COMPARING SIMPLE AND COMPLEX NATIVE FORAGE MIXTURES FOR GRAZING CATTLE IN SOUTHWESTERN SASKATCHEWAN

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ABSTRACT

Diverse forage mixtures have improved resilience to drought, improved persistence, ability to adapt to changing environmental conditions, reduced fertilizer costs, improved root mass and greater soil carbon sequestration but do they improve forage and animal production. The objective was to determine if complex native forage mixtures provide superior nutritional quality throughout the grazing season as compared to simple native mixtures. Three studies were conducted in 2007 at Swift Current, SK to evaluate forage production potentials, nutritive qualities and *in vitro* dry matter digestibility of native and tame forage species common to or having potential in Southwestern Saskatchewan. In study one, plots were seeded in 2006 on Chernozemic Orthic Brown Swinton Loam soils and consisted of 11 native and three tame monoculture species common to southwestern Saskatchewan. Clippings at a 5 cm stubble height occurred on June 20 and every 28 days after until October 10. Forage DM production, *in vitro* OMD, NDF, ADF, ADL, CP, Ca and P concentrations were measured. As species matured, production and OMD declined ($P \leq 0.05$) but NDF, ADF and ADL concentrations increased ($P \leq 0.05$). There were harvest date by species differences ($P \leq 0.05$) in forage production and nutritional qualities of C_3 and C_4 grass and legume species. Study two examined the *in situ* CP, NDF and DM disappearance of six selected species harvested in the fall. EDNDF and ADDM values did not differ ($P > 0.05$) among C_3 grasses. The C_4 grasses had higher ($P < 0.05$) EDNDF and EDDM and the legume, Canadian milkvetch had the highest ($P < 0.05$) EDDM but lowest EDNDF. Study three occurred in 2005, 2006 and 2007 to determine if complex native forage mixtures had superior forage and animal production as compared to simple forage stands. Grazing occurred from June through August to achieve 60% utilization. Animal weights and available, cage and residual forage yields were taken to determine production and utilization. Forage production and quality did not differ ($P > 0.05$) between simple and complex forage mixtures but animal production (AUD ha^{-1}) was higher on complex native mixtures. Overall results showed; 1) C_3 and C_4 grass and legume species have different growth patterns and qualities that can improve forage quality and degradability of the stand throughout the grazing season, 2) forage and animal production benefits associated with complex native forage mixtures largely depend on environmental conditions like temperature and moisture.

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LIST OF ABREVIATIONS

WWG	Western wheatgrass
NWG	Northern wheatgrass
GNG	Green needle grass
NTG	Needle and thread grass
MBG	Meadow brome grass
HBG	Hybrid brome grass
Jun	June grass
LBS	Little bluestem
BG	Blue grama
PSR	Prairie sandreed
Alf	Alfalfa
CMV	Canadian milkvetch
PPC	Purple prairie clover
AWG	Awned wheatgrass
CWR	Canada wildrye
War	Warm season grass mixture
C_4	Warm season species
C_3	Cool season species
DM	Dry matter
ADF	Acid detergent fibre
NDF	Neutral detergent fibre
ADL	Acid detergent lignin
OMD	*In vitro* organic matter digestibility
OM	organic matter
CP	Crude protein
Ca	Calcium
P	Phosphorus
N	Nitrogen
PLS	Pure live seeds

kg	kilogram
ha	hectare
SPARC	Semiarid Prairie Agricultural Research Center
EDDM	Effective rumen degradable fraction
RUDM	Rumen undegradable dry matter
Kp	Rumen passage rate
K_d	Degradation rate of D
S	Soluble fraction
D	Slowly degradable fraction
U	Undegradable fraction
SLADG	Season long average daily gains
ADG	Average daily gains (kg day^{-1})
TLP	Total live production per hectare (kg ha^{-1})
GD	Grazing days per acre
AYLD	Available forage yield
CYLD	Cage forge yield
RYLD	Residual forage yield
UT	Utilization
AUD ha^{-1}	Animal unit days per hectare
AIC	Akaike's Information Criteria
AICC	Finite-population corrected AIC value
BIC	Bayesian Information Criteria

CHAPTER 1
INTRODUCTION

1.1 Native Grasslands

In Canada, forage crops are grown on over 36 million ha of which 72% is native range (26 million ha), 17% is tame forage crops (6 million ha) and 11% is cultivated pasture (4 million ha) (Horton 1994; McCartney and Horton 1997). On the Canadian prairies 80% of the native grassland has been converted to alternate cropping systems (Samson and Knopf 1996). Despite this there are a number of different grassland types that exist on the Canadian prairies (Figure 1.1). The mixed grass prairie in Alberta and Saskatchewan consists of 6.5 million hectares (Willms and Jefferson 1993). These grasslands are considered some of the most diverse and from a cattle nutritional perspective, most valuable range types due to a variety of short, mid and tall grass species that combine the growth and forage quality characteristics of cool and warm season forages (Holechek et al. 2004). In recent years, there have been federal and provincial government programs (i.e. Greencover Canada Land Conservation and Saskatchewan Conservation Cover Program) as well as initiatives by conservation organizations like Ducks Unlimited Canada (DUC) that have increased producer interest in reestablishing forage stands, especially species native to the western Canadian prairies.

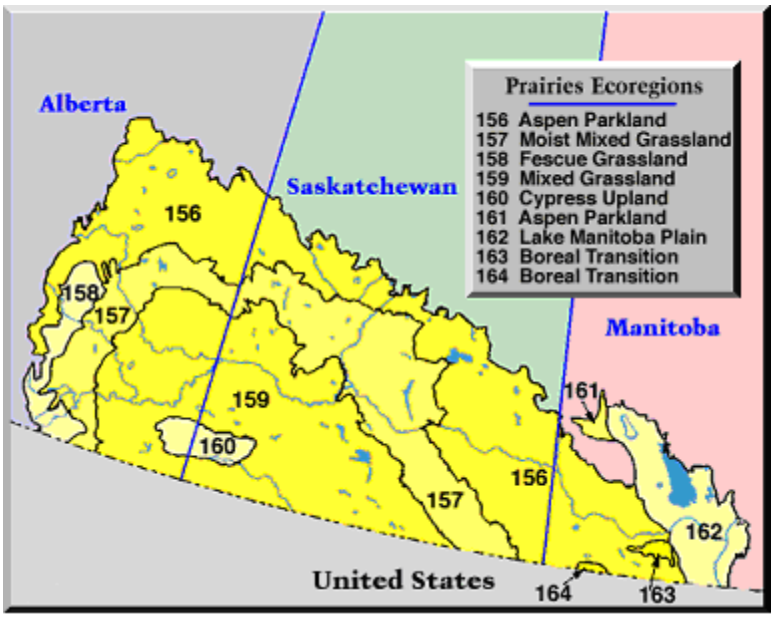

Figure 1.1 Grassland types within the prairie provinces (Wiken 1986).

The benefits of growing forages include lower production costs, increased persistence and environmental benefits like reduced soil erosion and water pollution (Jung and Allen 1995). There are many reasons why native forages have been encouraged, including improved sustainability, improved persistence, superior wildlife habitat, lower input requirements and the ability to adapt to changing environmental conditions (Jefferson et al. 2003; Smith and Whalley 2002).

What makes native grasses appealing to beef producers is their ability to "cure-on-the-stem" or maintain their physical form as they mature (Jefferson et al. 2003). This is due to the fact that the rate at which their leaves and stems deteriorate in nutritional value is much slower than for many tame species (Jefferson et al. 2005). It is for this reason that many producers stockpile native forages for grazing later in the season. However, there has been little published research to show the extent that different native and tame forage species maintain their forage quality as they mature through the grazing season from June to October.

The mixed prairie is home to about 15 % of all the beef cattle present in Alberta, Saskatchewan and Manitoba or approximately 1.3 million head (Willms and Jefferson 1993; Statistics Canada 2009). Cow-calf producers and stocker operators are able to supply more than 90% of the nutrient requirements of cattle through forages (Cherney and Kallenbach 2007). By extending the grazing season through the use of stored forages, feeding costs can be cut in half compared to the use of mechanically harvested forages (Cherney and Kallenbach 2007).

Forage quality can vary dramatically as plants mature or as environmental conditions change (Wallace et al. 1961). Thus it is essential to know the nutrient characteristics of native pasture plants since forage quality affects animal performance throughout the season (Abouguendia 1998). Proper grazing management and supplemental feeding programs may be required when the nutritional composition of the plants no longer meets the animal's requirements (Abouguendia 1998). Research is needed to examine how individual native forage species change in nutritive value as the plant matures.

When it comes to reestablishing native grasslands, questions arise about biodiversity and ecosystem stability. Biodiversity is directly related to an ecosystem's productivity and stability but can result in lower individual species stability (Tilman et al 2006). Diverse stands are more stable and productive because species mixtures are better able to adapt to

changing conditions and have increased root mass for energy and nutrient storage to buffer environmental variation (Tilman et al. 2006). The ability of more diverse native mixtures to better cope with environmental extremes is understood but will it relate to higher plant production per hectare and improved animal performance, under the semi-arid conditions of southwestern Saskatchewan? The objective of this literature review is to better understand native plant species and species mixtures that are better suited for reestablishing marginal land in southwestern Saskatchewan and provide a sustainable grazing resource that could be used to extend the grazing season later into the fall and early winter.

CHAPTER 2
LITERATURE REVIEW

2.1 Reestablishing Native Forage Species

Native forages are species that are found naturally in the ecosystem. They have adapted to local environmental conditions and naturally function with other species in the community (Brown 1980). Restored prairies will never completely resemble undisturbed native pasture because they lack diversity and original species composition. They do however, offer a source of nutrients for grazing animals, a rich habitat for wildlife, reduce exotic species colonization and lead to improved soil qualities versus annual cropping systems (Buyanovsky and Wagner 1998; Minns et al. 2001; Kennedy et al. 2002; Tracy and Sanderson 2004; Sanderson et al. 2005). Ideally, seed used for reestablishment should be collected from native pastures that have never been plowed and that closely resemble original prairie. It is believed that extensive genetic differences or "ecotypes" among native populations are the result of natural selection (Knapp and Rice 1997). These complex ecotypes consist of species that are adapted to local precipitation levels, soil types, temperature fluctuations and day length (Kilcher and Looman 1983).

Seeding native species cultivars or other improved populations that have evolved in different regions under different soil types and climates is little different than seeding tame species. This practice can also present problems with poor establishment and overall productivity of species, especially when imported from the southern United States and introduced into Saskatchewan (Kilcher and Looman 1983). This also raises issues with seed

establishment, species persistence and the risk for genetic contamination of the local ecotypes that could be detrimental to the overall survival of the species (Knapp and Rice 1997).

Seed prices have been one factor that has deterred many producers from seeding native species. The high seed price is often associated with a shortage of available seed adapted to the Canadian prairies. Limited development and research on Canadian cultivars has restricted the supply of seed for reclamation projects (Jefferson et al. 2002). Native forage seed production is extremely variable and depends greatly on growing conditions and environment. Even in ideal years, limited seed production occurs because these native species tend to partition energy into plant survival unlike annual crops that produce large volumes of seed (Smith and Smith 1997; Jefferson et al. 2002). Native seed quality can also be extremely variable due to lower levels of germination, viability and vigor. Seed dormancy of certain species can last for several years. This is a quality that provided native species an adaptive advantage but is a clear disadvantage for seed producers (Smith and Smith 1997). Other natural adaptations like the slow rate of establishment enables native forage species to grow on low fertility soils where tame species could not survive. Organizations like Ducks Unlimited Canada (DUC) and Agriculture and Agri-Food Canada (AAFC) have developed as many as 20 ecological varieties or ecovars™. An ecovar refers to a variety selected for improved growth characteristics and genetic diversity (Smith and Whalley 2002).

2.1.1 Advantages of Using Native Forages

A major question that arises when reseeding forages is, "why use native species"? Native forage species tend to be more expensive to establish because of higher seed prices and lower seed availability. Their use is encouraged and, in many cases required, for reclamation projects along roadsides, drilling sites, and utility lines (Roundy et al. 1997). The petroleum industry is now using native forage species for reclamation of right of ways and well sites throughout the ecologically sensitive Great Sandhills (Jefferson et al. 2005). Groups like DUC have encouraged the use of native instead of tame species for nesting water fowl habitat. The greatest concern associated with tame species is that they will out compete and eliminate natural vegetation. This risk is the greatest within the arid and semi-arid regions of North America. (D'Antonio and Vitousek 1992).

Tame forage species often seeded include crested wheatgrass *(Agropyron desertorum* (L.) Gaertn.), intermediate wheatgrass (*Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey), Russian wildrye (*Psathyrostachys junaceus* (Fisch.) Nevski), Altai wildrye (*Elymus angustus* Trin.) and meadow brome grass (*Bromus riparius* Rehm.) (Willms and Jefferson 1993). Research comparing native versus tame species has provided inconclusive comparisons of forage and animal production due in part to the difficulty in comparing the species. Often newly established tame stands are compared to well established native stands which are not a valid comparison (Coupland 1979). Forage biomass production is often overestimated in experimental trials where soil nutrients and weed control are often superior to those found under normal field conditions (Jefferson et al. 2005). Tame forages often peak in forage production, two to three years after seeding, then yields begin to decline (Knowles 1987). This has become more evident in the last few years with increasing fertilizer costs and the inconsistent responses to fertilizer in the semi-arid regions of western Canada where rainfall is variable (Jefferson et al. 2005).

Native grass stands encourage better soil properties including lower soil bulk density, higher organic matter and higher root mass than certain monoculture tame grass stands (Smoliak et al. 1967; Lesica and DeLuca 1996). The cultivation of land for annual crop production has resulted in soil organic matter reductions up to 75 % and nearly complete removal of soil carbon within 5 years of cultivation (Elliot 1986; Burke et al. 1995; Buyanovsky and Wagner 1998). It also leads to increased atmospheric CO_2 (Bazzac 1990), temperatures and evaporation levels (Mitchell et al. 1990). The seeding of marginally cropped land to native species could ultimately remove enough carbon from the atmosphere and trap it as soil organic matter to help Canada meet its international commitment to reducing greenhouse gases (Jefferson et al. 2005).

2.1.2 Pasture Biodiversity and Stability

Diversity is a natural aspect to native rangelands that help maintain the stability of the ecological community. Forage systems are a balance of plants, soils and environment and in most cases, animals. Land managers need to implement systems that best match animal needs throughout the grazing season (Cherney and Kallenbach 2007; Redmon and Hendrickson 2007). Different climatic zones result in the growth of different forage species

with distinct production curves. Plant diversity not only increases primary production but improves the ecosystem's ability to adapt to disturbances and improves nutrient cycling in the environment (Fridley 2001; Minns et al. 2001; Sanderson et al. 2005). Diverse forage stands tend to be more resistant to weed invasion because of competition for resources (Kennedy et al. 2002; Tracy and Sanderson 2004).

Diverse forage mixtures have the ability to adapt to changing environmental conditions. The mixed grass prairie is dominated by cool season (C_3) species but warm season (C_4) species may be more favorable under certain environmental and soil conditions (Jefferson et al. 2002). If conditions are adequate, both C_3 and C_4 forages can be found growing together. However, it must be recognized that they initiate growth at different times throughout the growing season (Baron and Bélanger 2007). Having a mixture of C_3 and C_4 season grasses in a sward, ultimately ensures that a high quality and nutritious forage source is available throughout the grazing season (Figure 2.1) (Trlica 1999). Warm season forages grow during the hot part of the summer when the yield and quality of C_3 forages decline (Jefferson et al. 2005). By having species with different growth periods it ultimately reduces interspecies competition and improves community production (Willms and Jefferson 1993). Cool season grasses and legumes provide the majority of available forage because they initiate growth early in the spring and produce about two thirds of their annual production before mid summer (Holechek et al. 2004; Jefferson et al. 2005; Cherney and Kallenbach 2007). General growth of legumes and C_3 grasses starts early in the spring and then may be reinitiated later in the fall when temperatures drop and moisture becomes available (Figure 2.2). The C_3 species begin growth in May and peak in production by July before going dormant in the summer, when high temperatures and low rainfall are not favorable for their growth (Baron and Bélanger 2007; Cherney and Kallenbach 2007). As temperatures decrease and if moisture becomes available C_3 species will reinitiate growth until the first killing frost. Warm season species initiate growth in June and grow throughout the hot summer periods and peak production is achieved by September because they are adapted to high temperatures and drought conditions (Baron and Bélanger 2007; Cherney and Kallenbach 2007). This growth during the hot part of the summer provides forage for the grazing animal after the spring grazing of C_3 species (Jefferson et al. 2002). Maximum above ground production on the mixed grass prairie is achieved during mid summer when the

C_3 grasses and C_4 grasses have both reached maximum production (Ehleringer and Monson 1993).

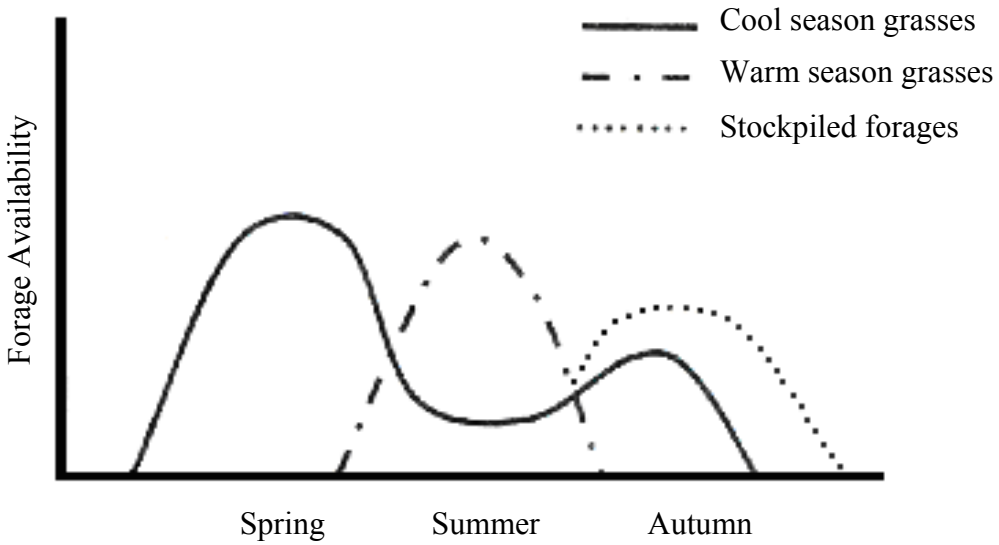

Figure 2.1 The typical availability of different forages throughout the growing season (Cherney and Kallenbach 2007)

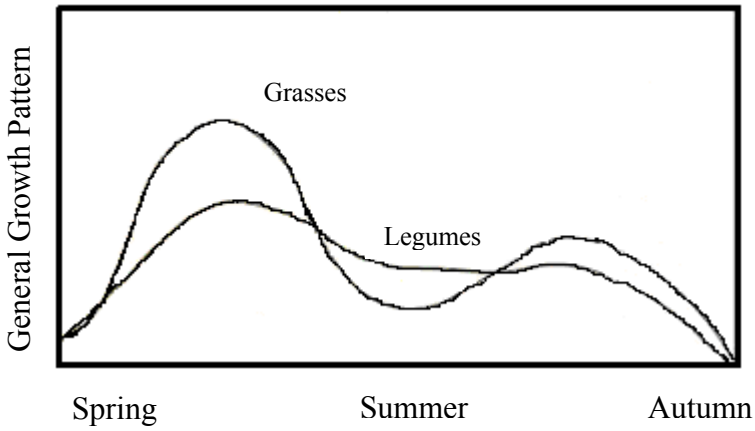

Figure 2.2 General growth pattern of forage grasses and forage legumes in the growing season (Barnhart 1998)

Warm season species have shown latitudinal adaptations that restrict the use of southern species in northern locations (Tober and Chamrad 1992). The distribution of C_4 plants is affected by temperature, aridity, humidity, soil water, nutrient status and ability to allocate resources between the roots and shoots (Stowe and Teeri 1978; Vogel et al. 1986; Hattersley 1992; Larcher 2003).

Forages within the semiarid regions of southern Saskatchewan experience dry, cold winters and common drought conditions (Baron and Bélanger 2007). It is evident from long term averages, that semi-arid regions of the prairie provinces have increased growing degree days and moisture deficits and in the future these trends are expected to continue (Nyirfa and Harron 2003). These semi-arid regions of the Canadian prairies have experienced almost every major drought within the last 80 years (Wheaton et al. 2005). Climate not only affects the length of the growing season and biomass production but has a major effect on species that grow within the area (Redmon and Hendrickson 2007). Cool season grasses tend to be better suited to survive harsh winter conditions than legume species (Baron and Bélanger 2007). Plants have the ability to adapt, both physiologically and morphologically to changing climatic patterns, management stresses and short term weather extremes to ensure their survival (Allard 1999; Baron and Bélanger 2007). Long term climate changes will alter species composition and ultimately change community dynamics (Willms and Jefferson 1993).

The majority of plant growth that is produced on the semi-arid prairies occurs early in the summer when the majority of moisture is received (Baron and Bélanger 2007). Precipitation throughout the growing season significantly affects production. However fall soil moisture is important to enable species to initiate growth early in the spring (Willms and Jefferson 1993). Greater diversity in forage stands leads to increased resistance to drought since different plant species utilize different photosynthetic pathways, initiate growth at different points within the growing season and distribute carbohydrates differently within the roots to the leaves (Glvnish 1994; Tilman and Downing 1994).

2.1.3 Advantages of Legumes in Forage Stands

The inclusion of native legumes in grass mixtures has been shown to increase forage yield and quality when compared to unfertilized grass pastures (Posler et al. 1993; Phillips and James 1998). Pasture production is known to decline within a few years of seeding, a theory termed pasture rundown in Australia (Cadish et al. 1994). Through the inclusion of persistent forage legumes, pasture sustainability can be improved because of nitrogen inputted into the system through N fixation (Cadish et al. 1994; Schellenberg and Banerjee 2002). This is a result of symbiotic relationships with Rhizobium bacteria that form nodules

on the root. The bacteria utilize energy to reduce atmospheric N making it available to the plant (Metcalfe and Nelson 1985; Kopp 2003). The extent to which N fixation occurs is dependant on herbage yield, nitrogen concentration in the plant and the percent of N derived from plant symbiosis with the bacteria (Cadish et al. 1994). This can subsequently reduce the need for fertilizer (Kopp 2003). Having legumes in forage stands can also improve the quality of the ruminant diet and ultimately animal performance (Jefferson et al. 2002; McGraw and Nelson 2003). This is because the leaves of legumes tend to have higher crude protein (CP) levels and cell soluble carbohydrates than grasses at similar stages of maturity (Holechek et al. 2004). However they also contain higher levels of lignin and undegraded neutral detergent fiber (NDF) than grass species (Hoffman et al. 2003). The effective DM degradability is higher in legumes, most likely because they have thinner cell walls than grasses (Spalinger et al. 1986; Hoffman et al. 1993; Yu et al. 2004). Nicholas and Johnson (1969) determined that by broadcasting biennial sweet clover on South Dakota native range, both forage yield and CP content improved. In other cases, by seeding alfalfa or cicer milkvetch with crested wheatgrass, significant improvements in forage production and protein levels were observed in the grass (Rumbaugh et al. 1982). Legume mixtures do require more management to ensure long term sustainability because they are less able to adapt to diverse environmental conditions (Metcalfe and Nelson 1985).

A major concern with legumes is the risk that they will cause bloat. Bloat occurs when the natural eructation of rumen fermentation gases is restricted and results in abnormal abdomen distention that restricts respiratory and circulatory systems (Berg et al. 2000; Popp et al. 2000). Bacterial fermentation of many species of legumes produces a stable gas trapping foam (frothy bloat) which cannot be eructated from the rumen and ultimately can be lethal to the grazing animal (Knopp 2003). This frothy bloat is believed to be caused by a number of factors like increased proportions of rapidly degraded chloroplast protein fractions (Coulman et al. 1999; Mayland et al. 2003) and the presence of saponins that disrupt rumen function and increase digestion in the small intestine (Lu and Jorgensen 1987). The maturity of legume plants is a major factor that affects bloat potential. Legumes in the pre-bud or vegetative stage have the highest potential to cause bloat. Other factors that can increase the risk of bloat include grazing damp immature plants or stands that have recently experienced frost (Knopp 2003). It is important to ensure that non-bloating legumes are used such as

sainfoin or the "bloat reduced" alfalfa cultivar, where the initial rate of digestion has been reduced through breeding (Berg 1997; McMahon et al. 2000; Berg et al. 2000; Coulman et al. 2000). Some research has shown increased levels of condensed tannins have been shown to bind plant proteins and prevent frothy bloat (Li et al. 1996; McMahon et al. 1999). Other options to reduce the risk of bloat include the use of ionophores, pluronic detergents, or altered management techniques (Majak et al. 1995; Anderson, 1997; Berg et al. 2000).

2.1.4 Grazing Mixed Native Swards

There has been a perception that tame forage species have a higher production potential. However, several studies have shown that there is no significant animal production differences between monoculture tame species versus improved native populations (Hanson et al. 1976; Hofmann et al. 1993; Jefferson et al. 1997). Lawerance and Ratzlaff (1989) and Knowles (1987) both found that tame species had higher production potential than native swards only when fertilizer was applied. Previous work in Swift Current, SK. showed that available crested wheatgrass forage production ranged from 1334 to 2307 kg ha^{-1} and peak production ranged from 3709 to 6302 kg ha^{-1} (Bruynooghe 1997). In contrast, studies done on native mixed grass prairie produced 1519 kg ha^{-1} in Montana (Sims et al. 1978); 1865 to 2199 kg ha^{-1} in Lethbridge, AB (Willms et al. 1986); and 1744 to 2271 kg ha^{-1} in western South Dakota (Johnson et al. 1951). On crested wheatgrass pastures, ADG ranged from 0.77 to 1.41 kg day^{-1} and total animal production ranged from 68 to 198 kg ha^{-1} (Bruynooghe 1997). Research by Jefferson et al. (2003) has shown that native grasses have the ability to "cure-on-the-stem." This means that native forages maintain their physical form and forage qualities as the plants mature because their leaves and stems drop in quality at a slower rate than many tame species (Jefferson et al. 2005). The curing of these native species usually occurs in late July but timing can vary with the season (Pigden 1952). This is important because as species mature, they become less palatable and animal production declines. This was demonstrated by research in Kansas, where ADG on pasture grazed from May to July was 0.80 kg day^{-1} versus pastures grazed from July to October that averaged 0.45 kg day^{-1} (Smith and Owensby 1978). A nine year study at Manyberries, AB. showed that the ADG of calves was 0.76 kg day^{-1} on continuously grazed mixed grass prairie (Smoliak 1960). Studies

have shown that increased forage production ultimately improves live weight gains ha^{-1} in cattle (Cook 1972; Ward 1988; Reid et al. 1990; Jackson 1999).

Having a diverse range of species ensures that the forage yield is distributed throughout the growing season and provides the opportunity to graze throughout the year (Cook, 1972; Cherney and Kallenbach 2007). By matching forage nutrient supply with the grazing animal's nutrient demand, input costs can be reduced and animal performance can be improved (Redmon and Hendrickson 2007). Grazing earlier in the spring and later in the fall/ early winter can increase returns by $50 to $90 per cow (Adams et al. 1994).

Each native species has evolved a characteristic seasonal growth curve that directly affects its nutritional quality and digestibility (Kamstra 1973; Abouguendia 1998). Having a mixture of C_3 and C_4 forages can improve pasture production and forage quality throughout the grazing season (Cook 1972; Ward 1988; Reid et al. 1990; Jackson 1999). Several studies have shown that complex forage mixtures produced had improved forage production when compared to simple mixtures (Deak et al. 2004; Tracy and Sanderson 2004a; Tracy and Sanderson 2004b). A more diverse forage stand offers improved forage production and provides the grazing animal a more nutritious and palatable forage (Smoliak and Bezeau 1967; Tilman et al. 1996; Ganskopp et al. 1997; Bargo et al. 2002). Legumes have higher energy and protein levels than grasses but their persistence can be lower (Cherney and Kallenbach 2007). Data from Utah, Texas and Wyoming show how grasses and forbs change in quality during the year (Cooke et al. 1959; Varner et al. 1979; Huston et al. 1981; Severson 1982; Krysl et al. 1984) but little information is available for the mixed grass prairie. Qualities like digestible energy (Figure 2.3), digestible protein (Figure 2.4) and phosphorus (Figure 2.5) are retained at different levels in grass, forbs and shrubs during the growing season and can compliment each other to meet the demands of ruminant animals.

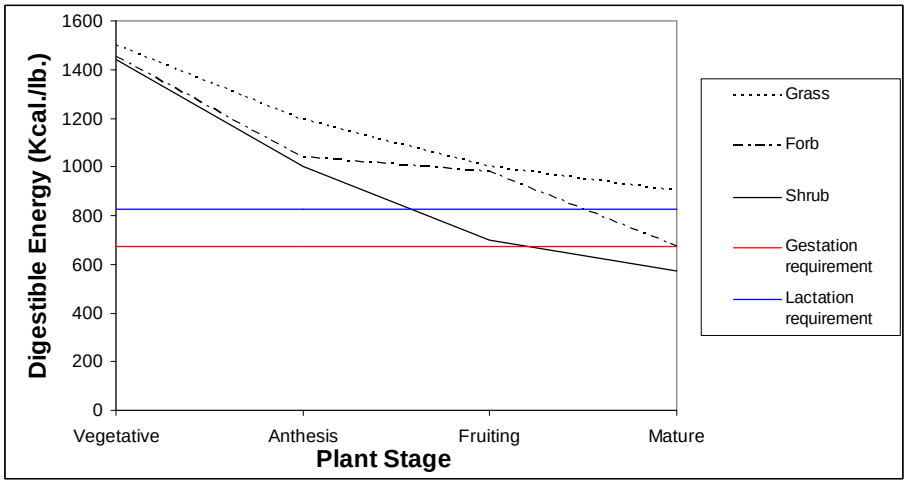

Figure 2.3 The average digestible energy for three forage classes at four phenological stages (Cooke 1972)

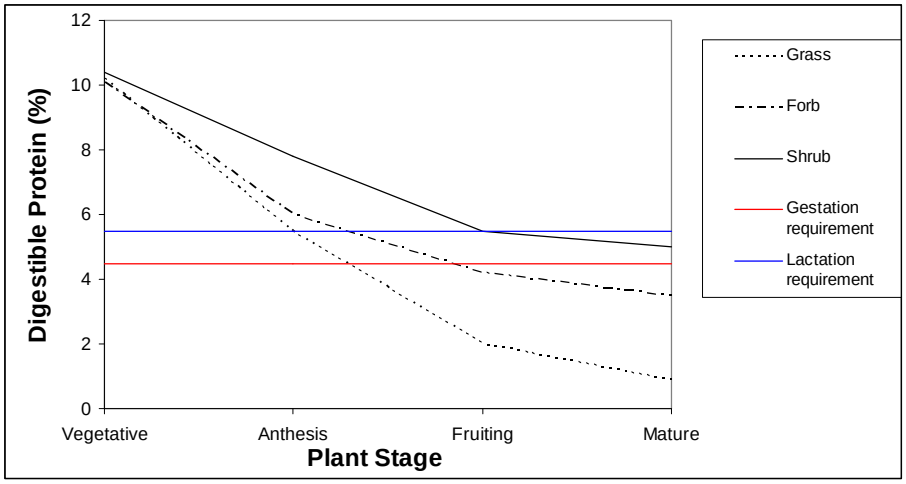

Figure 2.4 The average digestible protein for three forage classes at four phenological stages (Cooke 1972)

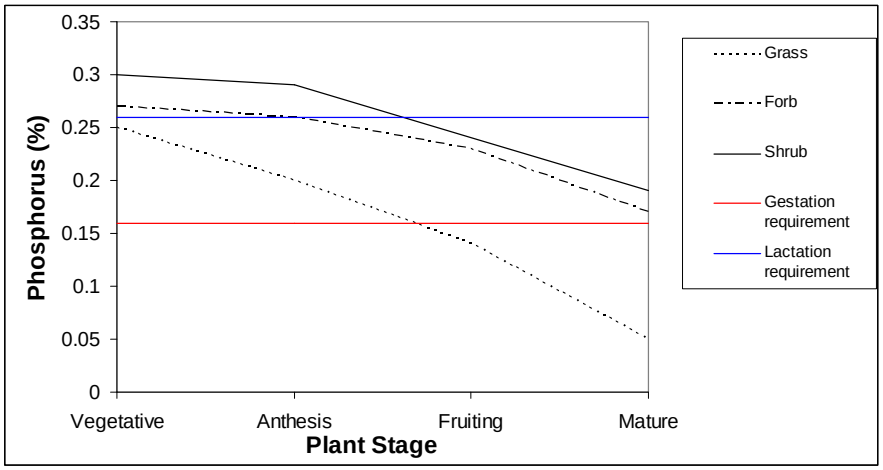

Figure 2.5 The average phosphorus level for three forage classes at four phenological stages (Cooke 1972)

A major concern arises with palatability differences between the C_3 and C_4 grasses which can alter the period of optimal pasture utilization or result in selective pressures on the sward composition. Some studies have observed that cattle avoided C_4 species and preferred forbs and C_3 species (Caswell et al. 1973; Kautz and van Dyne 1978). Cool season plants are often preferentially grazed over C_4 plants as long as the species are at the same growth stage (Trlica 1999). However, C_3 grasses tend to enter their reproductive phase around the same period when C_4 species initiate growth (Trlica 1999), at which point cattle are naturally attracted to the new growth of the C_4 grasses. Due to differences in species' morphological development associated with year, moisture and cultivar (Smith 1972) and the effect of maturity on nutritive quality, it is important to stage plants for consistent comparisons and improved pasture management (Wallace et al. 1961; Abouguendia 1998).

2.2 Plant Staging

Plant staging is important to compare different species and samples from different collection periods. It can be used to make decisions on when to initiate grazing, harvest seed or apply herbicide. Time of plant maturity will vary among years, locations and cultivars (Smith 1972). Forage plants exhibit morphological changes that represent stages in their life cycle and thus can be used to compare samples (Skinner and Moore 2007). Systems designed to stage plants not only have a defined structure to describe the morphological stage but have numerical indexes that correspond with a given stage (Skinner and Moore 2007).

There are several methods that can be used to stage perennial grasses (Haun 1973; Zadoks et al. 1974; Simon and Park 1983; Moore et al. 1991; Sanderson 1992). The methodology of Simon and Park (1983) was relatively complex and difficult to apply. A newer and simpler method of determining the growth stage of perennial grasses was developed by Moore et al. (1991). It used a universal set of morphological descriptors to apply numerical indices with phenological traits of C_3 and C_4 grasses (Skinner and Moore 2007). Moore et al. (1991) separated plant growth into five primary stages; germination, vegetative, elongation, reproductive and seed ripening (Table 2.1).

Table 2.1 Numerical indices and descriptors for staging perennial grass development

Stage	Index	Description
Germination		
G0	0.0	Dry seed
G1	0.1	Imbibitions
G2	0.3	Radical emergence
G3	0.5	Coleoptile emergence
G4	0.7	Mesocotyl and coleoptile elongation
G5	0.9	Coleoptile emergence from soil
Vegetative Leaf Development		
V0	1.0	Emergence of first leaf
V1	(1/N) + 0.9	First leaf collard
V2	(2/N) + 0.9	Second leaf collard
Vn	(n/N) + 0.9	Nth leaf collard
Elongation-Stem Elongation		
E0	2.0	Onset of stem elongation
E1	(1/N) + 1.9	First node visible
E2	(2/N) + 1.9	Second node visible
En	(n/N) + 1.9	Nth node visible
Reproductive-Floral development		
R0	3.0	Boot stage
R1	3.1	Inflorescence emergence/ First spikelet visible
R2	3.3	Spikelets fully emerged/ Peduncle not emerged
R3	3.5	Inflorescence emerged/ Peduncle fully emerged
R4	3.7	Anther emergence/ Anthesis
R5	3.9	Post anthesis/ fertilization
Seed Development and Ripening		
S0	4.0	Caryopsis visible
S1	4.1	Milk
S2	4.3	Soft dough
S3	4.5	Hard dough
S4	4.7	Endosperm hard/ Physiological maturity
S5	4.9	Endosperm dry/ Seed ripe

n = event number (number of leaves or nodes); N = number of events within the primary stage (total number of leaves or nodes developed); (Modified from Moore et al. 1991)

The physiology of legume forages is completely different than perennial grasses. There are also many different procedures to stage legumes (Albert 1927; Dotzenko and Ahlgren 1950; Kalu and Fick 1981; Fick and Mueller 1989; Ohlsson and Wedin 1989). Many of these techniques tend to focus more on the development of the stem and not on the transitional stages of the plants. Kalu and Fick (1981) modified the Gengenbach and Miller (1972) technique that uses ten categories to correspond with morphological development at

all growth stages (Table 2.2). It was created to better stage alfalfa plants but not other types of legumes (Skinner and Moore 2007).

Table 2.2 Definition of morphological stages of development for individual alfalfa stems

Stage	Stage Name	Description
0	Early Vegetative	Stem length ≤ 15 cm; no buds, flowers or seed pods
1	Mid Vegetative	Stem length 16 to 30 cm; no buds, flowers or seed pods
2	Late Vegetative	Stem length ≥ 31 cm; no buds, flowers or seed pods
3	Early Bud	1 to 2 nodes with buds; no flowers or seed pods
4	Late Bud	≥ 3 nodes with buds; no flowers or seed pods
5	Early Flower	One node with one open flower (standard open); no seed pods
6	Late Flower	≥ 2 nodes with open flowers; no seed pods
7	Early Seed Pod	1 to 3 nodes with green seed pods
8	Late Seed Pod	≥ 4 nodes with green seed pods
9	Ripe Seed Pod	Nodes with mostly brown mature seed pods

* Modified from Kalu and Fick (1981)

2.3 Photosynthetic Pathways

There are three different photosynthetic pathways that have been distinguished in plants. They include the Calvin Benson cycle (C_3 pathway), Hatch Slack cycle (C_4 pathway) and the Crassulacean acid metabolism (CAM) pathway. Photosynthesis is the process of converting water and carbon dioxide into glucose and oxygen through the use of sunlight energy (Smith and Smith 2003). The three pathways have resulted from plant adaptations to different environmental conditions. C_3 species grow optimally at temperatures ranging from 20 to 25°C and generally growth slows when temperatures drop below 5 and 7°C (Baron and Bélanger 2007). Whereas C_4 species have higher optimal growing temperatures, ranging from 30 to 35°C and growth slows at temperatures below 15°C (Barbour et al. 1987; Baron and Bélanger 2007). The CAM pathway is similar to the C_4 pathway but what makes it unique is that the conversion of $C0_2$ to malate (4 carbon acid) and the reverse reaction occur only in the mesophyll (Smith and Smith 2003). The CAM pathway is only found in the hot

deserts of the world and does not significantly contribute to the global carbon cycle (Ehleringer and Cerling 2002). To better distinguish the differences between common species grown in southwestern Saskatchewan it is important to better understand the C_3 and C_4 pathways.

The C_3 pathway (Calvin Benson cycle) is the oldest photosynthetic pathways from an evolutionary stand point (Ehleringer and Monson 1993). It evolved under conditions of high carbon dioxide (CO_2) and low oxygen (O_2) (Moore et al. 2004). The C_3 photosynthetic pathway or photosynthetic carbon reduction cycle utilizes a single chloroplast type to convert sunlight energy into chemical energy to fix CO_2 and produce important carbon compounds for plant growth. The ATP and NADPH used as energy sources in the pathway originate from the light reactions of photosynthesis. The dark reactions involve ribulose-1,5-biphosphate carboxylase/ oxygenase (RUBISCO) an enzyme that can either bind CO_2 (carboxylate) or O_2 (oxygenate) with ribulose-1,5-biphosphate (RuBP), a five carbon molecule (Figure 2.6) (Larcher 2003). RUBISCO primarily catalyzes carbon fixation to produce two molecules of 3-phoshoglycerate (PGA), each contains three carbon atoms hence the C_3 name. PGA is then reduced with the enzyme phosphoglycerate kinase and ATP to form 1,3-bisphosphoglycerate which then produces glyceraldehyde-3-phosphate (GAP) using the enzyme glycerol dehyde-3-phosphate dehydrogenase and NADPH (Ehleringer and Monson 1993). The GAP produced by the Calvin cycle is converted to fructose 6-phosphate and glucose 1-phosphate that react producing sucrose 6-phosphate that ultimately results in the production of sucrose, a disaccharide (Hames and Hooper 2005). The sucrose can then be translocated throughout the plant or retained in the chloroplast for starch synthesis. A portion of the GAP is then recycled through numerous reactions to produce RuBP which is required to reinitiate the Calvin Benson cycle.

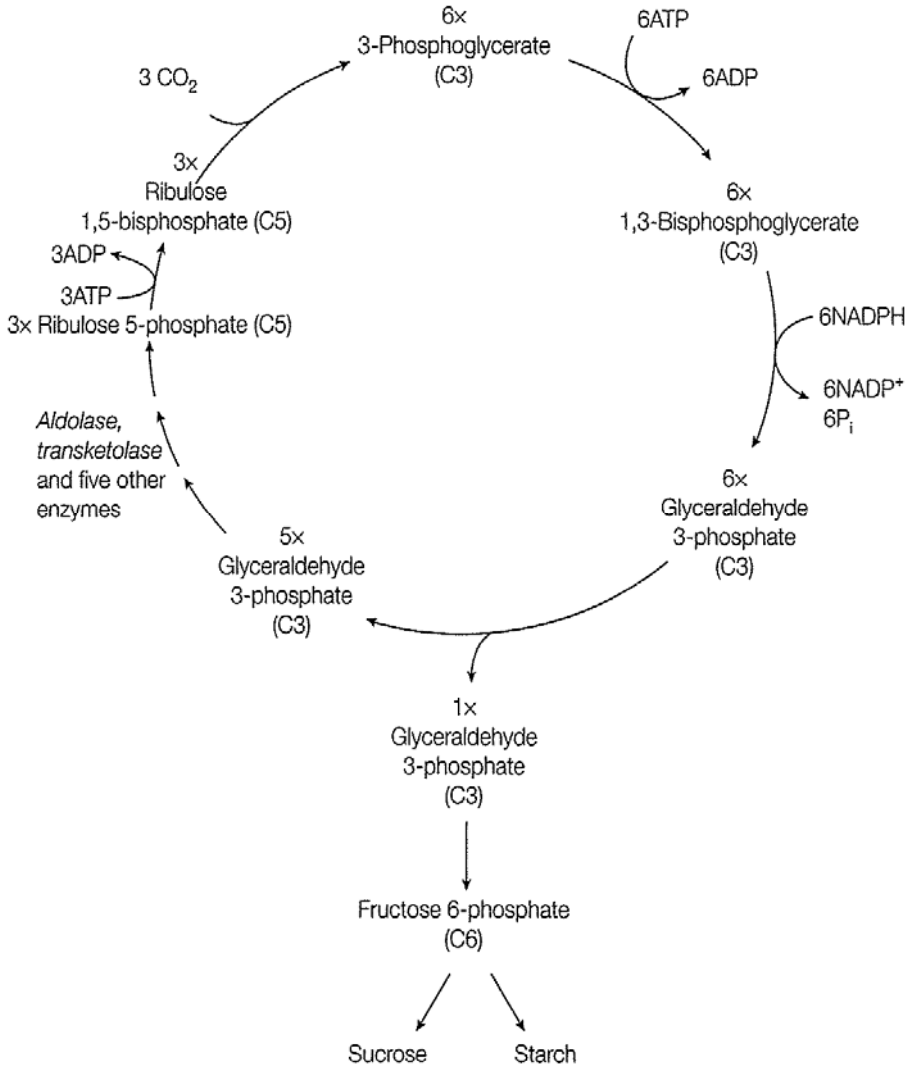

Figure 2.6 The C_3 plant photosynthetic pathway (Hames and Hooper 2005).

An increase in leaf temperature can ultimately increase photorespiration and reduce the photosynthetic efficiency. Environments with high light intensities, temperatures and arid conditions reduce the ability of RUBISCO to differentiate oxygen and carbon dioxide (Sheen, 1999; Ehleringer and Monson 1993). Carbon dioxide naturally has a high affinity for the RuBP but when there is insufficient CO_2 then O_2 will ultimately bind with the RuBP. This reaction (photorespiration) can result in the formation of one PGA and one molecule of 2-phosphoglycolate (2 carbon molecule) (Ehleringer and Monson 1993). This reduces the efficiency of the C_3 photosynthetic pathway because as atmospheric CO_2 levels decrease and air temperatures increase O_2 binds more of the RUBISCO. These conditions likely led to the evolution of C_4 species that were better adapted to such conditions (Hatterslley and Watson 1992; Cerling 1999; Kellogg 1999)

Warm season (C_4) plants have developed a unique leaf structure that enables their growth under drier and hotter conditions than C_3 species (Holechek et al. 2004). The C_4 pathway (Hatch Slack cycle) evolved to maximize the carboxylase activity of RUBISCO (Hames and Hooper 2005). The pathway increases the CO_2 concentrations in the mesophyll and then moves it into the bundle sheath cells where the Calvin Benson cycle proceeds (Figure 2.7) (Ehleringer and Monson 1993; Sheen 1999). The atmospheric CO_2 initially binds with phosphoenolpyruvate (PEP) involving the enzyme phosphoenolpyruvate carboxylase to produce oxaloacetate, a four carbon acid (Larcher 2003). Oxaloacetate is reduced to malate by malate dehydrogenase an $NADPH_2$ dependant enzyme, which is then diffused into the bundle sheath from the mesophyll. In the bundle sheath, malate is decarboxylated via enzymatic reactions including NADP-malic enzyme, NAD malic enzyme and PEP carboxykinase to produce pyruvate and higher concentrations of CO_2 (Ehleringer and Monson 1993; Larcher 2003). The CO_2 in the bundle sheath is taken up by ribulose-1,5-biphosphate (RuBP) and processed via C_3 photosynthetic pathway (Calvin cycle) while the pyruvate returns to the mesophyll cells where PEP is regenerated using ATP and the Pyruvate-P_i dikinase enzyme (Larcher 2003). With the bundle sheath cells being shielded from O_2, there is less RuBP and oxygen binding which reduces photorespiration and the resulting energy loss. Although the C_4 pathway requires the hydrolysis of two additional phosphate bonds for each molecule of CO_2 moved into the bundle sheath cell to reduce CO_2

and regenerate phosphoenolpyruvate, it is still more efficient (Kocacinar and Sage 2003; Hames and Hooper 2005).

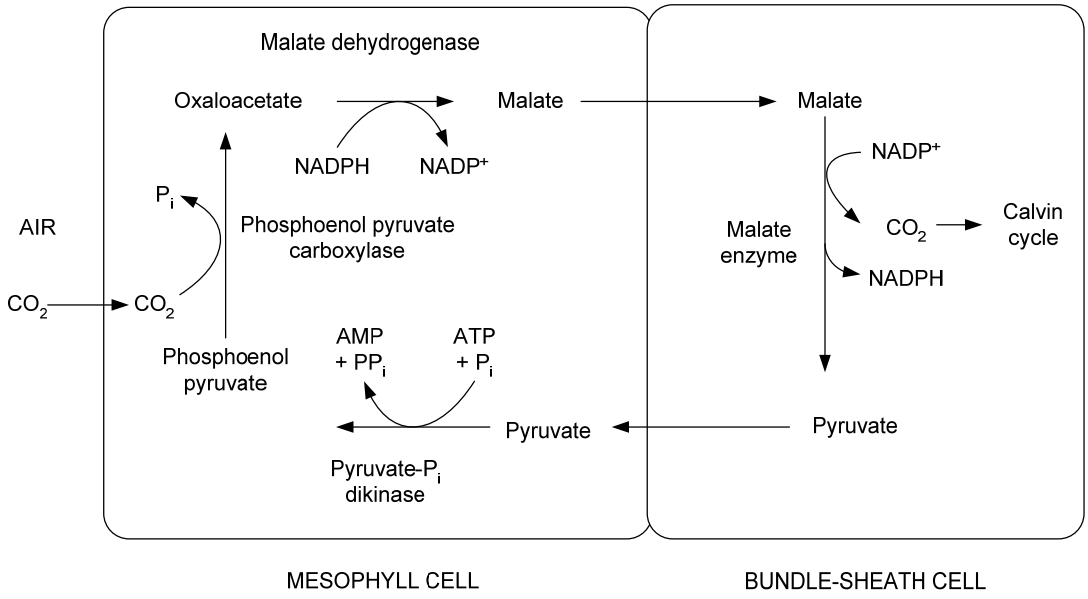

Figure 2.7 The C_4 photosynthetic pathway (Hames and Hooper 2005).

Some advantages that C_4 plants have over C_3 plants include a reduction in photorespiration, enhanced photosynthetic ability in arid climates, and improved water, N and light use efficiency (Kocacinar and Sage 2003). Warm season plants have the ability to photosynthesize even when there are low CO_2 concentrations within leaves. There continues to be transpiration water loss in C_4 species, but water loss is less per unit of photosynthetic carbon gain versus C_3 plants (Ehleringer and Monson 1993). The increased water use efficiency has led to differing xylem characteristics and increased carbon gain (Kocacinar and Sage 2003). Nitrogen efficiency is also improved because there is 3 to 6 times less RUBISCO in C_4 plants compared to C_3 plants where 25 to 30% of N is bound by the enzyme (Ehleringer and Monson 1993). The low N requirements can also be related to the relatively small amounts of protein in the mesophyll chloroplasts (Larcher 2003).

There are major differences in leaf anatomy and nutritive quality between C_3 and C_4 species (Wilson and Hattersley 1989). The C_3 grasses generally have a higher proportion of mesophyll tissue, less parenchyma-bundle sheath connection, less sclerenchyma, reduced

vascular and epidermal tissue, lower cell wall content and higher dry matter digestibility than C_4 species (Larche 2003). Warm season species usually have lower quality than C_3 species at the same stage due to higher proportions of structural tissue, lower protein levels and lower leaf to stem ratio (MacAdam and Nelson 2003). It has been shown that as much as 20 to 35% of the C_4 plants' cell wall remains undigested even after long rumen incubation periods (Reid et al. 1990; Hafley et al. 1993). Some studies have shown that C_4 plant palatability is lower than with C_3 species (Caswell et al. 1973; Waller and Lewis 1979). The CP concentration in C_4 plants has been shown to rapidly decline likely due to the development of thick bundle sheath cells that make protein relatively unavailable to the ruminant animal (Caswell et al. 1973; Caswell and Reed 1976; Ku et al. 1979; Trlica 1999).

2.4 Forage Species of Interest

It is estimated that 250 species co-exist on the mixed grass prairie (Saskatchewan Wetland Conservation Corporation 1996). Due to the often low availability of seed, difficulty in forage establishment and lower persistence in mixed swards the presence of many of these species can be variable. The reestablishment of native forage mixtures for grazing requires just the opposite; accessible seed, good stand establishment and persistent species to ensure optimal forage and animal production. The following sub-sections examine individual species commonly grown in the semi-arid region of southwestern Saskatchewan, including native C_3 and C_4 grasses, legume forages and common tame forage legume and grasses.

2.4.1 Western wheatgrass (WWG)

Western wheatgrass (*Pascopyrum smithii* Rydb.) is found in western Canada on the mixed grass prairie, the foothills region and in the parkland region. The plants form a loosely clustered sod with coarse culms and extensive creeping rhizomatous stems (USDA 2002). The majority of the roots are shallow (25 cm or less) but there are usually some feeder roots that can descend 150 cm (Pahl and Smreciu 1999). It begins growing when temperatures reach 12 °C, usually in May and flowering can occur between June and August. Western wheatgrass will go dormant during the summer when moisture conditions become limited but can reinitiate growth in the fall with lower temperatures and the availability of moisture

(Toole, 1976). Sedivec et al. (2007) found that WWG produced 36% of its total biomass by late May and 90% by mid June. It peaked in production by late July, then as it matured into the fall, growth stopped and herbage mass declined by 15%, likely due to leaf loss (Sedivec et al. 2007).

The role WWG plays in reclamation is important because it is a good soil binder that stabilizes moist, alkaline and saline soils which would otherwise face issues of erosion (Everson 1966; USDA 2002; Sedivec et al. 2007). Stands of WWG are slow to establish and can take several years to fully establish. However, following establishment its rhizomatous growth ensures reproductive success (USDA 2002; Sedivec et al. 2007). The ability of WWG to tolerate a wide variety of soils ranging from heavy alkaline and lighter upland soils to its ability to survive spring flooding, cold temperatures and moderate droughts make it a suitable option for reclamation projects (USDA 2002; Sedivec et al. 2007). Western wheatgrass does prefer heavier well drained soils that maintain moderate to high soil moisture (USDA 2002). With annual precipitation greater than 508 mm, WWG will tend to act as an increaser in forage stands. On heavy clay soils it can be found growing with Green needle grass (GNG) and on dry uplands it is found with Needle and thread grass (NTG) and Blue grama (BG) (Pahl and Smreciu 1999). When growing with BG it will initiate growth two to three weeks earlier but matures earlier in the growing season (USDA 2002).

Western wheatgrass has been a species recognized for its excellent curing ability and its ability to support winter grazing (Pahl and Smreciu 1999; Jefferson et al. 2005). It is recognized as a species that is moderately palatable to livestock year round (USDA 2002). However, the optimal grazing period based on plant production, quality and palatability would be during the late spring into the summer period (Sedivec et al. 2007). Knowles (1987) determined that WWG yields averaged 1925 kg ha^{-1} on western Canadian pastures and under optimal conditions could produce 4000 kg ha^{-1} depending on the cultivar. The Saskatchewan Forage Council variety testing program found that WWG forage production in southwestern SK. was 2988 kg ha^{-1} (SAFRR 2003). Previous work done at SPARC in Swift Current, SK. by Jefferson and Muri (unpublished) found that WWG production was 4704 kg ha^{-1} in the first year but production declined to 3069 kg ha^{-1} by the second year. They found that monoculture WWG stands had a six year average production of 1931 kg ha^{-1}. Other trials have found that production can range from 1191 to 2427 kg ha^{-1} (Sedivec et al. 2007).

As WWG matures it becomes coarse and less palatable (Sedivec et al. 2007). Western wheatgrass harvested in September had an organic matter digestibility 14% higher than northern wheatgrass (NWG) (Jefferson et al. 2004). The CP content of WWG averages 18% in the spring but will decline to around 3 to 4 % by October (Pahl and Smreciu 1999). Sedivec et al. (2007) demonstrated that the CP at the vegetative stage was 18% then declined to 10% at the seed set stage, 7% at the end of mid summer and dropped to 3% when fully mature. Acid detergent fiber content increased from 28% at the 2.5 leaf stage to 40% by early October when plants were fully matured and reached 46% by December (Sedivec et al. 2007). Toole (1976) determined that the digestible carbohydrate reserves (CHO) increased from 40% in the spring to 50% in the fall. However, frequent defoliation can diminish CHO reserves (Day and Ludeke 1986). The USDA (2002) recommendation is that 50 to 60% of the growth should remain after grazing to prevent the loss of carbohydrate reserves.

2.4.2 Northern wheatgrass (NWG)

Northern wheatgrass (*Elymus lanceolatus* Scribn & J.G. Sm.) is commonly found throughout the mixed grass prairie and into the parkland regions of the Canadian prairies. It is most suited for the sandy loam and loam soils with slightly acidic to moderately saline conditions where the water table is more than one meter from the soil surface (Redmann and Qi 1992). Northern wheatgrass requires between 203 and 508 mm of annual precipitation (Ogle and USDA 2006). It is a sod forming grass that produces rhizomes but not as aggressively as WWG (Ogle and USDA 2006). The majority of the roots are within 25 cm of the surface, although it does produce some deeper feeder roots that can reach 50 cm in depth (Pahl and Smreciu 1999).

Northern wheatgrass has long been recognized as a key species in the restoration of rangeland (Hardegree 1994). Its rapid establishment and vigorous sod forming characteristics stabilize soil and its tolerance to drought and cold make it very persistent (Ogle and USDA 2006). What makes NWG very appealing is its ability to maintain green biomass throughout drought conditions and its ability to rapidly reinitiate growth when moisture becomes available, even to a greater extent than WWG (Ogle and USDA 2006). It has an extensive root system along with some deeper roots that provide moisture through times of drought, however, with prolonged drought conditions leaf growth will slow

(Redmann 1976). Kowalenko and Romo (1998a) determined that only 50% of NWG plants could survive temperatures ranging from -29.5 to -36 °C. If plants were not slowly adapted to these temperatures, tiller numbers and biomass production were reduced (Kowalenko and Romo 1998a; Kowalenko and Romo 1998b). By retaining adequate litter levels on the soil surface, soil temperatures are increased by 4 to 5°C and cold stress is reduced (Kowalenko and Romo 1998a).

Northern wheatgrass can be found under natural range conditions with many native species ranging from indian ricegrass (*Oryzopsis hymenoides*), sand dropseed (*Sporobolus cryptandrus*), big sagebrush (*Artemisia tridentata*), prairie sandreed (*Calamovilfa longifolia*), bluebunch wheatgrass (*Agropyron spicatum*), fescue sp. (*Festuca sp*.), needlegrasses (*Stipa sp*.), WWG (*Agropyron smithii*), June grass (*Koeleria cristata*), and thread-leaved sedge (*Carex eleocharis*) (Redmann and Abouguedia 1978). However, its short stature reduces its presence in native stands to less than 10%. Previous work at SPARC in Swift Current, SK. by Jefferson and Muri (unpublished) found that NWG production was 3790 kg ha^{-1} in the first year but production declined to 2223 kg ha^{-1} by the second year. They found that monoculture NWG stands had a six year average production of 1325 kg ha^{-1} (Jefferson and Muri unpublished). Production values shown in the 2004 Saskatchewan Forage Crop Production Guide were 3694 kg ha^{-1} (SAFRR 2003). Northern wheatgrass is recognized as one of the most palatable and productive grasses on the Northern Great Plains (Pahl and Smreciu 1999). It is excellent forage for livestock with protein levels ranging from 16% in the spring and declining to 4% by October (Tannis 1997). Northern wheatgrass will "green up" about three weeks earlier and "head out" earlier than WWG but the amount of total biomass is usually lower (Ogle and USDA 2006). Pastures with NWG should only be grazed once per year, following the peak in forage production because it is slow to recover following defoliation (Zang and Romo 1994).

2.4.3 Awned wheatgrass (AWG)

Awned wheatgrass (*Elymus trachycaulus* ssp. *subsecundus* (Link.) A.& D. Löve) begins growing early in the spring and sets seed in late July or August (Pahl and Smreciu 1999). In Canada AWG is most commonly found on the western and northern parts of the prairie provinces (Pahl and Smreciu 1999). It can be found throughout the aspen parkland

and boreal forest in woodland openings and in moist locations on sandy soils. Awned wheatgrass is best suited for the brown, dark brown and black soil zones with moist, well drained, loamy soils that are not saline (Abouguendia 1995). It requires approximately 320 mm of annual precipitation to survive (Pahl and Smreciu 1999). It is often used in mixtures of grasses that are slower to establish because it establishes rapidly. The stand longevity of AWG plants depends on environmental conditions but in the semi arid region it tends to persist similarly to slender wheatgrass (*Elymus trachycaulus* (Link) Gould ex Shinners) which can disappear from the stand within five years (Wark et al. 1995). It has been used for many reclamation projects in the United States (Abouguendia 1995).

Awned wheatgrass tends to be less leafy than slender wheatgrass but maintains a similar nutritive value and is very palatable up until it initiates heading (Abouguendia 1995). It tends to produce large amounts of seed to ensure stand survival (Wark et al. 1995). The basal leaves of the plant are very palatable but the opposite is true for the stems and seed heads (Pahl and Smreciu 1999). Proper grazing management is important because it can be over utilized which can lead to a reduction in the stand.

2.4.4 June grass (June)

June grass *(Koeleria macrantha* Ledeb.; Schult.) is native not only to North America but also Europe and Northern Asia. It is one of the most common native grasses because it can be found throughout the dry prairies, rocky hillsides, openings in the northern boreal forest and sandy soils. It does however, prefer well drained silt, loam and sandy loam soils with a pH ranging from 6.5 to 8 (Ogle et al. 2006). June grass is a shorter plant that can vary in appearance based on growing conditions. Under dry prairie conditions the plants will be shorter and contain more basal leaves. In mixed grass prairie, June grass only made up 3 to 10% of the stand composition (Coupland 1950). It grows in association with many different species, for example in the mixed grass prairie it is associated with BG (*Bouteloua gracilis)* and NTG (*Stipa comata),* on the fescue grassland it is found growing with rough fescue (*Festuca hallii,)* and in forest openings it can be found with hairy wildrye (*Elymus innovatus)* and reed grasses (*Calamagrostis* spp) (Pahl and Smreciu 1999).

June grass is tolerant to a wide range of conditions including drought, cold and heat (Ogle et al. 2006). It produces a fibrous root system in a 15 to 20 cm zone and descends 50

cm in depth with some feeder roots reaching 75 cm (Pahl and Smreciu 1999). It is the shallow roots of June grass that allow it to take advantage of spring moisture and begin growth not only earlier in the spring but with late summer and fall rains (Coupland and Johnson 1965). For the species to perform best it requires between 305 mm and 508 mm of annual precipitation (Ogle et al. 2006). June grass is recognized as one of the first grasses to initiate vegetative growth in the spring, it flowers in early May and produces a seed head by July (Looman 1978). Seed production is important for the longevity of June grass stands because that is the primary way it spreads (Ogle et al. 2006). High seed production is common but viability tends to be low (Pahl and Smreciu 1999).

Research at Swift Current, SK has shown June grass clipped once per year produced between 150 and 3300 kg ha^{-1} of forage yield (Jefferson et al. 2005). This range in production was the result of moisture differences between years. During the spring, CP levels can reach 20% but it decline to around 4% by November (Pahl and Smreciu 1999). June grass is highly palatable to livestock early in the spring and after it cures in the fall otherwise it is undesirable to the animal (Ogle et al. 2006; Pahl and Smreciu 1999). When June grass is found in mixtures of wheatgrass and BG, grazing will decrease June grass persistence and production (Wilms et al. 1990; Wilms et al. 1993). The damage to June grass plants is increased if grazing occurs early in the growing season (Coupland 1950). It is recommended that grazing be deferred until plants are at least 10 cm in height (Ogle et al. 2006).

2.4.5 Green needle grass (GNG)

Green needle grass (*Stipa viridula* Trin.) is an erect bunch grass that grows throughout the mixed grass prairie and aspen parkland from British Columbia to Manitoba and south into Kansas and Arizona. It is one of the major species in the mixed grass prairie (Holechek et al. 2004). On the mixed grass prairie, GNG accounts for approximately 1% of the basal cover but on sites dominated by wheatgrasses and side oat grama it can contribute 9% of the plant cover (Coupland1950). It can be found in regions that receive between 305 to 457 mm of annual precipitation (Knudson and USDA 2005). It prefers deep fertile clay soils that are moderately dry to moist (Agriculture Canada 1992). It can also be found on loam, sandy loam, clay loam and even sandy soils where an underlying water source is

available (Sedivec et al. 2007; Pahl and Smreciu 1999). Green needle grass is moderately tolerant to saline soils (Sedivec et al. 2007). When growing on medium textured soils it tends to grow with WWG, NTG and BG but as the soil becomes finer, species like NTG and BG become less prominent (Knudson and USDA 2005). Growth initiates in mid to late April, flowering occurs in late June and seed heads are mature by late July or early August with culms reaching 50 to 120 cm in height (Pahl and Smreciu 1999; Coupland 1950). It has a fibrous root system that can descend 2 to 3 m (Pahl and Smreciu 1999; Coupland 1950).

Green needle grass is considered excellent forage for late season grazing because it remains palatable (Sedivec et al. 2007). It is one of the most desired grasses through all stages of growth (Pahl and Smreciu 1999). Unlike other awned species, the awns on GNG are not a risk for livestock (Knudson and USDA 2005). Its digestibility ranged from 70 to 75% in May and declined to 40 to 50% by December (Bezeau and Johnson 1962; Johnson and Bezeau 1961; White et al. 1972). Work done at Swift Current, SK determined that organic matter digestibility for GNG was 45% in August and 44% in September (Jefferson and Muri unpublished). The ADF was lowest (29%) in the vegetative stage and increased linearly through the growing season peaking at 47% after the plant had senesced (Sedivec et al. 2007). Jefferson and Muri (unpublished) found that over six year trial performed in Swift Current, SK, NDF was 69% and ADF was 37% in August and September. The CP levels started out at 20% in May and declined to 10% by the seed set stage and to 5% by mid August and 3% when the plant fully matured (Sedivec et al. 2007; Pahl and Smreciu 1999). Research from Hettinger, ND showed that CP levels were approximately 19% towards the end of April and declined to 5% by the end of August (Knudson and USDA 2005). A six year project by Jefferson and Muri (unpublished) showed that CP declined from 5.5% in August to 4.9% in September. By fertilizing GNG with N there can be increased vegetative production and CP values, provided there is adequate moisture. White and Brown (1972) found that by applying N to GNG stands; only 22% is used in the first year, while 7% of the applied N is still being utilized by the plant in the third year. Sedivec et al. (2007) found that GNG produced 32% of its total biomass by early June and 80% by mid June. Peak production was reached in August; it then declined by 12% into the fall due to weathering and leaf loss (Sedivec et al. 2007). Green needle grass communities grown in southern Saskatchewan yielded 1500 kg ha^{-1} (Heinrichs and Clark 1961). Research at Swift Current,

SK showed that GNG clipped once per year in mid July, yielded from 1,120 to 5,400 kg ha^{-1} (Jefferson et al. 2005). This range in production was the result of moisture differences between years. Other studies have shown that GNG production ranged from 785 kg ha^{-1} to 2331 kg ha^{-1} depending on soil type, moisture and the cultivar (Knudson and USDA 2005; Sedivec et al. 2007). Although it has vigorous seed growth and recovery after grazing, it is a species that decreases under grazing pressure (Knudson and USDA 2005; Kinch and Wiesner 1963). To optimize its nutritional qualities and forage DM production, it is best to allow GNG to mature before being grazed (Sedivec et al. 2007).

2.4.6 Needle and thread grass (NTG)

Needle and thread grass (*Stipa comata* Trin. & Rupr.) can be found from Ontario through to the Yukon and south into Texas and California (Ogle et al. 2006). It grows on the open prairies mainly on the south and southwest facing slopes (Coupland 1950). It prefers sandy to loamy soils and does not grow well on heavy clay soils (Coupland 1950; Pahl and Smreciu 1999). Ideally NTG requires 180 to 410 mm of annual precipitation but has been found in environments receiving as little as 120 mm of precipitation (Ogle et al. 2006). Needle and thread grass is a dominant species on the mixed grass prairie where it can be found with BG, thread leaved sedge, WWG and June grass (Hubbard and Smoliak 1953). On the mountain foothills it is often associated with bluebunch wheatgrass, Idaho fescue and bluegrass communities (Ogle et al. 2006). It also dominates stabilized sand dunes along with pasture sage and June grass.

Needle and thread grass is considered an excellent option for rangeland restoration because it is drought tolerant and has an extensive lateral distribution of roots that binds soil, reducing erosion (Ogle et al. 2006). Needle and thread grass contains a shallow root mass with 71% of roots within the first 15 cm of soil (Coupland and Brayshaw 1953). There are some feeder roots that can reach 150 cm and spread horizontally up to 90 cm. Needle and thread grass initiates growth in mid April, flowers in mid June and sets seeds by early July reaching heights up to 190 cm (Coupland 1950; Pahl and Smreciu 1999). If fall moisture is available, the plants will reinitiate growth (Ogle et al. 2006). One disadvantage of NTG is that it can take two growing seasons for the grass stands to fully develop (Pahl and Smreciu 1999). Heady (1952) found it could compete with many tame forages over the long term

once it was soundly established. It does require seed set in order to produce new plants so ideally seed production should be allowed every couple of years (Ogle et al. 2006). It initiates rapid spring growth to ensure a competitive advantage. Needle and thread grass establishment can be slow because competition decreases root vigor (Ogle et al. 2006). Wolf plants can develop because the old basal sheaths tend to cling to the crowns of older plants (Pahl and Smreciu 1999).

Grazing NTG in the spring and early summer is recommended because it not only allows plants to recover from the defoliation event but it avoids irritation to the animal caused by the awns (Ogle et al. 2006; Fiero 1941). When grazed in short duration rotations there were no effects on tiller weights even though tiller numbers increased (Reece et al. 1988). Crude protein levels tended to be around 19% in late May but declined to 8% by mid July and 5% when NTG matured (Coupland 1950; Lodge 1954; Pigden 1952) (Table 2.3). The palatability of NTG is affected by the formation of awns so it is best grazed either prior to inflorescence or following seed drop (Pahl and Smreciu 1999; Ogle et al. 2006). The digestibility of NTG was shown to decline at a relatively slow rate in the spring then more rapidly through the summer and fall (Ward 1971; Cogswell and Kamstra 1976). When found on pristine mixed grass prairie it can account for 36% of the total production (Frank and Hoffman 1989; Murray 1971; VanRyswyk et al. 1966). Its response to grazing depends not only to grazing pressure but also to the soil type. Grazing NTG grown on brown and dark brown soils tends to cause it to decline within the stand composition but in the black soil zone NTG increases with grazing disturbances (Ogle et al. 2006; Hart and Ashby 1998; Smoliak 1965; Wikeem and Pitt 1991; Pahl and Smreciu 1999).

Table 2.3 Fibre fractions (%), plant stage and protein composition of Needle and thread grass (modified from Cogswell and Kamstra, 1976)

	Stage	Protein	Hemicellulose	Cellulose	ADF	ADL
Jun-17	Vegetative	9.2	41.3	30.0	32.9	4.0
Jun-28	Early flowering	7.5	43.0	32.8	36.3	4.9
Jul-17	Seed ripe	6.0	44.5	33.2	38.8	6.9
Aug-16	Seed shatter	4.6	44.0	35.2	42.8	6.5
Sep-13	Some regrowth	4.9	40.1	36.3	43.2	6.4

2.4.7 Canada wildrye (CWR)

Canada wildrye (*Elymus canadensis* L.) can be found throughout most of North America except in the extreme southern and eastern states. It requires high moisture conditions for optimal growth (Bush and USDA 2002). For these reasons, it is most commonly found in the tall grass prairie or on sandy, porous soils near depressions, ponds and streams, and colonizes areas where disturbances have occurred. It grows on moist sandy soils and in wooded regions where moisture is readily available (Bush and USDA 2002). Canada wildrye produces a fibrous root system and rhizomatous stems. It is a poor competitor with other plants so it initiates growth early in the spring (Frischknecht and Plummer 1955).

Canada wildrye is considered an excellent species for controlling erosion because of its rapid establishment, vigorous seed growth and early colonization of disturbed land. Although seed vigor is high, plants are not overly competitive, so stands can be out competed by other plants. It initiates growth later in the spring and continues growing longer in the summer than most C_3 grasses (Bush and USDA 2002). McMillan (1959) found that in southern and western locations of the Great Plains, plants tended to mature sooner than comparable plants in northern and eastern locals. It is typically seeded in mixtures of C_3 and C_4 grasses and native forbs to improve reclamation success and forage production (Bush and USDA 2002). Canadian wildrye will produce seed in the first year of production but it will not be viable. By the second or third year, the seed viability will improve and overall plant production peaks. Following this, CWR rapidly disappears from the stand (Bush and USDA 2002). The plants are able to reproduce vegetatively but more commonly produce new growth through the distribution of large amounts of seed (Nieland and Curtis 1956). Canadian wildrye plants are moderately tolerant to drought, cold stress, saline soils and shading (Bush and USDA 2002).

Canadian wildrye is best grazed in the spring before the culms elongate. As plants mature they become more lignified and become less palatable to the grazing animal. Canada wildrye plants are considered good sources of energy but poor in protein (Bush and USDA 2002). Due to its poor competitive nature, CWR is negatively affected by grazing disturbance (Nieland and Curtis 1956). This is why grazing should be deferred until the plants are at least 12 cm in height (Bush and USDA 2002). Plants are subject to leaf and

stem rust and ergot infection which can negatively impact animal performance (Bush and USDA 2002).

2.4.8 Meadow brome grass (MBG)

Meadow brome grass (*Bromus riparius* Rehm.) is a long lived bunch grass that is considered an excellent option for reestablishing tame grass pastures. Originally from southwestern Asia, it was brought into the United States in 1949 (Sedivec et al. 2007). It is a species well adapted to Canadian growing conditions. It initiates growth early in the spring season when cool conditions are prevalent and can even survive spring frosts (Ogel et al. 2006a). It is considered very winter hardy and can survive when there is little or no snow to insulate the sword. Meadow brome grass grows optimally on well drained, coarse to medium textured soils that are moderately acidic, saline or alkali with 35 to 40 cm of annual precipitation (Ogle et al. 2006a; Sedivec et al. 2007). It will not grow on high saline or in areas with a high water table and frequent flooding. Plants require full sun light to achieve optimal growth. Production of MBG can be reduced with shading. It is a dual purpose grass that can be used as a forage source for grazing animals or used in hay production. Meadow brome grass is one of the most widely recognized grasses for use under intensive rotational grazing because of its high palatability and excellent recovery (Ogle et al. 2006a).

Although MBG forms dense rhizomatous stems, it is not as well suited for reclamation as other species. When compared to Smooth brome grass (SBG) the rhizomes are shorter and less aggressive but produce a higher canopy when dormant (Ferdinandez and Coulman 2001; Sedivec et al. 2007). This makes it less valuable than SBG for reclamation but a better option in seed mixtures, due to its less invasive nature and reduced potential to become sod bound, a condition where shoot density is reduced and nitrogen deficiency appears (Ogle et al. 2006a; Sedivec et al. 2007).

Seed germination and vigor is good, producing excellent seed establishment (Sedivec et al. 2007). For best production it is most commonly seeded with a legume species like alfalfa, cicer milkvetch, birdsfoot trefoil or sainfoin (Ogle et al. 2006a). There can be problems with silvertop and head smut as well as some types of leaf rusts that can reduce seed production and quality. It produces seed between mid July and early August (Ogle et al. 2006a).

Meadow brome grass does produce good quality hay but because of the plants low basal growth it can be extremely difficult to cut. If grown with alfalfa, the legume will provide support to the leaves (Sedivec et al 2007). Meadow brome grass is best suited for grazing, however, grazing should be deferred for at least one year following establishment (Ogle et al. 2006a). Plants are very slow to develop a root mass to resist grazing. Grazing too early could result in the damage and pulling out of immature plants. However, once established, MBG plant's deep root and basal tillers result in excellent growth throughout the summer, even during times when moisture is limited and after defoliation events (Ogle et al. 2006a; Sedivec et al. 2007).

Sedivec et al. (2007) found that MBG produced 30% of its total biomass by mid May and 47% by early June. It peaked in production by early July before loosing between 35 to 40% of the standing crop due to deterioration in the litter (Sedivec et al. 2007). A good rule of thumb is that plants should be at least 20 to 30 cm in height before utilization and no more than 50% of the annual growth should be grazed during the growing season (Ogle et al. 2006a). Sedivec et al. (2007) found that MBG produced between 1350 and 1489 kg ha^{-1} of dry matter at Hettinger, ND. This was very similar to the production found with Hybrid brome stands but during drier years the production was slightly lower than for SBG (Sedivec et al. 2007). The optimal time to graze MBG is from May through to the end of June because it is extremely palatable. The CP content of MBG was as high as 20% in the vegetative stage then declined to 10% at the pre-boot stage, 7% at seed set and 4% when the plant had fully senesced (Sedivec et al. 2007). Meadow brome grass in the vegetative stage tends to have higher fibre levels and slightly lower protein levels than SBG but these differences become less evident as plants mature (Knowles et al. 1993; Coulman 1998). The ADF levels in meadow brome were lowest in the vegetative stage (29%) and increase to 38% at the boot stage and 47% as the plant senesced (Sedivec et al. 2007).

2.4.9 Hybrid brome grass (HBG)

Hybrid brome grass (*Bromus riparius* Rehm X *Bromus inermis* Leyss) was first bred in the early 1980's at the Agriculture and Agri-Food Research Center in Saskatoon (Coulman 1998). It was produced by crossing SBG and MBG followed by several cycles of recurrent selection for plant vigor, floret fertility, reduced rhizome production and good fall regrowth

(Ferdinandez and Coulman 2001). The goal was to produce a multi-purpose grass that possessed intermediate characteristics such as faster regrowth and a higher canopy that could be used for both hay and pasture production (Coulman 1998).

Coulman (1998) found that HBG produced lower ADF and NDF concentrations than either SBG or MBG at similar stages of maturity. Ferdinandez and Coulman (2001) reported that the NDF and ADF values were higher for both MBG and SBG during the vegetative stage and CP was similar between MBG and HBG but lower than SBG. As the plants reached the heading stage, NDF was lower for MBG than for either SBG or HBG and the CP was lower in the hybrid population than for either of the other two species (Ferdinandez and Coulman 2001). Once the three types of brome reached the anthesis stage, there was no difference in NDF, ADF or CP (Ferdinandez and Coulman 2001). The Agriculture and Agri-Food Canada trials showed that HBG produced higher yields than SBG but less than MBG. Grazing data from Melfort and Swift Current, SK showed that HBG produced equal or better average daily gains, pasture yields and carrying capacity as MBG (Coulman 1998).

2.4.10 Little bluestem (LBS)

Little bluestem (*Schizachyrium scoparium* Michx.; Nash.) is a warm season (C_4) bunch grass that is commonly found on native grasslands across North America. It grows from Alberta to Nova Scotia and as far south as Mexico. It initiates growth in late spring and continues growing throughout the hot summer season until the first killing frost. Plants can tolerate between 250 to 1,020 mm of annual precipitation but for optimal growth 510 mm of annual moisture is required (Albertson 1937; USDA 2002a). Plants can vary in height depending on moisture and soil fertility but under semi-arid conditions can reach 45 cm (USDA 2002a). Under these conditions LBS tends to form sods 10 to 25 cm in diameter that are 13 to 25 cm away from other LBS plants (Albertson 1937; Weaver and Albertson 1944; Weaver 1958; USDA 2002a). Although LBS is found on a diverse range of soil types, it prefers well drained, dry soils with low fertility and neutral soils. In Saskatchewan it is primarily found in the brown and dark brown soils zones because of the higher temperature and lower availability of moisture (Pyle and Johnson 1990). Little bluestem is very tolerant to drought conditions and relatively tolerant to shading but can not tolerate an overabundance of moisture (USDA 2002a).

Little bluestem is considered an excellent species for the use in reclamation projects due to its ability to grow under a wide range of soil conditions especially on thin upland range sites. Root production peaks by the third year as roots reach depths of 1.75 m before gradually declining (Weaver and Zink 1946a; Weaver and Zink 1946b). In Montana, LBS initiates growth in late May and flowering occurs in July (McMillan 1959; McMillan 1965). Little bluestem reproduces either by rhizomes or seed production with seed heads that can be up to 7 cm in length (Weaver 1954; USDA 2002a). Its development and growth is largely dependant on photoperiod (Larsen 1947).

Little bluestem is readily grazed by livestock (USDA 2002a). The basal leaves are the most palatable part of the plant and seed heads tend to reduce palatability (Rogler 1944; Morris et al. 1950; Herbel and Anderson 1959). It is important to use controlled grazing on native range and not to overgraze, however an adequate grazing intensity is important because ungrazed plants can become very coarse and unpalatable. No more than 50% of the current year's growth should be removed by grazing (USDA, 2002a). Plants require at least one growing season to fully develop a root system so they will not be pulled out by the grazing animal. Mullahey et al. (1990) determined that grazing LBS stands during the year of seeding reduced the DM yield and tiller weight but did not reduce tiller numbers. One benefit of having LBS in the forage stand, is that its production remains consistent year after year even during drought (Gilbert et al. 1979). Under normal grazing, LBS is considered an increaser, however continued heavy grazing will result in a decline in plant vigor and the number of LBS plants but a concurrent increase in BG plants (Bukey and Weaver 1939; Tomanek and Albertson 1953; Gillen et al. 1998; Johnson and Nichols 1970). To maintain LBS in a stand, it is ideal to graze native pastures later in the fall. This reduces the composition of C_3 plants in the stand and opens the canopy for LBS growth. Ralston and Dix (1966) determined that LBS production ranged from 2,462 kg ha^{-1} in the Red River Valley to 4,719 kg ha^{-1} in the southern United States. During mid summer *in vitro* digestibility ranged from 52 to 58% and declined during the winter (Hobbs et al. 1945; Burzlaff 1967). A National Academy of Sciences (1982) review showed that CP levels declined from 12.8% at the early vegetative stage to 5.8% when plants were mature. This review also indicated that crude fibre levels increased from 24.9 to 34.2%, ash levels declined from 8.9 to 5.6%, Ca

dropped from 0.63 to 0.40%, P dropped from 0.20 to 0.12% and the ether extract levels declined from 2.8 to 2.4% (National Academy of Sciences 1982).

2.4.11 Blue grama (BG)

Blue grama (*Bouteloua gracilis* Willd. ex Kunth) is a warm season (C_4) grass that can be found throughout Alberta, Saskatchewan and Manitoba and as far south as Mexico (Dormar et al. 1981; Wynia and USDA 2007; Barnes 2007; Pahl and Smreciu 1999). It is less productive than the associated C_3 grasses on the Canadian prairies (Barnes 2007). It is recognized as one of the most naturally abundant species on harsh, dry, eroded and low fertility soils (Smith and Whalley 2002). It grows on a wide variety of soil types from sandy to clay textured soils but vigor declines in pure sand and clays. It can withstand severe drought conditions, moderate salinity and alkalinity levels but is unable to tolerate frequent flooding, shade or low pH soils (Wynia and USDA 2007). Optimal production for BG is achieved when there is between 300 and 360 mm of annual precipitation (Wynia and USDA 2007). Blue grama initiates growth in mid May or early June and flowers from July until early September (Pahl and Smreciu 1999). During drought conditions BG plants will become dormant until precipitation is received at which point they will reinitiate growth and even flower a second or third time (Rauzi et al. 1969). In the short grass prairie, BG can be found growing with buffalograss, NTG, WWG, June grass and GNG (Pahl and Smreciu 1999; Wynia and USDA 2007). In sandier soils, it grows in combination with Prairie sandreed (PSR) and sand sagebrush (Wynia and USDA 2007).

Blue grama is considered an excellent option for re-vegetating areas with poor soils that are prone to drought. Blue grama seeds develop an adventitious root system (Hyder et al. 1971) with most of the root mass developing in the top 75 cm of soil, however, some seminal roots can reach depths of 1.8 m (Pahl and Smreciu 1999). Established plants have a fine root system that can spread up to 46 cm in the upper soil horizons (Weaver 1926). Blue grama plants in Saskatchewan appear to have 84% of root mass within the first 15 cm of soil and only 9% within 15 to 30 cm (Coupland and Johnson 1965). If plants do not develop an adventitious root system within six to ten weeks after emergence, the seminal roots will no longer be sufficient to support further leaf expansion and plants will die (Briske and Wilson 1980; Pahl and Smreciu 1999). Well rooted plants will often appear thin in forage stands but

these plants will have extensive root systems (Coupland and Johnson 1965). Root growth will vary with environmental conditions, however generally between 30 to 60% of the current root mass is replaced during the growing season (Ares 1976). Depending on environmental conditions Blue grama is able to reproduce by rhizomes, seed production or tillering (Coupland and Johnson 1965; Trlica et al. 1977). Plants produce a vegetative cover that is characteristically short, forming a dense mat of twisted leaves (Pahl and Smreciu 1999). Under normal growing conditions BG grows as a bunch grass but under heavy defoliation it will grow as a sod (Wynia and USDA, 2007). Blue grama can alter its physiology to adapt to different environmental conditions and grazing intensities (Buwai and Trlica 1977). There are three ways that BG survives drought depending on the stage of the plant and severity of the drought. These include increased water uptake, optimization of leaf area and reduction in transpiration (Wilson et al. 1976). Blue grama is a bunch grass that is comprised primarily of basal leaves and vegetative shoots (Wynia and USDA 2007; Barnes 2007). Plant survival declines as the plants get older. A study in Nebraska showed that plant survival declined to 66% by the second year and dropped to 45% by the third year (Weaver and Zink 1946).

From a forage production stand point BG is poor; however it is a species that is very palatable year around for livestock. It is considered one of the most important forages on the short grass prairie (Wynia and USDA 2007). Blue grama is a recognized forage for deferred grazing because of its ability to cure on the stem. It is a species that is rarely grazed during the summer period but during the fall and winter periods animals will graze BG plants including the seed head (Pahl and Smreciu 1999). However, because of its low growing nature, production is low so best forage production is achieved by grazing once every two to three years (Wynia and USDA 2007). Average production on the Canadian prairies is only around 140 kg ha^{-1} (Tannas 2003). Research at Swift Current, SK. showed that the average forage production for BG clipped in mid July ranged from 400 to 4690 kg ha^{-1} (Jefferson et al. 2005). This range in production was the result of moisture differences between years. Blue grama has the ability to quickly recover from heavy defoliation and trampling due to its low growing nature which prevents the growing points from being removed and ensures some photosynthetic tissue remains on the plant (Weaver and Albertson 1944; Smoliak 1974;

Dormaar et al. 1981; Dormaar et al. 1994; Pahl and Smreciu 1999). Blue grama tends to increase in native pastures with heavy grazing (Dormaar et al. 1994).

The digestibility of BG increased until late June and early July where it peaked around 68% and then declined through the fall to about 50% (Cogswell and Kamstra 1976). Crude protein levels declined from 13.1% during the early vegetative stage to 6.5% as plants matured (National Academy of Sciences 1982). Uresk and Sims (1975) found that CP levels started out as high as 18% but declined throughout the growing season as the plants matured and that summer moisture had little effect on CP values. Cogswell and Kamstra (1976) determined that, as BG matured, there was an increase in the fibre constituents and a reduction in the amount of CP (Table 2.4). Crude protein levels tend to stay around 5% during the fall period (Pahl and Smreciu 1999). This research also showed that crude fibre increased from 27.2 to 32.7%, Ca dropped from 0.53 to 0.34%, P decreased from 0.19 to 0.12% and ether extract levels declined from 2 to 1.7%. Ash levels remained relatively consistent (Rauzi et al. 1969; Rauzi 1978; National Academy of Sciences 1982).

Table 2.4 Effect of growth stage on fibre and protein composition in blue grama (modified from Cogswell and Kamstra, 1976)

	Stage	Protein	Hemicellulose	Cellulose	ADF	ADL
Jun-17	Early vegetative	12.1	38.1	29.1	32.5	3.2
Jun-28	Vegetative	10.7	39.0	30.9	36.5	3.5
Jul-17	Develop seed stalk	8.8	38.7	30.6	36.3	3.6
Aug-16	Some seed stalk	6.7	40.7	30.0	37.0	3.5
Sep-13	Several seed stalk	4.5	40.8	32.8	41.0	4.8

2.4.12 Prairie sandreed (PSR)

Prairie sandreed (*Calamovilfa longifolia* Hook.; Scribn.) is a tall coarse long lived warm season grass (C_4) with rhizomatous growth. During favourable years with a long growing season it can produce seeds (Vogel et al. 1996; Duckwitz et al. 2006). It is a key species in the early colonization of sand dunes, stabilized blowouts, dune depressions, sandy ridges and dry valleys (Coupland 1950; Coupland and Johnson 1965; Hulett et al. 1966; Morrison and Yarranton 1974; Masters et al. 1990). It can be found throughout sandhill

communities from southern British Columbia to western Ontario, including the Great Sand Hills of Saskatchewan and south to Mexico (Coupland 1950; Masters et al. 1990; Pahl and Smreciu 1999). It requires between 250 and 500 mm of annual precipitation (Duckwitz et al. 2006). Plants tend to grow almost as a monoculture stand with a clear distinction between the surrounding vegetation (Aasa and Wight 1973). Growth initiates in early May (earlier than most C_3 grasses), reaches the boot stage by mid May and the majority of plants will produce seed heads by late July or early August and plants can continue to flower into September (Weaver 1958b). Although PSR colonies tend to have a water use efficiency 1.8 times greater than range communities consisting of WWG, BG, June grass, NTG, threadleaf sedge, needleleaf sedge and fringed sage, it produced nearly twice as much biomass (Aase and Wight 1973). The roots tend to be 2-3 mm thick and reach depths of 1.2 to 3.0 m before producing an enlarged 8 mm tip. Prairie sandreed ranges in height from 50 to 180 cm (Pahl and Smreciu 1999; Duckwitz et al. 2006).

Prairie sandreed is considered an excellent species for recolonization of marginal land. It has the ability to develop rhizomatous shoots and basal cover even on sandy or moderately alkaline soils but is not tolerant to salt (Mueller 1941; Coupland 1950; Masters et al. 1990; Abouguendia 1995; Duckwitz et al. 2006). It is a species that is able to establish with low soil moisture and once established it is extremely drought tolerant (Duckwitz et al. 2006). Establishment on sand dunes can be difficult because high soil temperatures, low soil fertility and moisture can inhibit seed germination and establishment (Maun, 1981). Kilcher and Looman (1983) were not able to get PSR established in south-western Saskatchewan likely due to poor soil moisture conditions. By using larger seeds and removing the protective seed coat, stand establishment and biomass production are improved (Maun and Riach 1981; Maun 1996). Grasshoppers, leaf rust and moulds, especially under irrigation, can reduce PSR production and reduce forage quality (Duckwitz et al. 2006; Pahl and Smreciu 1999).

Prairie sandreed has tremendous yield potential and its production occurs throughout the growing season (Duckwitz et al. 2006) ranging from 2,200 to 5,600 kg ha^{-1} (Masters et al. 1990). Depending upon moisture, stands grown at Swift Current, SK had a forage production between 660 and 5,400 kg ha^{-1} when plants were clipped in mid July (Jefferson et al. 2005). It is most palatable during the first month of growth and once plants cure in the fall, but the

stems are avoided by grazing animals (Pahl and Smreciu 1999). Its palatability seems to be lower than other native species largely because of higher silica levels (Clarke 1930). This is likely why it is considered an increaser on Saskatchewan rangeland under intense grazing conditions (Abouguendia 1990); even though it may take two to three years for PSR to fully establish (Duckwitz et al. 2006). During the spring and mid summer it is susceptible to trampling but in the fall becomes resilient to compaction (Quinn and Hervey 1970). It is an extremely important forage source during the late fall and winter because it cures in an upright position and can be accessed even after snowfall (Duckwitz et al. 2006). Grazing PSR from early June to August can increase biomass production especially during subsequent years, by stimulating tiller growth (Mullahey et al. 1991; Reece et al. 1999). However, grazing while the plants are actively growing can deplete the carbohydrate reserves (Welch 1968). Crude protein levels were as high as 16% in May but declined to 4% by November, available carbohydrate increased from 45 to 55%, ADF levels increased from 38 to 44%, Ca levels ranged from 0.25 to 0.5% and P levels were between 0.1 to 0.25%, respectively (Table 2.5) (Craig 2002; Pahl and Smreciu 1999; Northup and Nichols 1998; Perry and Moser 1974; Burlaff 1971). As PSR matured from June to September the *in vitro* DM digestibility declined from 67 to 52% (Mueller 1941; Cogswell and Kamstra, 1976).

Table 2.5 Fibre fractions (%), plant stage and protein composition of Prairie sandreed (modified from Cogswell and Kamstra, 1976)

	Stage	Protein	Hemicellulose	Cellulose	ADF	ADL
Jun-17	Early vegetative	11.1	34.4	36.0	37.7	3.1
Jun-28	Vegetative	9.0	36.7	37.8	41.5	4.2
Jul-17	Developing seed	6.2	42.9	39.5	43.2	3.8
Aug-16	Seed ripe	4.8	43.5	40.4	44.6	4.3
Sep-13	Seed shatter	3.0	43.5	38.5	43.9	4.4

2.4.13 Canadian milkvetch (CMV)

Canadian milkvetch (*Astragalus canadensis* L.) grows well on most types of soil. It is a native legume species that can be found from British Columbia to Quebec and south into Colorado, Virginia and Texas where soil moisture is available and there is full or partial sun (Jensen and USDA 2002; Hilty 2007). The plants form a large bushy structure that can range

in height from 30 and 102 cm (Jensen and USDA 2002). Canadian milkvetch flowers during mid summer and will continue for up to 3 months when oval pods form. Plants have a tendency to fall over unless supported by surrounding vegetation; however it does not have tendrils like other vetches (Hilty 2007). It is not uncommon for CMV leaves to begin yellowing (senescing) early in the growing season (Hilty 2007).

Canadian milkvetch is considered a good species to include in native mixtures. Its extensive rooting system will reduce erosion and it has the ability to fix N (Jensen and USDA 2002; Hilty 2007). It is a species that is adapted to a wide range of soil types and conditions but is not well suited to dry uplands or harsh winter conditions (Jensen and USDA, 2002). There are some concerns with toxic compounds like 3-nitroproprionic acid, 3-nitropropanol and nitrotoxin that can reduce energy availability to the brain and result in death (Stermitz and Lowry 1972; Burrows and Tyrl 2006). There are mixed findings about CMV toxicity. Some research with CMV has shown that unlike many milkvetches and locoweeds that are poisonous, it is non toxic (Hilty 2007). However, work done with CMV at Brookings, SD and SPARC, showed that toxicity levels ranged from non-toxic to extremely toxic (M.P. Schellenberg, personal comm.; A. Boe, personal comm). Toxicity levels are affected by genetics, plant maturity and environmental conditions (A. Boe, personal comm). It is palatable and nutritious for livestock and wildlife during certain periods throughout the growing season (Stubbendiek and Conard 1989; Jensen and USDA 2002). Plants can be extremely challenging to establish where rodents and wildlife can remove foliage from young plants. Canadian milkvetch plants utilize both a taproot and creeping root system to best utilize moisture and for reproductive success (Hilty 2007). A major concern with CMV is its short life expectancy of only three to four years (Jensen and USDA 2002). Persistence of CMV can be improved with proper management such as grazing or mowing to prevent seed head formation (Jensen and USDA 2002).

2.4.14 Purple prairie clover (PPC)

Purple prairie clover (*Dalea purpurea* Vent.) is a common legume species that grows on native rangeland through Canada and the United States. It is considered a climax species on the mixed grass prairie and a secondary species on the Fescue prairie (Coupland and Brayshaw 1953). Optimal growth occurs with 400 to 500 mm of annual precipitation but it

can be found in areas with as little as 300 mm of annual precipitation (Wynia et al. 2008). It grows from the Rocky Mountains east into Manitoba and south into Texas. Within Canada, it is most abundant in south-eastern Alberta and southern Saskatchewan on xeric sites ranging from clay loam to loamy sands including dry plains, prairies and open woodlands but is considered rare in Manitoba and Ontario (Coupland 1950; Abouguendia 1995; Wynia et al. 2008). On the Saskatchewan prairies it grows in swards with NTG and BG and is a common species found stabilizing sand dunes in the Great Sand Hills (Hulett et al. 1966; Abouguendia 1995). Purple prairie clover is a C_4 legume that grows in an upright form and can reach heights between 25 and 90 cm (Weaver and Fitzpatrick 1934; Lindgren 1992; Wynia et al. 2008). It prefers full sun but can tolerate moderate shade levels, is reasonably competitive with surrounding vegetation and is moderately drought tolerant (Hilty 2007; Wynia et al. 2008). Local ecotypes tend to be relatively well adapted to harsh winter conditions and will not winter kill (Wynia et al. 2008).

Purple prairie clover is recommended for use in reclamation projects. Seed is readily available and germination is reasonable with proper scarification (Wynia et al. 2008). It is able to fix N from the air, which can improve production of mixed forage stands (Posler et al, 1993; Hilty 2007; Wynia et al. 2008). It is extremely slow to develop but once established it is easily maintained (Hilty 2007). Weed control is essential to give PPC a competitive advantage. It produces a taproot that can be one to two meters deep and three to seven lateral roots within the upper 30 cm of soil (Wynia et al. 2008; Abouguendia 1995). The lateral roots can be up to 45 cm long and are usually pointed downward (Wynia et al. 2008). Plants growing in the Northern Great Plains begin flowering in July and continue into August when a cone-like spike of flowers begins to appear followed by seed production in mid to late August (Hilty 2007; Wynia et al. 2008).

Purple prairie clover produces between 1800 and 2100 kg ha^{-1} of production on rangeland in Nebraska, however if weed control was not performed, levels as low as 0 kg ha^{-1} have been observed (Beran et al 1999). The plant densities can range from 0.04 stems m^{-2} to 60 stems m^{-2} (Weaver and Fitzpatrick 1934; Coupland 1950). Purple prairie clover has been found to be very palatable, have a high nutritive value, is readily eaten by herbivores, but forage yields have been lower than other native legumes (Abouguendia 1995; McGraw et al. 2004; Hilty 2007). Having PPC improved the digestibility of mixed forage stands over pure

grass stands (Posler et al. 1993). Under continuous grazing pressure, PPC will decrease and could ultimately be removed from the stand by overgrazing (Ehrenreich and Aikman 1963). Other concerns include bloat if the grazing animal consumes too much of the legume (Abouguendia 1995; Wynia et al. 2008).

2.4.15 Alfalfa

Alfalfa (*Medicago sativa* L.) has been used as a forage for more than 3300 years and is one of the only forage species that is grown worldwide (Bolton et al. 1972). Alfalfa is a legume species that grows in one of two forms, either taproot or a creeping rooted. Tap rooted alfalfa varieties are some of the oldest and most evolved varieties (Bolton et al. 1972). They have the ability to draw water from deeper levels in the soil horizon (Berdhal et al. 1989) and produce large quantities of seed for natural reseeding (Rumbaugh and Johnson 1983). In recent years, creeping rooted varieties have been encouraged for grazing because plants are able to spread sideways using adventitious shoots. This characteristic was originally derived from crossing a yellow flowered subspecies (*falcata*) with a taprooted species (*sativa*) to combine the characteristics of both species (Heinrichs 1963; Piano et al. 1992). These *falcata* crosses have important survival traits like lower crowns that protect plants from trampling and winter injury (Berdahl et al. 1989), dormancy during drought conditions (Heinrichs 1975) and the ability to produce horizontal roots that can send out new shoots (Heinrichs 1963). This enables creeping rooted plants to persist better under grazing conditions (Berdahl and Frank 1998). The improved persistence of creeping rooted varieties, relates to their ability to recover from crown damage through the production of underground adventitious shoots and the fact that they escape complete grazing due to the lateral spread of plants (Gdara et al. 1991). F*alcata* varieties are recognized to have slower regrowth that increases root carbohydrate reserves (Smith 1972) and improves persistence under grazing conditions (Berdahl et al. 1986).

Grazing alfalfa has many benefits including higher livestock and forage production and improved forage quality (Iwaasa et al. 2006). Highest herbage yields and best stand persistence were obtained when cutting stage was delayed to the full bloom stage but protein was highest at the 10% bloom stage and the feeding value decreased as the alfalfa stand matured (Fulkerson et al. 1967; Smith 1972). By delaying the cutting of alfalfa until the full

bloom stage it allows the plants an opportunity to accumulate higher levels of carbohydrate root reserves and maintain plant vigor (Dotzenko and Ahlegren 1950; Reynolds and Smith 1962; Cooper and Watson 1968; Nelson and Smith, 1969). It also provides the plant an opportunity to recover from root and crown injuries caused by low winter temperatures (Grandfield 1934; Sprague and Graber 1944). Forage DM production increases until plants bloom mostly due to the increase in fibrous constituents caused by the elongation and enlargement of the upper internodes (Figure 2.8) (Nelson and Smith 1968; Smith 1972). This reduces the proportion of leaves and ultimately decreases the level of total digestible nutrients (TDN), protein and minerals. Alfalfa at the full bloom stage has higher proportions of stem tissue and lower proportion of leaves, which reduces the feeding value (Smith 1972). Smith (1969) determined that leaves had higher TDN, protein, fat, starch, total nonstructural carbohydrates, and minerals. Stems on the other hand were higher in total sugars, fiber and potassium. As alfalfa matured its CP declined and fiber fractions increased making it less suitable as a fall grazed forage (Table 2.6). The inclusion of alfalfa in grazing pastures is not widely accepted, as the bloat risk is high (Coulman et al. 2000; Smith and Singh 2000).

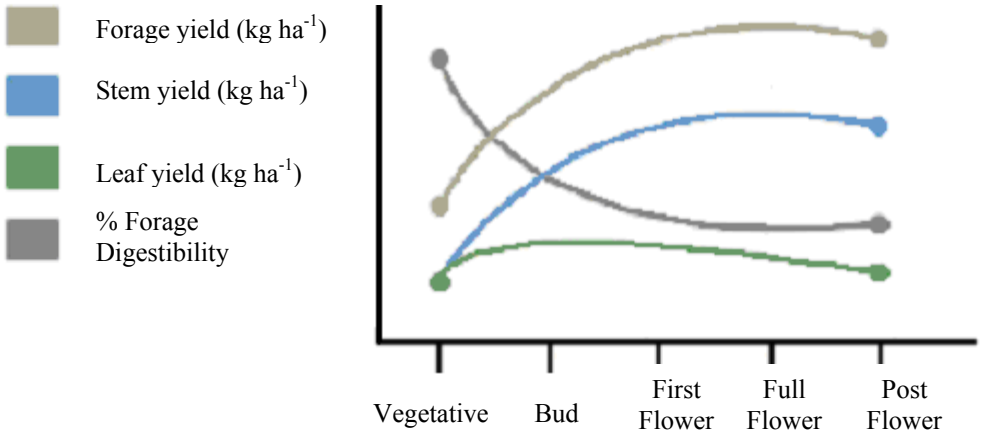

Figure 2.8 Trends in Alfalfa forage yield in relation to its forage quality (Alberta Agriculture, Food and Rural Development 2004)

Table 2.6 The composition of alfalfa at different stages and cured different ways (adapted from Cullison and Lowrey, 1987)

Stage	Basis	DM (%)	CP (%)	Hemicellulose (%)	Cellulose (%)	Lignin (%)	ADF (%)	TDN (%)
Late vegetative (fresh)	As fed	21	4.3	1	5	1	6	13
	DM	100	20.0	7	22	7	29	63
Midbloom (sun cured)	As fed	90	15.3	9	23	8	32	52
	DM	100	17.0	10	26	9	35	58

2.5 Summary of Literature Review and Research Objectives

Native forages have often been recognized for their ability to maintain their forage quality later into the fall. Differences in maintenance of quality with maturity are important for producers who are looking to extend the grazing season and reduce the need for supplementation. Comparing native and tame forage varieties can be difficult due to differences in establishment period, initial production and long term sustainability. Differences can even occur within species due to environmental, soil and moisture conditions. These differences in plant maturity vary among years, locations and cultivars. There has been little research to compare differences in individual native and tame forages common to southwestern Saskatchewan in terms of production, forage quality and digestibility.

Having a forage mixture that is sustainable is important to reduce fertilizer, seed and reestablishment costs. There has been previous work recognizing the benefits of native forage mixtures like improved rooting ability, soil quality, carbon sequestration and long term sustainability. Having a mixture of cool and warm season species ensures that forage yield and quality are distributed throughout the growing season. The inclusion of legumes also is beneficial due to their ability to fix nitrogen, improve forage crude protein levels and ultimately improve forage production. Little research is available comparing diverse pasture mixes to simpler cool season forage mixtures. Even less work has been done comparing reestablished mixed native stands in the semi-arid region of Saskatchewan.

The hypothesis of the research reported in this thesis was that mixtures of C_3 and C_4 native forage species (complex forage mixtures) will provide superior nutritional quality throughout the grazing season compared to mixtures composed of C_3 native species (simple forage mixtures). The objectives of the three studies conducted were to determine:

1) the biomass production, chemical composition and *in vitro* dry matter digestibility of different warm and cool season forage species from June through October;
2) the dry matter yield, neutral detergent fiber and crude protein degradability of selected species in terms of their suitability for fall grazing using the *in situ* digestion technique;
3) determine if nutritive qualities of complex native mixtures were superior to simple forage mixtures by determining forage yield, chemical composition, forage utilization and animal production.

CHAPTER 3
EVALUATION OF GROWTH AND NUTRITIVE VALUE OF INDIVIDUAL FORAGE SPECIES

3.1 Introduction

Forage quality and production are important variables that directly affect animal production. Understanding nutritive constituents (ie. NDF, ADF, ADL, CP, Ca and P content) and digestibility of individual forage species helps to distinguish their contribution to the nutritive value of native forage mixtures. Forage quality can vary with plant maturity and environmental conditions (Wallace et al. 1961). It is essential to know the nutritive value of native pasture plants since forage quality affects animal performance throughout the season (Abouguendia 1998). Knowledge of forage quality characteristics of specific plants allow range managers to better select forage species that compliment each other for improved animal production and reduced requirements for nutrient supplementation. Such knowledge can also help managers extend the grazing season thus reducing feeding costs (Cherney and Kallenbach 2007).

Forage species can be segregated by their photosynthetic pathway. Distinctive metabolic pathways produce different forage production growth curves for C_3 and C_4 plants resulting in differing abilities of plants to survive changing environmental conditions. These differing growth curves for C_3 and C_4 forages allow for species combinations that better meet the animal's nutrient requirements throughout the growing season (Waller et al. 1985). Cool season (C_3) forages produce the majority of their production early in the growing season when temperatures are 25°C or lower and soil moisture is readily available. They can reinitiate growth in the fall if temperatures and moisture levels become favourable. Warm season (C_4) species have improved water use efficiency and an optimal growing temperature between 30 and 35°C. They initiate growth during the summer when C_3 species have produced their inflorescence. At this point, the growing C_4 forages have a higher nutritive value than the mature C_3 plants as the relatively young C_4 plants are actively capturing and storing energy and synthesizing protein (Redmon and Hendrickson 2007). As plants mature, photosynthesis and plant growth slow but cell wall and fibre levels increase. Initially, forage

plants lay down higher levels of hemicellulose than other fibre fractions but as plants mature, lignin production increases at a faster rate (Cherney et al. 1997).

The inclusion of legumes into forage stands has many benefits including higher forage quality and reduced fertilizer costs. By including persistent forage legumes, pasture sustainability is improved because of nitrogen fixation (Cadish et al. 1994; Schellenberg and Banerjee 2002). This is the result of bacteria utilizing plant carbohydrates to reduce atmospheric N into a form that is available for plant growth (Metcalfe and Nelson 1985; Kopp 2003). The level of N fixation depends on herbage yield, plant nitrogen concentration and the amount of N derived from the symbiosis (Cadish et al. 1994). Legumes are not only desirable for their ability to symbiotically fix N but also for their ability to improve ruminant diet quality and improve animal performance (Jefferson et al. 2002; McGraw and Nelson 2003). The inclusion of native legumes in grass mixtures has been shown to increase forage yield and quality when compared to unfertilized grass pastures (Posler et al. 1993; Phillips and James 1998). Legumes tend to have higher energy and protein levels than grasses but their persistence is lower (Cherney and Kallenbach 2007). Their leaves tend to have thinner cell walls than that of grass species which means they break down and pass through the rumen faster (Spalinger et al. 1986). The leaves of legumes tend to have higher CP and cell soluble carbohydrate levels than grasses at similar stages of maturity (Holechek et al. 2004).

Different forage species respond differently to changing growing conditions. Their quality and production can be extremely variable depending on moisture, temperature, soil type and the forage species. The comparison of species is difficult because growing conditions and stress can directly affect forage production and quality. These conditions directly affect the morphological development of individual species that ultimately affect their nutritive value (Mitchell et al. 1997; Smart et al. 2001). There has been little work to compare native and tame forages under the same establishment, environmental and fertility conditions, especially in south western Saskatchewan. The objectives of this study were to determine the biomass production, chemical composition and *in vitro* dry matter digestibility of different warm and cool season forage species.

3.2 Materials and Methods

3.2.1 Plot Establishment and Maintenance

Trial plots were located at the Agriculture and Agri-Food Canada (AAFC) Semiarid Prairie Agricultural Research Center (SPARC) near Swift Current Saskatchewan (NW ¼ 16-15-13 W of 3rd) on a Chernozemic orthic brown Swinton loam soil (Ayres et al. 1985). The land had been previously cropped with barley in 2000, 2002 and 2004 and was fallow during 2001, 2003 and 2005. The whole plot area was fertilized with 9.2 kg of nitrogen ha^{-1} and 14.7 kg of phosphorus ha^{-1} on May 6, 2006. Trial plots consisted of twelve native species and three common tame species which are all grown in western Canada (Table 3.1). The certified seed was supplied by Viterra/Proven Seeds . Pure live seed (PLS) count values were supplied with each seed lot and ranged from 55% in June grass to as high as 99% in Awned wheatgrass (AWG). On June 2, 2006 forage treatments were seeded in plots 6.0 m by 1.53 m. The seeding rate was 98 PLS m^{-2} and seeding depth was 1.3 cm. Canadian milkvetch (CMV) seed was pretreated with liquid nitrogen to crack the outer seed coat and increase seed germination (Acharya, personal communication). Purple prairie clover (PPC) came scarified and inoculated from the seed distributor. Each plot consisted of five seeded rows with a 30.5 cm row spacing. The trial was a randomized complete block design where plots were replicated four times (Figure A1 in Appendix).

On September 7, 2006 all plots received 1.3 cm of artificial moisture using a manual irrigation system to ensure adequate soil moisture for the next spring's growth. On October 10, 2006 it was determined that all species had gone dormant and growth had ceased due to killing frosts. At this point, all treatments were clipped to a 5 cm stubble height to correspond with heavy grazing (Carman 1985; Olson and Richards 1988; Felker and East 1993). This ensured all plots were at the same height to avoid potential snow trap especially in taller species. This was done with a flail plot harvester (Swift Machine and Welding Ltd., Swift Current, SK.)

Purple prairie clover germination was poor and much of the above ground growth that was produced was scavenged by Richardson ground squirrels. Thus it was removed from the trial.

Table 3.1 Forage species used in trial plots grouped by native habitat (NH) and photosynthetic pathway (PSP)

NH and PSP	Species
Native Cool Season	WR Poole Western wheatgrass - (*Pascopyrum smithii* Rydb.) Polar Northern wheatgrass - (*Elymus lanceolatus* Scribn & J.G. Sm.) AC Mallard Green needle grass - (*Stipa viridula* Trin.) Sprig Awned wheatgrass - (*Agropyron subsecundum* Link.; Hitchc) Mandan Canada wildrye - (*Elymus canadensis* L.) AC Sharptail Needle and thread grass - (*Stipa comata* Trin. &Rupr.) Keystone June grass - (*Koeleria macrantha* Ledeb.; Schult.) AC Larmour Purple prairie clover - (*Dalea purpurea* Vent.) Great Plains Canadian milkvetch - (*Astragalus canadensis* L.)
Native Warm Season	Taylor Little bluestem - (*Schizachyrium scoparium* Michx.; Nash.) Butte Blue grama - (*Bouteloua gracilis* Willd. ex Kunth) Co1 Prairie sandreed - (*Calamovilfa longifolia* Hook.; Scribn.)
Introduced (Tame) Cool Season	AC Knowles Hybrid brome grass - (*Bromus riparius* Rehm X *Bromus inermis* Leyss) Montana Meadow brome grass - (*Bromus riparius* Rehm.) Spreder 4 Creeping rooted alfalfa - (*Medicago sativa* L.)

3.2.1.1 Weed Control

All plots were sprayed with Basagran, a group 6 herbicide (SAFRR 2006) on July 11. Little weed control was achieved from spraying since weeds were too advanced. All plots were hand weeded on July 26 and 27 and weed material was removed from the site to avoid reseeding. All plots were hand weeded again from May 16 to 18, 2007 and as required.

3.2.2 Small Plot Sample Collection

Forage samples were clipped each month from June through October of 2007. The first collection period took place June 20 and then every 28 days, through October 10. Plots were split into five 1.2 m subplots. Harvest dates were randomly assigned to each subplot and clippings were taken from randomly placed ¼ m^2 quadrates within each subplot. Only center rows of the plots were sampled to avoid micro environmental affects associated with the outer rows. Hand clippings were performed at a 5 cm stubble height to account for all new growth for that year.

Samples were weighed then dried to a constant weight in a forced air oven at 50° C. Dry material was weighed to determine dry matter yield. Dried samples were ground using a

Willey Mill (Model no. 4; Arthur H. Thomas Co., Philadelphia, PA) fitted with a 1mm screen.

3.2.3 Laboratory Analysis

Animals used in this experiment were cared for under the guidelines put forward by the Canadian Council of Animal Care (2008) and local AAFC-SPARC requirements. Two Hereford/Angus steers were surgically fitted with 10.2 cm cannulas during the winter of 2006-2007. Animals were housed outdoors in a corral bedded with straw, fed *ad libitum* brome grass hay and had free access to water. Rumen fluid was collected according to the protocol established by Iwaasa et al. (2001). *In vitro* organic matter digestibility (OMD) was determined according to the procedure established by Tilley and Terry (1963) as modified by Troelsen and Hanel (1966). Dry weights were recorded after drying over night at 105°C. Ash was determined by weighing a one gram of sample into porcelain crucibles. Samples were heated at 600°C for two hours to determine the ash content (AOAC method 923.03; AOAC, 2005). Calcium (Ca) was determined using the methodology adapted from Steckel and Flannery (1965). Phosphorus (P) levels were determined using the protocol adapted from Varley (1966) and Milbury et al. (1970). Standards were analyzed daily and consisted of L-cystine (General Biochemicals, Chagrin Falls, OH), crested wheatgrass and wheat (AAFC, 1998). Crude protein (CP) was determined using the protocol of the Methods Manual Scientific Support Section (AAFC 1998) that was adapted from Varley (1966) and Noel and Hambleton (1976). The total Kjeldahl N was multiplied by 6.25 to determine the level of crude protein (AOAC 1984). Neutral detergent fibre (NDF) was determined using the ANKOM^{200} fiber analyzer (Model 200; ANKOM; Fairport, New York). Acid detergent fibre (ADF) was performed using the procedure of Goering and Van Soest (1970). Acid detergent lignin (ADL) was determined using the ANKOM Technology-08/05, Method for Determining ADL in Beakers using the ANKOM^{200} fiber analyzer (Model 200; ANKOM; Fairport, New York; 14450).

3.2.4 Meteorological Data

All weather data was recorded at the AAFC SPARC at Swift Current, Saskatchewan. The weather station was located approximately 1 km from the plot site. The daily maximum

temperature, precipitation, monthly mean precipitation and temperature were recorded (Figure A2, A3 and A4 in Appendix).

3.2.5 Statistical Analysis

The data was analyzed as a five (harvest date) by fourteen (forage species) factorial using the Mixed Model procedure of SAS (SAS Institute, Inc. 2003). The plot was the experimental unit. Replicates were treated as a random blocking factor and harvest date was considered a repeated measure. Dependant variables included forage production (kg ha^{-1}), OMD, NDF, ADF, ADL, CP, Ca and P levels. The following covariance structures were tested for each variable; unstructured, ante-dependence, autoregressive, heterogeneous autoregressive, compound symmetry and heterogeneous compound symmetry. The final covariance structure was selected on the basis of the lowest AIC, AICC and BIC values. To explore the nature of any species by harvest date interactions, linear and polynomial regression analysis were carried out for each species. For presentation purposes, C_3, C_4 and legumes were grouped and regressions were run on the pooled analysis. Best fitted regressions (linear, quadratic, cubic and quartic) were selected based on the highest order polynomial that was significant ($P \leq 0.05$).

3.3 Results and Discussion

Understanding forage quality of individual native species is important to better distinguish their role in native mixtures for grazing. Forages contain much of their OM (35 to 80%) in the cell wall structure (Jung and Allen 1995). This can result in lower digestibility and ultimately limits the energy that animals can gain from forage diets. The literature is limited comparisons of native versus tame forage plants. The comparison of species is difficult because growing conditions and stress can directly affect forage production and nutritive value. In this study to properly compare individual species and ensure proper species identification, monoculture stands were grown under weed free conditions.

A significant ($P<0.01$) species by harvest date interaction was observed for forage DM production (kg ha^{-1}) (Table 3.2). This interaction is the result of C_3 and C_4 grasses and legumes having different growth patterns and responding differently to changing environmental conditions (Barnhart 1998; Baron and Bélanger 2007). Cool season grasses

and legumes initiate growth early in the season and produce around two thirds of their annual production before mid summer (Holechek et al. 2004; Jefferson et al. 2005); then they go dormant when moisture and high temperatures do not favour their growth (Baron and Bélanger 2007; Cherney and Kallenbach 2007). Warm season grasses produce the majority of their growth during the hot summer period when optimal growing temperatures are experienced (Jefferson et al. 2005; Baron and Bélanger 2007). The R^2 and standard error of predicted equations for DM production are shown in Table 3.3. The majority of C_3 grasses could not be fitted with any regression curve; instead they were compared by a simple mean value throughout the five harvest periods. This was an unexpected trend because plant production naturally increases through the spring before peaking and then slowing as plants senesce during the hot summer period until the fall when regrowth can occur if moisture is available (Baron and Bélanger 2007; Cherney and Kallenbach 2007). Cool season grasses produce the majority of their growth early in the spring (Holechek et al. 2004; Jefferson et al. 2005) so it is possible that our first sample period was not early enough to observe the rise and peak. There should also be a decline in forage production as leaves senesce and drop from the plants. However, the decline may have been too gradual to determine, with the number of harvest dates used in this trial. The lack of any significant regression could also have resulted from variation within the replicates (harvest date and plots) as a result of sampling only one year.

Exceptions to this included GNG, MBG and the pooled C_3 grasses where forage DM production (kg ha^{-1}) for all three declined in a linear ($P<0.05$) fashion. This linear decline in DM production can be explained if peak production had been reached prior to the first harvest date. The decline in forage production would then have been similar to that observed by Sedivec et al. (2007) for MBG. The decline in forage production could relate to leaf loss (Wilson 1981), losses associated with the leaching of soluble non-structural carbohydrates (Collins 1982) and the loss of minerals due to weathering (Koelling and Kucera 1965).

Table 3.2 Least square means for species by harvest date interactions (P<0.01) for forage dry matter production (kg ha^{-1}) throughout 2007*

	Date					Pooled	P-Values			
Species	Jun-20	Jul-18	Aug-16	Sep-12	Oct-10	SE	Linear	Quadratic	Cubic	Quartic
C_3 Grass										
AWG	4306	5322	4155	4828	4618	535.1	0.94	0.76	0.45	0.15
CWR	3802	5874	4803	5490	4667	535.1	0.55	0.14	0.47	0.18
GNG	3580	3230	2214	2535	2311	535.1	0.02	0.30	0.92	0.26
HBG	4416	4641	3932	3433	3311	535.1	0.15	0.86	0.57	0.87
Jun	671	1146	893	1223	1112	535.1	0.15	0.45	0.66	0.19
MBG	5023	5484	3198	3295	3071	535.1	0.04	0.76	0.39	0.30
NTG	5342	3907	4244	3727	3768	535.1	0.15	0.43	0.59	0.50
NWG	3908	5058	3731	4119	3069	535.1	0.28	0.35	0.66	0.25
WWG	2764	3653	3234	3478	3291	535.1	0.46	0.29	0.46	0.33
Pooled C_3**	3769	4252	3378	3570	3234	376.5	0.06	0.57	0.32	0.08
C_4 Grass										
LBS	75	297	573	437	256	535.1	0.17	0.03	0.89	0.43
BG	175	789	951	759	632	535.1	0.07	< 0.01	0.27	0.79
PSR	300	921	982	1487	1181	535.1	0.22	0.52	0.89	0.64
Pooled C_4**	184	666	832	885	708	475.4	0.05	0.05	0.91	0.84
Legumes										
CMV	4062	4798	3704	3912	3425	535.1	0.10	0.44	0.37	0.14
Alf	3101	3268	2348	1973	1956	535.1	< 0.01	0.89	0.18	0.51
Pooled legume**	3609	4039	3034	2946	2655	541.6	0.02	0.73	0.27	0.26

*Overall model exhibited species effect (P<0.01), harvest date effect (P<0.01) and species by harvest date interaction (P<0.01)

** Pooled samples exhibited a group effect (P<0.01), harvest date effect (P<0.01) and species by harvest date interaction (P = 0.04)

Table 3.3 Best fitted regressions for species by harvest date interaction (P<0.01) for dry matter forage production (kg ha^{-1}) throughout 2007

Species	Adjusted R^2	S_{xy}*	Mean or Intercept		Linear term		Quadratic term	
			Estimate	SE	Estimate	SE	Estimate	SE
C_3 Grass								
AWG	N/A	N/A	4645.8	231.5				
CWR	N/A	N/A	4927.2	320.0				
GNG	0.23	787.22	3420.6	304.9	-11.5	4.4		
HBG	N/A	N/A	3946.6	309.3				
Jun	N/A	N/A	1009.0	92.7				
MBG	0.18	1695.21	5232.8	656.6	-21.8	9.6		
NTG	N/A	N/A	4197.6	307.1				
NWG	N/A	N/A	3977.0	328.1				
WWG	N/A	N/A	3284.0	159.6				
Pooled C_3	N/A	N/A	3641.7	123.3				
C_4 Grass								
LBS	0.25	247.62	57.0	116.5	13.6	4.9	-0.1	0.04
BG	0.43	279.32	222.1	131.4	21.9	5.6	-0.2	0.05
PSR	N/A	N/A	974.2	244.6				
Pooled C_4	0.09	690.89	195.4	187.7	19.4	7.9	-0.1	0.06
Legumes								
CMV	N/A	N/A	3980.2	187.3				
Alf	0.38	636.80	3246.2	246.6	-12.8	3.6		
Pooled legume	0.12	1028.91	3829.2	281.8	-10.3	4.1		

* S_{xy} = Root mean square error

In this study, C_4 grasses exhibited a quadratic response in terms of DM production, peaking during the hottest part of the summer then declining into the fall as temperatures declined. This response with C_4 plants was similar to other studies (Baron and Bélanger 2007; Cherney and Kallenbach 2007) that demonstrated optimal growth during the summer before peaking in production by early fall. The exception was PSR which could not be fitted with a suitable regression to explain production trends. Pooled over all C_4 grasses, DM production showed a quadratic response ($P = 0.05$) during the growing season.

Within the legume species, Alf declined ($P<0.01$) in DM production linearly with harvest date while CMV showed a trend ($P=0.10$) towards a linear decline. Pooled data exhibited a linear decline ($P<0.01$) in DM production with time. These results correspond with work by Fuess and Tesar (1968) that found as legume plants mature, leaf loss becomes a concern. The fact that CMV could not be fitted to an appropriate regression equation could indicate that it retained its leaves later into the fall and would be better suited for fall grazing. Organic matter digestibility values for all the species at each of the five collection periods are reported in (Table 3.4). As with DM production, a species by harvest date interaction ($P < 0.01$) was observed. This interaction is again likely the result of differences in how each species matured. Best fitted linear and polynomial regression equations, the R^2 and standard errors are given in Table 3.5.

Organic matter digestibility for most of the C_3 grasses was best fitted with a cubic regression equation that declined from June until July then increased until September where OMD again declined. This was also the case for the pooled value for C_3 grasses where OMD declined ($P<0.05$) in a cubic fashion with advancing maturity. The decline in OMD is common in forages because increasing maturity normally results in a decrease in nutritive quality (Kilcher and Troelsen 1973; Buxton and Fales 1994; Karn et al. 2006). The improvement in OMD later in the growing season can be associated with later plant growth with cooler temperatures and available moisture (Wilkinson et al. 1970). Several C_3 grasses (AWG, GNG, HBG and MBG) differed in that OMD declined linearly ($P<0.05$) throughout the summer.

The OMD of the C_4 grasses were best fitted ($P<0.05$) with a quadratic regression equation, the only exception was BG which showed a linear ($P<0.05$) decline. Organic matter digestibility of the C_4 grasses was low during the June sample period, peaked in July

Table 3.4 Least square means for species by harvest date interactions (P<0.01) for organic matter digestibility (%) throughout 2007*

	Date					Pooled	P-Values			
Species**	Jun-20	Jul-18	Aug-16	Sep-12	Oct-10	SE	Linear	Quadratic	Cubic	Quartic
C_3 Grass										
AWG	61.63	53.40	52.82	49.72	44.29	1.550	< 0.01	0.71	0.17	0.58
CWR	62.69	52.21	52.72	47.84	42.78	1.550	< 0.01	0.36	0.04	0.12
GNG	56.98	54.31	54.30	53.13	47.80	1.550	< 0.01	0.30	0.20	0.95
HBG	59.67	52.89	55.45	49.77	44.55	1.550	< 0.01	0.35	0.07	0.05
Jun	67.91	63.28	65.11	64.84	60.02	1.550	0.01	0.68	0.04	0.64
MBG	60.29	53.08	55.34	52.29	48.57	1.550	< 0.01	0.81	0.10	0.23
NTG	55.15	48.34	49.94	48.85	43.50	1.550	< 0.01	0.96	< 0.01	0.36
NWG	53.81	46.90	50.13	46.73	40.99	1.550	< 0.01	0.46	0.02	0.11
WWG	60.76	52.33	54.61	52.63	45.95	1.550	< 0.01	0.87	< 0.01	0.18
Pooled C_3**	59.88	52.97	54.49	51.76	46.49	0.892	< 0.01	0.78	< 0.01	0.06
C_4 Grass										
LBS	61.41	62.72	60.39	53.01	46.44	1.550	< 0.01	< 0.01	0.28	0.51
BG	67.08	63.88	64.56	58.65	57.11	1.550	< 0.01	0.60	0.93	0.14
PSR	60.16	56.98	58.52	55.66	48.04	1.550	< 0.01	0.04	0.06	0.49
Pooled C_4**	62.88	61.18	61.17	55.77	50.56	1.542	< 0.01	0.01	0.70	0.23
Legumes										
CMV	81.37	73.46	70.12	64.78	52.67	1.550	< 0.01	0.12	0.06	0.90
Alf	72.65	64.25	59.42	54.38	45.44	1.550	< 0.01	0.79	0.08	1.00
Pooled legume**	79.96	68.84	64.77	59.60	49.11	1.883	< 0.01	0.44	0.15	0.96

*Overall model exhibited species effect (P<0.01), harvest date effect (P<0.01) and species by harvest date interaction (P<0.01)

** Pooled samples exhibited a group effect (P<0.01), harvest date effect (P<0.01) and species by harvest date interaction (P<0.01)

Table 3.5 Best fitted regressions for species by harvest date interactions (P<0.01) for organic matter digestibility (%) throughout 2007

Species	Adjusted R^2	S_{xy}*	Intercept Estimate	Intercept SE	Linear term Estimate	Linear term SE	Quadratic term Estimate	Quadratic term SE	Cubic term Estimate	Cubic term SE
C_3 Grass										
AWG	0.62	4.30	60.04	1.67	-0.14	0.02				
CWR	0.80	3.29	62.38	1.63	-0.50	0.15	7.62×10^{-3}	3.36×10^{-3}	-4.24×10^{-5}	1.97×10^{-5}
GNG	0.42	3.19	57.21	1.24	-0.07	0.02				
HBG	0.67	3.34	59.14	1.30	-0.12	0.02				
Jun	0.37	3.02	67.82	1.50	-0.31	0.14	6.79×10^{-3}	3.09×10^{-3}	-4.18×10^{-5}	1.82×10^{-5}
MBG	0.44	3.87	58.76	1.50	-0.09	0.02				
NTG	0.69	2.43	55.02	1.20	-0.41	0.11	8.11×10^{-3}	2.48×10^{-3}	-4.81×10^{-5}	1.46×10^{-5}
NWG	0.61	3.18	53.51	1.58	-0.37	0.14	7.56×10^{-3}	3.25×10^{-3}	-4.73×10^{-5}	1.91×10^{-5}
WWG	0.78	2.53	60.55	1.25	-0.49	0.11	9.75×10^{-3}	2.58×10^{-3}	-5.85×10^{-5}	1.52×10^{-5}
Pooled	0.37	5.48	59.67	0.91	-0.37	0.08	6.90×10^{-3}	1.87×10^{-3}	-4.16×10^{-5}	1.10×10^{-5}
C_4 Grass										
LBS	0.86	2.51	61.75	1.18	0.07	0.05	-1.89×10^{-3}	4.28×10^{-4}		
BG	0.55	3.23	67.29	1.25	-0.09	0.02				
PSR	0.61	3.17	59.09	1.49	0.04	0.06	-1.21×10^{-3}	5.41×10^{-4}		
Pooled	0.52	4.27	62.56	1.16	0.02	0.05	-1.13×10^{-3}	4.20×10^{-4}		
Legumes										
CMV	0.87	3.73	81.70	1.44	-0.24	0.02				
Alf	0.93	2.55	72.09	0.99	-0.23	0.01				
Pooled	0.73	5.68	76.89	1.55	-0.23	0.02				

* S_{xy} = Root mean square error

and then declined into the fall. This type of equation corresponds with warm season growth curves and is likely associated with increased proportion of leaf sheath, stem and flowering head (Minson 1990). This will result in higher levels of hemicellulose, cellulose and lignin. The OMD levels of the legume species were best fitted ($P<0.05$) with linear regressions. The % OMD declined as the levels of ADF and ADL increased linearly. It is well recognized that, as plants mature, quality declines due to increased indigestible fibre fractions (Cherney et al. 1997; Karn et al. 2006).

The decline in OMD of all species over the growing season can be explained by changes observed in chemical composition of the individual species. As the C_3 grasses matured there was a linear increase in NDF (Tables 3.6 and 3.7) and ADF (Tables 3.8 and 3.9). Exceptions were June grass which could not be fitted with any regression equation for NDF content, while NDF content was found to increase in a quadratic fashion for CWR and in a quartic fashion for NTG (Table 3.7). For the C_3 grasses, OMD declined ($P<0.01$) in a cubic fashion as NDF and ADF levels increased. Increased NDF and ADF content indicate that cellulose, hemi-cellulose and lignin levels in the plant are increasing with maturity. This has been well documented by other researchers (Mueller 1941;Cherney et al. 1997; Minson 1990; Ferdinandez and Coulman 2001). Higher NDF and ADF levels are related to increased proportions of leaf sheath, stem and flowering head as plants mature (Minson 1990; Ferdinandez and Coulman 2001). ADL values for cool season grasses (Table 3.10) were best fitted with a quadratic regression (Table 3.11). The peak in ADL was reached between August and September as plants fully matured then declined likely due to fall moisture that may have re-initiated growth. Species that could not be fitted with a quadratic regression for % ADL included June grass (no suitable regression) and AWG and HBG that linearly increased in ADL. Increasing lignin concentration associated with maturity could be due to higher proportions of stem to leaf tissue in mature plants and the higher lignin in stem tissue (Sosulski et al. 1960; Kilcher and Troelsen 1973; Jung and Allen, 1995; Buxton and Redfearn 1997). The quadratic increase in lignin corresponds with the cubic decline in OMD. Lignin acts as a physical barrier that restricts microbial degradation (Jung and Deetz 1993; Buxton and Redfearn 1997) and can form cross-linkages to polysaccharides (Jung and Allen 1995).

Table 3.6 Least square means for species by harvest date interactions (P<0.01) for neutral detergent fibre (%) throughout 2007*

	Date					Pooled	P-Values			
Species	Jun-20	Jul-18	Aug-16	Sep-12	Oct-10	SE	Linear	Quadratic	Cubic	Quartic
C_3 Grass										
AWG	57.68	64.02	68.14	68.92	72.66	1.611	< 0.01	0.41	0.55	0.74
CWR	51.93	62.39	68.24	71.92	76.35	1.611	< 0.01	< 0.01	0.09	0.95
GNG	61.11	64.10	67.44	68.04	70.63	1.611	< 0.01	0.56	0.75	0.56
HBG	55.27	64.29	66.30	67.30	73.48	1.611	< 0.01	0.43	0.10	0.99
Jun	56.60	57.04	58.25	56.88	58.03	1.611	0.57	0.84	0.71	0.50
MBG	56.68	64.92	68.84	68.70	73.51	1.611	< 0.01	0.18	0.18	0.62
NTG	69.00	72.49	77.61	75.74	79.67	1.611	< 0.01	0.07	0.14	0.01
NWG	63.19	68.03	71.07	71.01	75.39	1.611	< 0.01	0.61	0.35	0.62
WWG	55.72	62.78	63.74	65.64	71.11	1.611	< 0.01	0.50	< 0.01	0.55
Pooled C_3**	56.66	63.63	67.47	68.46	74.80	0.852	< 0.01	0.08	0.06	0.42
C_4 Grass										
LBS	N/A	59.04	60.33	56.88	65.79	1.483	< 0.01	< 0.01	< 0.01	N/A
BG	62.82	61.53	62.48	60.71	65.71	1.611	0.23	0.05	0.27	0.18
PSR	64.22	65.91	63.48	64.10	68.52	1.611	0.03	0.02	0.02	0.40
Pooled C_4**	63.19	61.64	63.27	62.43	67.00	0.970	0.03	< 0.01	0.05	0.07
Legumes										
CMV	24.97	35.62	48.03	49.64	59.80	1.611	< 0.01	0.06	0.18	0.03
Alf	27.75	39.68	53.47	53.15	63.46	1.611	< 0.01	0.01	0.12	0.01
Pooled legume**	25.56	38.30	50.60	51.86	60.17	1.503	< 0.01	0.01	0.06	< 0.01

*Overall model exhibited species effect (P<0.01), harvest date effect (P<0.01) and species by harvest date interaction (P<0.01)

** Pooled samples exhibited a group effect (P<0.01), harvest date effect (P<0.01) and species by harvest date interaction (P<0.01)

Table 3.7 Best fitted regressions for species by harvest date interactions (P<0.01) for neutral detergent fibre (%) throughout 2007

			Intercept		Linear term		Quadratic term		Cubic term		Quartic term	
Species	Adj R^2	S_{xy}*	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
C_3 Grass												
AWG	0.49	5.06	59.31	1.96	0.12	0.03						
CWR	0.95	1.96	52.46	0.92	0.35	0.04	-1.30×10^{-3}	3.34×10^{-4}				
GNG	0.55	2.96	61.67	1.15	0.08	0.02						
HBG	0.61	4.50	57.44	1.74	0.14	0.03						
Jun	N/A	N/A	57.36	0.61								
MBG	0.61	4.27	59.04	1.65	0.13	0.02						
NTG	0.84	1.68	69.00	0.84	-0.20	0.17	1.91×10^{-2}	7.51×10^{-3}	-3.09×10^{-4}	1.07×10^{-4}	1.45×10^{-6}	4.76×10^{-7}
NWG	0.49	3.95	64.26	1.53	0.10	0.02						
WWG	0.90	1.69	55.78	0.84	0.39	0.08	-6.36×10^{-3}	1.73×10^{-3}	3.67×10^{-5}	1.02×10^{-5}		
Pooled	0.36	5.90	60.01	0.76	0.11	0.01						
C_4 Grass												
LBS	0.72	2.03	35.90	8.44	1.42	0.46	-2.48×10^{-2}	7.28×10^{-3}	1.30×10^{-4}	3.45×10^{-5}		
BG	0.16	2.57	63.07	1.21	-0.08	0.05	9.01×10^{-4}	4.39×10^{-4}				
PSR	0.48	1.80	64.31	0.89	0.14	0.09	-4.23×10^{-3}	1.96×10^{-3}	2.98×10^{-5}	1.14×10^{-5}		
Pooled	0.25	3.07	64.06	1.00	-0.13	0.04	1.29×10^{-3}	3.22×10^{-4}	0.25	0.31		
Legume												
CMV	0.94	3.05	24.97	1.52	-0.09	0.30	2.78×10^{-2}	1.36×10^{-2}	-4.59×10^{-4}	1.95×10^{-4}	2.16×10^{-6}	8.65×10^{-7}
Alf	0.94	3.33	27.75	1.67	-0.16	0.33	3.52×10^{-2}	1.49×10^{-2}	-5.85×10^{-4}	2.13×10^{-4}	2.76×10^{-6}	9.45×10^{-7}
Pooled	0.92	3.65	26.36	1.29	-0.12	0.26	3.15×10^{-2}	1.15×10^{-2}	-5.22×10^{-4}	1.65×10^{-4}	2.46×10^{-6}	7.31×10^{-7}

* S_{xy} = Root mean square error

Table 3.8 Least square means for species by harvest date interactions (P<0.01) for acid detergent fibre (%) throughout 2007*

	Date					Pooled	P-Values			
Species	Jun-20	Jul-18	Aug-16	Sep-12	Oct-10	SE	Linear	Quadratic	Cubic	Quartic
C_3 Grass										
AWG	29.46	33.55	36.79	37.66	40.01	1.328	< 0.01	0.48	0.74	0.77
CWR	26.39	33.66	37.25	40.66	42.81	1.328	< 0.01	< 0.01	0.27	0.43
GNG	28.87	31.24	33.76	35.45	37.63	1.328	< 0.01	0.81	0.94	0.84
HBG	29.60	35.33	37.37	38.62	41.84	1.328	< 0.01	0.45	0.39	0.99
Jun	31.76	32.47	33.61	33.65	35.28	1.328	< 0.01	0.79	0.62	0.50
MBG	30.50	36.21	38.22	39.17	42.07	1.328	< 0.01	0.31	0.30	0.98
NTG	35.87	39.12	43.57	41.98	45.15	1.328	< 0.01	0.03	0.11	0.01
NWG	35.01	38.40	40.80	41.00	43.94	1.328	< 0.01	0.65	0.52	0.69
WWG	27.64	32.07	32.82	34.39	37.80	1.328	< 0.01	0.64	0.02	0.55
Pooled C_3**	30.54	34.67	37.12	38.07	40.73	0.666	< 0.01	0.07	0.11	0.57
C_4 Grass										
LBS	N/A	27.98	29.50	28.58	33.29	1.271	< 0.01	0.05	0.03	N/A
BG	24.69	27.51	27.82	28.25	30.56	1.328	< 0.01	0.79	0.13	0.91
PSR	30.84	33.36	32.06	32.72	37.55	1.328	< 0.01	0.02	0.01	0.53
Pooled C_4**	27.87	29.64	29.74	29.92	33.72	1.159	< 0.01	0.18	0.04	0.73
Legumes										
CMV	20.88	28.40	36.49	38.99	47.56	1.328	< 0.01	0.50	0.22	0.14
Alf	21.14	30.65	40.77	41.21	50.23	1.328	< 0.01	0.09	0.13	0.06
Pooled legume**	21.07	29.62	38.63	40.06	48.83	1.353	< 0.01	0.09	0.06	0.07

*Overall model exhibited species effect (P<0.01), harvest date effect (P<0.01) and species by harvest date interaction (P<0.01)

** Pooled samples exhibited a group effect (P<0.01), harvest date effect (P<0.01) and species by harvest date interaction (P<0.01)

Table 3.9 Best fitted regressions for species by harvest date interactions (P<0.01) for acid detergent fibre (%) throughout 2007

			Intercept		Linear term		Quadratic term		Cubic term		Quartic term	
Species	Adj R^2	S_{xy}*	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
C_3 Grass												
AWG	0.43	4.04	30.45	1.56	0.09	0.02						
CWR	0.95	1.34	26.70	0.63	0.25	0.03	-9.50×10^{-4}	2.28×10^{-4}				
GNG	0.61	2.46	29.04	0.95	0.08	0.01						
HBG	0.51	3.83	31.00	1.48	0.10	0.02						
Jun	0.41	1.38	31.71	0.53	0.03	0.01						
MBG	0.56	3.29	32.01	1.27	0.09	0.02						
NTG	0.86	1.33	35.87	0.67	-0.15	0.13	1.60×10^{-2}	5.96×10^{-3}	-2.61×10^{-4}	8.50×10^{-5}	1.23×10^{-6}	3.78×10^{-7}
NWG	0.42	3.36	35.73	1.30	0.07	0.02						
WWG	0.86	1.34	27.69	0.66	0.23	0.06	-3.63×10^{-3}	1.37×10^{-3}	2.10×10^{-5}	8.04×10^{-6}		
Pooled	0.42	3.96	31.49	0.51	0.08	0.01						
C_4 Grass												
LBS	0.66	1.46	15.93	6.07	0.71	0.33	-1.19×10^{-2}	5.23×10^{-3}	6.14×10^{-5}	2.48×10^{-5}		
BG	0.51	1.72	25.27	0.67	0.04	0.01						
PSR	0.75	1.30	30.89	0.65	0.18	0.06	-4.49×10^{-3}	1.33×10^{-3}	3.03×10^{-5}	7.81×10^{-6}		
Pooled	0.28	2.92	27.72	1.02	0.15	0.08	-3.19×10^{-3}	1.79×10^{-3}	2.12×10^{-5}	1.04×10^{-5}		
Legumes												
CMV	0.91	2.84	21.67	1.10	0.23	0.02						
Alf	0.87	3.78	23.06	1.46	0.25	0.02						
Pooled	0.88	3.48	22.36	0.95	0.24	0.01						

* S_{xy} = Root mean square error

Table 3.10 Least square means for species by harvest date interactions (P<0.01) for acid detergent lignin (%) throughout 2007*

	Date					Pooled	P-Values			
Species	Jun-20	Jul-18	Aug-16	Sep-12	Oct-10	SE	Linear	Quadratic	Cubic	Quartic
C_3 Grass										
AWG	2.86	4.25	4.71	5.08	5.44	0.261	< 0.01	0.13	0.43	0.80
CWR	1.91	4.00	5.11	5.42	5.52	0.261	< 0.01	< 0.01	0.36	0.86
GNG	3.17	3.99	4.10	4.58	4.48	0.261	< 0.01	0.02	0.79	0.13
HBG	3.28	4.41	4.77	4.55	5.15	0.261	< 0.01	0.18	0.13	0.65
Jun	2.47	2.82	2.85	2.52	2.53	0.261	0.75	0.14	0.28	0.63
MBG	3.09	4.03	4.33	4.38	4.60	0.261	< 0.01	0.04	0.23	0.99
NTG	4.00	5.36	5.94	5.53	5.74	0.261	< 0.01	< 0.01	0.07	0.36
NWG	3.68	4.35	5.05	5.18	5.13	0.261	< 0.01	0.04	0.79	0.63
WWG	2.01	3.51	3.92	3.78	4.22	0.261	< 0.01	< 0.01	< 0.01	0.60
Pooled C_3**	2.96	4.07	4.54	4.56	4.74	0.139	< 0.01	< 0.01	0.08	0.80
C_4 Grass										
LBS	N/A	2.19	2.44	2.32	2.87	0.268	0.04	0.42	0.23	N/A
BG	2.09	2.36	2.45	2.65	3.14	0.261	< 0.01	0.36	0.36	0.91
PSR	1.88	2.51	2.30	2.39	2.87	0.261	< 0.01	0.99	< 0.01	0.25
Pooled C_4**	1.98	2.34	2.41	2.45	2.95	0.261	< 0.01	0.30	0.01	0.91
Legumes										
CMV	3.78	6.35	9.07	9.23	11.29	0.261	< 0.01	0.69	0.86	0.77
Alf	2.64	4.02	5.59	6.97	8.75	0.261	< 0.01	0.06	0.18	0.07
Pooled legume**	3.14	5.11	7.33	8.13	10.09	0.300	< 0.01	0.46	0.56	0.37

*Overall model exhibited species effect (P<0.01), harvest date effect (P<0.01) and species by harvest date interaction (P<0.01)

** Pooled samples exhibited a group effect (P<0.01), harvest date effect (P<0.01) and species by harvest date interaction (P<0.01)

Table 3.11 Best fitted regressions for species by harvest date interactions (P<0.01) for acid detergent lignin (%) throughout 2007

Species	Adjusted R^2	S_{xy}*	Intercept		Linear term		Quadratic term		Cubic term	
			Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
C_3 Grass										
AWG	0.58	0.72	3.27	0.28	2.14×10^{-2}	4.07×10^{-3}				
CWR	0.88	0.50	1.99	0.23	7.96×10^{-2}	9.92×10^{-3}	-4.35×10^{-4}	8.50×10^{-5}		
GNG	0.72	0.30	3.21	0.14	2.65×10^{-2}	6.07×10^{-3}	-1.34×10^{-4}	5.20×10^{-5}		
HBG	0.42	0.65	3.65	0.25	1.39×10^{-2}	3.65×10^{-3}				
Jun	N/A	N/A	2.64	0.08						
MBG	0.63	0.63	3.17	0.18	2.92×10^{-2}	7.76×10^{-3}	-1.53×10^{-4}	6.65×10^{-5}		
NTG	0.64	0.49	4.11	0.23	4.67×10^{-2}	9.76×10^{-3}	-3.00×10^{-4}	8.36×10^{-5}		
NWG	0.61	0.46	3.64	0.21	3.38×10^{-2}	9.09×10^{-3}	-1.83×10^{-4}	7.79×10^{-5}		
WWG	0.91	0.25	2.01	0.12	8.68×10^{-2}	1.13×10^{-2}	-1.31×10^{-3}	2.56×10^{-4}	6.36×10^{-6}	1.50×10^{-6}
Pooled	0.33	0.91	3.02	0.14	3.81×10^{-2}	6.07×10^{-3}	-2.10×10^{-4}	5.20×10^{-5}		
C_4 Grass										
LBS	0.22	0.37	1.98	0.23	6.78×10^{-3}	2.97×10^{-3}				
BG	0.56	0.30	2.06	0.12	8.60×10^{-3}	1.72×10^{-3}				
PSR	0.68	0.21	1.90	0.11	3.81×10^{-2}	9.68×10^{-3}	-7.83×10^{-4}	2.19×10^{-4}	4.66×10^{-6}	1.29×10^{-6}
Pooled	0.49	0.30	1.98	0.10	2.43×10^{-2}	8.37×10^{-3}	-4.70×10^{-4}	1.82×10^{-4}	2.96×10^{-6}	1.05×10^{-6}
Legumes										
CMV	0.90	0.73	2.56	0.28	5.42×10^{-2}	4.12×10^{-3}				
Alf	0.88	0.97	4.36	0.37	6.40×10^{-2}	5.45×10^{-3}				
Pooled	0.72	1.48	3.46	0.40	5.91×10^{-2}	5.90×10^{-3}				

* S_{xy} = Root mean square error

In contrast to C_3 grasses, the NDF levels in the warm season grasses were best fitted with a cubic regression curve (Table 3.6 and 3.7). The only exception to this was BG which showed a quadratic (P=0.05) increase in NDF content. For the C_4 grasses, ADF concentration was fitted with a cubic regression except BG which was linear (Table 3.8 and 3.9). The ADL was best fitted with a cubic equation except for BG and LBS (Table 3.10 and 3.11). The OMD of C_4 grasses declined in a quadratic fashion while cubic increases in NDF, ADF and ADL were experienced. Again this is expected due to increased lignin concentrations associated with maturity (Sosulski et al. 1960; Kilcher and Troelsen 1973; Jung and Allen, 1995; Buxton and Redfearn 1997) that restrict microbial degradation (Jung and Deetz 1993; Buxton and Redfearn 1997) due to cross-linkages with polysaccharides (Jung and Allen 1995).

The ADF and ADL levels of the legume species over time were best fitted with a linear regression. The % OMD declined as the levels of ADF and ADL increased linearly. It is recognized that as plants mature NDF, ADF and ADL concentrations increase (Cherney et al. 1997). However, there are lower cell wall concentrations in legume species versus grasses that ultimately improves their digestibility (Elizalde et al. 1999). However, legumes do contain more lignin which results in relatively lower degradability (Buxton and Redfearn 1997). The NDF levels were best fitted with a quartic regression curve. Based on the regression curve it would appear that % NDF peaked prior to our first sampling period likely due to the dry spring that caused plant dormancy that delayed the vegetative growth. As moisture became available in early June, growth was initiated and NDF levels gradually increased into August as plants matured. These linear increases in ADF and ADL and quartic increase in NDF help explain the linear decrease in OMD levels.

The different fibre fractions (NDF, ADF and ADL) in C_3 and C_4 grasses and legumes ultimately affect forage digestibility. There appeared to be differences in regression equations between C_3 and C_4 grasses and legumes, although all OMD values declined and NDF, ADF and ADL increased over time. Previous work has shown no consistent correlation between a single structural component and forage digestibility (Van Soest 1994). However, it is believed that structural characteristics of plant tissue affect digestibility (Lee and Pearce 1984; Mosely and Jones 1984). Lignin has been shown to negatively affect digestibility due to its ability to prevent enzymatic hydrolysis of polysaccharides (Jung and Allen 1995). Although other studies have found some type of relationship, these relations

can vary with forage species and sampling number (Barton et al. 1976; Burritt et al. 1985a; Burritt et al. 1985b). The anatomical features (sclerenchyma, parenchyma bundle sheaths and lignified tissue) of C_4 species often make them less digestible than C_3 species (Akin and Barton 1983; Akin 1989). In our study it appeared that the C_4 grasses were more digestible than C_3 grasses (Table 3.4), likely due to the vegetative nature of the C_4 grasses later into the growing season (Smart et al. 2001). There also appeared to be higher digestibility of legumes than grass species. Differences in OMD between grass and legume species could be explained by anatomical differences in the arrangement of vascular cells (McLeod and Minson 1988; Kelly and Sinclair 1989; Kennedy and Doyle 1993), the lower concentration of lignin-carbohydrate bonds in legumes (Grenet 1988) or the lower NDF concentration in legumes. Physical differences like the shorter and more cubical shape of legume digesta compared to the longer, thinner and more fibre like grass digesta could explain the slightly higher digestibility observed in legumes (Troelson and Campbell 1968; Moseley and Jones 1984; Emanuele and Staples 1988).

Crude protein values for all the species at each of the five collection periods are reported in Table 3.12. A significant ($P < 0.01$) species by harvest date interaction was observed. This interaction is again the result of differences in the rate of maturity of different species (Barnhart 1998; Baron and Bélanger 2007). Best fitted regression equations with the R^2 and standard errors are given in Table 3.13. The majority of the C_3 and C_4 grasses and all of the legume species were best fitted with a quadratic regression curve. In our trial the % CP tended to decline during the growing season. Other research has shown that CP values are highest in young plant tissue and then decline as plants mature (Coyne et al. 1995). This type of curve is likely the result of the plants fully maturing by August or September and the CP concentrations being diluted within the plant (Coyne et al. 1995). With the availability of fall moisture, plant growth likely reinitiated resulting in a slight improvement in CP values. Exceptions were AWG, GNG, NWG and PSR where values were better fitted with linear regressions that declined through the growing season. It has been well recognized that CP levels decline as forages mature (Hoffman et al. 1993; Elizalde et al. 1999). This decline in CP has been shown to be related to ADF and NDF concentrations. Early in the growing season, CP fractions consist mainly of soluble protein but as plants mature it becomes less degradable due to the tight association with ADF and NDF (Janicki et al. 1988; Elizalde et al.

Table 3.12 Least square means for species by harvest date interaction (P<0.01) for crude protein (%) throughout 2007*

	Date					Pooled	P-Values			
Species	Jun-20	Jul-18	Aug-16	Sep-12	Oct-10	SE	Linear	Quadratic	Cubic	Quartic
C_3 Grass										
AWG	12.84	9.03	7.91	6.48	5.75	0.800	< 0.01	0.23	0.67	0.75
CWR	10.97	7.27	5.41	3.75	3.38	0.800	< 0.01	0.02	0.80	0.64
GNG	13.06	9.92	9.06	7.55	7.17	0.800	< 0.01	0.11	0.64	0.47
HBG	12.25	4.98	4.92	4.00	4.50	0.800	< 0.01	0.01	0.19	0.37
Jun	14.42	10.47	9.81	8.98	8.78	0.800	< 0.01	< 0.01	0.06	0.16
MBG	10.56	5.86	5.66	4.80	4.91	0.800	< 0.01	0.02	0.24	0.39
NTG	9.17	6.48	4.42	4.69	3.91	0.800	< 0.01	< 0.01	0.17	0.12
NWG	9.64	6.09	4.77	4.22	3.64	0.800	< 0.01	0.07	0.44	0.94
WWG	12.20	8.58	7.22	5.67	4.69	0.800	< 0.01	0.02	0.30	0.46
Pooled C_3**	11.67	7.62	6.57	5.57	5.19	0.311	< 0.01	< 0.01	0.06	0.29
C_4 Grass										
LBS	N/A	12.14	7.80	6.66	6.22	0.805	< 0.01	< 0.01	0.28	N/A
BG	18.56	12.77	11.17	9.28	8.77	0.800	< 0.01	< 0.01	0.17	0.25
PSR	14.13	11.38	8.61	6.34	3.67	0.800	< 0.01	0.78	0.85	0.79
Pooled C_4**	16.37	12.08	9.18	7.49	6.19	0.615	< 0.01	< 0.01	0.67	0.94
Legumes										
CMV	19.84	15.66	13.42	11.52	10.45	0.800	< 0.01	0.03	0.63	0.73
Alf	18.28	12.38	9.58	8.16	6.28	0.800	< 0.01	< 0.01	0.07	0.98
Pooled legume**	19.18	14.10	11.49	9.86	8.26	0.707	< 0.01	0.01	0.34	0.87

*Overall model exhibited species effect (P<0.01), harvest date effect (P<0.01) and species by harvest date interaction (P<0.01)

** Pooled samples exhibited a group effect (P<0.01), harvest date effect (P<0.01) and species by harvest date interaction (P<0.01)

Table 3.13 Best fitted regressions for species by harvest date interactions (P<0.01) for crude protein (%) throughout 2007

			Mean or Intercept		Linear term		Quadratic term	
Species	Adjusted R^2	S_{xy}*	Estimate	SE	Estimate	SE	Estimate	SE
C_3 Grass								
AWG	0.41	2.79	11.75	1.08	-0.06	0.02		
CWR	0.83	1.28	10.87	0.60	-0.14	0.03	6.25×10^{-4}	2.18×10^{-4}
GNG	0.63	1.56	12.18	0.60	-0.05	0.01		
HBG	0.53	2.71	11.52	1.28	-0.21	0.05	1.34×10^{-3}	4.62×10^{-4}
Jun	0.86	0.81	14.09	0.38	-0.12	0.02	6.68×10^{-4}	1.38×10^{-4}
MBG	0.54	1.86	10.11	0.87	-0.14	0.04	8.17×10^{-4}	3.16×10^{-4}
NTG	0.85	0.80	9.08	0.37	-0.11	0.02	5.59×10^{-4}	1.36×10^{-4}
NWG	0.52	1.89	8.45	0.73	-0.05	0.01		
WWG	0.88	0.99	11.99	0.47	-0.12	0.02	4.64×10^{-4}	1.69×10^{-4}
Pooled	0.48	2.37	11.39	0.37	-0.13	0.02	6.73×10^{-4}	1.35×10^{-4}
C_4 Grass								
LBS	0.85	0.99	17.81	1.38	-0.24	0.04	1.25×10^{-3}	3.15×10^{-4}
BG	0.88	1.30	18.19	0.61	-0.19	0.03	9.35×10^{-4}	2.21×10^{-4}
PSR	0.91	1.15	14.01	0.44	-0.09	0.01		
Pooled	0.75	1.94	16.24	0.63	-0.16	0.02	6.51×10^{-4}	2.04×10^{-4}
Legumes								
CMV	0.86	1.37	19.70	0.64	-0.15	0.03	5.99×10^{-4}	2.33×10^{-4}
Alf	0.93	1.20	17.93	0.56	-0.20	0.02	8.60×10^{-4}	2.04×10^{-4}
Pooled	0.76	2.13	18.81	0.71	-0.17	0.03	7.30×10^{-4}	2.57×10^{-4}

* S_{xy} = Root mean square error

1999). The decline in crude protein coincides with an increase in the proportion of stem, flowers and seed in mature forages (Minson, 1990). Crude protein levels are usually higher in the leaves than stems (Bunderson 1986).

The NRC (2000) requirements for a 381kg animal gaining 0.33 kg day^{-1} indicate that the animal requires around 6.8% CP on a dry matter basis. We could conclude from our results that CP supplementation would be required from August through the fall with C_3 grasses and in October with C_4 grasses but legumes should be suitable to meet these NRC requirements. To improve gain in the same animal to 0.91 kg d^{-1}, the CP requirement increases to 8.8% on a DM basis (NRC 2000). Cows require 6 – 8% CP for maintenance but during lactation CP requirements can increase up to 12% (Holechek and Herbel 1986). From our results we could conclude that CP would be adequate in C_4 and legume species throughout the growing season to meet the maintenance requirements of range cows. Work by Abouguendia (1998) showed that CP in legumes increased from 6.6% in April to 29.5% in June before declining to 13.1% by October while CP levels in C_3 grasses increased from 4.8% in April to 10.9% in May and then declined to 5.6% by October. Warm season grasses followed a similar trend increasing from 4.7% in April to 9.9% in June and declining to 5.3% in October (Abouguendia 1998). In the present study similar trends were found where CP declined from June through to October; however legume values were consistently lower and the values for C_3 and C_4 grasses were higher in June but by October our values were lower than those shown by Abouguendia (1998).

Calcium (Table 3.14) values were reported for each species at each of the five collection periods. A significant ($P < 0.01$) species by harvest date interaction was observed for Ca (%). This interaction could have been the result of C_3, C_4 and legume species exhibiting different growth characteristics and environmental responses (Barnhart 1998; Baron and Bélanger 2007). As plants mature, it is common for Ca content to decline (George et al. 2001). Best fitted regression equations with R^2 and standard errors are given in Table 3.15. Throughout the growing season Ca levels were the highest in legumes followed by C_4 and C_3 grasses. This is expected and agrees with other research in Saskatchewan (Abouguendia 1998). Although within C_3 grasses there were minimal changes in Ca levels as the plants matured, statistically, Ca levels decreased ($P<0.01$) in a quartic fashion in most C_3 grasses. The range of the C_3 grasses in Ca content during the growing season was 0.25 to 0.30%. Similar comments can be made for C_4 grasses where a

Table 3.14 Least square means for species by harvest date interactions (P<0.01) for calcium (%) throughout 2007*

	Date					Pooled	P-Values			
Species	Jun-20	Jul-18	Aug-16	Sep-12	Oct-10	SE	Linear	Quadratic	Cubic	Quartic
C_3 Grass										
AWG	0.28	0.29	0.23	0.27	0.23	0.041	0.10	0.94	0.96	0.09
CWR	0.29	0.25	0.21	0.26	0.25	0.041	0.22	0.06	0.44	0.17
GNG	0.29	0.34	0.29	0.27	0.27	0.041	0.08	0.38	0.04	0.51
HBG	0.30	0.27	0.21	0.28	0.31	0.041	0.88	0.09	0.89	0.22
Jun	0.29	0.39	0.38	0.43	0.33	0.041	0.03	< 0.01	0.52	0.01
MBG	0.28	0.32	0.28	0.31	0.27	0.041	0.77	0.15	0.67	0.08
NTG	0.20	0.30	0.24	0.26	0.23	0.041	0.64	0.01	0.05	0.01
NWG	0.22	0.25	0.23	0.25	0.24	0.041	0.48	0.24	0.57	0.16
WWG	0.33	0.31	0.27	0.28	0.25	0.041	0.01	0.72	0.81	0.41
Pooled C_3**	0.27	0.29	0.25	0.27	0.24	0.013	0.22	0.33	0.52	< 0.01
C_4 Grass										
LBS	N/A	0.44	0.44	0.53	0.38	0.043	0.39	0.01	0.01	N/A
BG	0.47	0.49	0.38	0.39	0.27	0.041	< 0.01	0.05	0.94	0.01
PSR	0.35	0.50	0.48	0.54	0.43	0.041	0.32	0.10	0.97	0.39
Pooled C_4**	0.45	0.48	0.41	0.50	0.36	0.031	0.23	0.01	0.47	0.07
Legumes										
CMV	1.35	1.26	0.83	0.88	0.57	0.041	< 0.01	0.88	0.90	0.04
Alf	2.18	1.83	1.19	1.30	0.99	0.041	< 0.01	0.01	0.65	0.01
Pooled legume**	1.40	1.74	1.06	0.97	0.85	0.044	< 0.01	0.32	0.84	0.06

*Overall model exhibited species effect (P<0.01), harvest date effect (P<0.01) and species by harvest date interaction (P<0.01)

** Pooled samples exhibited a group effect (P<0.01), harvest date effect (P<0.01) and species by harvest date interaction (P<0.01)

Table 3.15 Best fitted regressions for species by harvest date interactions (P<0.01) for calcium (%) throughout 2007

Species	Adj R^2	S_{xy}*	Intercept		Linear term		Quadratic term		Cubic term		Quartic term	
			Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
C_3 Grass												
AWG	N/A	N/A	0.26	0.01								
CWR	N/A	N/A	0.25	0.01								
GNG	0.26	0.04	0.29	0.02	3.64×10^{-3}	1.65×10^{-3}	-9.00×10^{-5}	3.73×10^{-5}	5.02×10^{-7}	2.19×10^{-7}		
HBG	N/A	N/A	0.28	0.02								
Jun	0.72	0.03	0.29	0.01	1.15×10^{-2}	2.94×10^{-3}	-4.21×10^{-4}	1.32×10^{-4}	5.87×10^{-6}	1.88×10^{-6}	-2.67×10^{-8}	8.37×10^{-9}
MBG	N/A	N/A	0.29	0.01								
NTG	0.50	0.03	0.20	0.02	1.26×10^{-2}	3.06×10^{-3}	-4.79×10^{-4}	1.37×10^{-4}	6.18×10^{-6}	1.96×10^{-6}	-2.59×10^{-8}	8.70×10^{-9}
NWG	N/A	N/A	0.24	0.00								
WWG	0.35	0.04	0.33	0.01	-6.66×10^{-4}	1.99×10^{-4}						
Pooled	0.05	0.06	0.28	0.01	6.19×10^{-3}	1.87×10^{-3}	-2.83×10^{-4}	8.38×10^{-5}	3.98×10^{-6}	1.20×10^{-6}	-1.75×10^{-8}	5.32×10^{-9}
C_4 Grass												
LBS	0.54	0.05	0.88	0.20	-2.76×10^{-2}	1.07×10^{-2}	4.96×10^{-4}	1.70×10^{-4}	-2.58×10^{-6}	8.04×10^{-7}		
BG	0.80	0.04	0.47	0.02	1.03×10^{-2}	3.86×10^{-3}	-5.27×10^{-4}	1.73×10^{-4}	7.47×10^{-6}	2.47×10^{-6}	-3.33×10^{-8}	1.10×10^{-8}
PSR	N/A	N/A	0.46	0.03								
Pooled	0.09	0.10	0.41	0.03	2.66×10^{-3}	1.29×10^{-3}	-2.64×10^{-5}	1.06×10^{-5}				
Legume												
CMV	0.72	0.18	1.35	0.09	2.71×10^{-2}	1.76×10^{-2}	-1.71×10^{-3}	7.88×10^{-4}	2.52×10^{-5}	1.12×10^{-5}	-1.13×10^{-7}	5.00×10^{-8}
Alf	0.88	0.16	2.18	0.08	2.48×10^{-2}	1.61×10^{-2}	-2.14×10^{-3}	7.20×10^{-4}	3.29×10^{-5}	1.03×10^{-5}	-1.49×10^{-7}	4.57×10^{-8}
Pooled	0.51	0.34	1.73	0.09	-8.68×10^{-3}	1.36×10^{-3}						

* S_{xy} = Root mean square error

quartic (P=0.05) decline in Ca concentration was seen with increasing maturity for BG and pooled results. The Ca peak for the C_4 grasses between July and September corresponds with research by Poland and Manske (2004). Again, the range of Ca content in the C_4 grasses during the growing season was 0.31 to 0.45%. Other research has shown that the Ca content in C_3 and C_4 grasses ranged from 0.3 to 0.4% from May to October (Abouguendia 1998).

In legumes the decline in Ca concentration was more drastic. With the pooled legume values, the initial Ca concentration was 1.42% while in late fall it had declined to 0.85% (P=0.05) (Table 3.14). Legume species % Ca over time was best fitted with a quartic regression that likely peaked prior to the initial harvest date. The Ca levels then gradually declined until just after our August harvest date at which time they increased slightly into September before declining into the fall. This quartic type regression observed in the C_3, C_4 and legume species could be explained by the plants senescing during the hot part of the summer, loosing leaves and then as fall moisture becomes available there is a slight increase in Ca due to regrowth but not to the same extent as the peak seen earlier in the growing season. The Ca levels observed in the C_3, C_4 and legume species would appear to meet the grazing animal's requirements. However, calcium supplementation may be required because Ca requirements can vary with the animal's age, weight and stage of production (NRC 2000). Steers weighing 381 kg that gain between 0.33 kg day^{-1} and 0.91 kg day^{-1} require 0.20% and 0.30% Ca, respectively on a dry matter basis (NRC 2000). Previous studies have shown that the Ca concentration of native range is adequate to ensure season long maintenance, growth and lactation in the grazing animal (Abouguendia 1998; Poland and Manske 2004). The availability of calcium to the grazing animal can be reduced due to the presence of compounds like calcium oxalate or calcium phytate that can bind Ca making it less available to the ruminant animal (Fahey et al. 1994; NRC 2000).

Phosphorus (Table 3.16) values were reported for each species at each of the five collection periods. A significant ($P < 0.01$) species by harvest date interaction was also observed for P (%). Best fitted regression equations with R^2 and standard errors for % P are given in Table 3.17. Throughout the growing season P levels were the highest in C_4 grasses followed by legumes and C_3 grasses. The results of this trial differed from those of (Abouguendia 1998) who found that legumes had P levels of 0.42% in June and declined to 0.15% in October while C_3 and C_4 grasses peaked at 0.18% in June and declined to 0.1% in

Table 3.16 Least square means for species by harvest date interactions (P<0.01) for phosphorus (%) throughout 2007*

	Date					Pooled	P-Values			
Species	Jun-20	Jul-18	Aug-16	Sep-12	Oct-10	SE	Linear	Quadratic	Cubic	Quartic
C_3 Grass										
AWG	0.18	0.12	0.10	0.08	0.07	0.010	< 0.01	0.13	0.48	0.68
CWR	0.17	0.12	0.08	0.05	0.04	0.010	< 0.01	< 0.01	0.84	0.88
GNG	0.14	0.09	0.08	0.08	0.08	0.010	0.01	0.07	0.60	0.84
HBG	0.18	0.07	0.07	0.05	0.05	0.010	< 0.01	< 0.01	0.09	0.21
Jun	0.22	0.14	0.11	0.11	0.11	0.010	< 0.01	< 0.01	0.06	0.87
MBG	0.15	0.07	0.06	0.05	0.06	0.010	< 0.01	< 0.01	0.07	0.31
NTG	0.11	0.08	0.05	0.05	0.04	0.010	< 0.01	0.06	0.63	0.19
NWG	0.14	0.07	0.05	0.05	0.05	0.010	< 0.01	< 0.01	0.14	0.57
WWG	0.16	0.10	0.08	0.06	0.05	0.010	< 0.01	< 0.01	0.24	0.77
Pooled C_3**	0.15	0.11	0.08	0.06	0.06	0.005	< 0.01	< 0.01	0.06	0.47
C_4 Grass										
LBS	N/A	0.20	0.14	0.12	0.09	0.009	< 0.01	0.02	0.03	N/A
BG	0.25	0.18	0.16	0.14	0.13	0.010	< 0.01	< 0.01	0.08	0.18
PSR	0.19	0.17	0.12	0.08	0.05	0.010	< 0.01	0.66	< 0.01	0.43
Pooled C_4**	0.20	0.18	0.14	0.11	0.09	0.009	< 0.01	0.19	0.59	0.63
Legumes										
CMV	0.21	0.16	0.15	0.12	0.11	0.010	< 0.01	0.06	0.47	0.26
Alf	0.16	0.10	0.08	0.06	0.04	0.010	< 0.01	0.05	0.28	0.63
Pooled legume**	0.18	0.14	0.09	0.08	0.07	0.010	< 0.01	0.16	0.58	0.64

* Overall model exhibited species effect (P<0.01), harvest date effect (P<0.01) and species by harvest date interaction (P<0.01)
** Pooled samples exhibited a group effect (P<0.01), harvest date effect (P<0.01) and species by harvest date interaction (P<0.01)

Table 3.17 Best fitted regressions for species by harvest date interactions (P<0.01) for phosphorus (%) throughout 2007

Species	Adj R^2	S_{xy}*	Intercept		Linear term		Quadratic term		Cubic term	
			Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
C_3 Grass										
AWG	0.51	0.03	0.16	1.27×10^{-2}	-8.48×10^{-4}	1.85×10^{-4}				
CWR	0.92	0.01	0.17	6.74×10^{-3}	-2.20×10^{-3}	2.85×10^{-4}	9.34×10^{-6}	2.44×10^{-6}		
GNG	0.31	0.03	0.12	1.05×10^{-2}	-4.73×10^{-4}	1.53×10^{-4}				
HBG	0.71	0.03	0.17	1.46×10^{-2}	-3.18×10^{-3}	6.19×10^{-4}	1.91×10^{-5}	5.30×10^{-6}		
Jun	0.90	0.01	0.22	6.93×10^{-3}	-3.02×10^{-3}	2.93×10^{-4}	1.89×10^{-5}	2.51×10^{-6}		
MBG	0.76	0.02	0.15	9.92×10^{-3}	-2.65×10^{-3}	4.20×10^{-4}	1.71×10^{-5}	3.59×10^{-6}		
NTG	0.68	0.02	0.10	6.73×10^{-3}	-6.25×10^{-4}	9.81×10^{-5}				
NWG	0.76	0.02	0.13	8.82×10^{-3}	-2.18×10^{-3}	3.73×10^{-4}	1.30×10^{-5}	3.20×10^{-6}		
WWG	0.89	0.01	0.15	6.55×10^{-3}	-1.98×10^{-3}	2.77×10^{-4}	9.57×10^{-6}	2.37×10^{-6}		
Pooled	0.59	0.03	0.16	4.79×10^{-3}	-2.20×10^{-3}	2.03×10^{-4}	1.23×10^{-5}	1.73×10^{-6}		
C_4 Grass										
LBS	0.93	0.01	0.38	4.83×10^{-2}	-8.96×10^{-3}	2.64×10^{-3}	1.10×10^{-4}	4.17×10^{-5}	-4.75×10^{-7}	1.98×10^{-7}
BG	0.87	0.02	0.24	7.91×10^{-3}	-2.16×10^{-3}	3.34×10^{-4}	1.00×10^{-5}	2.86×10^{-6}		
PSR	0.98	0.01	0.19	4.35×10^{-3}	1.36×10^{-4}	3.95×10^{-4}	-3.58×10^{-5}	8.95×10^{-6}	2.09×10^{-7}	5.26×10^{-8}
Pooled	0.74	0.03	0.22	6.85×10^{-3}	-1.20×10^{-3}	9.65×10^{-5}				
Legumes										
CMV	0.80	0.02	0.19	6.25×10^{-3}	-7.95×10^{-4}	9.12×10^{-5}				
Alf	0.80	0.02	0.14	7.63×10^{-3}	-9.73×10^{-4}	1.11×10^{-4}				
Pooled	0.46	0.04	0.17	1.04×10^{-2}	-8.84×10^{-4}	1.51×10^{-4}				

* S_{xy} = Root mean square error

October. In this study within the C_3 grasses, P levels were relatively low and declined ($P<0.01$) in a quadratic fashion, with minimal changes in the September and October harvest dates. The pooled C_4 grass values decline in P with increasing maturity was best fitted with a linear regression ($P<0.01$). Research by Abouguendia (1998) also demonstrated that the declining level of P in grasses tended to be small. In legumes the decline was also linear ($P<0.01$) through the growing season dropping from 0.18 to 0.07% (Table 3.16). Phosphorus requirement for steers weighing 381 kg that are gaining between 0.33 and 0.91 kg day^{-1} is between 0.13% and 0.16% (NRC, 2000). The values observed in this trial for C_3, C_4 and legume species would only meet those requirements in June but C_4

grasses would be adequate for the grazing animal up to August. Previous studies have shown that there is only a short time during the grazing season when there are adequate plant P levels to maintain animal growth or lactation (Jefferson et al. 2005). Phosphorus deficiency in grazing animals is one of the most common mineral deficiencies (McDowell, 1992). The P deficiency in forages can result from phosphorus deficient soils, drought conditions and forage maturity (Poland and Manske, 2004).

3.4 Summary and Conclusion

Results from this trial showed that there were species by harvest date interactions occurring for DM production as well as for all measured nutritive value traits. Such differences are not unexpected due to the nature of C_3, C_4 and legume growth. The nature of the interaction for dry matter production ranged from simple means (i.e. no regression response) for the majority of C_3 grasses and linear declines in production for legume species to quadratic increases that declined in the fall for C_4 grasses. These differences in DM production are due to variation in growth patterns related to their physiological pathways and adaptation to different environmental conditions. The C_3 grasses and legume species produce the majority of their DM production early in the season whereas C_4 grasses experience optimal growth during the warm summer conditions. The decline in DM production is normal and likely due to leaf loss and leaching of soluble non-structural carbohydrates due to weathering.

As the species matured, the OMD declined due to increases in NDF, ADF and ADL. There were differences in the pattern of OMD decline between C_3 and C_4 grasses and legume species due to the nature of their growth. The OMD for C_3 grasses typically declined ($P<0.01$) in a cubic fashion with advancing maturity as NDF and ADF fractions increased linearly ($P<0.01$) and ADL increased ($P<0.01$) in a quadratic fashion. The OMD declined ($P<0.01$) in a cubic fashion for most of the C_4 grasses with advancing maturity as NDF and ADF fractions increased linearly ($P<0.01$) and ADL increased ($P<0.01$) in a quadratic fashion. The OMD for the legume species declined ($P<0.01$) in a linear fashion due to the linear increases in ADF and ADL. These decreases in OMD appear to be the result of increasing NDF, ADF and ADL concentrations likely as a result of increasing proportions of leaf sheath, stem and flower head and the loss of leaves as the plants senesce.

As forages matured CP and P declined. Both the CP and P concentrations in C_3 grasses declined ($P<0.01$) in a quadratic fashion. The CP concentration in C_4 grasses and legumes declined ($P<0.01$) in a quadratic fashion as species matured and P levels declined ($P<0.01$) in a linear fashion. The decline in CP and P is extremely important because they can negatively influence growth and are common deficiencies. However, calcium concentrations did not change a great deal during the growing season although statistically a quartic regression was fitted ($P=0.05$) for the C_3, C_4 and legume species. The Ca concentrations in the C_3, C_4 and legume species was adequate to meet the nutritional requirements of yearling steers. The decline in OMD and increasing NDF, ADF and ADL fractions is problematic because it can reduce intake and ultimately animal gains. The consequence of these changes is that grazing animals may require strategic nutrient supplementation (i.e. energy, protein, minerals) to maintain body condition and improve weight gain.

From this trial it appears that having mixed swards of C_3, C_4 and legume species would complement each other in forage stands based on production and nutritional quality. However, because this is only one year of research and the high variability associated with climate and individual species more research is required. Further research is needed to determine if having more diverse forage mixtures will improve animal performance and increase forage yield.

CHAPTER 4
COMPARISON OF *IN SITU* DRY MATTER AND NEUTRAL DETERGENT FIBER DEGRADABILITY OF SIX FORAGE SPECIES COMMON TO WESTERN CANADA

4.1 Introduction

Extending the grazing season by grazing native forage mixtures later into the fall can reduce costs relative to feeding stored forages (Cherney and Kallenbach 2007). However, as determined from the results of chapter 3, the nutritive quality of forages declines as plants mature into the fall and supplemental feeding may be required to meet the animal's nutrient demands (Abouguendia, 1998). There has however, been little work to demonstrate how plant maturity affects forages grown in the northern USA and Canada (Lawrence and Warder, 1979). It has been recognized that increasing maturity ultimately decreases rumen degradation of grasses and alfalfa (Balde et al. 1993). However, the extent different forages maintain their nutritive value into the fall is not well known (Cooke 1972).

Forages looked at in this trial can be segregated into cool season grasses (C_3), warm season grasses (C_4), and legumes. The C_3 grasses produce the majority of their growth early in the summer and can reinitiate growth in the fall if temperatures and moisture levels become favourable. The C_4 grasses initiate growth during the summer when higher temperatures inhibit C_3 growth. At this point, the growing C_4 forages have a higher nutritive value than the mature C_3 plants as the young C_4 plants are actively capturing and storing energy and synthesizing protein and carbohydrates (Redmon and Hendrickson 2007). As plants mature, photosynthesis and plant growth slow but cell wall and fibre levels increase. Legumes are not only desirable for their ability to symbiotically fix N but also for their ability to improve ruminant diet quality and improve animal performance (Posler et al. 1993; Phillips and James 1998; Jefferson et al. 2002; McGraw and Nelson 2003). Legumes tend to have higher energy and protein levels than grasses but their persistence in the stand is lower (Cherney and Kallenbach 2007). The leaves of legumes tend to have thinner cell walls than grass leaves and stems which mean they break down and pass through the rumen faster (Spalinger et al. 1986). Legumes

tend to have higher CP levels and cell soluble carbohydrates than grasses at similar stages of maturity (Holechek et al. 2004) and ultimately higher CP and NDF degradation values than grasses due to higher sugar, starch, pectin and organic acid levels (Canale et al. 1992; NRC 2001).

From a livestock nutrition perspective, the biggest concern with stockpiled forages is their crude protein and energy content. The concern is that as plants mature, they become less digestible, have higher fiber levels and are lower in CP. As plants mature, the soluble and degradable CP fractions become tightly associated with ADF and NDF (Janicki and Stallings 1988). This results in reduced CP availability (Janicki and Stallings 1988). These tight associations with fiber limit bacterial access to forage cell constituents and ultimately restrict nutrient availability. The degree of lignification reduces the rate and extent of digestion in the rumen, ultimately decreasing forage intake (Forbes 1996; Cherney et al. 1997). This was demonstrated by Krysl et al. (1987) who found that voluntary DM intake of grazing steers dropped from 2.2% of body weight when plants were actively growing to approximately 1.5% at dormancy. The decrease in dry matter digestibility of forages can be associated with an increase in the proportion of leaf sheath, stem, flowering head, cellulose, hemicellulose and lignin as they mature (Minson 1990; Ferdinandez and Coulman 2001). Although initial forage qualities may appear adequate nutrients must be accessible by the animal throughout the grazing season, otherwise supplementation will be required.

The *in situ* digestion procedure enables one to determine forage nutrient digestibility characteristics (Vanzant et al. 1998). It provides a means of comparison of species and helps to explain the availability of a forage to the ruminant animal. There are many variables that can affect digestibility including stage of maturity, forage species, cultivar, soil type, climatic conditions, growing conditions and preservation method (Varga and Hoover 1983; Cherney et al. 1992; Hoffman et al. 1993; Ruess 2001; Yu et al. 2004).

The objective of this study was to determine the *in situ* DM, NDF and CP degradability of five forage species (WWG, NWG, MBG, GNG, CMV) and one composite group of warm season grasses (Warm). The goal was to identify which species would be better suited for late fall grazing.

4.2 Materials and Methods

4.2.1 Selected Species

Forage samples used in this trial were obtained by combining the September and October small plot clippings from 2007 (Chapter 3 of this thesis). Samples included four C_3 grasses (WWG, NWG, MBG, and GNG), one legume species (CMV) and one composite sample of C_4 grasses (Warm). Species comprising the Warm composite sample included 11.5% LBS, 28.8% BG and 59.7% PSR. The *in situ* trial was restricted to these six species due to limitations in the number of samples that could be incubated, as well as the amount of sample available. Priority was also given to species common to western Canada. Western wheatgrass and Green needlegrass were selected because seed is readily available and they are commonly recognized for their ability to maintain their nutritive value into the fall. Northern wheatgrass seed is also readily accessible for reclamation projects and is one of the most common species found growing on the semi-arid prairie in Saskatchewan. Meadow brome grass is a tame species that is commonly grown for grazing production and has been considered a reasonable forage for fall grazing. Canadian milkvetch is a native legume in which little research has been done, however it is able to fix N and maintains high protein levels into the fall. The Warm was a combination of C_4 grasses grown in the small plot trial that are common in the drier southern corner of Saskatchewan.

4.2.2 Sample Preparation

Forage samples used in the small plot trial project were dried then ground using a Willey Mill fitted with a 1mm screen. To ensure adequate sample was available for the entire *in situ* trial, samples were combined across replicates and across the September and October 2007 collection periods. Pooling of samples was done in equal proportions. The only exception was the C_4 grasses, where all available samples had to be used to ensure enough forage material for analysis.

4.2.3 Rumen *In situ* Trial

The rumen *in situ* trial followed the procedure of Vanzant et al. (1998). Three Red Angus cross steers (575 ± 39 kg) fitted with a 10.2 cm rumen cannula (Bar Diamond

Inc., Parma, ID, USA) were used (Iwaasa et al. 2001). The animals were cared for under the guidelines of the Canadian Council of Animal Care (2007). They were kept outdoors in individual pens (6m X 30m) that were bedded with wood chips. Steers were fed meadow brome grass hay that was harvested in 2007 (89% DM) at 1.5% of body weight (DM basis). Each animal had free access to water and a salt block containing trace levels of cobalt and iodine.

Five gram samples were weighed into number coded dakron bags (10 X 20 cm) with a 50 micron (±15) pore size (ANKOM Company, Fairport, NY). Bags were heat sealed 2 cm from the top to produce a sample size to surface area ratio of 13.9 mg cm^{-2}. Treatments were randomly allocated between steers within the incubation period. The samples were placed in weighted lingerie bags to keep them in the ventral sac of the rumen. The lingerie bags were attached to a 50 cm cord to assist with retrieval from the rumen (Hoffman et al. 1993b).

Incubations were performed using the "gradual addition/ all out" schedule (Yu et al. 2004). The incubations were performed for 0, 2, 4, 8, 12, 24, 48, 72 h starting at 1900 h. Bags were inserted at 1900 (day 1), 1900 (day 2), 1900 (day 3), 0700 (day 4), 1100 (day 4), 1500 (day 4), 1700 (day 4) and all bags were removed at 1900 (day 4). During each run 17 bags were incubated in each animal. Duplicate samples were run for each time period resulting in a total of 38 bags for each treatment (2 bags for incubation times 0 – 24 h and 3 and 4 bags for 48 and 72 h, respectively).

All samples, including the 0 h samples were placed in cold water upon removal to stop digestion (Hoffman et al. 1993). Then bags were rinsed using the delicate cycle in a domestic washer (Kenmore; model 4226090). The samples were rinsed five times with 55 L of cold water allowing a 1 minute agitation and a 2 minute spin per rinse cycle. The samples were then dried to a constant weight in a forced air oven at 50°C. Dry matter content was determined by vacuum drying according to AOAC Official Method 925.09 (AOAC 2005). The duplicate bags were then combined within the run and analyzed for CP and NDF.

4.2.4 Laboratory Analysis

Total N was determined using a Technicon Autoanalyzer II® after undergoing a Kjeldahl digest (Varley 1966). The CP content was determined by multiplying N content by 6.25 (AOAC 1984). The NDF was determined using an ANKOM^{200} fibre analyzer (Model 200; ANKOM; Fairport, New York).

4.2.5 Rumen Degradation Models and Statistical Analysis

The *in situ* rumen degradation kinetic parameters were estimated using the NLIN (non linear) procedure of SAS 9.1.3 statistical software (SAS Institute, Inc. 2003) and the iterative least square regression (Gauss-Newton method) procedure via the modified first order kinetics equation with a lag time (Ørskov and McDonald 1979):

$$R(t) = c + b*\exp^{-kd*(T - T0)}$$

where R(t) is the residue (%) of incubated material remaining after t (hours) of rumen incubation. The effective rumen degradable fraction (EDDM) and the undegradable rumen dry matter (RUDM) were calculated based on a rumen passage rate (Kp) of 6% h^{-1} (Holden et al. 1994; Elizalde et al. 1999). They were calculated as follows:

$$EDDM\ (\%) = a + b*Kd/(Kd+Kp)$$

$$RUDM\ (\%) = c + b*Kp/(Kd+Kp)$$

The analysis of variance was performed for a completely randomized design using the Proc GLM on the SAS program (SAS Institute, Inc. 2003):

$$Y = mean + feed + error$$

The treatment means were carried out using the F test. Standard errors (SE) were determined and the treatment effects were considered significant if $P<0.05$ using the Tukey's test (Steel and Torrie 1980).

4.3 Results and Discussion

Fall grazing is becoming more popular to reduce production costs but declining forage quality associated with maturing forages can negatively affect animal performance to the extent that supplementation may be required (Abouguendia, 1998; Cherney and

Kallenbach 2007). Chemical compositions of the six forage samples used in this trial are given in Table 4.1. Due to sample limitations it was not possible to have replicates and statistically analyze this data. However it can be seen that CMV, a native legume had the highest CP and lowest NDF values. Higher CP and lower cell wall fiber content is expected when comparing legumes to grass species (Spalinger et al. 1986; Shaver et al. 1988; Elizalde et al. 1999; Yu et al. 2004; Holechek et al. 2004). There appeared to be differences in CP and NDF between the grass species this differed from findings by Elizalde et al. (1999) that showed grasses were relatively similar. The NDF values of the samples in this study were noticeably higher than previous reports that showed alfalfa hay normally has an NDF content of 35 to 40% (DM basis) and grass hays are as high as 60% NDF at similar stages of maturity (Robinson, 1998). Crude protein requirements for a 381kg animal gaining 0.33 kg day^{-1} are around 6.8% CP on a dry matter basis (NRC 2000). From Table 4.1 it appears that CP levels are adequate only in CMV and GNG. However the CP maintenance requirements for beef cows is between 6 and 8% so warm season grasses could also be suitable to meet their requirements (Holechek and Herbel 1986). However, the availability of CP can be reduced due to tight connections with fibre, which make it inaccessible to the rumen microbes (Janicki et al. 1988).

Table 4.1 Crude protein and NDF content of samples collected during the 2007 harvest period and used in the *In situ* digestion trial

Species	CP (%)	NDF (%)
Canadian Milkvetch	11.75	56.05
Western Wheat grass	5.44	69.12
Meadow Brome Grass	4.47	73.16
Green Needle grass	7.56	71.55
Warm Season Grass	6.31	68.18
Northern Wheatgrass	4.03	74.12

The rate of degradation (Kd) for DM (Table 4.2) and NDF (Table 4.3) were similar for all the grass species but was greater ($P<0.05$) for CMV. These findings were similar to previous studies that compared legumes and grass digestibility (Hoffman et al. 1993b). The DM Kd value for CMV was 10.85 % h^{-1} which was similar to the 11.4% Kd

value observed in alfalfa at the late flowering stage (Elizalde et al. 1999) and 9 % Kd at the full bloom stage (Shaver et al. 1988). The DM Kd values observed for our five grass species ranged from 2.82 % h^{-1} in NWG up to 4.62 % h^{-1} in MBG, which also corresponded to values observed in previous studies for tall fescue, perennial ryegrass, timothy and bromegrass (Shaver et al. 1988; Hoffman et al. 1993a; Elizalde et al. 1999). No significant differences were noted in the DM Kd for the grass species, a finding that was observed by other researchers (Elizalde et al. 1999). The NDF Kd value observed in our trial for CMV were similar to values observed by Canale et al. (1992) in alfalfa. The NDF Kd values observed for the grass species correspond with values reported for Smooth bromegrass (Shaver et al. 1988).

Table 4.2 Effects of species on *in situ* dry matter disappearance (degradation rate of D (K_d), soluble fraction (S), slowly degradable fraction (D), undegradable fraction (U), effective dry matter degradability (EDDM) and rumen undegradable fraction (RUDM))

Feed	K_d (% h^{-1})	S (%)	D (%)	U (%)	% EDDM	% RUDM
	---------- g kg^{-1} DM ----------					
CMV	10.85 b	20.72 b	40.35 a	38.93 c	46.65 c	53.35 a
WWG	3.25 a	19.51 b	58.73 bc	21.76 b	40.08 ab	59.92 bc
MBG	4.62 a	16.22 a	52.67 b	31.11 bc	38.93 ab	61.07 bc
GNG	3.19 a	17.07 a	59.87 b c	23.06 b	37.81 a	62.19 c
Warm	3.28 a	21.07 b	67.58 c	11.35 a	44.81 bc	55.19 ab
NWG	2.82 a	16.27 a	59.37 bc	24.36 b	35.01 a	64.99 c
SE	0.39	0.63	2.30	2.15	1.52	1.52

a - c Within the column, numbers followed by a different letter (a-c) are statistically significant ($P<0.05$) as determined by Tukey's test. SE represents standard error

Table 4.3 Effects of species on *in situ* neutral detergent fibre disappearance (degradation rate of D (K_d), soluble fraction (S), slowly degradable fraction (D), undegradable fraction (U), effective neutral detergent degradability (EDNDF) and rumen undegradable fraction (RUNDF))

Feed	K_d (% h^{-1})	S (%)	D (%)	U (%)	% EDNDF	% RUNDF
	---------- g kg^{-1} NDF ----------					
CMV	7.73 b	1.16 a	40.95 a	57.89 c	23.65 a	76.35 c
WWG	3.50 a	2.19 ab	73.40 bc	24.42 ab	29.11 abc	70.89 abc
MBG	4.11 ab	2.55 ab	65.27 b	32.17 b	28.72 abc	71.28 abc
GNG	3.33 a	3.86 b	71.89 bc	24.25 ab	29.48 bc	70.52 ab
Warm	3.39 a	4.35 b	78.60 c	17.05 a	32.48 c	67.52 a
NWG	2.73 a	2.98 ab	74.88 bc	22.14 a	26.02 ab	73.98 bc
SE	0.69	0.75	2.44	1.94	1.35	1.35

a - c Within the column, numbers followed by a different letter (a-c) are statistically significant ($P<0.05$) as determined by Tukey's test. SE represents standard error

The soluble DM fraction (S) was higher ($P<0.05$) for WWG, Warm and CMV compared to MBG, GNG and NWG. However, the soluble fraction of NDF was lower ($P<0.05$) in CMV than GNG and Warm but no differences ($P>0.05$) were observed for WWG, MBG and NWG. Canadian milkvetch had the lowest ($P<0.05$) D fraction and highest ($P<0.05$) U fraction for both DM and NDF. Previous studies have shown that Red clover also has a higher DM U fraction than grass species (Hoffman et al. 1993). The U values observed in this study for CMV were higher and the D values were lower than values for alfalfa observed by Yu et al. (2004) due to the advanced maturity of our stand and inherent differences between alfalfa and CMV. The Warm mixture had the highest ($P<0.05$) D fraction and lowest U fraction for both DM and NDF.

Effective dry matter degradability (EDDM) was highest in CMV but similar to Warm. Previous studies have shown that EDDM is higher in legumes than grasses (Elizade et al. 1999). It had lower NDF and ADF concentrations than the grasses which could explain the improved microbial degradation (Elizade et al. 1999). It is believed that structural characteristics of plant tissue affect digestibility (Lee and Pearce 1984; Mosely and Jones 1984). However, the EDDM observed in CMV was lower than values observed for mature alfalfa stands likely due to phenological growth differences between these species (Hoffman et al. 1993; Elizade et al. 1999). Results in chapter 3 showed that CMV had higher lignin levels than other species. Lignin has been shown to negatively

affect digestibility (Erdman et al. 1987) due to its ability to prevent enzymatic hydrolysis of polysaccharides (Jung and Allen, 1995). Previous work has shown no consistent correlation between a single structural component and forage digestibility (Van Soest 1994). Differences in EDDM between grass and legume species could be explained by anatomical differences in the arrangement of vascular cells (McLeod and Minson 1988; Kelly and Sinclair 1989; Kennedy and Doyle 1993) and the lower concentration of lignin-carbohydrate bonds in legumes (Grenet 1989). Physical differences like the shorter and more cubical shape of legume digesta versus longer, thinner and more fibre like grass digesta could explain the slightly higher digestibility observed in legumes (Troelson and Campbell 1968; Moseley and Jones 1984; Emanuele and Staples 1988). The leaves of legumes tend to have thinner cell walls than grasses that allow them to break down and pass through the rumen faster (Spalinger et al. 1986) and they contain more sugars, starch, pectin and organic acids (NRC 2001). Studies have shown that degradability is more related to the chemical composition of lignin than the amount of lignin present (Reeves 1985; Buxton and Russell 1988). Warm was also similar ($P>0.05$) to WWG and MBG in EDDM (Table 4.2). The lowest ($P<0.05$) EDDMs were found in NWG and GNG but they were similar to WWG and MBG. The higher EDDM in Warm was unexpected because C_4 species normally have higher lignin levels that would reduce digestion. Our results are likely due to vegetative nature of the C_4 grasses later into the growing season due to the shortage of heat units to advance C_4 grasses into later stages (Smart et al. 2001). The anatomical features (sclerenchyma, parenchyma bundle sheaths and lignified tissue) of C_4 species often make them less digestible than C_3 species (Akin and Barton 1983; Akin 1989). Previous analysis of ADL showed that the pooled Warm values were lower in ADL than most of the C_3 species and legume species which could explain the better than expected EDDM. There is no doubt that increasing NDF, ADF and ADL associated with mature forages ultimately reduces EDDM (Elizade et al. 1999).

The effective neutral detergent fiber digestibility (EDNDF) was higher ($P<0.05$) in Warm than NWG and CMV. There were no differences in EDNDF among Warm, GNG, MBG or WWG. Green needle grass had a higher ($P<0.05$) EDNDF than CMV. The EDNDF of WWG and MBG were not different than any of the other species. The lower EDNDF values observed in legumes has been documented in previous research

(Varga and Hoover 1983; Shaver et al. 1988; Hoffman et al. 1993b; Yu et al. 2004). This could be due to higher ADF concentrations and lower NDF concentration in legumes (shown in Chapter 3) that negatively affect rumen degradable NDF (Hoffman et al. 1993a; Yu et al. 2004). The low EDNDF in CMV could also be the result of differences in phenolic acids (Jung and Allen 1995). The EDNDF can be affected by variables like the type of forage species, cultivar, soil type, climate conditions, growing conditions, stage of maturity and preservation method (Varga and Hoover 1983; Cherney et al. 1992; Hoffman et al. 1993b; Yu et al. 2004).

It was not possible in this trial to evaluate *in situ* CP digestive kinetics. After running the least square regression (Gauss-Newton method) using the modified first order kinetics equation with a lag time (Ørskov and McDonald 1979) it was evident that due to bacterial contamination, N had been reintroduced into the samples during rumen incubation. This resulted in some cases of more N in the residues after rumen incubation than was present in the original forage sample prior to incubation (Table A1 in appendix). The mean CP disappearance values for each of the incubation periods are shown in Appendix Table A1.

The increase in CP associated with many of theses forages after rumen incubation is the result of microbial contamination of the *in situ* residue due to the samples' low initial CP and degradability characteristics (Madsen and Hvelplund 1985; Canale et al. 1992; Dixon and Chanchai 2000; Kamoun et al. 2007). Bacterial contamination is a clear possibility because there are many types of bacteria that bind to the plant cell wall via the glycoprotein matrix (Akin 1976; Akin and Amos 1975). The strength of these bonds can vary with the surface area of the plant material and the types of plant structure (Akin 1976; Nocek 1988). The effect of microbial contamination on CP in forages tends to be higher in forages than concentrates, likely because initial protein levels are lower (Nocek and Grant 1987; Beckers et al. 1995). Previous studies have shown that CP degradation is related to CP and NDF concentrations in the forage (Janicki and Stallings 1988; Elizalde et al. 1999). Bacterial contamination has been shown to increase curvilinearly with incubation time at which point attachment sites become limited (Nocek 1988; Kamoun et al. 2007). The time it takes for a peak in N from microbial contamination varies from one feed to another; it can range from 6 to 96 hrs for forages and 10 to 20 hrs

for concentrates (Nocek and Grant 1987; Nocek 1987; Michalet-Doreau and Ould-Bah 1992). There is also increased microbial contamination with smaller particle size and increased bag pore size (Nocek 1988). To accurately predict N digestion using the *in situ* technique under such conditions it is necessary to use a reliable measure to quantify microbial contamination on undigested residues. There are several types of bacterial nitrogen markers that can be used to distinguish microbial contamination including internal markers like diaminopimelic acid, nucleic acids or external isotopic markers like ^{15}N or ^{35}S (Michalet-Doreau and Ould-Bah 1992; Broderick and Merchen 1992).

4.4 Conclusion

There were differences in DM and NDF degradation associated with mature legume, C_4 and C_3 grasses. The values observed for NDF and DM degradation in the C_3 grass species were relatively similar. Effective dry matter degradability was highest in CMV and Warm and the EDNDF was highest in Warm but lowest in CMV. There appears to be soluble fractions in CMV other than NDF that are being removed, possibly compounds such as protein, minerals, fat, pectin and soluble carbohydrates that are more digestible in legumes than in grasses. The lower EDNDF in CMV is probably associated with the low initial NDF concentrations. To properly determine CP digestion it would require the use of microbial protein markers to determine levels of microbial contamination. All the C_3 grasses were similar in EDDM and EDNDF but differed from the legume and C_4 grasses. By including legumes in mixtures EDDM and CP availability improved but EDNDF declines due the solubility of other fractions. Warm season grasses were high in EDDM and EDNDF, however, D fractions were higher showing that they degraded at a slower rate and depended on rumen retention to be fully degraded. Digestive characteristics during the fall grazing period could be improved by including legumes and C_4 grasses in forage mixtures along with C_3 grasses.

CHAPTER 5
NUTRITIVE QUALITIES OF SIMPLE VERSUS COMPLEX NATIVE FORAGE MIXTURES FOR GRAZING CATTLE

5.1 Introduction

There are many advantages with diverse forage stands. With a more diverse forage species mixture, stands are better able to adapt to changing environmental conditions. More diverse forage mixtures tend to be more resistant to drought (Glvnish 1994; Tilman and Downing 1994). This is due to their larger root mass that ensures energy and nutrient stores are available to buffer against environmental variation (Tilman et al. 2006). Mixed swards consist of species with different rooting depths that ultimately increase moisture utilization at different levels in the soil. Diverse swards improve the ecosystem's ability to adapt to disturbances and improve nutrient cycling in the environment (Fridley 2001; Minns et al. 2001; Sanderson et al. 2005). Weed pressure and invasion is reduced in complex forage mixtures because of competition for resources (Kennedy et al. 2002; Tracy and Sanderson 2004b).

Although they are more stable and better adapted to environmental change, there is varying data about production benefits associated with complex forage mixtures. Some studies have shown that diverse forage mixtures are more productive and have more consistent biomass production over time (McNaughton 1993; Tilman et al. 1996; Chapin et al. 2000). Biodiversity is directly related to an ecosystem's productivity and stability (Tilman et al 2006). Some studies have shown that plant diversity increases primary production (Fridley 2001; Minns et al. 2001; Sanderson et al. 2005). This is understandable because a mixture of C_3 and C_4 forages utilize different photosynthetic pathways that initiate growth at different times within the growing season and distribute carbohydrates differently within the roots and leaves (Glvnish 1994). Cool season grasses tend to enter their reproductive phase around the same period when C_4 species begin growth (Trlica 1999). Cattle are naturally attracted to the new growth, so the C_4 grasses are grazed. Having a diverse range of species ensures that forage yields and nutrient supplies are distributed throughout the grazing season and the grazing animal's nutrient requirements are met (Cook 1972; Waller et al. 1985; Cherney and Kallenbach 2007; Redmon and Hendrickson 2007). Nutritional qualities such as digestible energy content, digestible protein and phosphorus

content vary in grass, forbs and shrubs during the growing season. A balanced mix of these plant species will compliment each other from a nutrient perspective and better meet the ruminant animal's demands (Cooke 1972). Research has shown that more diverse forage mixtures had higher production and provided a more nutritious and palatable forage source than less diverse mixtures (Smoliak and Bezeau 1967; Tilamn et al. 1996; Ganskopp et al. 1997; Bargo et al. 2002; Deak et al. 2007; Tracy and Sanderson 2004a; Tracy and Sanderson 2004b). Other studies comparing monoculture tame forage stands to improved native ecovars or natural mixed grass prairie have shown no differences in animal production or grazing capacity (Hanson et al. 1976; Hofmann et al. 1993b; Jefferson et al. 1997). If fertilizer is applied tame forages are more productive than native grasslands but with increased costs (Knowles 1987; Lawerance and Ratzlaff 1989). The objective of this study was to compare simple (native C_3 grasses and legume) and versus complex (native C_3 and C_4 grasses with legume) mixtures of native forage species in terms of forage yield, chemical composition, and animal grazing potential.

5.2 Materials and Methods

5.2.1 Pasture Design

There were four (two-hectare) paddocks that were seeded in 2001 to a simple or complex native seed mixture at a rate of 9.5 kg ha^{-1}. The experiment utilized a completely randomized design. There were two treatments (simple and complex) and two replicates (Table 5.1) for a total of 4 pastures. The study was performed over three years starting 2005 and continuing through 2007.

5.2.2 Livestock

5.2.2.1 Grouping and Randomization

Eight, cross bred yearling steers (Hereford x Angus) (360 ± 30 kg) were randomly assigned to one of the four season long continuously grazed pastures (two steers per pasture). Stocking rates for the pastures were based on estimated carrying capacity (Smoliak et al. 1982; Wroe et al. 1988) to achieve approximately two months of grazing. Pastures were grazed at a 40 to 50% utilization rate. All cattle were treated for fly control with CyLence Pour-On (Bayer Animal Health) at the beginning of the grazing season and as required throughout the summer. All livestock had free access to water and salt blocks containing

Table 5.1 Native species composition of complex and simple forage mixtures seeded to pastures that were continuously grazed

Complex Mixture	% of Mix*	Simple Mixture	% of Mix*.
Cool season		Cool season	
Western wheatgrass	15	Western wheatgrass	31
Northern wheatgrass	9	Northern wheatgrass	12
Green needle grass	26	Green needle grass	36
Awned wheatgrass	5	Awned wheatgrass	15
June Grass	2	June Grass	2
Canada wildrye	2	Slender wheatgrass	3
Needle and thread grass	10		
Legume		Legume	
Purple prairie clover	2	Purple prairie clover	1
Warm season			
Prairie Sandreed	3		
Little bluestem	23		
Blue grama	3		

* by seed weight

trace levels of cobalt and iodine. Animals used in this experiment were cared for under the guidelines put forward by the Canadian Council on Animal Care (2007).

5.2.2.2 Animal Production and Grazing Days

Steers were weighed after being fasted for 24 hours without feed or water to obtain a shrunk body weight. Each year, grazing was initiated at the end of June (June 24, 2005; June 27, 2006 and June 29, 2007) and ended in August (Aug. 23, 2005; Aug. 21, 2006 and Aug. 24, 2007 for the complex pastures and Aug. 12, 2005; Aug. 15, 2006 and Aug. 17, 2007 for the simple pastures). The following equations were used to calculate the season long average daily gain (SLADG), total live animal production per hectare (TLP), grazing days per hectare (GRD) and animal unit day per hectare (AUD ha^{-1});

SLADG (kg d^{-1}) = (Shrunk end weights – Shrunk start weights) / # of days grazing

GRD (d ha^{-1}) = (# of animals X # of days grazing)/ Hectare

TLP (kg ha^{-1}) = SLADG X GRD

AUD ha^{-1} = (# of animals X (average body wt/1000) X # of days grazing)/ Hectare

5.2.3 Sampling Procedure

5.2.3.1 Sampling Dates

All clippings were performed at a 5 cm stubble height (Carman 1985; Olson and Richards 1988). Clippings were taken prior to grazing, following the completion of grazing, and within graze free cages. These were used to calculate available (AYLD), residual (RYLD) and cage (CYLD) yields, respectively. Ten randomly collected ¼ m^{-2} pasture clippings were taken to determine the available and residual yields. There were six cages randomly placed throughout the pasture to determine total pasture production or cage yield.

Clipped material was placed in brown paper bags and dried to a constant weight in a forced air oven at 50° C. Dried forage yields were recorded and samples from the same period were pooled within pasture. These samples were ground using a Willey Mill (Model no. 4; Arthur H. Thomas Co., Philadelphia, PA) fitted with a 1mm screen. Ground samples were put in marked resealable glass jars. Dry matter content on ground samples was determined by using the Association of Official Analytical Chemists Official Method 925.09 (AOAC 2005). This data was used to determine the forage yield, level of utilization (UT) and the chemical composition.

UT = ((Available yield – Residual yield)/ Available yield) X 100

5.2.4 Laboratory Analysis

The *in vitro* organic matter digestibility was determined using the procedures outlined by Tilley and Terry (1963) as modified by Troelson and Hanel (1966). Dry matter was determined using a vacuum oven according to the AOAC Method 925.09 (AOAC 2005). Calcium concentration was analyzed using flame atomic absorption spectroscopy (Hitatchi Polarized Zeeman Z8200 flame/furnace atomic absorption spectrometer) following a nitric-perchloric acid digestion. Total Kjeldahl N and P were determined using a Technicon Autoanalyzer II® after undergoing a Kjeldahl digest (Varley 1966). Crude protein was calculated by multiplying the level of nitrogen by 6.25 (AOAC, 1984). Acid detergent fibre was determined using a Velp Raw Fibre Extractor (Velp Scientifica 6 place Raw Fibre Extractor; Model FIWE; Stazione, Italia; 20040) and Goering and Van Soest (1970)

procedure. The NDF and the ADL were determined using an ANKOM^{200} (Model 200; ANKOM; Fairport, New York; 14450) according to Ankom (2005).

5.2.5 Meteorological Data

All weather data was recorded at the Semiarid Prairie Agricultural Research Center (SPARC), Agriculture and Agri-Food Canada (AAFC), at Swift Current, Saskatchewan. The weather station was located approximately 1 km away and recorded the average monthly temperature for 2005, 2006 and 2007 and the monthly average precipitation for 2005, 2006, and 2007 (Figure A5 and A6 in Appendix).

5.2.6 Statistical Analysis

Data was analyzed as a two (seedmix) by three (year) factorial using the Mixed Model procedure (Proc Mixed) in the SAS 9.1.3 statistical program (SAS Institute, Inc. 2003). It was a completely randomized desin where pasture was the experimental unit. Year was treated as a repeated measure and the covariance structure for each variable was selected from the following; unstructured, ante-dependence, autoregressive, heterogeneous autoregressive, compound symmetry and heterogeneous compound symmetry. The final covariance structure was selected on the basis of the lowest AIC, AICC and BIC values. Standard errors (SE) were determined and if there were significant year or seedmix effects ($P<0.05$), protected least significant difference was used for mean separation (Steel and Torrie 1980). If seedmix by year interactions ($P<0.05$) were observed, column graphs were used to explain the interaction.

5.3 Results and Discussion

This project utilized season long continuous grazed pastures to distinguish nutritional differences between simple and complex forage mixtures. Forage production and utilization values are given in Table 5.2. These parameters are important because animal production is directly related to forage production. A seedmix by year interaction ($P<0.05$) was found for AYLD (Figure 5.1). This interaction was caused by the higher ($P<0.05$) production from the complex pastures observed in 2007 versus other years. The higher AYLD observed for complex seedmix in 2007 can be related to warm dry spring conditions in 2007 that reduced C_3 growth and summer moisture that improved C_4 plant growth. These results are in

agreement with theories that plant diversity improves the swards' ability to adapt to disturbances and drought while improving forage production (Glvnish 1994; Tilman and Downing 1994; Fridley 2001; Minns et al. 2001; Kennedy et al. 2002; Tracy and Sanderson 2004; Sanderson et al. 2005). Stand composition and biomass production is affected by climate and the length of the growing season (Allard 1999; Redmon and Hendrickson 2007; Baron and Bélanger 2007). Several studies have shown that complex forage mixtures produced higher levels of forage than simple mixtures (Deak et al. 2004; Tracy and Sanderson 2004a; Tracy and Sanderson 2004b). Cool season grasses and legumes provide the majority of available forage because they initiate growth early in the spring and produce about two thirds of their annual production before mid summer (Jefferson et al. 2005; Cherney and Kallenbach, 2007). Warm season species initiate growth in June throughout the hot summer periods and peak production is achieved by September because they are adapted to high temperatures and drought conditions (Baron and Bélanger, 2007; Cherney and Kallenbach, 2007). This growth during the hot part of the summer provides forage for the grazing animal after the spring grazing of C_3 species (Jefferson et al. 2002). There was a year effect ($P<0.05$) exhibited with the CYLD because production is directly related to growing conditions that varies from year to year. The year effect is only evident in CYLD because it measures plant growth over the entire period of the grazing experiment. Residual yields (RYLD) exhibited a significant seedmix effect ($P<0.05$) with more forage material being removed on the complex pastures. There was a seedmix by year interaction ($P<0.05$) noted for pasture utilization (Figure 5.2). This interaction occurred in 2007 when simple pasture utilization was lower ($P<0.05$) than simple and complex utilization values in 2005 and 2006. The lower utilization of the simple seedmix observed in 2007 was likely caused by the hot and dry summer conditions that reduced the simple seedmix production and caused the C_3 species to mature earlier in the growing season. Utilization has been shown to decline with decreased production (Arnold 1987). The higher utilization of complex mixtures could be related to the higher quality forage associated with the initiation of C_3 and C_4 grasses at different times throughout the growing season (Trlica 1999; Baron and Bélanger 2007). Previous studies have shown that more diverse pastures tend to be utilized more uniformly even under changing conditions (Webb 2008).

Table 5.2 Dry matter yield (Kg ha^{-1}) prior to grazing (AYLD), following grazing (RYLD) and in non grazed enclosures (CYLD) along with the estimated utilization (%) by seedmix and time for the grass mixtures

Analysis	Seedmix (SM)		Year (Yr)			SE	P-Value		
	Simple	Complex	2005	2006	2007		SM	Yr	SM * Yr
AYLD (Kg ha^{-1})	1069.0	1013.1	988.5	1025.5	1109.2	90.40	0.57	0.39	0.04*
RYLD (Kg ha^{-1})	598.2 a	390.8 b	466.5	472.5	544.5	63.95	0.02 *	0.26	0.38
CYLD (Kg ha^{-1})	1526.4	1506.0	1865.4 a	1210.5 b	1472.8 b	114.43	0.65	0.03 *	0.41
Utilization (%)	43.6	61.2	53.1	54.0	50.7	3.80	0.07	0.11	0.02*

* signifies a statistically significant value ($P<0.05$)

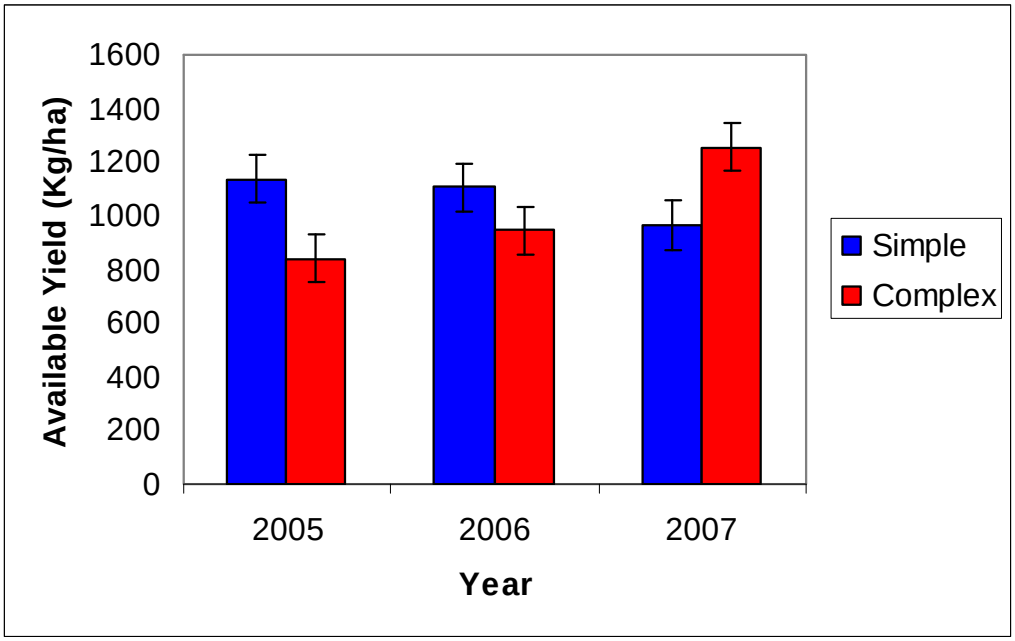

Figure 5.1 Seedmix by year interactions (P = 0.04) for available forage yield (Kg/ha)

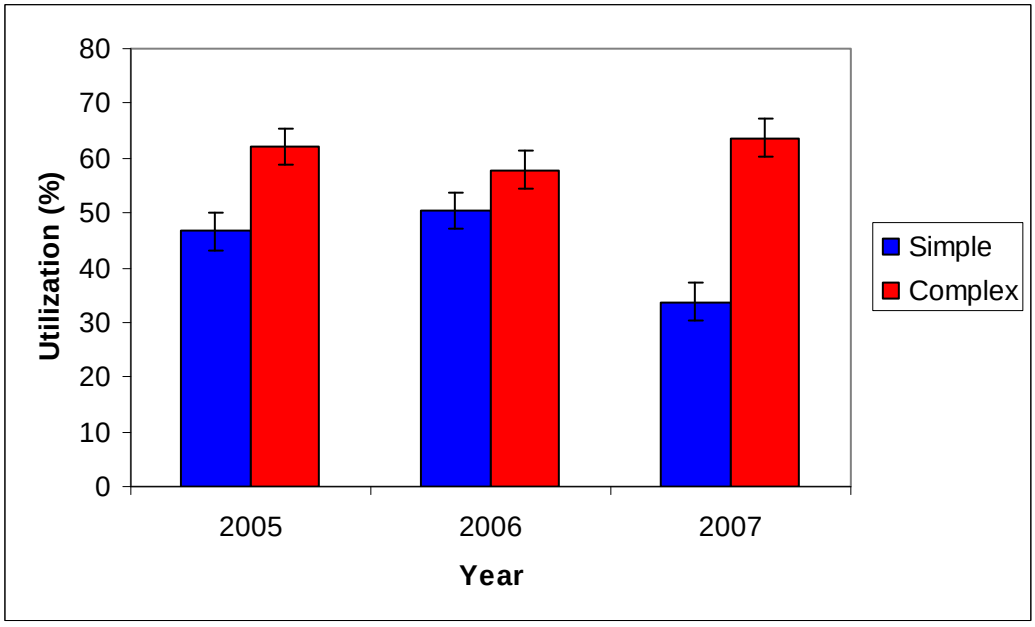

Figure 5.2 Seedmix by year interactions (P = 0.02) for utilization (%)

In this study animal production was measured by calculating ADG, TLP and AUD ha^{-1} (Table 5.3). Nutritive qualities of the forage mixtures including OMD, ADF, NDF, CP and P content were determined prior to the initiation of grazing (AYLD) (Table 5.4) and

following grazing in grazing free cages (CYLD) (Table 5.5). There was no significant effect of seedmix or year ($P>0.05$) for ADG or total live production (TLP). Forage quality was not affected by seedmix however there was a significant ($P<0.05$) year effect for certain forage qualities (ie. OMD,ADF and NDF). These results correspond with other studies that have shown no significant animal production differences (animal production or grazing capacity) between monoculture introduced species versus re-established native species or natural mixed grass prairie (Hanson et al. 1976; Hofmann et al. 1993; Jefferson et al. 1997). The reason no statistical differences in animal production were recorded could be the result of high animal variability, seasonal differences or the need for more replicates. The year effect on forage quality is directly related to the growing conditions. It has been shown by other researchers that forage quality can vary not only as plants mature but with changing environmental conditions (Wallace et al. 1961; Kilcher and Looman 1983; Abouguendia 1998). During drought conditions forage yield is reduced, the leaf to stem ratio increases, maturity is delayed and forage quality is higher (Peterson and Sheaffer 1992; Scheaffer et al. 1992). There were significant ($P<0.05$) seedmix and year effects shown for AUD ha^{-1} (Table 5.3). Levels were significantly higher ($P<0.05$) for complex mixtures. This is expected because studies (Cooke 1972; Ward 1988; Reid et al. 1990; Jackson 1999) have shown that live cattle weight gains per hectare can improve as pasture condition and diversity increases. Having a diverse forage stand results in yield distribution throughout the growing season and allows the opportunity to graze longer in the year (Cooke 1972; Cherney and Kallenbach 2007). The complimentary growth pattern of C_3 and C_4 forages could allow cattle to graze C_3 species early in the season and then new C_4 growth later in the summer (Trlica 1999). Other studies showed that cattle avoided C_4 species in preference for forbs and cool season species (Caswell et al. 1973; Kautz and van Dyne 1978). However, in these studies the C_4 species fully matured which was not the case in my study where the growing season is too short. Having a more diverse forage stand offers improved forage production and provides the grazing animal more nutritious and palatable forage choices (Smoliak and Bezeau 1967; Tilamn et al. 1996; Ganskopp et al. 1997; Bargo et al. 2002). The inclusion of native legumes in grass mixtures has been shown to increase forage yield and quality (energy and protein) because of nitrogen inputted into the system through N_2 fixation (Posler et al. 1993; Cadish et al. 1994; Phillips and James 1998; Schellenberg and Banerjee 2002; Cherney and Kallenbach 2007).

Table 5.3 Performance of yearling steers (average daily gains (ADG), total live production (TLP) and animal unit days per hectare (AUD ha^{-1})) by seedmix and year grazing the grass mixtures

Analysis	Seedmix (SM)		Year (Yr)			SE	P-Value		
	Simple	Complex	2005	2006	2007		SM	Yr	SM * Yr
ADG	0.82	0.75	0.85	0.85	0.66	0.11	0.46	0.25	0.08
TLP	34.27	36.91	32.06	42.16	32.54	5.52	0.61	0.18	0.14
AUD ha^{-1}	40.89a	46.95b	43.83c	45.94d	42.00c	0.69	0.02 *	0.01 *	0.21

* signifies a statistically significant value (P<0.05)

Table 5.4 Pasture quality (i.e. organic matter digestibility (OMD), acid detergent fiber (ADF), neutral detergent fiber (NDF), crude protein (CP) and phosphorus (TP)) by seedmix and year at start of grazing period (AYLD)

Analysis	Seedmix (SM)		Year (Yr)			SE	P-Value		
	Simple	Complex	2005	2006	2007		SM	Yr	SM * Yr
AYLD OMD (%)	51.800	51.844	48.550 a	50.987 b	55.929 c	0.4764	0.93	< 0.01 *	0.52
AYLD ADF (%)	33.450	33.743	35.248 a	33.868 a	31.673 b	0.5530	0.59	0.02 *	0.32
AYLD NDF (%)	59.877	61.567	63.201 b	60.347 a	58.618 a	0.8759	0.17	0.02 *	0.64
AYLD CP (%)	6.359	6.255	6.671	6.196	6.055	0.3984	0.75	0.08	0.13
AYLD TP (%)	0.176	0.176	0.187	0.168	0.173	0.0090	0.95	0.08	0.11

* signifies a statistically significant value (P<0.05)

Table 5.5 Pasture quality (i.e. organic matter digestibility (OMD), acid detergent fiber (ADF), neutral detergent fiber (NDF), crude protein (CP) and phosphorus (TP)) by seedmix and year at the end of grazing season in grazing free enclosures (CYLD)

Analysis	Seedmix (SM)		Year (Yr)			SE	P-Value		
	Simple	Complex	2005	2006	2007		SM	Yr	SM * Yr
CYLD OMD (%)	50.184	49.356	47.543 a	48.328 b	53.439 c	0.3973	0.07	< 0.01*	0.19
CYLD ADF (%)	34.199	35.070	36.297 b	34.436 b	33.172 a	0.5797	0.30	0.01 *	0.81
CYLD NDF (%)	60.396	61.947	62.864 b	61.370 b	59.280 a	0.9245	0.22	0.03 *	1.00
CYLD CP (%)	5.185	4.476	5.573 b	4.387 a	4.532 a	0.2270	0.07	0.01 *	0.35
CYLD TP (%)	0.167	0.141	0.168	0.150	0.144	0.0071	0.06	0.20	0.87

* signifies a statistically significant value (P<0.05)

The OMD values were approximately 2 % lower, ADF was 1 % higher, NDF was similar and CP values were approximately 1.5 % lower in the CYLD than in AYLD. The lower qualities in CYLD samples related to the maturity of the plants. The CYLD samples were fully matured. Any mature seeds had been dropped and leaf loss was likely occurring by this clip period whereas AYLD forages were in vegetative to early seed set and plants were still actively growing. Crude protein levels were slightly lower and fiber levels were higher in complex mixtures versus the simple seedmix, especially in CYLD. The CP of the samples collected for AYLD would be adequate to meet maintenance requirements but by late summer levels are low enough supplementation will be required especially if animal performance becomes impacted. Phosphorus levels would appear to be high enough to meet the animal's maintenance requirements. NRC (2000) states that 381 kg animals gaining between 0.33 and 0.91 kg day^{-1} require 0.13% and 0.16% P (NRC 2000). Previous research has shown that C_3 and C_4 native grasses remained relatively stable in P content throughout the season (Poland and Manske 2004) but work by Jefferson et al. (2005) contradicted our findings by claiming there is only a short time during the grazing season when phosphorus levels are adequate to maintain animal growth. It is important to remember that these levels are whole plant measures and actual levels being consumed by the animal would be higher because of selective grazing.

5.4 Conclusion

There were no clear advantages to using more diverse mixtures of native forages containing warm season grass species. It is evident that these mixtures are beneficial some years depending on environmental and growing conditions. Year is a major variable that directly affects forage and animal production and forage quality. Temperature and moisture conditions can fluctuate greatly with year which can encourage or restrict the growth of some forages. The C_3 and legume species produce most of their biomass early in the growing season when cooler temperatures and moisture are available. Warm season grasses on the other hand prefer warmer and drier growing conditions making them more favourable during drought years when C_3 and legume growth is inhibited. Although we never observed significant differences in forage quality associated with complex forage mixtures, the benefits of C_3 and C_4 grasses along with legumes in mixtures was still evident with higher animal production (AUD ha^{-1}) and pasture utilization. Differences between complex and

simple forage mixtures could be occurring due to the effects of animal preference. It is possible that larger fields, more repetition and more years would likely strengthen the seedmix effect.

CHAPTER 6
CONCLUSION

Using native forages for stockpiled grazing is considered an excellent option to reduce winter feeding costs. Native forages are recognized for their ability to hold their forage nutritional qualities because of greater leaf retention. This research project compared forage production potentials, nutritive values and *in vitro* digestibility of native and tame species commonly grown in southwestern Saskatchewan.

This study was able to show changes in forage characteristics over the growing season among different forage species. Generally the forages showed a similar trend where OMD, CP, P and Ca values declined over time while NDF, ADF and ADL concentrations increased. From this trial it appears that having mixed swards of C_3 and C_4 grasses and legume species would complement each other in forage stands based on production and nutritional quality differences of the individual species. The physiological differences between C_3 and C_4 grasses and legumes resulted in forage production and quality differences during the growing season. This study demonstrated that C_3 grasses provide optimal forage for early summer grazing while C_4 grasses and legumes provide better quality forage for later summer and early fall grazing. This could explain why pasture production is improved on diverse forage mixtures and how pasture quality could be maintained at or above the animal's maintenance requirements longer into the fall.

Nutrient accessibility in forages is important because as species become more fibrous, important nutrients like CP and energy can be tightly bound with fiber making these important components inaccessible to the rumen microbial population. Our findings showed that CMV had the highest EDDM and CP availability versus the grass species. Warm species had high digestibility, slightly different than expected however it was likely because they were less mature than the C_3 species. Species like WWG and GNG are recognized as suitable forages for extending fall grazing and this was shown in this study where their EDDM and EDNDF values were relatively high. Values observed for CP disappearance indicate that microbial contamination was occurring due to the low initial CP values and the tight association with fiber fractions. Further testing is required to determine environmental effects on the species of interest and better quantify CP digestion through the use of N

markers to distinguish microbial contamination. Our results would demonstrate that rumen fermentation conditions can be enhanced by strategic mixing of these forages in reestablished pastures.

This project set out to determine if there were advantages associated with complex native forage mixture versus simple swards. There were no clear advantages in nutritive values associated with the complex mixture, however, AUD ha^{-1} was significantly higher. From our grazing trial it was observed that complex mixtures of forages were better able to adapt to drier environmental conditions and provide a longer grazing season. This appeared to be the result of having C_4 grasses present in the mixture that grow better during drought conditions. It is evident that year is a major variable in forage and animal production and the quality of the forages. Having larger fields, more repetition and more years would likely strengthen the seedmix effect.

Our results would indicate by having a more diverse pasture mixture containing cool and warm forage species could improve the pasture nutritional profile, forage yield and animal performance throughout the grazing season due to the biological differences in plant growth.

CHAPTER 7

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APPENDIX

North Side

Rep 4	Rep 3	Rep 2	Rep 1
Co1 Prairie Sandreed	AC Knowles Hybrid Brome Grass	Great Plains Canadian Milkvetch	AC Sharptail Needle and Thread
Mandan Canada Wildrye	Mandan Canada Wildrye	Montana Meadow Brome Grass	Taylor Little Bluestem
Spredor 4 Creeping Rooted Alfalfa	Montana Meadow Brome Grass	AC Larmour Purple Prairie Clover	Butte Blue Grama
Butte Blue Grama	AC Sharptail Needle and Thread	Polar Northern Wheatgrass	WR Poole Western Wheatgrass
Sprig Awned Wheatgrass	AC Larmour Purple Prairie Clover	Butte Blue Grama	AC Knowles Hybrid Brome Grass
AC Sharptail Needle and Thread	Sprig Awned Wheatgrass	Taylor Little Bluestem	AC Larmour Purple Prairie Clover
Taylor Little Bluestem	Taylor Little Bluestem	AC Sharptail Needle and Thread	AC Mallard Green Needle Grass
Keystone June Grass	Great Plains Canadian Milkvetch	AC Mallard Green Needle Grass	Montana Meadow Brome Grass
Montana Meadow Brome Grass	Co1 Prairie Sandreed	Spredor 4 Creeping Rooted Alfalfa	Co1 Prairie Sandreed
AC Larmour Purple Prairie Clover	AC Mallard Green Needle Grass	Sprig Awned Wheatgrass	Keystone June Grass
AC Mallard Green Needle Grass	Spredor 4 Creeping Rooted Alfalfa	Keystone June Grass	Great Plains Canadian Milkvetch
WR Poole Western Wheatgrass	Keystone June Grass	Mandan Canada Wildrye	Sprig Awned Wheatgrass
AC Knowles Hybrid Brome Grass	WR Poole Western Wheatgrass	WR Poole Western Wheatgrass	Spredor 4 Creeping Rooted Alfalfa
Polar Northern Wheatgrass	Polar Northern Wheatgrass	AC Knowles Hybrid Brome Grass	Polar Northern Wheatgrass
Great Plains Canadian Milkvetch	Butte Blue Grama	Co1 Prairie Sandreed	Mandan Canada Wildrye

Figure A1. Plot map of the 15 randomized species within four replicates

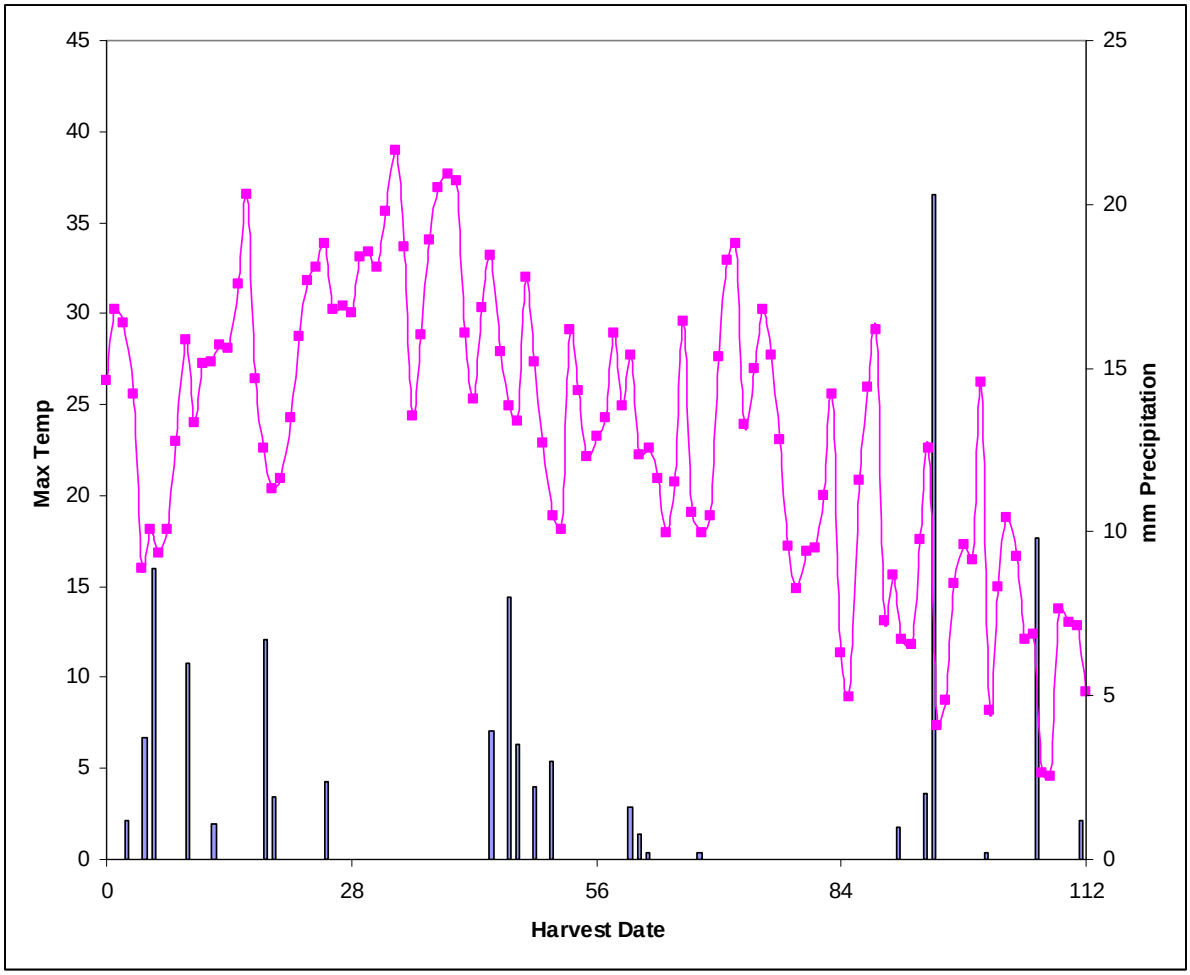

Figure A2. Max daily temperature (°C) (pink lines) and precipitation (bars) received during the growing season at Swift Current, Sask.

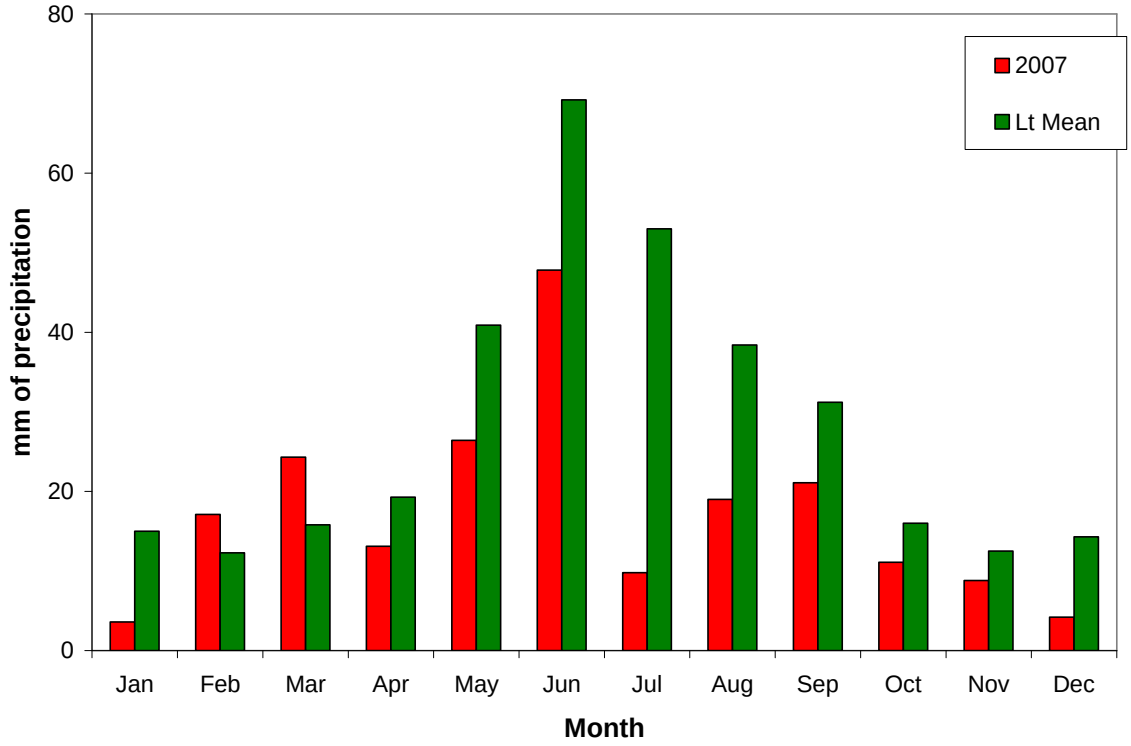

Figure A3 Monthly average precipitation received in 2007 and the long term average at Swift Current, Sask.

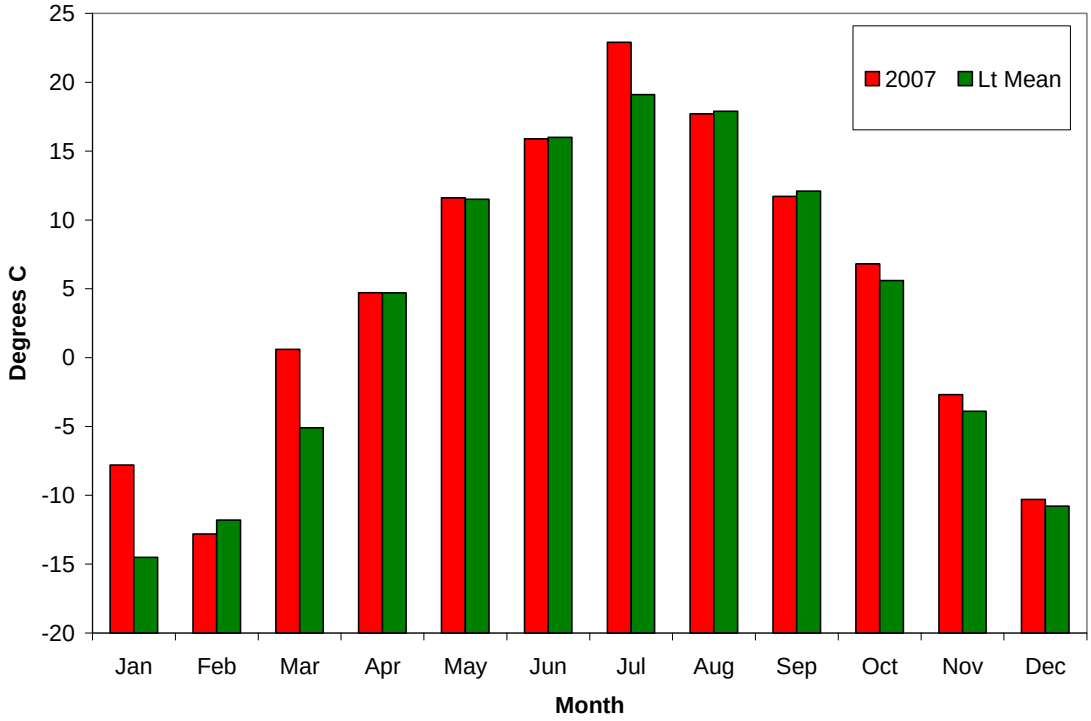

Figure A4 Monthly recorded average temperature received in 2007 and the long term average at Swift Current, Sask.

Table A1 Effect of species on *in situ* crude protein disappearance as a percent

Rumen Incubation Time	Species					
	CMV	WWG	MBG	GNG	Warm	NWG
0	26.86	44.34	35.94	35.48	38.66	41.80
2	28.38	42.24	33.60	39.72	41.63	39.89
4	35.70	42.34	28.91	39.55	40.23	36.16
8	46.99	42.56	30.81	39.94	44.50	32.03
12	56.60	42.12	35.05	42.13	44.60	27.09
24	68.46	43.88	36.25	48.03	51.26	27.62
48	70.37	51.93	35.09	55.31	61.69	25.38
72	71.04	56.31	39.82	60.22	66.24	30.98

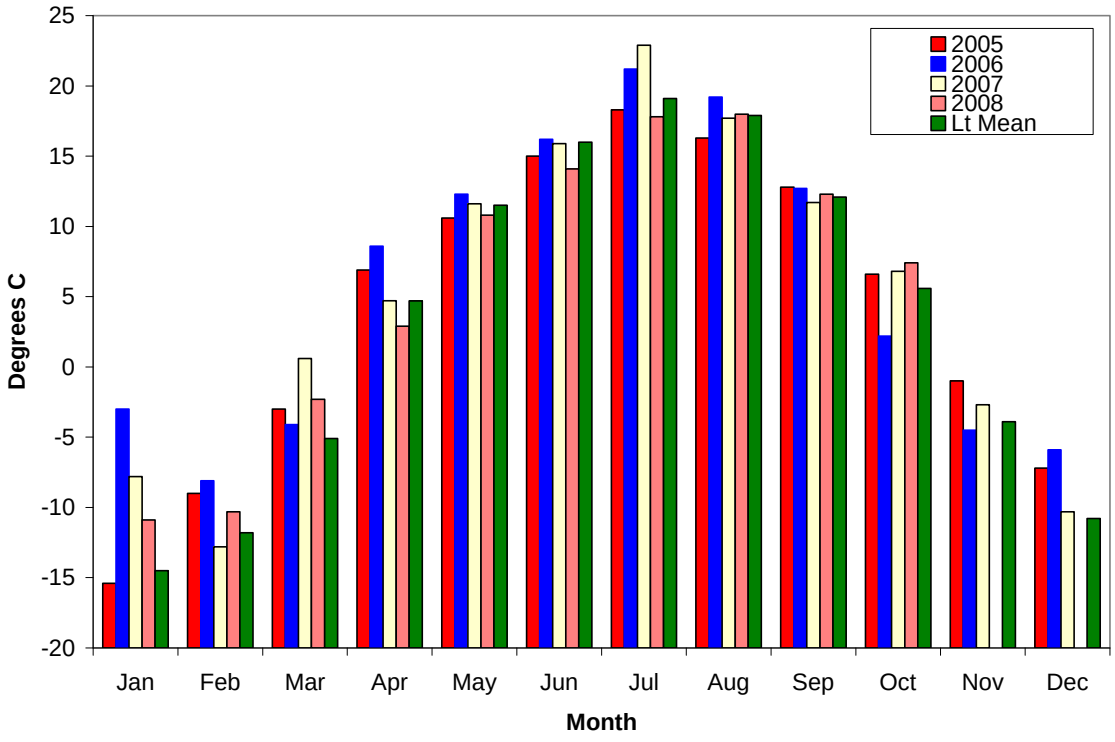

Figure A5 The average monthly temperature for 2005 (red), 2006 (blue), 2007 (yellow) , 2008 (pink) versus the long term average (green) for Swift Current, Sask.

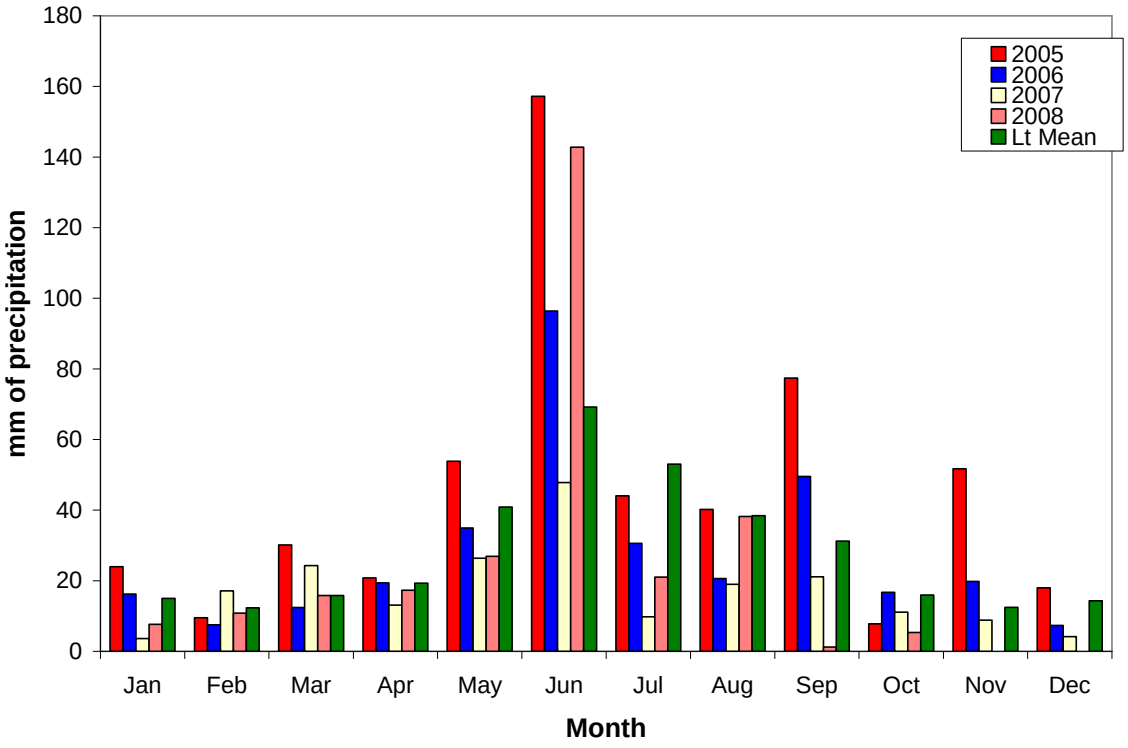

Figure A6 The average monthly precipitation for 2005 (red), 2006 (blue), 2007 (yellow), 2008 (pink) versus the long term average (green) for Swift Current, Sask.