhead	0.1
	Fleet	Oxley II	0.1
Hybrid brome	Success	------------	0.1
	Success	Algonquin	0.1
	Success	Yellowhead	0.1
	Success	Oxley II	0.1
Tall fescue	Courtenay	------------	0.1
	Courtenay	Algonquin	0.2
	Courtenay	Yellowhead	0.2
	Courtenay	Oxley II	0.1
Orchardgrass	Killarney	-------------	0.1
	Killarney	Algonquin	0.1
	Killarney	Yellowhead	0.1
	Killarney	Oxley II	0.1
Alfalfa	Algonquin	------------	0.1
	Yellowhead	------------	0.1
Cicer milkvetch	Oxley II	------------	0.1

3.4 Discussion

The study examined a wide range of traits of 23 cool-season perennial cultivars and mixtures to thoroughly assess the potential of each species in stockpiling system. Environmental conditions and stockpile initiation date affected many of the measured traits as cultivars/mixtures exhibited significant differences between years under different stockpile initiation. Forage yield and nutritive values were evaluated to select species that would meet the requirements of winter grazing animals' survival and maintenance.

The results of this study showed that cultivars/mixtures exhibited significant differences first cut dry matter in June (DMJ) and stockpiled dry matter (SDM) yields. The very low precipitation in May and June (Table 3.4) in year 2015 most likely caused the lower mean yield of all species in June harvest time compared with the June yield in 2016. Plant density was generally lower in the spring of 2015 compared with spring of 2016, especially for cicer milkvetch and orchardgrass likely due to the dry conditions (Table 3.5). Biligetu et al (2014) reported that stand density and forage production of cicer milkvetch was reduced by drought compared to alfalfa. Plants were also found to grow taller in June 2016 than in June 2015 (Appendix A). If around 3.5 Mg ha^{-1} of biomass was produced in summer time under proper management, livestock will have at least two-thirds of the dry matter required for maintenance (Alberta Agriculture and Forestry, 1998). In year 2015, pure stands of the meadow brome cultivars Armada and Fleet achieved this yield goal and showed even higher yields than in year 2016 (Table 3.7). Among other pure stands, Algonquin alfalfa and Success hybrid brome grass also showed high yields with 4.2 and 4.4 Mg ha^{-1}, respectively (Table 3.7). These two species seem to also be drought tolerant. In a 3-yr study conducted in Lanigan, Saskatchewan (Lardner et al., 2013), and a study done at five black soil zone sites in Saskatchewan (Lardner et al., 2000), meadow and hybrid bromegrasses were found to have a high production in a June harvest producing dry matter yields close to 4.0 Mg ha^{-1}. In the present study, the early growth of meadow bromegrass likely allowed it to accumulate dry matter prior to soil conditions becoming too dry from the lack of rainfall in May and June. It has been found that mild drought may induce earlier maturity of certain species that may lead to faster accumulation of dry matter (Xu et al., 2013). Species which develop growth later in the spring under semi-arid conditions in Saskatchewan, such as orchardgrass, tall fescue and cicer milkvetch were the lowest yielding and failed in meeting the spring/summer production requirements as their main period of growth was during the driest period in late May and June, 2015. This also explained why mixtures which contained either Armada or Fleet meadow brome generally yielded higher than mixtures with other grasses, while Killarney orchardgrass and Courtenay tall fescue mixed with cicer milkvetch ranked the lowest. June botanical compositions confirmed that in most grass-cicer milkvetch mixed stands, grass accounted for more than half of the total biomass (Appendix A). The majority of pure stands or mixtures showed no significant differences in yield between 2015 and 2016, in spite of the difference in May/June rainfall between the two years. The two that did show significant differences were Killarney orchardgrass and cicer milkvetch which yielded higher in 2016. In a previous study, both meadow brome and hybrid brome yielded higher with more precipitation in second-year stands (Lardner et al., 2013), which was not in agreement with our study. Our experiment showed that adequate May/June rainfall in 2016 ensured that yields of both early and late growing species reached the minimum goal for spring/summer production (Table 3.7).

Whether a perennial pure or mixed stand could be considered a candidate for winter stockpiling depends largely on its stockpiled dry matter yield. Abundant forage available before winter would ensure animal performance during colder months (Manitoba Government, 2016). The year 2015 experienced a hot summer (Table 3.4) with heat stress reducing the growth of cool-season species. Most cool-season grasses are known to grow best in the moderate temperatures of spring and fall or a cool summer (Ehlke and Undersander, 1990). This explained why cool-season species tended to yield better in 2016 with a cooler summer. Species were further found to be less mature in year 2015 around the October harvesting time under early stockpile initiation. Less than a third of legume stands produced seed pods in 2015, while half of the grass stands headed over 20% and over 60% of legumes bore seed pods around the same time in year 2016 according to the stage of maturity analysis (Appendix A). The early stockpile initiation (June cut only) had 3.5 Mg ha^{-1} of SDM yield, which was significantly higher than the late initiation (June/August cut) which had 1.9 Mg ha^{-1} production. The late initiation had a shorter accumulation period following the 2nd cut in late July or August compared with the early initiation which was cut only in June. The early stockpiled forage was observed to be taller and contained more reproductive tillers at cutting in October. From previous studies (Alberta Agriculture Food and Rural Development, 2008), at least 2.0 Mg ha^{-1} of herbage are needed to maintain high grazing efficiency. This was obtained for the early stockpile treatment; the late stockpile yield was slightly below this level. The latter treatment did not have enough time for regrowth to accumulate sufficient biomass. Longer accumulation periods resulted in more biomass production (Alberta Agriculture Food and Rural Development, 2008) which was in accordance with our studies.

Stockpiled yields varied among species/mixtures with cicer milkvetch, orchargrass, Algonquin alfalfa, Yellowhead alfalfa and hybrid brome/cicer milkvetch failing to meet the minimum winter stockpiled forage yield. Mixed stands, particularly those with meadow brome had significantly higher dry matter yield than pure legume and Killarney orchardgrass stands (Table 3.8). Our study found that meadow bromegrass, in either pure or mixed stands ranked the highest in SDM, which is in accordance with previous studies. Baron et al. (2005) found that meadow brome had consistent high yield and its regrowth was enough for winter grazing animals. Smith et al. (1986) reported that tall fescue was adapted to temperate regions with high rainfall. Rogers et al. (2014) found that tall fescue had a dormancy strategy to avoid severe drought stress in summer. Our study found that tall fescue in either pure or mixed stands also had high late fall dry matter yield (Table 3.8). Tall fescue showed dominance in stand density when mixed with cicer milkvetch, producing high yields. Baron et al. (2004) found that orchardgrass performed well in the black soil zone of the Canadian prairie provinces with superior biomass production. The results of the present study, however, found that orchardgrass did not yield high enough for winter stockpiling in the dark brown soil site at Saskatoon. Perhaps orchardgrass requires higher moisture that would be found in the black soil zone region. The SDM yields of cicer milkvetch and orchardgrass were much higher in 2016 than in 2015 (Data not shown). The low yields in 2015 may be partially due to the harvester used to a higher percentage of forage not being harvested. Species grew taller in year 2016 after a cool summer growing period (Data not shown) and thus more biomass was above the height of the cutter blade on the harvester. In 2015 stands were shorter and biomass close to the ground was not actually cut by the machine. This was not as much an issue with the other species, since they grew taller. However, animals can graze close to the ground and prefer certain species over the others, which indicated that the cut forage for these species may not give a totally accurate indication of what is available to the grazing animals. Based on SDM and TDM yields, meadow bromegass in pure or mixed stands would have the highest potential as a forage for both summer and stockpiled grazing. Hybrid bromegass and tall fescue mixtures also have the yield potential for stockpiled forage grazing (Tables 3.8 & 3.9).

The nutritive value of forage is important to grazing livestock since they rely on the energy and protein provided by the plants. More nutritious winter pasture also reduces the supplemental feed required, thus reducing the production costs. All stands were found to be more nutritious and less fibrous in year 2015 than in year 2016, likely related to the higher yields and greater stem development in 2016. NASEM (2016) stated that the CP and TDN requirements for mature cows and heifers in pre-calving, postpartum, lactating and pregnant, mid-gestation periods ranged from 62 to 129 g kg^{-1} and 449 to 645 g kg^{-1} respectively. One thousand pound mature beef cows required the most CP and TDN 2-3 months after calving and the least during mid-gestation. Beef cows with higher mature weight required less CP and TDN 2-3 months after calving and slightly more nutrients in mid-gestation. Regardless of the climate and stockpiling initiation (early or late), CP and TDN levels of the majority of cultivars/mixtures in this study met these basic requirements (Table 3.11 & 3.12). Growing cattle with body weight ranging from 300 to 650 pounds, finishing at 1000 to 1500 pounds, required 71 to 179 g kg^{-1} CP and 510 to 750 g kg^{-1} TDN (NASEM, 2016). Growing steers and heifers could have higher nutritional requirements ranging from 87 to 190 g kg^{-1} for CP and 540 to 830 g kg^{-1} for TDN (NASEM, 2016). All pure and mixed stands in this experiment provided enough CP to at least meet the lower values of these ranges except for pure stands of orchardgrass and mixed stands of orchardgrass and cicer milkvetch in year 2016 (Table 3.11). Baron et al. (2004) also found that meadow brome easily met the minimum CP requirement of midpregnancy brood cows which is 71 g kg^{-1} according to NASEM (2016). Pure legume species ranked the highest in CP and TDN, especially under late stockpile initiation. Both Algonquin alfalfa and cicer milkvetch showed the highest potential with their mixed stands having the highest CP concentrations (Table 3.11). Both pure and mixed stands performed similarly in TDN concentration except that both pure alfalfa stands and mixtures of Algonquin alfalfa with either Fleet meadow brome and Success hybrid brome failed to maintain the minimum TDN level (510.0 g kg^{-1}) for grazing cattle in year 2016 under the early stockpile initiation date (Table 3.13). This suggests avoiding alfalfa stands for stockpiling in a year with a cool summer period if high energy forage is desired. Cicer milkvetch ranked the highest in TDN level in year 2015, however, it was not the highest in TDN under late stockpiling in year 2016. This may be because the plants were too short to be cut by the harvester in the second cut which resulted in the over maturity of the October stands relative to those cultivars/mixtures for which most of the biomass was taken in the second cut and the October biomass was mainly regrowth. (Table 3.13).

Forage fiber concentrations are also important considerations in the evaluation of late fall forage quality since low fiber stands would have relatively high leaf soluble consitituents (Baron et al., 2004). According to NASEM (2016), grass/mixed stands that had lower than 500 g kg^{-1} or 450 g kg^{-1} NDF would be considered above-average or high quality, respectively, while those having higher concentrations than 600 g kg^{-1} were considered low quality. Legume stands that had lower than 400 g kg^{-1} NDF were considered good quality while over 500 g kg^{-1} were considered poor quality. Meanwhile, any forage stands that had lower than 350 g kg^{-1} ADF were considered ideal quality. Based on this finding, the NDF levels of the majority of the stockpiled stands in our study were either idreal or below the upper limit thus they would not be considered low quality. Only alfalfa stands under early stockpile initiation after a cool summer exceeded the level for low quality (Table 3.16). All stands had high ADF contents after a cool summer growing season which reduced forage quality to some extent while species tended to have low ADF after a warm summer due to the reduction of growth (Table 3.16). A previous study (Alberta Agriculture Food and Rural Development, 2008) specifically examined stockpiled species like meadow bromegrass in the Canadian black soil zone region and found that it had high *in vitro* digestible organic matter (IVDOM) and maintained good mid-October digestibility (58%). Neutral detergent fiber increased about 5 % in October, however, forage quality was still well above maintenance level (71 g kg^{-1} CP content) for dry beef cows in the second or third trimester of gestation when using these species. Forage quality dropped to maintenance level for dry pregnant beef cows and cows with calves. It was estimated that cows could still gain weight approaching 1 kg hd^{-1} day^{-1}. Baron et al. (2004) mentioned that meadow brome stockpiled in the black soil zone had increased ADF but decreased NDF concentrations from September to October. Its IVDOM still remained high and stable, indicating forage digestibility did not decrease with the increasing ADF. Kulathunga et al. (2016)

conducted a 3-yr experiment in the Saskatchewan black soil zone at the Western Beef Development Centre, confirming that stockpiled perennials had similar nutritive value as hay used for drylot feeding. These results further proved that stockpiled forage could at least meet the minimum requirement of grazing livestock even with ADF content not ideal in a year with cool summer period. It was further stated that high annual fall (August, September and October) rainfall amounts would result in a high leaf-to-stem ratio and low fiber composition (Kulathuga et al., 2016). This was in accordance to what we have been observed, as the wet summer in 2015 reduced stem elongation and species tended to be less mature in fall. Matches and Burns, (1995), however, found that legume species lost leaves due to frost or maturity; thus NDF content was too high for animals in certain periods such as lactation. Alfalfa stands were also noticed to have high ADF in our experiment. Cicer milkvetch, however, was found to be still low in fiber contents and it did not lose its leaves following a frost like alfalfa, which is an advantage for winter stockpiling systems.

For forage Ca concentration, our study found that stockpiled pure and mixed stands could fulfill the requirement of grazing of different classes including pre-calving, postpartum, lactation and mid-gestation (1.8 to 9.0 g kg^{-1}) (NASEM, 2016). Phosphorus concentrations were also adequate; based on NASEM (2016), all of our stands could meet the minimum requirement of beef cows of 1.2 g kg^{-1}. None of the species/mixtures tested showed a high tetany ratio. Nitrate concentrations were also well below levels considered to be a toxicity risk, with the exception of pure stands of Armada meadow bromegrass (Table 3.21). This single high nitrate concentration appears to be an anomaly as mixtures with Armada and both pure and mixed stands of Fleet meadow bromegrass had low nitrate concentrations.

3.5 Conclusions

Regardless of the weather conditions, the majority of the species/mixtures tested in this study provided high summer forage yields and adequate stockpiled forage for winter grazing animals. Early stockpiling provided higher SDM yields and lower, but adequate, nutritive value for winter grazing cattle. Thus, early stockpiling is recommended to ensure adequate forage for winter grazing. Pure stands and mixtures of meadow bromegrass provided the highest SDM yield. The nutritive value of meadow bromegrass stands was lower than other species/mixtures, but still met the requirements of winter grazing animals.

It was strongly suggested that producers select species and stockpiling system carefully when practicing winter stockpiling. Due to large climatic variation, no single pure or mixed stand stood out in all aspects. If yield was the major concern, early stockpiling with meadow brome, tall fescue and hybrid brome grown together with alfalfa stands would be the top choice. Late spring growing species like orchardgrass and cicer milkvetch are poorer choices because of the low production in both June and October; none of the mixed strands including these two species showed high yields at either time. Pure alfalfa stands also tended to be lower in productivity. In some situations, producers are seeking species that are high in nutritive value to reduce the winter supplementing costs. Most of the species in this experiment would be good candidates regardless of the stockpiling initiation time except for pure alfalfa due to the leaf loss after frost. Cicer milkvetch ranked the highest in nutritive value but its low productivity and low contribution to grass mixtures would limit its value for stockpiling. This was the opposite of what we had hypothesized. We further found that pure grass stands had the lowest CP and Ca concentrations but other nutritive value measurements were similar to most of the mixed stands.

4.0 Evaluating the forage production and nutritive value of stockpiled annual forage species

4.1 Introduction

The use of annual species for winter stockpiled forage has been of an interest to many beef producers since the early 1990s. Annual forage crops offer flexibility to the stockpiling systems as they may produce higher stockpiled forage yields than perennials under variable climatic conditions. Producers were seeking alternative to cope with drought and shortage of perennial pasture (McCartney et al.,2008). Certain annual species are also known to be more drought tolerant than perennial forage species (Manitoba Government, 2016).

Annual forage species vary in total and seasonal dry matter production (Figure 4.1) and nutritive values in stockpiling systems. Several species that have been examined in recent studies possess certain traits that might make them good supplement for perennial pastures if additional feed is needed (Manitoba Government, 2016). Corn is recognized as a highly productive forage crop. Baron et al. (2014) demonstrated that winter stockpiled corn could provide adequate nutrients for livestock in winter months. Corn has a low acid detergent fiber (ADF) concentration, thus a high digestible energy content (Rusby and Martin, 2016). As a warm-season crop, corn can tolerate intense heat and drought conditions that sometimes occur in the summer of the Canadian prairies, however, it does not grow rapidly under cool spring and fall temperatures. Corn has tall stems which make it easier for cattle to graze even in deep snow and its height provides shelter for animals from strong winds, which reduces the energy requirement (Manitoba Government, 2004). Recently, glyphosate-resistant corn varies have been released and targeted research is required to access the traits and merits of using this early variety (McCartney et al.,2008).

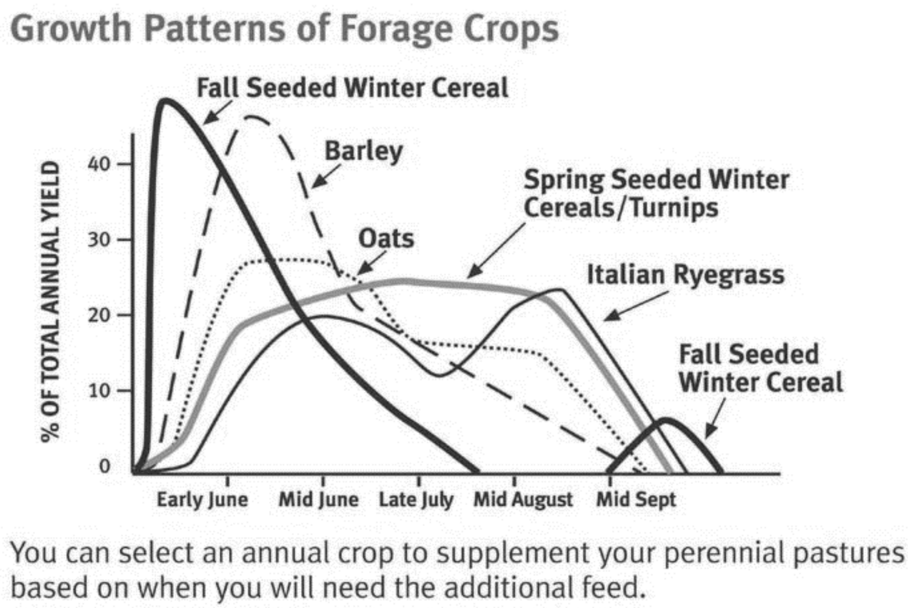

Figure 4.1 Percent of yield produced over time (Source: Manitoba Government, 2016)

Foxtail millet is another warm-season crop that has rapid growth in the summer. The popular variety, Golden German foxtail millet, has high palatability to the grazing livestock (Government of Saskatchewan, 2016). However, it is also sensitive to cool environmental conditions and its shallow roots make it easier to be pulled out of the ground by grazing animals (Johns, 2015).

Fall rye is an ideal winter cereal for stockpiling and is known for its late season growth with high amount of energy (Manitoba Government, 2016). Fall rye can be seeded in mid-August and provide abundant forage early in the following season when other summer annuals are still establishing (Government of Alberta, 2011).

Annual ryegrass was found to produce high quality regrowth forage and was suitable for any class of cattle. It was considered to be feasible to grass-fatten feeder cattle on annual ryegrass forage. Forage nutritive value in October was still above maintenance level of most classes of dry beef cows; however, an additional energy supplement might be needed for producing cows in early lactation (Alberta Agriculture Food and Rural Development, 2008; Kallenbach et al., 2003).

Oats and barley are both spring cereals that can be used for grazing, hay or silage production in the summer. Grazing of oats and barley field could occur 4-6 weeks after seeding. Similar to corn, they have high energy concentrations when used as silage or stockpiled grazed. When stockpiled, the late season yield increases with plant maturity, but quality declines dramatically after plant heading, species tended to be more fibrous though more starch was produced (Ministry of Agriculture, Food and Rural Affair, Ontario, 2016). Starch is insoluble and the highly branched chains needed to be phosphorylated first in order to be accessible for degrading enzymes. This suggests that starch is not an easy energy form to use. However, oats was also found to be cold tolerant with more water-soluble carbohydrate storage and even the quality of late maturity forage was adequate for dairy heifers (Contreras-Govea and Albrecht, 2006; Coblentz and Walgenbach, 2010a; Coblentz et al., 2012).

Soybean is an annual legume that has potential for use in stockpiling systems. Soybean fixes its own N and has high protein and digestibility (Blout et al., 2015). However, much of its energy comes from seed and leaf loss following frost damage makes it less desirable for grazing cattle in the late season (Blout et al., 2015).

Using annual species with different life cycles in different fields will help ensure a sufficient amount of feed supply (Manitoba Government, 2016). Small grain annual species like oat have been reported to cause grass tetany in animals under certain conditions (Harris and Shearer, 2003). Also, annual cereal crops have been found to be more susceptible to build up of high level of nitrates compared with perennials (Manitoba Government, 2016). Annual species have often been examined for forage yield and nutritive values for summer grazing, there is a lack of information on stockpiled annual forage performances in Canadian prairie regions. In the present study, a two-year field experiment was undertaken to examine the relative potential of annual species for stockpiled forage production to extend the grazing season.

4.2 Materials and Methods

4.2.1 Plant materials

Seven species, including six grasses and one legume were used in this study. The species and the cultivars were as follows: corn (*Zea mays* L.) cv. Fusion; foxtail millet (*Setaria italica* (L.) P. Beauvois) type Golden German; oat (*Avena sativa* L.) cv. Haymaker; fall rye (*Secale cereale* L.) cv. Hazlet; barley (*Hordeum vulgare* L.) cv. Maverick; annual ryegrass (*Lolium* L.) cv. Aubade; and soybean (*Glycine max* (L.) Merr.) cv. Mammoth (Table 4.1). Seeding rates were based on recommended cropping practices and were adjusted for germination percentages.

Table 4.1 Species and seeding rates in annual forage field experiments.

	Cultivar or Type	Seeding rate (seeds m^{-2})
Corn	Fusion	40
Foxtail Millet	Golden German	80
Oat	Haymaker	80
Fall Rye	Hazlet	80
Barley	Maverick	80
Ryegrass	Aubade Westerwold	80
Soybean	Mammoth	80

4.2.2 Experimental location and design

A field experiment was conducted at the Agriculture and Agri-Food research center farm located in Saskatoon, SK, Canada (52°07′ lat, 106°38′ long) in 2014 and 2015. The soil type was a Sutherland Clay Loam (Typic Haploboroll). Plots were seeded on June 2, 2014 and on May 29, 2015. The Fusion Corn was seeded at a rate of 40 pure live seeds (PLS) m^{-2}. All other species in the study were seeded at a rate of 80 PLS m^{-2} (Table 4.1). Plot size was 1.25 × 6.0 m (15 m^2) consisting of four rows, spaced 30 cm apart. The exception was the plot of corn which was 2.5 × 6.0 m (15 m^2), with four rows spaced 61 cm apart. Guard rows of Kirk crested wheatgrass were planted on each side of the trial. A randomized complete block design with four replicates was utilized each year and each plot was considered an experimental unit with treatment factor as cultivars (Figure 4.1). Fertilizer was applied in spring of each year consisting of 112 kg ha^{-1} of nitrogen and 28 kg ha^{-1} of phosphorus.

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
Entry		4	3	1		6	5	7	2	
Plot	G	401	402	403		404	405	406	407	G
Entry		3	5	2	7	4	6	1		
Plot	G	301	302	303	304	305	306	307		G
Entry		6	3	7	2	5	4	1		
Plot	G	201	202	203	204	205	206	207		G
Entry		7	1		2	6	3	5	4	
Plot	G	101	102		103	104	105	106	107	G

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
Entry		5	3	1		4	2	7	6	
Plot	G	401	402	403		404	405	406	407	G
Entry		4	6	3	2	1		7	5	
Plot	G	301	302	303	304	305		306	307	G
Entry		2	1		7	5	6	3	4	
Plot	G	201	202		203	204	205	206	207	G
Entry		3	5	7	6	4	2	1		
Plot	G	101	102	103	104	105	106	107		G

Code: G, guard rows; 1, Fusion Corn (4 rows at 24" spacing); 2, Golden German Foxtail millet; 3, Haymaker Oats; 4, Hazlet Fall Rye; 5, Maverick Barley; 6, Aubade Westerwold Ryegrass; 7, Mammoth Soybean.

Figure 4.2 Experimental design layout for year 2014 (top) and 2015 (bottom).

4.2.3 Experimental procedures

4.2.3.1 Plant height measurement

Plant height was measured monthly from August to October each year. The height was measured in centimeters from the base of the plant (soil level) to the top of the highest stems of the plants using a meter stick. The height of each forage species was measured at three random locations in each plot, and then averaged to obtain a single height value for each plot. Data are presented in appendix B.

4.2.3.2 Plant lodging estimation

Lodging was scored at maturity prior to October harvest each year. The percentage area of plot that was lodged and the angle of stem lodging were estimated (e.g. an angle of 10º from the perpendicular is scored as 10 whereas prostrate stems are scored as 90). Lodging for the plot was then calculated as: (% plot area lodged × angle of lodging from vertical)/90.

4.2.3.3 Forage dry matter yield

Stockpiled dry matter yield was determined on October 15 in 2014 and 2015 by cutting entire plots to a height of 5cm using a WinterSteiger-CiBus harvester (WinterSteiger, Salt lake City, UT). Each corn stem was hand cut and removed, leaving 5cm of stubble height remaining. All forages harvested were then weighed fresh and subsamples were taken. All subsamples were dried in an air forced oven at a temperature of 60 degrees Celsius for 48 h. The dry matter percentage was then used to calculate dry matter yield of each species. Aubade Westerwold Ryegrass was cut one additional time on August 5, 2014 and two additional times on July 27 and August 25, 2015. This was done because of the rapid growth and development of Aubade, so the harvest done on this species on October 15 was regrowth biomass. A total yield of Aubade was determined by adding the yields of all cuts.

4.2.3.4 Forage composition (nutritive value) determination

Samples were taken from each plot around mid-August and mid-September in each year, in addition to the sample taken in the mid-October harvest described in session 4.2.3.3. These dry matter samples were ground in a Wiley Mill to pass through a 1 mm screen and then sent to the Central Testing Lab in Winnipeg, Manitoba to be analyzed for nutrient composition. Variables measured are listed in Table 4.2. Monthly subsamples were used to determine the trend of nutritive value with advancing maturity in both years, however, these trends were not a focus of this thesis. The nutritive value of the October sampling was the focus of the thesis as this was the stockpiled forage.

Table 4.2 Measurements of annual forage composition.

	Categories	
Protein and fiber	Energy variables	Mineral variables
Crude protein (CP)	Digestible energy (DE)	Potassium (K)
Total digestible nutrients (TDN)	Metabolizable energy (ME)	Calcium (Ca)
Acid detergent fiber (ADF)	Net energy of maintenance (NEM)	Magnesium (Mg)
Neutral detergent fiber (NDF)	Net energy of gain (NEG)	Nitrates (NO_3)
	Net energy of lactation (NEL)	Phosphorus (P)

4.2.3.5 Forage tetany ratios

Annual forage potentials to cause grass tetany were calculated from % units of Mg, Ca and K: Ratio = (K * 255.74) / (Ca * 499 + Mg * 882.64). There is a greater susceptibility of the tetany symptoms to occur in cattle grazing the specific forage when the ratio is above 2.2 (Bohman et al., 1983; Horn, 1983; Littledike and Bohman, 1984).

4.2.4 Statistical analysis

Analysis of variance (ANOVA) was performed in a randomized complete block design (RCBD) with four replicates using SAS mixed procedure (SAS Institute, 2014). Year was treated as a fixed effect and the random effect consisted of block nested within year. The two-way interaction, year × species was used to determine if the data should be combined over years. When the interaction was significant, data were presented for the individual factors separately by years. When no significant interaction was shown, data were combined over the two years. Mean separation was performed using Tukey's HSD at $P < 0.05$. A coefficient of variance was calculated to express the variability of the model.

4.3 Results

4.3.1 Climate data

Monthly temperature and precipitation of experimental years are listed in Table 4.3. During 2014, annual forage were seeded in a cool but wet June and experienced a very dry summer and fall period with much less rainfall from July to October compared with the average precipitation in these months (Table 4.3). The growing season in 2015 was variable with extremely low rainfall in May and June but much higher precipitation accompanied by higher temperatures from July to October than in 2014. Monthly precipitation in 2015 from July to October was 35%, 35%, 54%, and 92% higher than the long-term average, respectively (Table 4.3).

Table 4.3 Monthly mean temperature and precipitation during 2014, 2015, and 2016, and long-term average monthly temperature and precipitation in Saskatoon.

	Monthly mean temperature			Monthly precipitation		
	2014	2015	Avg.†	2014	2015	Avg.†
Month		°C			mm	
January	-15.0	-11.8	-14.8	6.1	5.8	15.0
February	-19.2	-17.4	-11.0	2.1	16.5	11.0
March	-10.1	-1.2	-4.3	5.8	5.7	12.0
April	1.7	6.2	5.3	74.2	41.1	24.0
May	10.1	11.3	12.2	61.1	6.3	52.0
June	14.1	18.1	16.6	94.8	20.2	60.0
July	18.3	20.1	19.1	44.5	85.1	63.0
August	17.9	18.6	18.0	18.5	58.2	43.0
September	12.4	12.9	12.2	10.7	50.8	33.0
October	6.7	7.9	5.5	14.1	32.7	17.0
November	-9.7	-1.8	-4.7	30.5	15.6	13.0
December	-9.4	-8.1	-12.4	2.5	4.0	14.0
Total	NA‡	NA	NA	364.9	342.0	357.0

† Average of 30 yr. in Saskatoon (1981-2010), obtained from Environment Canada (2017).
‡ NA, denotes not applicable.

4.3.2 Lodging measurements

All species except corn were found to have more lodging in year 2015 compared with year 2014; however there was No lodging, in corn. Oats, however, had the highest lodging scores among all the species in year 2015, with 45% of the whole plot lodged 30° from vertical. Fall rye and barley were found to have 20% of the plot slightly lodged 15° and 10° respectively in year 2014 while 40% and 35% of the plots lodged 15° in year 2015. The majority of the stands, however, remained upright. All other species were found to have little lodging in both years (Table 4.4 & 4.5).

Table 4.4 Annual species lodging score in year 2014.

Species	Cultivars	Lodged area (%)	Angle	Score
Fall Rye	Hazlet	20	15	3.3
Barley	Maverick	20	10	2.2
Corn	Fusion	0	0	0.0
Soybean	Mammoth	0	0	0.0
Ryegrass	Aubade Westerwold	5	5	0.3
Oats	Haymaker	2	5	0.1
Millet	Golden German Foxtail	5	10	0.6

Loding score range: 0.0, 100% plot erect; 50.0, 100% plot flat.

Table 4.5 Annual species lodging score in year 2015.

Species	Cultivars	Lodged area (%)	Angle	Score
Fall Rye	Hazlet	40	15	6.7
Barley	Maverick	35	15	5.8
Corn	Fusion	0	0	0.0
Soybean	Mammoth	4	15	0.7
Ryegrass	Aubade Westerwold	10	5	0.6
Oats	Haymaker	45	30	15.0
Millet	Golden German Foxtail	3	15	0.5

Loding score range: 0.0, 100% plot erect; 50.0, 100% plot flat.

4.3.3 Stockpiled dry matter yield

Annual forage stockpiled dry matter yield (SDM) exhibited significant species by site-year interaction ($P < 0.001$) (Table 4.6).

Table 4.6 P-values for stockpiled dry matter yield (SDM), crude protein (CP), total digestible nutrients (TDN), acid detergent fiber (ADF), neutral detergent fiber (NDF), Calcium (Ca), phosphorus (P) and nitrate (NO_3) concentrations of annual species in 2014 and 2015.

Source	SDM	CP	TDN	ADF	NDF	Ca	P	NO_3
Species (S)	< 0.001***	< 0.001***	< 0.001***	< 0.001***	< 0.001***	< 0.001***	< 0.001***	0.043*
Year (Y)	NS	NS	< 0.001***	< 0.001***	< 0.001***	NS	NS	NS
S × Y	< 0.001***	NS	< 0.001***	< 0.001***	< 0.001***	< 0.001***	0.007**	NS

*, **, ***, significant at the 0.05, 0.01 and 0.001 probability levels. NS, nonsignificant.

There was no significant difference in the mean production between years with 6.2 Mg ha^{-1} and 6.4 Mg ha^{-1} for 2014 and 2015. Oats and millet consistently had high SDM across years. The yield of corn, however, was two times higher in 2015 (15.8 Mg ha^{-1}) than in 2014 (6.8 Mg ha^{-1}) (Figure 4.3). Production of barley and soybean on the contrary, dropped dramatically in the year of 2015 compared with that in the previous year. Fall rye consistently had the lowest yield (Figure 4.3).

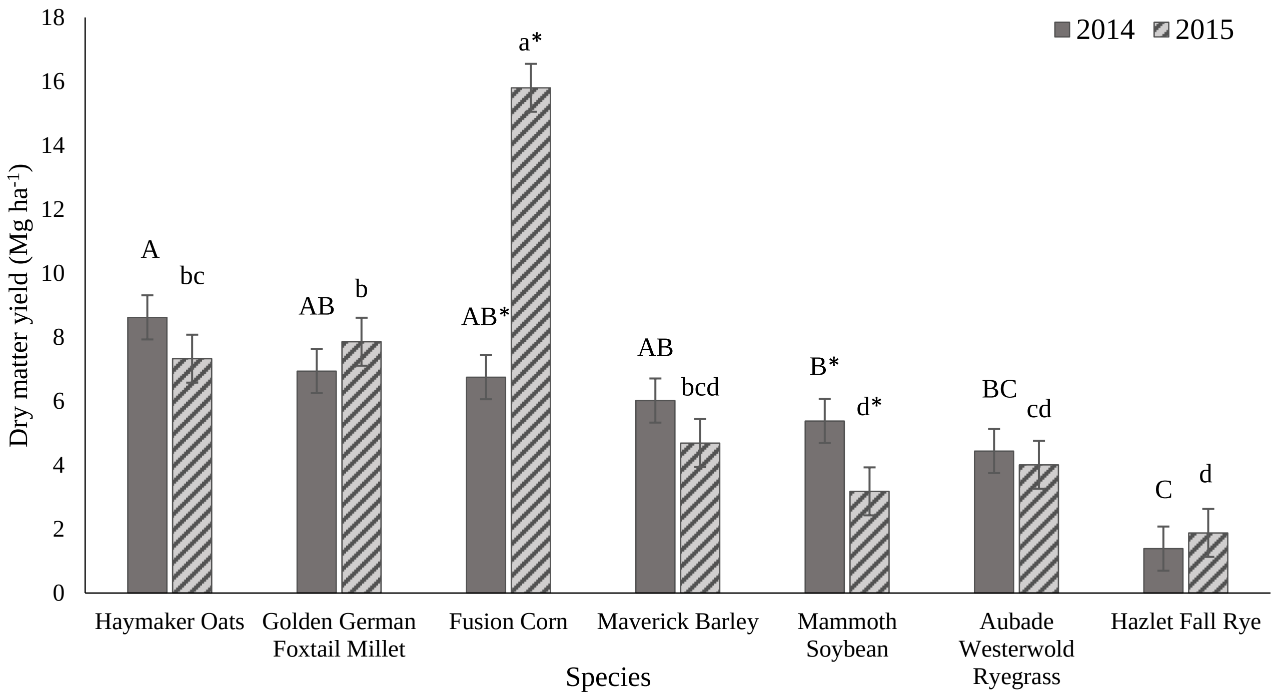

Figure 4.3 Stockpiled dry matter yield of annual species in 2014 and 2015. Error bars represents the standard error. The same uppercase letters indicate no significant difference in year 2014 based on $HSD_{0.05}$. The samelower case letters indicate no significant difference in year 2015 based on $HSD_{0.05}$. Letters with ‘*’ indicate significant differences between years.

4.3.4 Nutritive values

4.3.4.1 Crude protein and energy concentrations

Annual species differed significantly from each other in CP concentrations (P < 0.001) (Table 4.6). Fall rye and soybean had the highest protein concentrations among all species. Crude protein concentrations of other species ranged from 60.2 g kg^{-1} (Millet) to 82.3 g kg^{-1} (Ryegrass), and were not significantly different (Figure 4.4).

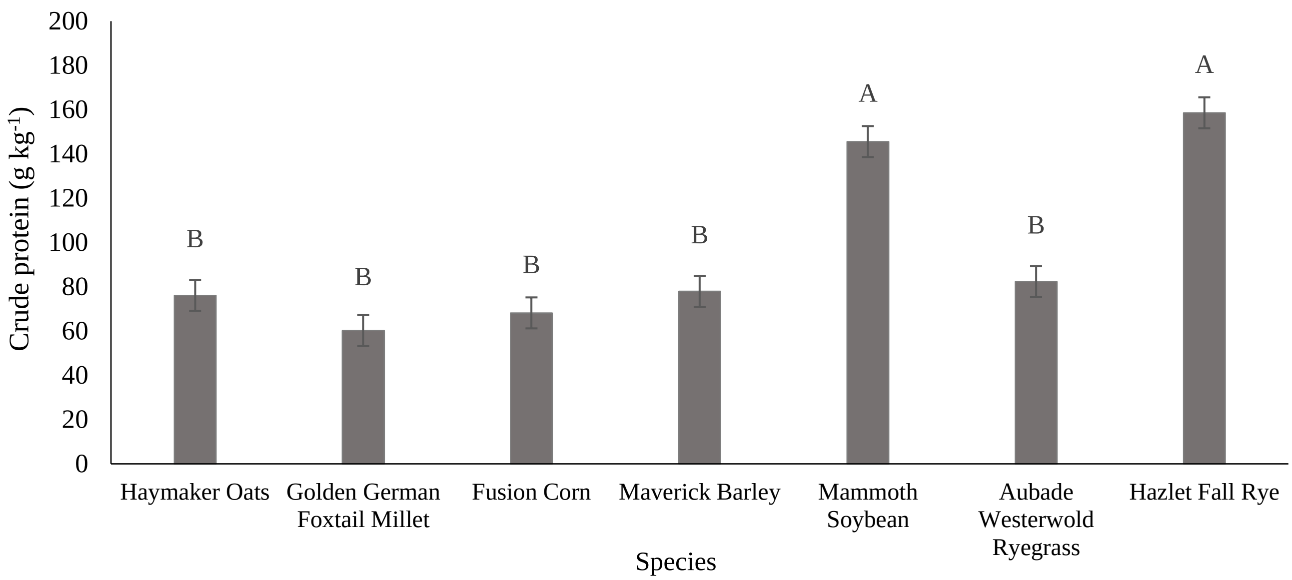

Figure 4.4 Crude protein concentration of annual species in 2014 and 2015. Error bars represents the standard error. The same letters indicate no significant difference based on $HSD_{0.05}$.

Forage TDN concentrations exhibited significant species by year interaction (P < 0.001) (Table 4.6). Mean TDN concentration in 2015 was significantly higher than that in 2014 (P < 0.001) (Table 4.6). Ryegrass, barley and oats ranked higher in TDN in 2015 than in 2014 (Figure 4.5). All other species had TDN values that were not significantly different between the two years.

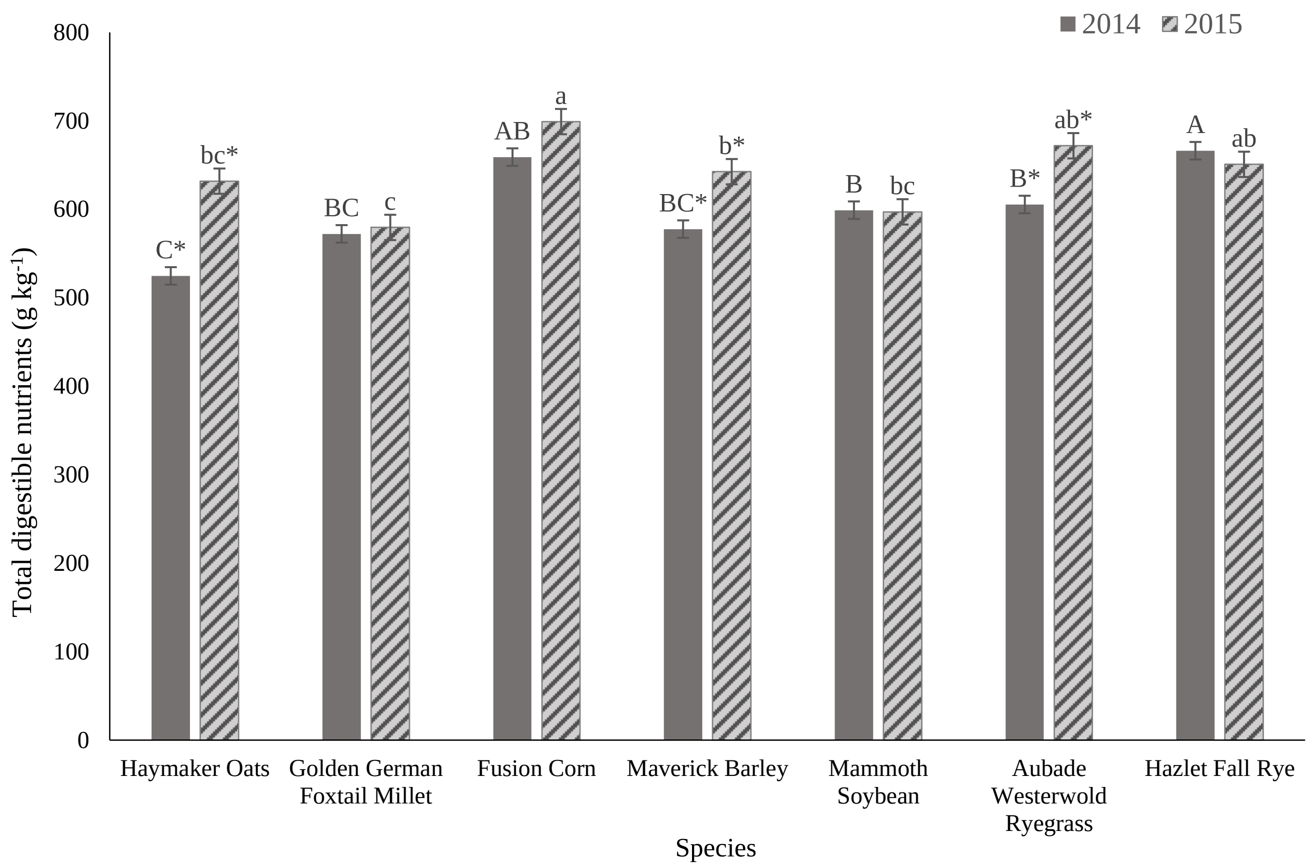

Figure 4.5 Total digestible nutrients of annual species in 2014 and 2015. Error bars represents the standard error. The same uppercase letters indicate no significant difference in year 2014 based on $HSD_{0.05}$. The same lower case letters indicate no significant difference in year 2015 based on $HSD_{0.05}$. Letters with '*' indicate significant difference between years.

4.3.4.2 Forage fiber concentrations

Fiber contentrations were significantly influenced by species × year interaction ($P < 0.001$) (Table 4.4). Species tended to have lower fiber concentrations in 2015 than in 2014, with oats, barley and ryegrass being significantly lower in both ADF and NDF in 2015 .. Corn was significantly lower in ADF than most species, while soybean was significantly lower than most species in NDF (Figures 4.6 and 4.7).

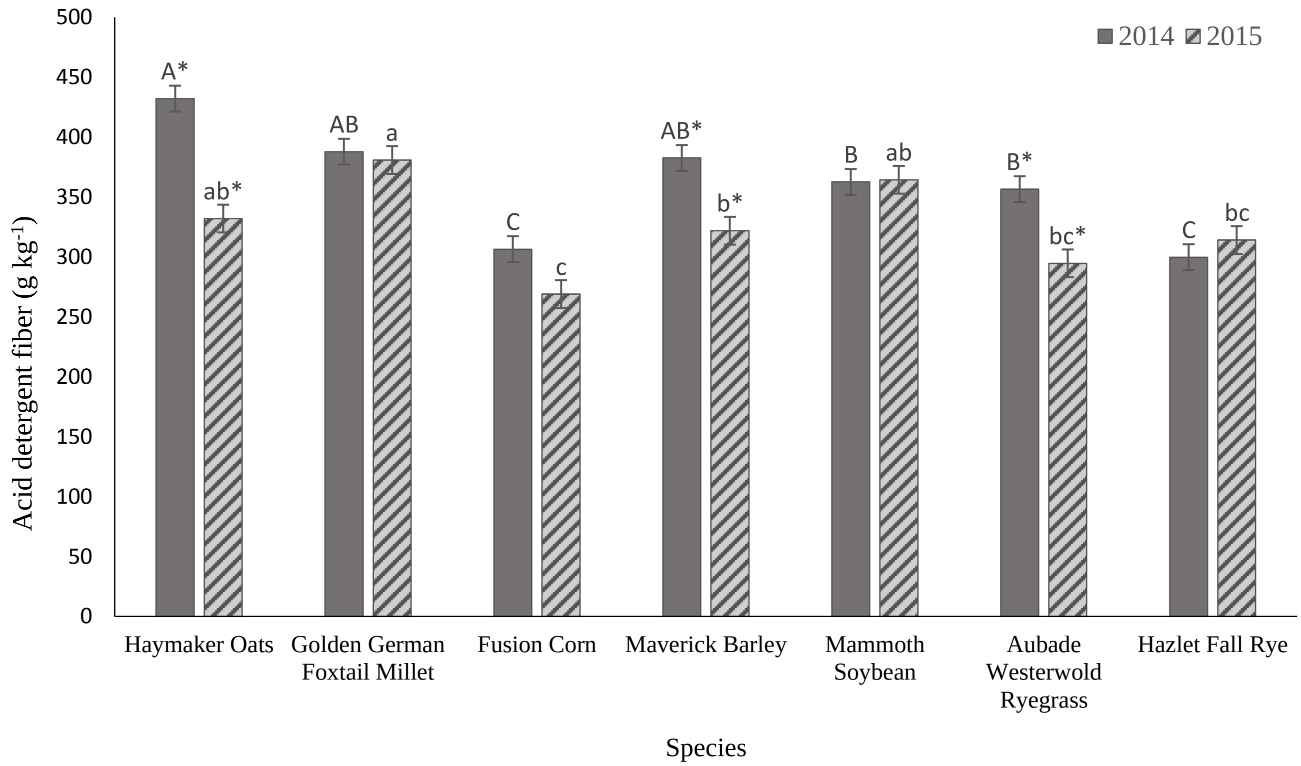

Figure 4.6 Acid detergent fiber of annual species in 2014 and 2015. Error bars represents the standard error. The same uppercase letters indicate no significant difference in year 2014 based on $HSD_{0.05}$. The same lower case letters indicate no significant difference in year 2015 based on $HSD_{0.05}$. Letters with '*' indicate significant difference between years.

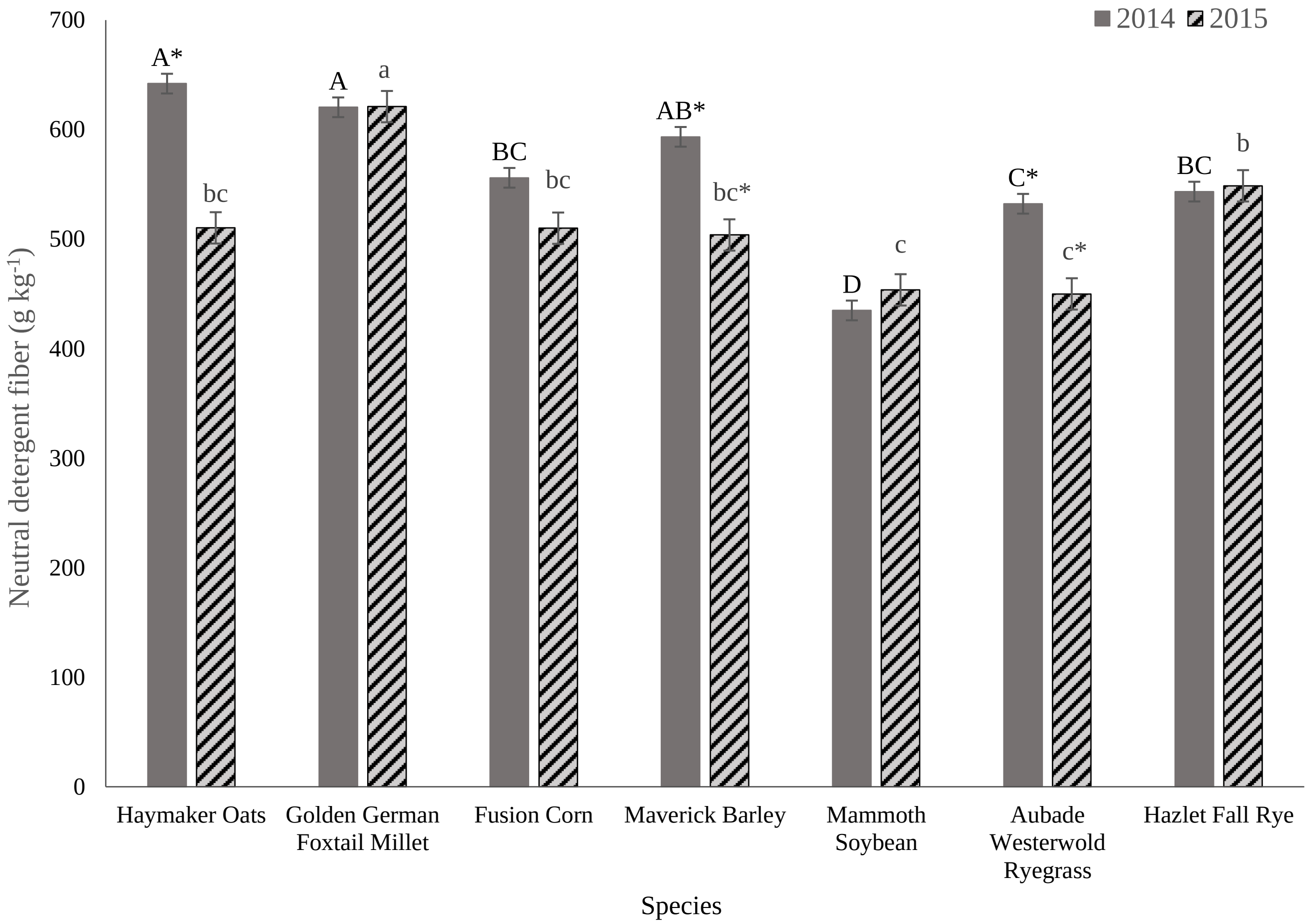

Figure 4.7 Neutral detergent fiber of annual species in 2014 and 2015. Error bars represents the standard error. The same uppercase letters indicate no significant difference in year 2014 based on $HSD_{0.05}$. The same lower case letters indicate no significant difference in year 2015 based on $HSD_{0.05}$. Letters with '*' indicate significant difference between years.

4.3.4.3 Forage Calcium (Ca) and phosphorus (P) concentrations

Both forage Ca and P concentrations exhibited significant species by site-year interaction ($P <$ 0.001) (Table 4.4). There was no yearly difference found in species mean mineral concentrations ($P >$ 0.05) (Data not shown). Soybeans had significantly higher Ca concentrations in both years compared with other species, There were some small, but significant, differences in Ca concentrations between years for some species (Figure 4.8).

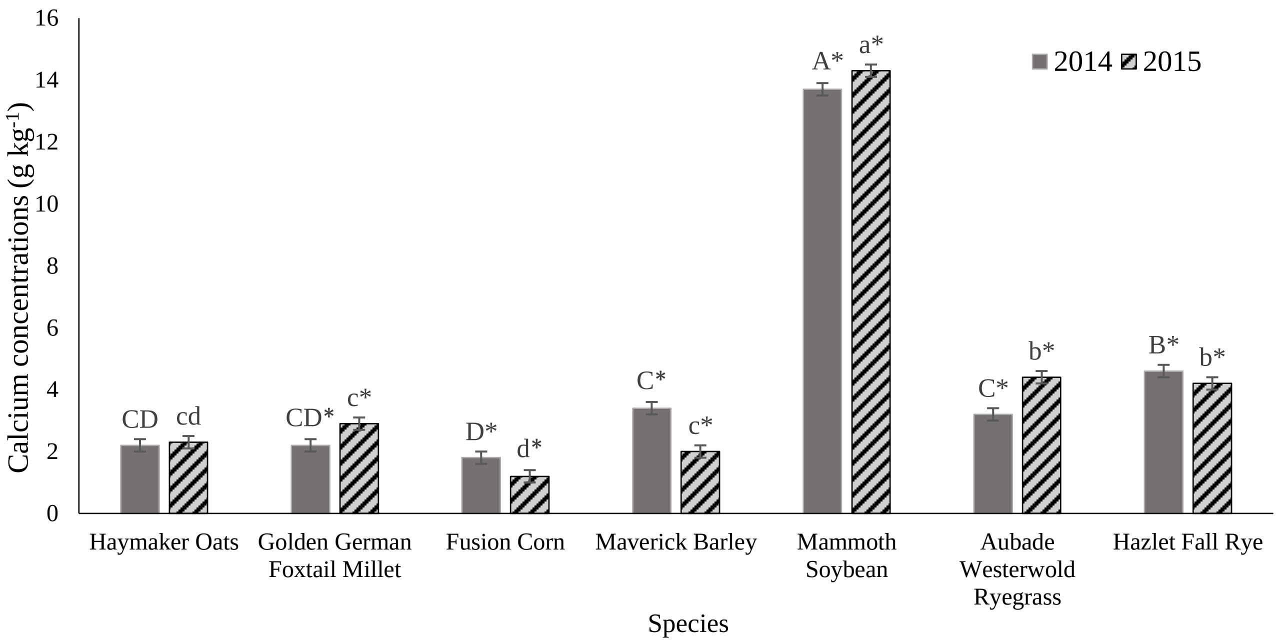

Figure 4.8 Calcium concentration of annual species in 2014 and 2015. Error bars represents the standard error. The same uppercase letters indicate no significant difference in year 2014 based on $HSD_{0.05}$. The same lower case letters indicate no significant difference in year 2015 based on $HSD_{0.05}$. Letters with '*' indicate significant difference between years.

For P concentrations, fall rye had significantly higher P concentrations than all species in both years (Figure 4.9). The only species that differed in P concentration between years was ryegrass (Figure 4.9).

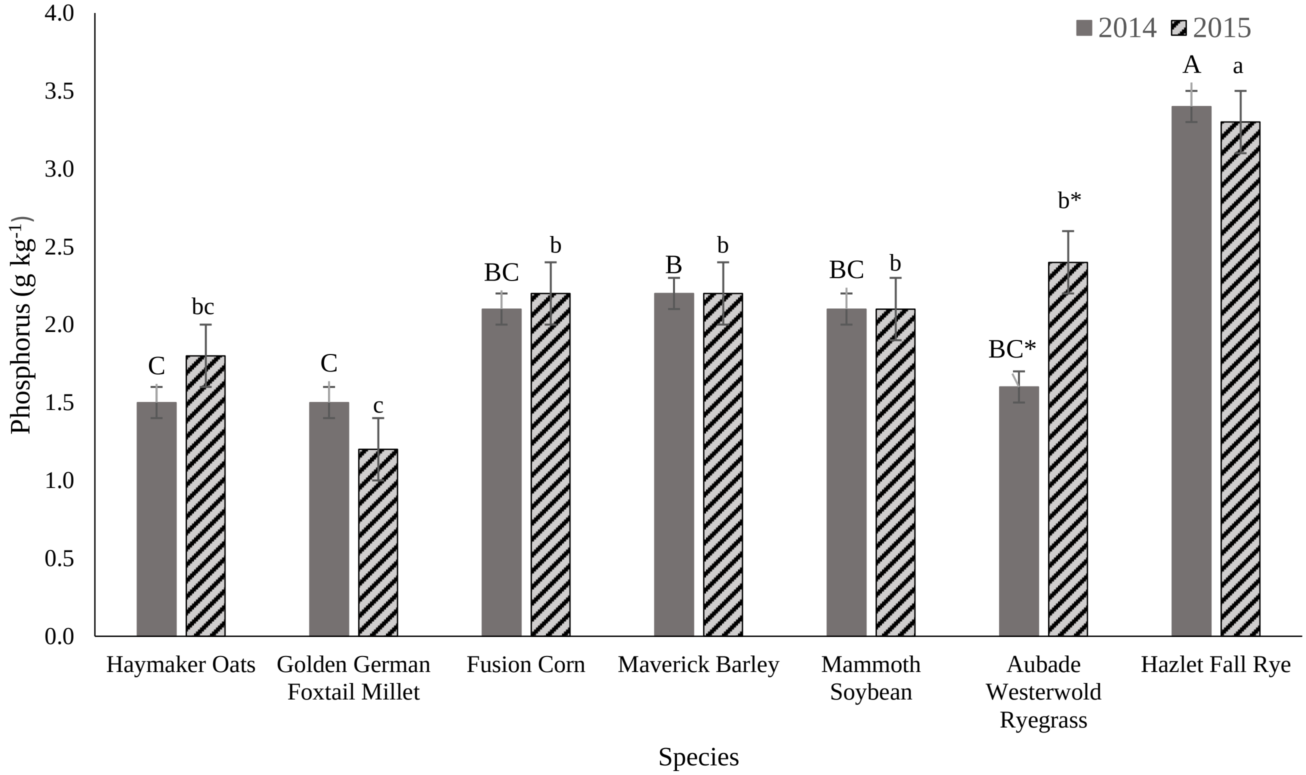

Figure 4.9 Phosphorus concentration of annual species in 2014 and 2015. Error bars represents the standard error. The same uppercase letters indicate no significant difference in year 2014 based on $HSD_{0.05}$. The same lower case letters indicate no significant difference in year 2015 based on $HSD_{0.05}$. Letters with '*' indicate significant difference between years.

4.3.5 Tetany ratios and nitrate concentration

Tetany ratios of annual species varied between years (Table 4.7). Fall rye and barley had among the highest ratios in both years with that in year 2014 exceeding the critical value of 2.2, indicating grass tetany symptoms could occur when animals were grazing these two species. Other species had ratios which were below 2.2 (Table 4.7).

Nitrate concentrations were significantly different among species but showed no species by year interaction (Table 4.4). Nitrate concentrations of all annual forages were well below 0.5 %, meaning there was no safety concern for animals utilizing stockpiled forage (Table 4.8).

Table 4.7 Annual forage tetany ratios in 2014 and 2015.

Species	Cultivars	2014	2015
Fall Rye	Hazlet	2.3	1.8
Barley	Maverick	2.5	1.7
Corn	Fusion	0.5	0.4
Soybean	Mammoth	1.7	1.4
Ryegrass	Aubade Westerwold	1.5	1.8
Oats	Haymaker	0.8	0.9
Millet	Golden German Foxtail	1.0	1.0

Table 4.8 Nitrate concentrations of annual species of year 2014 and 2015.

	NO_3
Species	%
Aubade Westerwold Ryegrass	0.36
Haymaker Oats	0.22
Mammoth Soybean	0.16
Fusion Corn	0.14
Maverick Barley	0.13
Golden German Foxtail Millet	0.09
Hazlet Fall Rye	0.06
Mean	0.17
HSD†	0.29
CV%‡	23.1

† HSD (P < 0.05), tests among means for NO_3.

‡ CV, coefficient of variation.

4.4 Discussion

The results from this study demonstrated the variability in yield and nutritive value among annual forage species in a stockpiling system. This is similar to previous studies that showed that annual species differed in forage yield and nutritive value, which offered flexibility in grazing management (Manitoba Government, 2016). Whether additional biomass or higher quality forage is needed to accompany perennial forage, producers have options for choosing the right species.

All species had dry matter production well above the minimum requirement (2.0 Mg ha^{-1}) except for fall rye that failed to meet the minimum requirement for biomass production in both years. Corn, had significantly lower production in 2014 compared with year 2015 (Figure 4.3) mostly due to the low density stands resulting from Canada geese feeding on seedlings. The low crop density contributed to the low yield that year. In addition, corn production requires sufficient heat, expressed as "corn heat units" (CHU). When the grain is not sufficiently filled due to lower heat unit accummulation, corn total biomass yield will be lower (Alberta Agriculture and Forestry, 2014). The year 2015 was warmer than 2014 in the months of June, July and August (Table 4.3). For example, June temperatures were four degrees cooler in 2014 likely contributing to the lower yields that year. However, corn still produced 6.8 Mg ha^{-1} biomass in 2014, higher than barley which has been reported to out yield corn (Alberta Agriculture Food and Rural Development. 2008). Millet was found to only have high yield without previous cutting since its regrowth ability was limited (Manitoba Government, 2004). When directly saved for winter stockpiling the present study, millet showed consistent moderate to high yields (Figure 4.3). Barley and soybean had lower production in the warmer year of 2015 perhaps because the growth of cool-season species is less in hotter summer conditions (Alberta Agriculture Food and Rural Development. 2008). The dry conditions in May and June may also have reduced yields of barley. Soybean, was also found to be severely damaged by frost in October, 2015 with plants turning black and losing leaves, reducing yield and nutritive value. Frosts have been previously found to reduce the energy content of soybeans (Blout et al., 2015). Mild lodging may also limit the use of these two species in winter sockpiling (Table 4.5 & 4.6). Ryegrass had a total biomass (8.1 Mg ha^{-1}) which was much more than its stockpiled biomass. Due to its rapid maturity, additional cuts were applied, indicating that cattle could start grazing annual ryegrass in mid to late summer when other annual crops are still immature. Fall rye showed little potential for stockpiled production with SDM yields less than 2.0 Mg ha^{-1}, which is contrary to a previous report that fall rye can grow well late in the season (Manitoba Government, 2016). Spring seeded fall rye remains vegetative in the year of seeding reducing its yielding ability (Government of Alberta, 2011). Oats ranked the second highest in yield, however, it tended to have a severe lodging problem after a wet and hot summer (Table 4.6).

Forage nutritive value is also an important factor in assessing the potential of annual forage species for stockpiling. Crude protein concentration is key to the health and growth of grazing animals. Fall rye and soybean had higher October protein concentrations than the other tested species. Grazing animals have different nutritional requirements based on their stage of production (NASEM, 2016). Mature cows and heifers required at least 62 g kg^{-1} CP 7 months post-calving and up to 129 g kg^{-1} in the postpartum stage. During mid-gestation period, the CP requirement was lower with the range from 65 to 89.0 g kg^{-1} (NASEM, 2016). In the present study, corn barely met the lactation stage requirement while millet did not provide sufficient CP. Barley, oats and ryegrass had high enough CP to be utilized during the lactation or mid-gestation periods. Fall rye and soybean, however, had high enough CP concentrations for all animal stages. Growing cattle being raised for 1000-1500 pounds finishing weight need between 71 to 179 g kg^{-1} CP contents (NASEM, 2016). Again, only soybean and fall rye were able to reach this requirement and would potentially reduce the supplemental feed costs. Alberta Agriculture Food and Rural Development (2008) stated that annual ryegrass had good potential for winter stockpiling since the regrowth had nutrient concentrations that were adequate for all classes of beef cattle in October, which was not found in our study. Annual ryegrass did show higher CP concentration in September because of its less mature regrowth (Data not shown); however, its October CP concentration was not high enough for most of the cattle classes. Our experiment further found that CP contents of all species, except for ryegrass, dropped during the August to October period as the plants reached more advanced stages of maturity. In August, species tended to have much higher CP contents and were suitable for most of the cattle classes (Data not shown). This indicated that producers could use annual forage in late summer to provide more nutritious feed instead of saving for stockpiling.

Total digestible nutrients represent the energy content of the forage crop, which is a crucial factor in maintaining stable body temperature under winter conditions (Government of Alberta, 2011). All species in our study were found to have suitable TDN contents for all stage cow and heifers, and grazing cattle that had finishing weight ranging from 1000 to 1500 pounds (Figure 4.5). Corn has been reported to have consistent high energy concentration (Rusby and Martin, 2016) and was suggested to be utilized during the coldest months of the winter as cattle required higher energy intake at this time (Baron et al., 2014). Our study also showed that corn had the highest energy levels of the species tested. However, all species were adequate in providing energy, meaning no supplementation would be required

The experiment examined species fiber contents (ADF & NDF) that were closely related to TDN. Lower ADF concentrtions are associated with higher digestibility of species. Our study showed that corn had the lowest ADF and intermediate NDF among the species tested (Figures 4.6 & 4.7) which was similar to previous study by Rusby and Martin (2016). Golden German millet consistently had high fiber concentrations (Figures 4.6 & 4.7). Despite the higher fiber, millet is recognized as a palatable species to grazing livestock (Government of Saskatchewan, 2016). Several of the tested cool-season species showed the trend of being less fibrous and lower in yield in the summers of the two years (Figure

4.3). This trait has been noted for cool-season perennial species in other studies. Fall-grown oat was studied as an emergency crop in several plot-scale projects throughout central Wisconsin, USA and found to store enough water-soluble carbohydrates to be less fibrous and more cold tolerant (Contreras-Govea and Albrecht, 2006; Coblentz and Walgenbach, 2010; Coblentz et al., 2012). Both CP and TDN levels exceeded requirements for dairy heifers even with monthly precipitation fluctuation. It is further stated that fall-grown oat had a slower maturation rate due to the interruption of the long-day photoperiod requirement for flowering compared with spring established oats (Dennis, 1984). Our study, using spring-seeded oats, showed high fiber contents, especially ADF, which was in accordance with what had been observed in other studies.

Forage Ca and P concentrations in all tested species were found to meet the requirement of all cow and beef cattle in various classes (NASEM, 2016). Forage tetany ratio, however, may be a concern. It was found that fall rye and barley had a higher tetany ratio when stockpiled following a cooler and drier growing season. Producers should have forage analyzed for tetany potential when stockpiling these two species. Forage nitrate concentration was not an issue in October stockpiled forage in our study; none of the species examined had nitrate concentrations higher than the risk level (Table 4.5). Annual forage are generally recognized to have a higher risk of excessive nitrate concentrations compared with perennials (Manitoba Government, 2016).

Both forage biomass and nutritive value are important factors in deciding whether a crop can be used in stockpiling systems. Seed price is another consideration in choosing species for stockpiled grazing. In regards to the economics, soybean and corn are among the highest seed costs. Corn can often make up for this higher seed cost by providing higher yields with more energy (Manitoba Government, 2016). Soybean have the advantage of fixing its own nitrogen, thus reducing fertilizer costs. However, it is also sensitive to frost damage and may lose many of its leaves which are the most nutritious plant part. Oats and barley have lower seed prices, but are not as high yielding as corn. The other issue related to oats is the lodging that might reduce the forage production. It is safe and beneficial to practice winter stockpiling in Canadian western prairie regions with a variety of annual forages.

4.5 Conclusions

This study examined various traits of seven annual species under a stockpiling system. Many differences were found among these species, including forage yield, nutritive value and toxicity level. Fall rye and soybean, for example, had the highest protein concentration but the lowest dry matter yield. If high forage yield is desirable for producers to compensate for a shortage of forage, then corn, millet and oats would be good candidates. Producers might desire crops to graze in August, then ryegrass could provide high quality forage during these months and its regrowth could be stockpiled for winter months. If a high energy crop is required, corn would be selected since its TDN was the highest regardless of year. If high protein is required, fall rye would be a good choice, although its yields were the lowest. Soybean is a legume crop with high protein contents but it should be utilized before leaf loss. Most species did not show substantially higher fiber contents in October compared with August. Nitrate concentration was not a major concern in our study, however, barley and fall rye should be tested for tetany ratio especially following a cooler summer. The results of this research demonstrated that annual species can be used for winter stockpiling for grazing animals. Certain protein and mineral supplements might be required at specific stages of animal development depending on the species selection. In the long-term, this research could benefit producers by providing forage to extend the grazing season.

5.0 General discussion and conclusions and future research

5.1 General discussion

As well as providing stockpiled forage, most of the perennial species/mixtures in this study provided enough biomass for spring/summer grazing (Table 3.8). Pure stands including two meadow brome cultivars Armada and Fleet, Algonquin alfalfa and Success hybrid brome reached the spring/summer production requirements (3.5 Mg ha^{-1}) (Alberta Agriculture and Forestry, 1998) regardless of environmental conditions. These species were also drought tolerant. Species such as orchardgrass, tall fescue and cicer milkvetch that developed growth later in the spring had the lowest June yield. Accordingly, mixed stands with grass part meadow brome yielded significantly higher than cicer milkvetch in mixtures with orchardgrass or tall fescue. We further observed that adequate May/June rainfall was important in maintaining spring/summer production of both early and late growing species.

Perennial species under early stockpile initiation had higher mean regrowth production but lower nutritive value than species under late stockpile initiation, which was in accordance with our first hypothesis. Species following late stockpile initiation failed to meet the minimum production requirement (2.0 Mg ha^{-1}) for late fall/winter grazing (Alberta Agriculture Food and Rural Development, 2008). We further observed that cool-season species would be more productive but more mature and less nutritious in a cool summer compared to species that experienced a hot summer. The majority of the pure and mixed stands could meet the minimum production requirement for late fall/winter grazing, among which meadow bromegrass, in either pure or mixed stands ranked the highest in SDM. This was in accordance with what Baron et al. (2005) found. The next most productive species for SDM were tall fescue, with either pure or mixed stands and hybrid brome-legume mixed stands. Cicer milkvetch, orchargrass, Algonquin alfalfa, Yellowhead alfalfa and hybrid brome/cicer milkvetch failed to meet the minimum winter stockpiled forage yield, indicating their unreliability for winter stockpiling.

Regardless of the effects of environment as well as stockpile initiation, the majority of cultivars/mixtures in this study met these basic requirements for CP, TDN and fiber concentrations (NASEM 2016). Pure legume species ranked the highest in CP and TDN, especially under late stockpile initiation while grass stands in our study had significantly lower quality compared with legume stands which was opposite from our second hypothesis. Several mixed and pure stands failed to maintain the minimum nutrition requirements but only in the year with a cooler summer. Mineral concentrations for all the stands were adequate for winter grazing animals.

Seven annual species showed varying performances in SDM and nutritive value. Corn had the highest DM yield with high TDN concentration regardless of the year, which made it attractive in stockpiling systems. The other warm-season crop, millet, had reasonably high yields but low CP concentration. Fall rye and soybean had the highest protein concentration but the lowest dry matter yield. Ryegrass could provide high quality forage during summer months and its regrowth could be stockpiled for winter months, but its SDM is low. Barley and oat were intermediate in SDM and nutritive value and would be adequate for stockpiling systems. The risk of grass tetany may be an issue following a warmer growing season. Our results identified several annual species that can be used for stockpiled forage that could supplement production from perennial species.

Research from this thesis showed that utilizing perennial and annual species in stockpiling systems was a viable option to extend the grazing season in the Canadian great plains region. Weather conditions cause variation in species performance as the performance and ranking of some of the tested species varied over the two years of study. It may be advantageous for livestock farms to practice stockpiling with both perennial and annual species; perennials require a longer time to establish, while annuals are more expensive to establish and manage (Manitoba Government, 2015). When perennials are in short supply, producers can rely on highly productive annual species for forage late in the fall.

Based on the number of the livestock and their production stages, different species can be chosen with specific accumulation periods to get either abundant biomass or highly nutritious forage to reduce the nutrient supplements required in winter.

5.2 Future research

This 2-yr study has provided a an examination of the potential of a range of annual and perennial stands for use in winter stockpiling systems. Twenty-three pure and mixed perennial stands and five cool- and two warm-season annuals were evaluated. All experiments were conducted under field conditions. Studies like this are somewhat limited since no follow up experiments related to actual animal grazing were conducted; neither was there a direct comparison between stockpiling feeding and a conventional dry lot winter feeding. It is difficult to estimate the economic benefits without doing actual feeding studies. Research conducted to date has focused on animal performance of stockpiled forage of a single or few species like meadow bromegrass and alfalfa li Future studies should combine stockpiling practice and animal grazing together so that both plant and animal performance could be evaluated. In addition, this study was conducted at one location in the dark brown soil zones, so it is unknown whether our results can be extrapolated to other zones in the Canadian great plains. Similar experiments should be conducted in other soil zones; in fact, data from the same studies have also been collected from black soil zone sites and our results will be compared to results from these other sites.

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Appendix A

Table A1 Forage height in June for perennial species in 2015 and 2016.

			Forage height in June			
			2015		2016	
Species	Cultivars	Legume in mixtures	Grass	Legume	Grass	Legume
			cm			
Meadow brome	Armada	------------	95	0	99	0
	Armada	Algonquin	88	39	98	42
	Armada	Yellowhead	81	37	91	44
	Armada	Oxley II	98	27	101	33
	Fleet	------------	97	0	102	0
	Fleet	Algonquin	88	42	91	47
	Fleet	Yellowhead	91	38	102	47
	Fleet	Oxley II	80	22	85	35
Hybrid brome	Success	------------	80	0	94	0
	Success	Algonquin	72	43	79	43
	Success	Yellowhead	68	37	89	41
	Success	Oxley II	85	24	90	30
Tall fescue	Courtenay	------------	39	0	47	0
	Courtenay	Algonquin	41	37	48	40
	Courtenay	Yellowhead	45	36	51	41
	Courtenay	Oxley II	37	26	42	34
Orchardgrass	Killarney	-------------	38	0	44	0
	Killarney	Algonquin	47	37	52	42
	Killarney	Yellowhead	46	33	50	44
	Killarney	Oxley II	50	34	61	45
Alfalfa	Algonquin	------------	0	44	0	54
	Yellowhead	------------	0	36	0	38
Cicer milkvetch	Oxley II	------------	0	22	0	32
Mean			59	27	70	32
HSD†			27	19	21	17
CV%‡			27	29	26	28

† HSD ($P < 0.05$), tests among means for forage height amon species within forage type.

‡ CV, coefficient of variation.

Table A2 Forage botanical composition in June for perennial species in 2015 and 2016.

			Forage botanical composition in June			
			2015		2016	
Species	Cultivars	Legume in mixtures	Grass	Legume	Grass	Legume
			%			
Meadow brome	Armada	------------	100	0	100	0
	Armada	Algonquin	57	43	45	55
	Armada	Yellowhead	61	39	72	28
	Armada	Oxley II	82	18	88	12
	Fleet	------------	100	0	100	0
	Fleet	Algonquin	54	46	49	51
	Fleet	Yellowhead	67	33	59	41
	Fleet	Oxley II	86	14	90	10
Hybrid brome	Success	------------	100	0	100	0
	Success	Algonquin	42	58	45	55
	Success	Yellowhead	44	56	23	77
	Success	Oxley II	78	22	58	42
Tall fescue	Courtenay	------------	100	0	100	0
	Courtenay	Algonquin	37	63	76	24
	Courtenay	Yellowhead	69	31	49	51
	Courtenay	Oxley II	82	18	75	25
Orchardgrass	Killarney	-------------	100	0	100	0
	Killarney	Algonquin	34	66	18	82
	Killarney	Yellowhead	41	59	51	49
	Killarney	Oxley II	83	17	71	29
Alfalfa	Algonquin	------------	0	100	0	100
	Yellowhead	------------	0	100	0	100
Cicer milkvetch	Oxley II	------------	0	100	0	100
Mean			62	39	60	40
HSD†			19	19	18	21
CV%‡			15	22	17	21

† HSD ($P < 0.05$), tests among means for forage botanical composition in June among species within forage type.

‡ CV, coefficient of variation.

Table A3 Forage botanical composition in October for perennial species in 2015 and 2016.

			Forage botanical composition in October			
			2015		2016	
Species	Cultivars	Legume in mixtures	Grass	Legume	Grass	Legume
			%			
Meadow brome	Armada	------------	100	0	100	0
	Armada	Algonquin	41	59	37	63
	Armada	Yellowhead	44	56	48	52
	Armada	Oxley II	90	10	90	10
	Fleet	------------	100	0	100	0
	Fleet	Algonquin	70	30	78	22
	Fleet	Yellowhead	65	35	67	33
	Fleet	Oxley II	85	15	93	7
Hybrid brome	Success	------------	100	0	100	0
	Success	Algonquin	10	90	12	88
	Success	Yellowhead	24	76	18	82
	Success	Oxley II	50	50	60	40
Tall fescue	Courtenay	------------	100	0	100	0
	Courtenay	Algonquin	38	62	30	70
	Courtenay	Yellowhead	42	58	38	62
	Courtenay	Oxley II	90	10	88	12
Orchardgrass	Killarney	-------------	100	0	100	0
	Killarney	Algonquin	20	80	14	86
	Killarney	Yellowhead	44	56	40	60
	Killarney	Oxley II	85	15	97	3
Alfalfa	Algonquin	------------	0	100	0	100
	Yellowhead	------------	0	100	0	100
Cicer milkvetch	Oxley II	------------	0	100	0	100
Mean			56	44	60	43
HSD†			38	33	36	37
CV%‡			33	29	31	40

† HSD (P < 0.05), tests among means for forage botanical composition in June among species within forage type.

‡ CV, coefficient of variation.

Table A4 Forage stage of maturity in June for perennial species in 2015 and 2016.

Forage stage of maturity in June						
			2015		2016	
Species	Cultivars	Legume in mixtures	Grass	Legume	Grass	Legume
Meadow brome	Armada	------------	3.3	0	3.3	0
	Armada	Algonquin	3.1	2	3.3	3
	Armada	Yellowhead	3.1	2	3.3	2
	Armada	Oxley II	3.3	1	3.3	2
	Fleet	------------	3.3	0	3.3	0
	Fleet	Algonquin	3.0	2	3.1	3
	Fleet	Yellowhead	3.1	2	3.1	3
	Fleet	Oxley II	3.1	1	3.1	2
Hybrid brome	Success	------------	3.1	0	3.0	0
	Success	Algonquin	3.0	2	3.0	2
	Success	Yellowhead	3.1	2	3.1	3
	Success	Oxley II	3.1	2	3.1	2
Tall fescue	Courtenay	------------	2.6	0	2.8	0
	Courtenay	Algonquin	2.8	2	2.8	3
	Courtenay	Yellowhead	2.6	2	2.7	2
	Courtenay	Oxley II	2.4	2	2.6	2
Orchardgrass	Killarney	-------------	2.9	0	2.8	0
	Killarney	Algonquin	2.7	2	2.7	3
	Killarney	Yellowhead	2.7	2	2.6	2
	Killarney	Oxley II	2.6	2	2.7	2
Alfalfa	Algonquin	------------	0.0	2	0.0	2
	Yellowhead	------------	0.0	2	0.0	3
Cicer milkvetch	Oxley II	------------	0.0	2	0.0	2
Mean			2.6	1	2.6	2

Note: the method of Kalu and Fick (1981) was used for legumes. The method of Moore et al., (1991) was used for grasses.

Table A5 Forage stage of maturity in October for perennial species in 2015 and 2016.

			2015		2016	
Species	Cultivars	Legume in	Grass	Legume	Grass	Legume
			Heading	Ripe pod	Heading	Ripe pod
			%			
Meadow brome	Armada	------------	5	-------	20	-------
	Armada	Algonquin	3	0	15	0
	Armada	Yellowhead	1	0	25	5
	Armada	Oxley II	0	5	25	10
	Fleet	------------	3	-------	20	-------
	Fleet	Algonquin	5	0	25	2
	Fleet	Yellowhead	3	0	10	0
	Fleet	Oxley II	5	0	10	2
Hybrid brome	Success	------------	30	-------	70	-------
	Success	Algonquin	10	1	60	0
	Success	Yellowhead	10	0	50	2
	Success	Oxley II	30	3	50	0
Tall fescue	Courtenay	------------	0	-------	15	-------
	Courtenay	Algonquin	0	1	25	1
	Courtenay	Yellowhead	0	0	10	0
	Courtenay	Oxley II	2	0	15	5
Orchardgrass	Killarney	-------------	1	-------	5	-------
	Killarney	Algonquin	0	0	15	2
	Killarney	Yellowhead	0	0	20	2
	Killarney	Oxley II	2	0	5	2
Alfalfa	Algonquin	------------	-------	0	-------	0
	Yellowhead	------------	-------	0	-------	1
Cicer milkvetch	Oxley II	------------	-------	1	-------	3

Table A6 Digestible energy for perennial species under early and late stockpile initiation throughout year 2015 and 2016.

Forage DE						
			2015		2016	
Species	Cultivars	Legume in mixtures	ES	LS	ES	LS
			Mcal kg^{-1}			
Meadow brome	Armada	------------	2.7	2.8	2.3	2.6
	Armada	Algonquin	2.6	3.0	2.4	2.6
	Armada	Yellowhead	2.7	2.9	2.3	2.6
	Armada	Oxley II	2.8	2.9	2.4	2.6
	Fleet	------------	2.8	2.9	2.4	2.6
	Fleet	Algonquin	2.7	3.0	2.2	2.6
	Fleet	Yellowhead	2.6	2.9	2.3	2.6
	Fleet	Oxley II	2.8	2.9	2.4	2.7
Hybrid brome	Success	------------	2.8	3.0	2.5	2.7
	Success	Algonquin	2.8	3.1	2.2	2.7
	Success	Yellowhead	2.9	3.2	2.3	2.6
	Success	Oxley II	3.0	3.1	2.7	2.8
Tall fescue	Courtenay	------------	3.1	3.1	2.8	2.8
	Courtenay	Algonquin	2.9	3.1	2.4	2.8
	Courtenay	Yellowhead	3.0	3.1	2.3	2.8
	Courtenay	Oxley II	3.0	3.1	2.7	2.9
Orchardgrass	Killarney	-------------	2.8	2.9	2.4	2.5
	Killarney	Algonquin	2.6	3.1	2.2	2.6
	Killarney	Yellowhead	2.7	3.0	2.4	2.7
	Killarney	Oxley II	2.9	2.9	2.5	2.6
Alfalfa	Algonquin	------------	2.6	3.1	2.1	2.8
	Yellowhead	------------	2.7	2.9	2.2	2.4
Cicer milkvetch	Oxley II	------------	3.0	3.1	2.7	2.9
Mean1			2.8	3.0	2.4	2.6
HSD1†			0.3	0.3	0.5	0.4
Mean2			2.9		2.5	
HSD2‡			0.2		0.3	
CV%§			8.8	11.3	10.6	7.4

† HSD1 ($P < 0.05$), tests among means for forage DE among species within stockpile initiation dates.
‡ HSD2 ($P < 0.05$), tests among means for species between stockpiled initiation dates. The interaction of species and stockpile initiation date was significant ($P < 0.05$).
§ CV, coefficient of variation.

Table A7 Metabolizable energy for perennial species under early and late stockpile initiation throughout year 2015 and 2016.

Forage ME						
			2015		2016	
Species	Cultivars	Legume in mixtures	ES	LS	ES	LS
			Mcal kg^{-1}			
Meadow brome	Armada	------------	2.2	2.4	1.9	2.2
	Armada	Algonquin	2.2	2.5	2.0	2.1
	Armada	Yellowhead	2.3	2.4	2.0	2.2
	Armada	Oxley II	2.3	2.4	2.0	2.1
	Fleet	------------	2.2	2.3	2.0	2.1
	Fleet	Algonquin	2.3	2.5	1.9	2.1
	Fleet	Yellowhead	2.2	2.4	1.9	2.2
	Fleet	Oxley II	2.3	2.4	2.0	2.2
Hybrid brome	Success	------------	2.4	2.5	2.1	2.3
	Success	Algonquin	2.3	2.6	1.8	2.2
	Success	Yellowhead	2.4	2.7	1.9	2.1
	Success	Oxley II	2.5	2.6	2.2	2.3
Tall fescue	Courtenay	------------	2.5	2.6	2.3	2.3
	Courtenay	Algonquin	2.4	2.6	2.0	2.3
	Courtenay	Yellowhead	2.5	2.6	1.9	2.3
	Courtenay	Oxley II	2.5	2.6	2.3	2.4
Orchardgrass	Killarney	-------------	2.3	2.4	2.0	2.1
	Killarney	Algonquin	2.2	2.6	1.8	2.2
	Killarney	Yellowhead	2.2	2.5	2.0	2.2
	Killarney	Oxley II	2.4	2.4	2.1	2.1
Alfalfa	Algonquin	------------	2.2	2.6	1.8	2.3
	Yellowhead	------------	2.3	2.4	1.8	2.0
Cicer milkvetch	Oxley II	------------	2.6	2.7	2.3	2.1
Mean1			2.3	2.5	2.0	2.2
HSD1			0.2	0.2	0.4	0.3
Mean2			2.4		2.1	
HSD2			0.2		0.2	
CV%			8.9	7.6	9.7	7.3

† HSD1 ($P < 0.05$), tests among means for forage ME among species within stockpile initiation dates.
‡ HSD2 ($P < 0.05$), tests among means for species between stockpiled initiation dates. The interaction of species and stockpile initiation date was significant ($P < 0.05$).
§ CV, coefficient of variation.

Table A8 Net energy for lactation of perennial species under early and late stockpile initiation throughout year 2015 and 2016.

Forage NEL						
			2015		2016	
Species	Cultivars	Legume in mixtures	ES	LS	ES	LS
			Mcal kg^{-1}			
Meadow brome	Armada	------------	1.4	1.5	1.2	1.3
	Armada	Algonquin	1.3	1.6	1.2	1.3
	Armada	Yellowhead	1.4	1.5	1.2	1.3
	Armada	Oxley II	1.4	1.5	1.2	1.3
	Fleet	------------	1.4	1.4	1.2	1.3
	Fleet	Algonquin	1.4	1.5	1.1	1.3
	Fleet	Yellowhead	1.3	1.5	1.1	1.3
	Fleet	Oxley II	1.5	1.5	1.2	1.4
Hybrid brome	Success	------------	1.5	1.6	1.3	1.4
	Success	Algonquin	1.4	1.6	1.1	1.4
	Success	Yellowhead	1.5	1.7	1.1	1.3
	Success	Oxley II	1.6	1.6	1.4	1.4
Tall fescue	Courtenay	------------	1.6	1.6	1.4	1.4
	Courtenay	Algonquin	1.5	1.6	1.2	1.5
	Courtenay	Yellowhead	1.5	1.6	1.2	1.5
	Courtenay	Oxley II	1.6	1.6	1.4	1.5
Orchardgrass	Killarney	-------------	1.4	1.5	1.2	1.3
	Killarney	Algonquin	1.3	1.6	1.1	1.3
	Killarney	Yellowhead	1.4	1.5	1.2	1.4
	Killarney	Oxley II	1.5	1.5	1.3	1.3
Alfalfa	Algonquin	------------	1.3	1.6	1.1	1.4
	Yellowhead	------------	1.4	1.5	1.1	1.2
Cicer milkvetch	Oxley II	------------	1.6	1.7	1.4	1.3
Mean1			1.4	1.6	1.2	1.4
HSD1			0.1	0.1	0.3	0.2
Mean2			1.5		1.3	
HSD2			0.1		0.2	
CV%			11.7	10.3	10.7	6.1

† HSD1 ($P < 0.05$), tests among means for forage NEL among species within stockpile initiation dates.
‡ HSD2 ($P < 0.05$), tests among means for species between stockpiled initiation dates. The interaction of species and stockpile initiation date was significant ($P < 0.05$).
§ CV, coefficient of variation.

Table A9 Net energy for maintenance of perennial species under early and late stockpile initiation throughout year 2015 and 2016.

Forage NEM						
			2015		2016	
Species	Cultivars	Legume in mixtures	ES	LS	ES	LS
			Mcal kg^{-1}			
Meadow brome	Armada	------------	1.4	1.5	1.1	1.3
	Armada	Algonquin	1.3	1.6	1.2	1.3
	Armada	Yellowhead	1.4	1.5	1.1	1.3
	Armada	Oxley II	1.4	1.5	1.1	1.3
	Fleet	------------	1.4	1.4	1.2	1.3
	Fleet	Algonquin	1.4	1.6	1.0	1.3
	Fleet	Yellowhead	1.3	1.5	1.0	1.3
	Fleet	Oxley II	1.5	1.5	1.2	1.4
Hybrid brome	Success	------------	1.5	1.6	1.2	1.4
	Success	Algonquin	1.4	1.7	1.0	1.4
	Success	Yellowhead	1.5	1.7	1.0	1.3
	Success	Oxley II	1.6	1.7	1.3	1.4
Tall fescue	Courtenay	------------	1.6	1.7	1.5	1.4
	Courtenay	Algonquin	1.5	1.7	1.2	1.5
	Courtenay	Yellowhead	1.6	1.7	1.1	1.5
	Courtenay	Oxley II	1.6	1.7	1.5	1.5
Orchardgrass	Killarney	-------------	1.4	1.5	1.1	1.3
	Killarney	Algonquin	1.3	1.7	1.0	1.3
	Killarney	Yellowhead	1.3	1.6	1.1	1.4
	Killarney	Oxley II	1.5	1.5	1.2	1.3
Alfalfa	Algonquin	------------	1.3	1.7	0.9	1.4
	Yellowhead	------------	1.4	1.6	1.0	1.2
Cicer milkvetch	Oxley II	------------	1.7	1.8	1.4	1.2
Mean1			1.5	1.6	1.2	1.3
HSD1			0.2	0.2	0.4	0.3
Mean2			1.5		1.2	
HSD2			0.1		0.2	
CV%			9.9	8.6	6.5	12.1

† HSD1 ($P < 0.05$), tests among means for forage NEM among species within stockpile initiation dates.
‡ HSD2 ($P < 0.05$), tests among means for species between stockpiled initiation dates. The interaction of species and stockpile initiation date was significant ($P < 0.05$).
§ CV, coefficient of variation.

Table A10 Net energy for gestationof perennial species under early and late stockpile initiation throughout year 2015 and 2016.

Forage NEG						
			2015		2016	
Species	Cultivars	Legume in mixtures	ES	LS	ES	LS
			Mcal kg^{-1}			
Meadow brome	Armada	------------	0.8	0.9	0.5	0.7
	Armada	Algonquin	0.7	1.0	0.6	0.7
	Armada	Yellowhead	0.8	0.9	0.5	0.7
	Armada	Oxley II	0.8	0.9	0.6	0.7
	Fleet	------------	0.8	0.8	0.6	0.7
	Fleet	Algonquin	0.8	1.0	0.5	0.7
	Fleet	Yellowhead	0.7	0.9	0.5	0.7
	Fleet	Oxley II	0.9	0.9	0.6	0.8
Hybrid brome	Success	------------	0.9	1.0	0.7	0.8
	Success	Algonquin	0.9	1.1	0.4	0.8
	Success	Yellowhead	0.9	1.1	0.5	0.7
	Success	Oxley II	1.0	1.1	0.8	0.8
Tall fescue	Courtenay	------------	1.0	1.1	0.9	0.9
	Courtenay	Algonquin	0.9	1.1	0.6	0.9
	Courtenay	Yellowhead	1.0	1.0	0.5	0.9
	Courtenay	Oxley II	1.0	1.1	0.9	0.9
Orchardgrass	Killarney	-------------	0.8	0.9	0.6	0.7
	Killarney	Algonquin	0.7	1.1	0.5	0.7
	Killarney	Yellowhead	0.8	1.0	0.6	0.8
	Killarney	Oxley II	0.9	0.9	0.7	0.7
Alfalfa	Algonquin	------------	0.7	1.0	0.4	0.8
	Yellowhead	------------	0.8	1.0	0.4	0.6
Cicer milkvetch	Oxley II	------------	1.1	1.2	0.8	0.7
Mean1			0.9	1.0	0.6	0.8
HSD1			0.2	0.2	0.4	0.3
Mean2			0.9		0.7	
HSD2			0.1		0.2	
CV%			6.6	9.4	5.7	7.2

† HSD1 ($P < 0.05$), tests among means for forage NEG among species within stockpile initiation dates.
‡ HSD2 ($P < 0.05$), tests among means for species between stockpiled initiation dates. The interaction of species and stockpile initiation date was significant ($P < 0.05$).
§ CV, coefficient of variation.

Appendix B

Table B1 Annual species plant heights in August, September and October in year 2014 and 2015.

	Forage height		
	Aug.	Sep.	Oct.
Species		cm	
Haymaker Oats	118	108	116
Golden German Foxtail Millet	70	120	114
Fusion Corn	131	218	199
Maverick Barley	112	102	106
Mammoth Soybean	60	97	103
Aubade Westerwold Ryegrass	107	89	101
Hazlet Fall Rye	41	44	43
Mean	91	111	112
HSD1†	10	29	17
HSD2‡		11	
CV%§	5	9	3

† HSD1 ($P < 0.05$), tests among means for forage height among species under years within each month.
‡ HSD2 ($P < 0.05$), tests among means for forage height among species between months.
§ CV, coefficient of variation.

Table B2. Digestible energy concentration of annual grasses in October as affected by species and years.

	Forage DE		
	2014		2015
Species		Mcal kg^{-1}	
Hazlet Fall Rye	2.9		2.9
Fusion Corn	2.9		3.1
Aubade Westerwold Ryegrass	2.7		3.0
Mammoth Soybean	2.6		2.6
Maverick Barley	2.6		2.8
Golden German Foxtail Millet	2.5		2.6
Haymaker Oats	2.3		2.8
Mean	2.7		2.8
HSD1†	0.2		0.3
HSD2‡		0.2	
CV§	11.1		7.9

† HSD1 ($P < 0.05$), tests among means for DE among species within years.
‡ HSD2 ($P < 0.05$), tests among means for species between years. The interaction of species and year was significant ($P < 0.05$).
§ CV, coefficient of variation.

Table B3 Metabolizable energy concentration of annual grasses in October as affected by species and years.

	Forage ME	
	2014	2015
Species	Mcal kg^{-1}	
Hazlet Fall Rye	2.4	2.4
Fusion Corn	2.4	2.3
Aubade Westerwold Ryegrass	2.2	2.5
Mammoth Soybean	2.2	2.2
Maverick Barley	2.1	2.4
Golden German Foxtail Millet	2.1	2.1
Haymaker Oats	1.9	2.3
Mean†	2.2	2.3
HSD1†	0.2	0.2
HSD2‡	0.1	
CV%§	5.7	6.6

† HSD1 (P < 0.05), tests among means for ME among species within years.
‡ HSD2 (P < 0.05), tests among means for species between years. The interaction of species and year was significant (P < 0.05).
§ CV, coefficient of variation.

Table B4 Net energy for lactation concentration of annual grasses in October as affected by species and years.

	Forage NEL	
	2014	2015
Species	Mcal kg^{-1}	
Hazlet Fall Rye	1.0	0.9
Fusion Corn	0.9	1.1
Aubade Westerwold Ryegrass	0.8	1.0
Mammoth Soybean	0.8	0.8
Maverick Barley	0.7	0.9
Golden German Foxtail Millet	0.7	0.7
Haymaker Oats	0.5	0.9
Mean†	0.8	0.9
HSD1‡	0.2	0.2
HSD2§	0.11	
CV%	7.1	9.9

† HSD1 (P < 0.05), tests among means for NEL among species within years.
‡ HSD2 (P < 0.05), tests among means for species between years. The interaction of species and year was significant (P < 0.05).
§ CV, coefficient of variation.

Table B5 Net energy for maintenance concentration of annual grasses in October as affected by species and years.

Species	Forage NEM 2014		Forage NEM 2015
		Mcal kg^{-1}	
Hazlet Fall Rye	1.5		1.5
Fusion Corn	1.5		1.6
Aubade Westerwold Ryegrass	1.4		1.5
Mammoth Soybean	1.4		1.4
Maverick Barley	1.3		1.5
Golden German Foxtail Millet	1.3		1.3
Haymaker Oats	1.2		1.4
Mean	1.4		1.5
HSD1†	0.1		0.1
HSD2‡		0.1	
CV%	3.7		7.4

† HSD1 ($P < 0.05$), tests among means for NEM among species within years.
‡ HSD2 ($P < 0.05$), tests among means for species between years. The interaction of species and year was significant ($P < 0.05$).
§ CV, coefficient of variation.

Table B6 Net energy for gain concentration of annual grasses in October as affected by species and years.

Species	Forage NEG 2014		Forage NEG 2015
		Mcal kg^{-1}	
Hazlet Fall Rye	1.6		1.5
Fusion Corn	1.5		1.7
Aubade Westerwold Ryegrass	1.4		1.8
Mammoth Soybean	1.3		1.3
Maverick Barley	1.3		1.5
Golden German Foxtail Millet	1.2		1.3
Haymaker Oats	1.1		1.4
Mean	1.3		1.5
HSD1†	0.2		0.2
HSD2‡		0.1	
CV%	5.6		9.3

† HSD1 ($P < 0.05$), tests among means for NEG among species within years.
‡ HSD2 ($P < 0.05$), tests among means for species between years. The interaction of species and year was significant ($P < 0.05$).
§ CV, coefficient of variation.