THE EFFECT OF PERENNIAL GRASS SPECIES ON FORAGE GROWTH AND QUALITY, ETIOLATED GROWTH, ANIMAL PERFORMANCE AND ECONOMICS

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Abstract

A series of experiments were conducted during 2005 and 2006 to evaluate five perennial grass species for forage yield and quality, steer performance and grazing capacity, animal intake, plant energy reserves and economic return under grazed conditions. In 1999, two 0.8 ha replicates each of ‘Paddock’ meadow bromegrass (*Bromus riparius* Rehm.), ‘Carlton’ smooth bromegrass (*Bromus inermis* Leyss.) and ‘AC Knowles’ hybrid bromegrass (*B. riparius* x *B. inermis*) were seeded. In 2003, two 0.8 ha replicates each of ‘AC Goliath’ crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.), hybrid bromegrass, and ‘Courtenay’ tall fescue (*Festuca arundinacea* Schreb.) were seeded. A long established stand of crested wheatgrass acted as the control pasture. For 2003 established pastures, AC Goliath crested wheatgrass (7515 kg ha^{-1}) had greater ($P<0.05$) cumulative dry matter yield than hybrid bromegrass (3136 kg ha^{-1}) during the 2005 grazing season. Average (2005-2006) crude protein (CP) was greatest ($P<0.05$) for hybrid and smooth bromegrass for 1999 established pastures at start and middle of period one. Control pastures had the greatest ($P<0.05$) neutral detergent fiber (NDF) mid-grazing period. Over 2 years, smooth bromegrass had greater acid detergent fiber (ADF) ($P<0.05$) than control pastures at the end of the grazing period one. Average (2005-2006) in vitro organic matter digestibility (IVOMD) was greatest for hybrid and meadow bromegrass ($P<0.05$) at the start of grazing period one. Control pastures (129 g kg^{-1}) had lower CP levels at the start of the 2005-2006 (average) grazing period 1 ($P<0.05$) compared to species seeded in 2003. Control and hybrid bromegrass pastures had the greatest NDF and ADF levels at the start of grazing period 1 (2005-2006 average) while tall fescue pastures had the lowest ($P<0.05$) NDF and ADF levels. Over 2 years, control pastures had the lowest IVOMD at start of grazing ($P<0.05$). In 2006, hybrid and smooth bromegrass had greater etiolated re-growth than control pastures ($P<0.05$). In 2006, grazed plants seeded in 1999 had greater ($P<0.05$) etiolated re-growth than ungrazed plants. For 2003 seeded grasses, crested wheatgrass produced greater ($P<0.05$) etiolated re-growth than tall fescue and control pastures. Average daily gain was similar ($P>0.05$) for all 1999 and 2003 seeded grasses. Overall, bromegrasses seeded in 1999 produced greater animal grazing days (AGD) than control pastures ($P<0.05$). Total beef production (TBP) was greater ($P<0.05$) for hybrid and meadow bromegrass compared to the control.

All species seeded in 2003 produced greater AGD ($P<0.05$) compared to the control. Crested wheatgrass produced greater ($P<0.05$) TBP than the control over both years of the study. The C_{33}:C_{32} alkane ratio estimated greater DMI ($P<0.05$) for hybrid bromegrass (9.9 kg d^{-1}) and control pastures (9.6 kg d^{-1}) compared to crested wheatgrass (6.8 kg d^{-1}) or tall fescue (6.8 kg d^{-1}) during period 1 in 2006. Over 2 years, net return to labor, equity and personal draw was greater ($P<0.05$) for hybrid bromegrass (\$91.24 ha^{-1}) compared to the control (-\$54.32 ha^{-1}). For 2003 seeded pastures, all pastures generated positive returns over 2 years. Crested wheatgrass (\$92.49 ha^{-1}) had greater net return than control pastures (-\$54.32 ha^{-1}) ($P<0.05$). Finally, the results of this grazing study indicate beef producers can manage these grasses during the summer grazing season and maintain high levels of animal performance and pasture production. This study has demonstrated that bromegrasses, crested wheatgrass and tall fescue could work well in a complementary grazing system.

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1 Introduction

In the past decade, the number of forage acres in western Canada has been increasing (Saskatchewan Ministry of Agriculture 2008) as many producers have considered producing forages favorable compared to producing annual crops. Furthermore, initiatives such as the Greencover Canada program (Agriculture and Agri-Food Canada, Government of Canada) have provided financial incentives and access to technical expertise to producers to increase the number of hectares in perennial cover in Canada. As part of the program, livestock producers were encouraged to seed perennial forages and adopt beneficial management practices on their operation. While this program recently ended, other programs such as the Canada-Saskatchewan Environmental Farm Plan (Government of Canada – Government of Saskatchewan), have continued to encourage producers to seed perennial cover and manage their operations in an environmentally sustainable manner. Other agencies such as Ducks Unlimited Canada have also developed programs to help livestock producers with land conversion. As producers convert their land to perennial forages for grazing, they need access to timely and relevant information that will help them choose the forage species and varieties that will be best suited to their livestock operation.

While all forage varieties must demonstrate merit before they are commercially released to livestock producers, the majority of variety testing occurs in small-plot format. Small plot trials use mechanical methods of defoliation, such as mowing or clipping. Mechanical treatments fail to impose grazing animal effects, such as pulling, treading, manure and urine deposition and short stubble heights, which may cause different responses than frequent clipping (McCartney and Bittman 1994). Few grass forage species have been evaluated for livestock performance and stand persistence under grazed conditions before being commercially released. Recognition of the differences between small-plot results and actual results under grazing situations has lead to the current study where new forage varieties are compared to a standard, long established crested wheatgrass stand.

Historically, crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) and smooth bromegrass (*Bromus inermis* Leyss.) have been used as both hay and pasture species in western Canada. The high quality, early spring growth of crested wheatgrass makes it suitable for use in complementary grazing systems. Crested wheatgrass is very drought tolerant, winter hardy and tends to persist for long periods of time. Smooth bromegrass is an up-right growing, rhizomatous perennial grass that forms a dense sod. A native to western Europe, this species is extremely winter hardy and is drought and heat tolerant. Since its introduction to North America in the 1880's, smooth bromegrass has been widely used as both hay and pasture species, but its slow regrowth makes it more suited to hay production (Smith et al. 1986).

More recently, meadow bromegrass (*B. riparius* Rehm.), hybrid bromegrass (*B. riparius* x *B. inermis*) and tall fescue (*Festuca arundinacea* Schreb.) have been examined for their pasture potential in western Canada. Meadow bromegrass, a bunch-type grass, shows increased regrowth following defoliation compared to smooth bromegrass, and the basal nature of the leaves makes this species more suitable for pasture rather than hay production. This species is often used in mixtures with alfalfa and other legumes and there is little published data on forage and livestock performance in pure stands (Knowles et al. 1993). Breeding programs initiated at the Saskatoon Research Centre of Agriculture and Agri-food Canada developed hybrid bromegrass, which is a cross between smooth and meadow bromegrass. This species was selected to have characteristics that are intermediate to the two parental lines (Coulman 2004) and has been shown to be suitable for hay and pasture production (Knowles and Baron 1990). Tall fescue is a deep-rooted, bunch-type grass which is less winter-hardy than smooth bromegrass. Its forage quality persists into the fall and it has been demonstrated to provide excellent fall and winter grazing forage (Smith et al. 1986). This species is generally adapted to humid, temperate areas of the world, and its stand persistence in the western Canada climate is unknown.

A two-year grazing study was initiated at the Western Beef Development Center's Termuende Research Ranch near Lanigan, Saskatchewan. The objectives of the study were to evaluate the five above-mentioned perennial grasses for forage quality and yield, plant energy reserves, animal performance, grazing capacity, total beef production and economic return to a livestock operation.

The hypothesis was that new forage varieties, including ‘AC Goliath’ crested wheatgrass, ‘AC Knowles’ hybrid bromegrass and ‘Courtenay’ tall fescue, would provide greater forage yield and improved quality, greater etiolated re-growth, animal production, intake and economic returns than older forage varieties, including ‘Carlton’ smooth bromegrass, ‘Paddock’ meadow bromegrass and long established stands of crested wheatgrass of an unknown cultivar.

2 Literature Review

2.1 Grass Species

2.1.1 Crested Wheatgrass

The widespread adaptability of crested wheatgrass, *A. cristatum*. (Fairway/diploid type) and *A. desertorum* (Fisch.) Schult. (standard/tetraploid type), has lead to its extensive use in the livestock industry of western Canada and the United States. Native to eastern Russia, western Siberia and central Asia, this species was first introduced to the University of Saskatchewan in 1911 and throughout western Canada in 1927 (Smoliak and Bjorge 1981). In the 1930's, crested wheatgrass was used for the extensive regrassing of abandoned farmlands and overgrazed rangelands of the prairies. Since then, it has become an important pasture and hay species. Rogler and Lorenz (1983) stated that "it is the most successful introduced species in the northern Great Plains and much of the West."

Crested wheatgrass is a winter-hardy, long-lived, drought tolerant bunchgrass with a deep, extensive fibrous root system. It resists trampling and close grazing but does not tolerate prolonged flooding or high water tables (Smoliak and Bjorge 1981). Long life and persistence under adverse conditions, strong competitive ability, ease of establishment and high forage productivity have also lead to its widespread use in the western United States and Canada (Rogler and Lorenz 1983). Crested wheatgrass is particularly suited to early spring grazing as it produces abundant high quality spring growth from mid-April to mid-June (Hart et al. 1983a; Vogel et al. 1993). When this species reaches maturity it becomes unpalatable and quality declines rapidly, which may limit its use to spring and fall grazing; however, crested wheatgrass works well in complementary grazing systems that utilize both crested wheatgrass and native range or mid to late summer type forages (Smoliak et al. 1981).

2.1.2 Smooth Bromegrass

Smooth bromegrass was first introduced to Canada from northern Germany in 1888, but it was not until the drought of the 1930's that it gained importance and became one of the most widely utilized grasses in western Canada. Smooth bromegrass is a long-lived, vigorous rhizomatous perennial that is well-adapted to a variety of climatic and soil conditions. It can tolerate short periods of spring flooding, but does best on well-drained soils of the Black and Gray Wooded soil zones. A deep root system provides tolerance to some heat and drought as well as winter-hardiness. When growing conditions are favorable, smooth bromegrass responds very well to nitrogen fertilization (Smoliak and Bjorge 1981).

Smooth bromegrass is best suited to hay production due to its leafy, up-right growth form and slow regrowth after defoliation. Grazing of this species is also common on the prairies but it does have some limitations. Spring grazing may occur without detriment to subsequent growth if it occurs while the plant is leafy and prior to the elevation of growing points. Once tillers have elongated, defoliation treatments will remove the growing points and any new growth must initiate from crown buds. Thus, shoot elongation is the critical period for smooth bromegrass and defoliation treatments during shoot elongation may limit rate of regrowth and subsequent herbage production. Smooth bromegrass is often established in association with alfalfa (*Medicago sativa* L.) to utilize fixed nitrogen and increase overall forage yield and quality; however, the forage stand is often managed for the alfalfa, which may be disadvantageous to smooth bromegrass (Smith et al. 1986).

2.1.3 Meadow Bromegrass

In 1980, the first variety of meadow bromegrass, 'Regar', was registered in Canada. More recently, newer varieties such as 'Fleet' and 'Paddock' have been successfully used for pasture production in western Canada. Meadow bromegrass is a bunch-type, perennial grass species best adapted to cool, moist areas of the prairies including the Black and Gray Wooded soil zones, and some areas of the Dark Brown soil zone. It is sensitive to flooding and less tolerant to salinity than smooth bromegrass. Meadow bromegrass also has less winter-hardiness than smooth bromegrass and crested wheatgrass but has better frost tolerance than smooth bromegrass. This species has a reduced creeping habit compared to smooth bromegrass. It has greater regrowth potential than smooth bromegrass after defoliation as regrowth is initiated in existing tiller bases and not from the crown as in smooth bromegrass (Knowles et al. 1993). Thus, meadow bromegrass is adapted to multiple defoliations and is well suited for grazing purposes (Knowles 1987; Knowles et al. 1993).

Meadow bromegrass is palatable, readily grazed by livestock and is well suited for use in pastures with legumes (Knowles et al. 1993). It was not until recently that this species was evaluated for grazing animal production as a monoculture (Thompson 2003). Meadow bromegrass is also utilized as fall pasture as it grows well under cooler temperatures and holds its quality later into the grazing season compared to many cool season grasses; however, forage quality is marginally lower than smooth bromegrass (Knowles et al. 1993; Ferdinandez and Coulman 2001; Thompson 2003). When used for hay production, meadow bromegrass yields lower than smooth bromegrass and hybrid bromegrass (Knowles and Baron 1990; Coulman 2004).

2.1.4 Hybrid Bromegrass

A breeding program was initiated at the Agriculture and Agri-food Canada Saskatoon Research Centre in the 1980's to develop a forage variety that was adapted to both hay and pasture production. Hybrid bromegrass varieties were developed by crossing smooth bromegrass and meadow bromegrass. The resulting hybrids share characteristics of both parental species (Ferdinandez and Coulman 2000; Coulman 2004). In simulated grazing experiments (three cuts per season), hybrid bromegrasses outperformed smooth bromegrass but not meadow bromegrass; while in a hay system (two cuts per season), the hybrids outperformed meadow bromegrass but not smooth bromegrass (Coulman and Knowles 1995).

Similar to meadow bromegrass, hybrid bromegrass is capable of elongating cut tillers and has greater regrowth potential compared to smooth bromegrass. Similar to smooth bromegrass, hybrid bromegrass has leaves present higher in the sward than meadow bromegrass and is also suited for hay production. Ferdinandez and Coulman (2001) and Thompson (2003) evaluated the nutritive quality of hybrid bromegrass in comparison to meadow and smooth bromegrass and reported hybrid bromegrass to be intermediary to the parental lines. In the early 1990's, the variety 'Knowles' was selected for increased vigor, improved floret fertility, better seed types (lacking awns or pubescence), reduced creeping habit, good regrowth and fall greenness. Coulman (2004) suggested that this variety is best adapted to the drier areas of the prairies.

2.1.5 Tall Fescue

Tall fescue was originally introduced to North America from Europe as a grass that was adapted to a wide range of soil and climatic conditions. This grass is predominately found in the humid, temperate areas of North America and has had limited use on the Northern Great Plains (Moore 2003). It is well-adapted to low, wet areas and persists well during cool, winter months but may be damaged severely in northern areas (Smoliak and Bjorge 1981; Moore 2003). It is well suited to pasture production and under irrigation it produces tremendous growth when combined with high fertility. It is predominately a bunchgrass but will spread by short rhizomes to form a dense sod when grazed or mowed frequently. Tall fescue is not as aggressive as smooth bromegrass or reed canarygrass (*Phalaris arundinacea* L.) (Balasko 1986).

Tall fescue is characterized by numerous shiny, relatively broad, dark green, ribbed leaves (Smoliak and Bjorge 1981). Palatability of tall fescue is best when it is grazed frequently and managed to remain in a vegetative stage of growth. Mid-summer palatability is limited by coarse, tough leaves and it is not recommended for finishing animals during that period. In the autumn, palatability of tall fescue improves and provides excellent stockpiled forage for winter grazing (Balasko 1986).

Tall fescue is commonly associated with anti-quality factors, including endophytes and alkaloids, which can cause fescue toxicity in grazing animals. Fescue toxicity is characterized by “fescue foot”, fat necrosis and poor animal performance (including poor reproductive performance, reduced voluntary intake, decreased average daily gain and reduced milk production) (Balasko 1986). Endophyte-free varieties such as “Courtenay” are being developed and evaluated for persistence and grazing capacity (Hoveland et al. 1997; Bouton et al. 2001).

2.2 Energy Reserves in Forages

Plants produce energy through the process of photosynthesis. Energy derived from photosynthesis is used for cell growth, cell division and plant maintenance. When photosynthates are produced in the plant at greater rates than needed for cell growth, division and maintenance, surplus energy will accumulate in the plant (Brown and Blaser 1965). Plant energy reserves were defined by Graber et al. (1927) as "…those carbohydrates and nitrogen compounds elaborated, stored and utilized by the plant itself as food for maintenance and for the development of future top and root growth." They have an important role in regrowth following defoliation, over-winter survival and initiation of spring growth in forage crops (Brown and Blaser 1965). Thus, numerous studies have evaluated factors such as defoliation (Davidson and Milthorpe 1966b; Buwai and Trlica 1977; Menke and Trlica 1983; Richards and Caldwell 1985), moisture conditions (Boschma et al. 2003), and fertility (Raese and Decker 1966; McKee et al. 1967; Dovrat et al. 1972) on carbohydrate and protein reserves in forages. The ability of forages to respond to these factors will ultimately affect the resilience, persistence and productivity of the plant.

2.2.1 Role of Total Non-Structural Carbohydrates for Growth and Regrowth

Total non-structural carbohydrates (TNC) represent the portion of the carbohydrate pool that is available as energy to the plant. Total non-structural carbohydrates and photosynthates are converted to structural components of new and expanding cells and their availability may control the rate of growth (Davidson and Milthorpe 1966a).

In general, TNC levels in the crown, stubble, and roots are low during the period of rapid spring growth and for a number of days following defoliation. Trlica and Cook (1972) reported that approximately 50 to 60% of TNC reserves stored in the fall were used for respiration and initial spring growth the following spring in crested wheatgrass and Russian wildrye (*Elymus junceus* Fisch.). In the first four days following defoliation, Volenec (1986) reported approximately a 50% decrease in TNC levels in tall fescue. Similarly, Bahrani et al. (1983) found that TNC levels in tillers decreased for the first five days after defoliation and then increased thereafter, likely due to photosynthesis resuming.

Previous studies have evaluated the role of TNC in herbage production following defoliation. There is evidence that TNC may only be important immediately after defoliation, after which leaf area and photosynthesis may play a larger role in regrowth (Ward and Blaser 1961; Davidson and Milthorpe 1966b; Richards and Caldwell 1985; Hogg and Lieffers 1991b; Morvan-Bertrand et al. 1999). Richards and Caldwell (1985) concluded that at least 89-99% of the carbon in regrowth of crested wheatgrass (*Agropyron desertorum* (Fisch.) Schult.) and bluebunch wheatgrass (*A. spicatum* (Pursh) Scribn. and Smith) is derived from current photosynthate. They also suggest that in most grazing situations where defoliations may not be as severe as clipping treatments, photosynthesis would contribute far more carbon to regrowth than TNC reserves.

2.2.2 Role of Proteins for Growth and Regrowth

Many studies have indicated TNC as being the primary compounds associated with the initiation of growth following winter or defoliation, but few have studied the contribution of nitrogenous compounds (White 1973). Nitrogen and proteins are important for the synthesis of enzymes, membranes and other cell materials as new rapidly expanding tissues have characteristically high protein contents. Therefore, if the nitrogen supply is limited, protein synthesis, new tissue formation, and growth rates of plants would be inhibited (Brown and Blaser 1965). Davidson and Milthorpe (1966b) reported that TNC reserves and photosynthate production in the first two days following defoliation of orchardgrass (*Dactylis glomerata* L.) was insufficient to account for the synthesis and respiration of new leaf material that appeared. Similarly, Richards and Caldwell (1985) suggested that other labile substances such as proteins play a role in plant regrowth potential and must be used for the development of new leaf material. These results are in contrast to Morvan-Bertrand et al. (1999) who concluded that there was no direct relationship of nitrogen and soluble proteins to shoot production during the first two days of regrowth in perennial ryegrass (*Lolium perenne* L.); however, they did suggest that nitrogenous compounds may be important 2 to 28 days following defoliation.

In contrast to TNC levels which had significant seasonal changes, Hogg and Lieffers (1991a) found very little seasonal change in the nitrogen levels of rhizomes of marsh reed grass (*Calamagrostis canadensis* (Michx.) Beauv.). Their results provide little evidence to support the suggestion that seasonal changes in nitrogen content contribute to seasonal changes in energy reserves. Similarly, in a review by White (1973), it was suggested that nitrogenous compounds are used in respiration and growth, but are not ultimately stored and utilized as an energy source as TNC reserves are. Thus, there may be interactions occurring between TNC and nitrogenous compounds that will influence the energy and substrate supply for the growth of new leaves (Morvan-Bertrand et al. 1999).

2.2.3 Location of Energy Reserves

Historically, the location of energy reserves was thought to be in a plant's underground organs (Weinmann 1948; Troughton 1957). More recent literature has suggested that stem bases (stolons, corms, and rhizomes) (White 1973) and tissues closest to stem bases (internodes, leaf blade, and sheath tissue closest to stem bases) (Dovrat et al. 1972; Turner et al. 2006) contain higher TNC and proteins than their below ground counterparts. Matches (1969), in an attempt to identify accurate methods of measuring energy reserves, also indicated that stubble and stem bases were the primary storage organs for TNC and protein as increasing stubble height increased the quantity of etiolated growth produced.

2.2.4 Methods of Measuring Energy Reserves

Energy reserves can be measured through expensive and laborious laboratory methods or etiolated growth measurements in field or greenhouse conditions. A number of laboratory methods have been identified to measure plant TNC and nitrogen reserves (Smith et al. 1964; Adegbola and McKell 1966); however, these methods may provide an erroneous measure of reserve levels (McKendrick and Sharp 1970). Edwards (1964) identified problems with lab techniques, which included differences between TNC and structural carbohydrate material that may not be evident in laboratory results, inaccuracies with the recovery and sampling of underground plant organs as well as the varying proportions of reserve TNC in plant parts. A less invasive technique called etiolated growth has been adopted by many researchers to measure plant reserves.

2.2.4.1 Etiolated Growth

Etiolated growth represents the potential contribution of stored organic reserves to shoot regrowth without the confounding effects of photosynthesis. Etiolated growth is measured by removing above-ground growth and then covering plants with light-proof boxes so that the plant is unable to access sunlight. Aerial growth occurring in darkness is considered to be an indicator of the potential vigor of the plant for regrowth. This method is relative rather than an actual measure of reserves, because respiration occurs and utilizes TNC while etiolated growth is being produced and measured (Edwards 1964). Edwards (1964) suggested a number of advantages to this technique, including the need for minimal skill, knowledge, labor, field and laboratory equipment. Slight modifications can be made to the technique depending upon the type of plant (ie. rhizomatous grasses) (Reece et al. 1997). This method has been widely accepted and it has been shown to positively correlate to the quantity of TNC measured in laboratory situations (Raese and Decker 1966; Moriyama et al. 2003).

2.3 Effect of Defoliation on Forages

Defoliation of forages, particularly grazing events, results in morphological as well as physiological responses in individual plants (Jameson 1962). While direct effects include the removal of plant tissue and potential energy sources for growth, indirect effects include changes in litter accumulation, soil structure and microclimate. In grazing situations, livestock impose effects such as random defoliation heights, selection of individual plants and/or plant parts, pulling and treading of plants, hoof action as well as fecal and urine deposition which clipped forages are not subject to (Jameson 1962). Responses of forages to defoliation have been strongly linked to leaf area index (or active photosynthetic tissue) and energy reserves of the plant. Therefore, management of forage stands should include considerations of plant morphology and aim for a balance between photosynthetic tissue and energy reserves for optimum growth.

2.3.1 Effect of Defoliation on Energy Reserves

Grazing or clipping results in the removal of plant material capable of photosynthesis. Therefore, immediate regrowth is dependent upon the energy reserves of the plants and any remaining plant material that is capable of photosynthesis. Immediately following defoliation, there is generally a decline in TNC of both the roots and stubble (Davidson and Milthorpe 1966b; Bahrani et al. 1983; Richards and Caldwell 1985; Volenec 1986). Depending on the severity and frequency of defoliation as well as the plant phenological stage, there will be varying plant responses. The ability of a plant to adjust carbon allocation in favor of shoot regrowth following defoliation may allow certain species to withstand defoliation better than others (Richards and Caldwell 1985).

White (1973) identified differences between clipping and grazing on plants. While grazing may reduce plant vigor by changing competition interactions with other plants, it can also be less detrimental to plant vigor than clipping because some leaves and/or tillers may be left ungrazed and capable of photosynthesis. Thus, TNC studies that remove all or nearly all aboveground growth may overestimate the detrimental effect of grazing on TNC levels; however, nearly all studies examining the effect of defoliation on TNC reserves use clipping at relatively severe, uniform heights to predict energy reserves.

Repeated defoliations within a growing season generally decreases the overall TNC status of the plant (Trlica et al. 1977; Mislevy et al. 1978; Turner et al. 2006). Turner et al. (2006) reported higher tiller death rates and decreased TNC reserves associated with frequent defoliations. Similarly, more frequent defoliation (clipping when regrowth reached 30 mm) reduced TNC accumulation compared to less frequent defoliation (clipping when regrowth reached 40 mm) in a number of perennial grasses in Australia (Boschma et al. 2003). In marsh reedgrass, multiple defoliations within the growing season decreased TNC reserves, while a single defoliation increased TNC reserves compared to non-defoliated plants (Hogg and Lieffers 1991b). In contrast, Ogden and Loomis (1972) suggested that multiple defoliations (two or three) within a season are possible without detriment to the plant as long as there is a period of fall regrowth to replenish total non-structural carbohydrates. In Rhodes grass (*Chloris gayana* Kunth.), Dovrat and Cohen (1970) reported that defoliation at 28 day intervals produced less etiolated growth and TNC levels than plants defoliated at 14 day intervals. This may be unrealistic in temperate climates as Rhodes grass is a subtropical grass subject to longer growing seasons, higher temperatures and unlimited moisture (Dovrat and Cohen 1970).

The quantity of foliage removed during defoliation may have a significant impact on the rate of regrowth and energy reserves of the plant (Davidson and Milthorpe 1966a). Western wheatgrass (*A. smithii* (Rydb.) Gould) showed decreased vigor and TNC levels when heavily defoliated (90% herbage removal) compared to moderate defoliation (60% herbage removal) (Buwai and Trlica 1977).

A number of studies have evaluated the effect of defoliation on TNC reserves at various phenological stages. Buwai and Trlica (1977) and Trlica et al. (1977) demonstrated the effects of single and/or multiple defoliations on TNC levels and plant recovery on nine shortgrass range species. In western wheatgrass, a single defoliation at quiescence had little effect on herbage yield, vigor and TNC levels after 14 to 25 months of rest (Trlica et al. 1977). A single defoliation at quiescence also had minimal effects on blue grama (*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths).

In research by Turner et al. (2006), TNC levels were greatest for plants defoliated at the four-leaf stage compared to plants defoliated at the one or two-leaf stage. Plants defoliated at the four-leaf stage also showed the greatest decline in TNC levels after defoliation which was associated with greater regrowth compared to the plants defoliated at the one or two-leaf stage. In field conditions, crested wheatgrass and Russian wildrye plants clipped at quiescence and/or at early growth produced more growth than plants clipped at anthesis or maturity (Trlica and Cook 1972). Fall quiescence corresponded to a time of relatively high TNC levels and where TNC's were not immediately needed for growth following defoliation. Plants defoliated at early growth had sufficient time to replenish TNC reserves prior to fall. Plants clipped at anthesis or maturity showed the greatest decline in herbage production and TNC as they did not have time to replenish reserves after the initiation of fall regrowth (Trlica and Cook 1972). The results of Trlica and Cook (1972) suggest that crested wheatgrass and Russian wildrye are well suited to fall or early spring grazing as they are able to replenish TNC reserves when defoliated at those times. However, grazing these species at or near maturity may not allow adequate time for replenishment of TNC reserves and may be detrimental to the overall health of the plant.

2.3.2 Effect of Defoliation on Regrowth

The effect of defoliation on the regrowth of forages is variable depending upon the timing, severity and frequency of defoliation. In many types of forage, such as alfalfa, the apical meristem is the source of new leaves and is elevated by stem elongation. When a plant is defoliated and the apical meristem removed or damaged, stem elongation and leaf expansion stops at that axis. Any subsequent regrowth/leaf replacement and tillering must arise from dormant basal meristems which may be a slow process. In contrast, if a plant is defoliated prior to stem elongation, the apical meristems are not removed as they are still near the crown of the plant, and growth does not have to be initiated from dormant basal buds. Thus, swards can be managed to maximize regrowth rates if one considers plant phenology. Other plant species, such as meadow bromegrass, do not elevate their apical meristems and have much faster regrowth rates because their apical meristem is not removed and regrowth arises from active meristematic tissue. Many species of grasses also have intercalary meristems that allow leaves to continue to grow even if the elevated part of the leaf is removed. Intercalary meristems provide the most rapid form of regrowth (Hyder 1972; Olson and Richards 1988). Thus, the survival of many forages following defoliation is dependent upon the location of the meristems which largely influence subsequent growth rates and foliage reestablishment.

Caldwell et al. (1981) further examined the ability of grasses to cope with herbivory by comparing photosynthetic capacity and resource allocation in two bunchgrasses. They attributed greater grazing tolerance in crested wheatgrass (*A. desertorum*) compared to bluebunch wheatgrass due to the rapid reestablishment of the plant photosynthetic tissue in crested wheatgrass even though the photosynthetic capacity per unit of surface area was lower than that of bluebunch wheatgrass plants. Lower nitrogen and biomass investments per unit of photosynthetic tissue, more tillers and leaves per bunch and shorter lived stems were also attributed to grazing tolerance;

however, rapid allocation of resources to above-ground growth may occur at the expense of below-ground growth (Caldwell et al. 1981) and root initiation and elongation (Carman and Briske 1982).

The effect of defoliation will also depend on species and severity of defoliation. Davidson and Milthorpe (1966a) reported a severe decrease in leaf area and leaf number when orchardgrass plants were defoliated to a height of 2.5 centimeters. Similarly, McLean and Wikeem (1985) reported that clipping rough fescue (*Festuca scabrella* Torr.) to a 5 cm stubble height resulted in high mortality rates and reduced vigor compared to plants clipped at either a 10, 15 or 20 cm stubble height.

Other studies have examined the effect of multiple or frequent defoliations on plant yield and vigor. Buwai and Trlica (1977) reported that most heavy defoliations reduced forage yield and vigor of a number of range species including western wheatgrass, blue grama and fourwing saltbush (*Atriplex canescens* (Pursh) Nutt.). Rough fescue and Parry oat grass (*Danthonia parryi* Scribn.) plants also produced less forage when frequently defoliated (one, two or four-week intervals) compared to plants defoliated only once or twice during the growing season (Willms 1991). In addition, there were species differences, as Parry oat grass responded more favorably to two clippings and had greater regrowth compared to rough fescue. Thus, plant response to defoliation will vary depending upon the species, frequency and severity of defoliation as well as the phenological stage at which plants are defoliated.

2.4 Forage Yield

The evaluation of forages for livestock consumption should consider the overall forage production potential. Weight of herbage is one of the most important characteristics of forages and may be the single best measure of plant growth and production potential (Cook and Stubbendieck 1986). It is of particular importance in pasture studies as it is important to know the availability of forage for livestock and management practices that could affect overall production. Forage yields are also important for grassland and rangeland assessments and evaluation of new species and cultivars (t'Mannetje 2000). A number of authors have reviewed methods for determining forage yield (Cook and Stubbendieck 1986; t'Mannetje 2000).

2.4.1 Methods of Measuring Forage Yield

A number of methods of determining herbage weight or yield are available, but the one that is most suitable will depend on the type of vegetation, area to be sampled, topography, availability of facilities and secondary uses for the samples (ie. botanical or chemical analysis). Consideration must also be given to sward physiognomy, density, height and species composition as well as the availability of resources, including time, labor and finances (t'Mannetje 2000). Essentially there are two methods of estimating forage yield: destructive and non-destructive methods. While clipping is a destructive method, height and density measurements, ocular estimates and predictions based on precipitation are non-destructive. Cook and Stubbendieck (1986) and t'Mannetje (2000) have reviewed various methods of determining forage yield.

2.4.1.1 Vegetation Weight Determination by Clipping

Clipping is one of the most common methods for determining forage yield, even though it may be time consuming. Clipping results in a direct and objective measure of forage yield. It can provide additional information on a pasture stand, particularly if the samples are separated into live and dead components or individual species, which may be of great importance in mixed swards (Cook and Stubbendieck 1986). In some situations, it is of value to measure the annual growth of herbage with the use of permanent grazing exclosures, while other situations require the measurement of total growth and regrowth throughout the duration of a grazing period (Klingman et al. 1943).

2.4.1.2 Cage Comparison Technique

When evaluating forages it is often advantageous to estimate forage yield under actual grazing conditions. Klingman et al. (1943) outlined a cage comparison method for determining forage yield. This method assumes that the difference in yield between a protected area and a nearby grazed area is equal to the forage consumed. It also assumes that the difference in forage inside a cage at a given date and the forage that was outside a cage at a previous clipping date is equal to the growth or regrowth that occurred in the elapsed time period. Thus, this technique allows for a measurement of cumulative forage yield for the duration of the grazing period without a permanent grazing exclosure. When using this method grazing exclusion cages are periodically relocated during the grazing period. Because grazing is not uniform and there can be tremendous variation in soil and herbage between the caged and non-caged areas, there can be a relatively large source of error associated with this technique. Grazing uniformity can not be controlled easily, but choosing grazed areas that are similar to the ungrazed cages can minimize the error associated with this technique. Klingman et al. (1943) reported that three cages per paddock would be necessary to estimate yield accurately within 561 kg ha^{-1} in a 4.9 ha pasture, while 308 cages per paddock would be needed to estimate yield accurately within 56 kilograms per hectare; however, as uniformity of pastures increases or decreases, the number of cages needed to accurately measure forage yield may also change (Wilson 1966).

2.4.1.3 Height and Density of Vegetation

Height and density measurements are most commonly obtained using the 'drop-disc' or 'weighted disc' technique (t'Mannetje 2000). This method uses round or square discs on central rods to measure compressed sward height. The height at which the disc meets resistance from the forage and rests is recorded and used to estimate forage yield based on previous calibration data. This has been shown to provide rapid and relatively accurate estimates of forage yield as it accounts for both sward height and density; however, as forages mature, the presence of stemmy material and the occurrence of lodging have shown to have detrimental effects on the accuracy of yield predictions (Douglas and Crawford 1994).

2.4.1.4 Ocular Estimations

Because all forage can not be harvested and weighed, it is important to utilize techniques that give reasonable estimations of weight (Ahmed et al. 1983). Pechanec and Pickford (1937) described a weight estimate method to determine herbage yield using quadrats. This technique involves visual estimates of herbage mass and is based on extensive training prior to visual estimation with actual clippings to adjust estimates and improve accuracy. This technique is fast, reasonably accurate, largely non-destructive and results can easily be validated by clipping. The disadvantages of this technique include skill development of the estimator, a high degree of concentration and variation among observers (Cook and Stubbendieck 1986). Without any calibration cuts, the procedure may be of limited value in many research trials (t'Mannetje 2000).

2.4.1.5 Double Sampling Technique

Some researchers have used visual estimations in conjunction with quadrat clippings and regression equations to estimate forage yield (Wilm et al. 1944; Ahmed et al. 1983). The double sampling technique involves estimating forage yield by weight (and by individual species if desired) and then clipping a set number of those quadrats to determine actual forage yield values. Regression analysis is used, with estimated weights as the dependent variable and actual weights as the independent variable, to adjust values by a regression equation. The major advantage of this technique is the ability to estimate a large sample size in much less time that what it would require to clip the same number of samples (Cook and Stubbendieck 1986).

2.4.1.6 Precipitation

Annual and growing season precipitation has been suggested to provide accurate predictions of forage yield. Currie and Peterson (1966) reported that precipitation accounted for 87% or more of the differences in crested wheatgrass yield in Colorado. Specifically, rainfall in April determined forage yield for spring grazed pastures while May and July rainfall determined forage yield for fall grazed pastures. In the shortgrass prairie, Smoliak (1956) found a highly significant positive correlation (r=0.859) when

May and June precipitation was correlated with forage yield. Similarly, Duncan and Woodmansee (1975) found that correlations between forage yield and precipitation were improved by using the best 2 or 3 month's precipitation values in the annual grasslands of California. These results suggest that the quantity and distribution of rainfall during the growing season can accurately be used to predict forage yield.

2.5 Forage Quality

2.5.1 Forage Quality and Chemical Composition

Feed costs are one of the greatest costs associated with livestock production. Therefore, it is important that diets are formulated to optimize animal productivity as economically as possible. For grazing animals, this can be determined by knowledge of the botanical composition of the diet, the nutrients in diet constituents and how management practices can alter the nutrient composition of feedstuffs.

Unlike concentrates, the chemical composition of forages can vary widely according to the physiological age of the plant, the time of grazing or harvest, plant species, degree of contamination and botanical composition (Adesogan et al. 2000). To accurately determine forage quality, it is important to obtain representative samples from different parts of the forage being evaluated. Samples used for forage quality analysis should reflect the purpose of the study. For example, trials that evaluate change in mineral or element concentration over time should use plant parts of equivalent physiological age, while trials that evaluate the chemical composition of animal diets, should use samples that are similar in form and composition to that eaten by the animals. In grazed pastures, estimating botanical composition of the diet and portions of plant parts ingested can be difficult, laborious and time-consuming.

2.5.2 Protein Determination

Nitrogen estimation and a conversion factor of 6.25 (which reflects the quantity of nitrogen in protein) can be used to determine the protein concentration of forages. For most analysis the conversion factor of 6.25 is sufficient to estimate protein content but because it may include non-protein N, it is an estimate of crude protein (CP) not true protein. There are two commonly used techniques to measure crude protein. The first method, the Kjeldahl technique, is quite sensitive to nitrogen concentration and gives accurate results of protein concentration. The second method, automatic nitrogen analysis, uses the Dumas combustion method (e.g. LECO nitrogen determinators). Automatic nitrogen analyzers are advantageous in that they involve fewer analytical steps, require smaller sample sizes and allow analysis of more samples in a day compared to the Kjeldahl method; however, automatic nitrogen analyzers may give less accurate results (overestimate protein content) as they measure some additional N-compounds such as nitrates.

When more precise values of proteins are required, true protein can be measured using high-pressure liquid chromatography which determines the individual amino acids in a sample. This method is expensive and underestimates protein concentration if 6.25 is used as a conversion factor to determine protein content. Other techniques to determine protein concentration include the use of a ninhydrin assay or colormetric techniques. The reagent required for the ninhydrin assay is difficult to prepare and utilize which has limited the wide-spread usage of this technique. Colormetric methods largely measure soluble N and require pre-digestion or maceration of the sample prior to analysis. This method requires standardization with another method such as the Kjeldahl method (Adesogan et al. 2000).

2.5.3 Fiber Determination

The greatest determinant of the extent of forage digestion is the degree of lignification and cell wall/fiber content. Traditionally, cell wall content was estimated by crude fiber content in order to predict forage digestibility; however, crude fiber analyses often give inaccurate measures of crude fiber content and produce predictions of digestibility that vary with cutting date, species and maturity. Instead, various digestibility prediction equations have been produced using lignin analysis which have been shown to have a higher degree of accuracy than equations based on crude fiber estimates. Disadvantages of lignin analysis include the cost and complexity of analysis as well as accuracy of results due to contamination with other substances (Adesogan et al. 2000).

An alternative system was proposed by Van Soest (1967) which separated the total fiber fraction (neutral detergent fiber (NDF)) from the less digestible fiber fraction (acid detergent fiber (ADF)). Neutral detergent fiber is the portion of the plant that remains after digestion in a neutral detergent solution and includes cellulose, hemicellulose and lignin, of which only cellulose and hemicellulose are partially available for digestion. The nutritive availability of the cell wall or NDF fraction is not uniform among different forages. Neutral detergent solubles include sugar, soluble carbohydrates, pectins, protein, nonprotein nitrogen and lipids, which are considered to be readily and almost completely available to the ruminant animal. Further digestion of the NDF fraction with an acid detergent solution yields acid detergent fiber, which is the sum of cellulose and lignin, of which lignin is indigestible (Van Soest 1967). Van Soest (1967) suggested that the use of a single chemical factor to predict digestibility is likely to result in erroneous estimates of digestibility.

2.5.4 Digestibility

Digestibility is a measure of the proportion of the feed or feed component that has been digested and does not appear in the feces (Coates and Penning 2000). Digestibility can be estimated through three primary techniques: *in vivo*, *in situ* or *in vitro* digestibility trials. In theory, *in vivo* and *in situ* measurements should provide greater accuracy compared to *in vitro* techniques. *In vivo* and *in situ* trials are not utilized as often as *in vitro* trials as the former two methods often make it difficult to measure a large amount of samples and they are usually expensive, labor intensive and require the use of fistulated animals. *In vitro* alternatives should be relatively inexpensive, accurate, simple to use and possible to run a large number of samples with relative ease and repeatability (Adesogan et al. 2000).

2.5.4.1 in vivo

To measure dry matter digestibility *in vivo*, two distinct methods have been identified; those which use the knowledge of animal intake and total fecal output and those which use internal (endogenous) markers found in the forage to relate dry matter digestibility to the chemical composition of the feces (fecal-index technique). The former technique is well suited to situations where animal are housed and individual intake and fecal output can be easily measured. Grazing experiments favor the latter method as animal intake can be difficult to measure in free-ranging livestock. Using the fecal-index technique, the most extensively studied internal markers used to determine diet digestibility *in vivo* have included lignin, acid insoluble ash and more recently, alkanes. Other fecal markers have included silica, iron, chromogen and potentially indigestible cellulose; however, incomplete fecal recoveries have limited their use in digestibility studies (Minson 1990).

2.5.4.1.1 Lignin

Although lignin has been extensively used in digestion studies as an internal marker, problems exist with fecal recovery, quantification and isolation which limit its ability to accurately determine diet digestibility. In a review of lignin as a marker, Fahey and Jung (1983) reported that a number of studies concluded that lignin may be digested, degraded or form a complex with other dietary components in the digestive tract of ruminant animals, while other studies have indicated that lignin was indigestible.

Thonney et al. (1979) reported that use of permanganate lignin as an internal marker underestimated digestibility compared to the total fecal collection method by approximately 23.9% as a result of low fecal recovery of lignin. They concluded that it was an unreliable internal marker for estimating diet digestibility. Momont et al. (1994) also found a large range of alkaline hydrogen peroxide lignin recovery in fecal samples (82.4 to 118%) which resulted in predictions of digestibility and dry matter intake that varied from the actual values. Thus, inconsistent fecal recovery may limit this technique for digestibility and dry matter intake estimates. Fahey and Jung (1983) also suggested that there may be some serious experimental errors in the procedure by which feed and fecal samples are analyzed for lignin concentration. Depending on the procedure used, cutin, Maillard-type browning products, tannins, pigments or proteins may be measured as lignin while some true lignin may be destroyed.

2.5.4.1.2 Acid Insoluble Ash

The acid insoluble ash (AIA) technique can be used to estimate digestibility by measuring the amount of ash insoluble to diluted hydrochloric acid for both feed and fecal samples. Van Keulen and Young (1977) evaluated the accuracy of three different analytical procedures to determine digestibility by the AIA technique in comparison to the total fecal collection method. Despite differences between the three analytical procedures, all three procedures estimated digestibility values similar to those determined by total fecal collection. This procedure does not appear to have any diurnal pattern when estimating digestibility (Van Keulen and Young 1977).

Ferreira et al. (2004) reported accurate dry matter intake estimates when AIA was used in conjunction with Cr_2O_3 to determine intake. Thonney et al. (1979) also reported that digestibility estimates determined using AIA were very similar to those measured by total fecal collection. Limitations to the AIA technique may occur when there is a high quantity of orts in the diet (which may have a variable AIA content) and/or diets are inadequately mixed to reduce feed sorting and selection (Block et al. 1981). Contamination of feeds and feces with soil and dust could also cause a greater number of incorrect estimates of digestibility with the AIA method compared to other marker methods (Van Keulen and Young 1977).

2.5.4.2 in situ

Estimates of *in situ* digestibility are theoretically superior to estimates of *in vitro* digestibility as the former technique provides information on forage digestion dynamics in the rumen and the latter does not; however, this technique can have a large amount of variation associated with it as results may be affected by sample preparation, washing and drying procedure, bag type, pore size, individual animal and modeling. An additional challenge affecting *in situ* estimates of rumen digestibility is the accurate correction for particulate losses occurring through the pores of the *in situ* bag which may exaggerate the immediately soluble fraction and alter the degradation curve produced by modeling, as well as choice of an appropriate outflow rate (Adesogan et al. 2000).

2.5.4.3 in vitro

For *in vitro* techniques to be widely used and accepted as accurate indicators of *in vivo* digestibility, they must provide digestibility values that are similar to *in vivo* values for many forages. The rumen fluid-pepsin method of Tilley and Terry (1963) and variations of their method have been widely accepted for *in vitro* digestibility determination. This method requires the collection of rumen fluid from fistulated animals which may cause slight variations in results due to the variability of the rumen fluid composition and activity between individual animals. To minimize variation, similar samples should be compared in the same run and a set of standards should also be used. This technique assumes that the final residue after *in vitro* digestion is similar to fecal material excreted by the animal; however, the presence of metabolic fecal nitrogen present *in vivo* will cause some differences between *in vitro* and *in vivo* estimates of digestibility. As well, *in vitro* residues may contain bacterial residues and other substances which would have been digested in the distal part of the digestive tract *in vivo*. This technique may also have limited accuracy with non-fresh forage samples as there may be differences in the sample form, particle outflow, nitrogen supply to rumen microbes and the production of Maillard products when comparing *in vivo* to *in vitro* values (Adesogan et al. 2000).

When access to fistulated animals is limited, Akhter et al. (1999) suggested that fecal material may be utilized as a source of microbes for *in vitro* digestion in place of rumen fluid. They reported that digestibility estimates using fecal material were lower than those that were determined using rumen fluid but that there was a good relationship between the two techniques. Alternative *in vitro* techniques to determine digestibility include *in vitro* digestion with pepsin and cellulase (McLeod and Minson 1978) or measurement of gas production (Menke and Steingass 1988). Although the pepsin-cellulase technique is simple and highly repeatable, it is expensive and requires a constant supply of cellulase of constant activity (Adesogan et al. 2000).

When determining the organic matter digestibility of a number of legumes and grasses, Gosselink et al. (2004) reported the greatest accuracy with the *in situ* technique, followed by the gas production technique, the Tilley and Terry (1963) technique and lastly, the pepsin-cellulase technique. In contrast, Rinne et al. (2006) found that the pepsin-cellulase technique was the most accurate in predicting digestibility (R^2=0.965), followed by the gas production technique (R^2=0.944), the Tilley and Terry (1963) method (R^2=0.940) and finally, the *in situ* technique (R^2=0.925). Thus, depending upon the forages analyzed and the *in vitro* technique used, the results of digestibility trials may vary.

2.6 Voluntary Animal Intake

2.6.1 Factors Affecting Voluntary Intake

Voluntary intake is controlled by the interaction of many plant, animal and environmental factors. It is the major dietary factor determining level and efficiency of ruminant production. Difficulties occur in trying to predict dietary intake due to the numerous factors and interactions that occur within the grazing animal. In theory, if an animal could eat enough forage, it could satisfy its nutrient requirements regardless of forage quality; however, total intake is limited by physical factors of plants and animals, animal physiological status and the environment (Allison 1985).

Plant factors that have been suggested to affect animal intake include: forage moisture content (which may be a large factor affecting animal selectivity and may not actually limit intake) (Allison 1985); plant cell structure and digestibility, including the proportion of cell contents to cell walls (Campling 1964; Van Soest 1965); forage quality (ie. CP and energy content) (Horn et al. 1979); forage availability (Allden and Whittaker 1970); forage species and the inherent differences between grasses and legumes (Thornton and Minson 1973). These factors ultimately affect the rate of degradation in the reticulo-rumen, rate of absorption and rate of passage from the reticulo-rumen (Campling et al. 1961; Thornton and Minson 1973).

There is high variability between individual animals in regards to voluntary intake due to the large number of animal factors which affect feed intake. For example, pregnancy generally results in decreased dry matter intake, particularly in the last few weeks prior to parturition, while lactation usually results in increased dry matter intake (Jordan et al. 1973). Body composition, particularly the percentage of body fat, can also affect feed intake and is often considered when using intake prediction equations (National Research Council 1987). Sex, age and frame size may also impact feed intake (Allison 1985; National Research Council 2000).

Finally, the environment can impact feed intake, particularly if temperatures are outside of the thermoneutral zone. Wind, precipitation and mud can further add to temperature effects. Seasonal or photoperiod effects are also suggested to have some impact on feed intake but the effects are not as well understood (National Research Council 2000).

2.6.2 Regulation of Voluntary Intake

Most forage diets are considered to be relatively fibrous and bulky with low digestible energy content. A number of papers have concluded that voluntary intake of forages is limited by the capacity of the reticulo-rumen, rate of passage and rate of absorption from the gastro-intestinal tract (Campling et al. 1961; Thornton and Minson 1973). In contrast, a review by Ketelaars and Tolkamp (1992) suggests that sufficient evidence does not exist to suggest that a physical restriction such as rumen fill is the primary factor regulating intake, as animals appear to have the ability to adapt to different levels of gut fill and digesta turnover depending upon physiological status and environmental conditions. They suggest that metabolic factors such as changes in basal metabolism and the efficiency of utilization of metabolizable energy play a large role regulating intake and that an animal will eat to optimize energy balance in the body. They also concluded that feed characteristics commonly associated with the fill effects of roughages also profoundly affect the basal metabolism of the host animal. Thus, it appears that there are numerous factors that affect the voluntary intake of forages which may lead to difficulties in predicting individual dry matter intake.

2.6.3 Methods to Estimate Voluntary Intake

In grazing animals, intake is generally estimated by measuring both fecal output and the digestibility of the diet either directly or with fecal markers. A number of alternative methods to measure intake have also been identified including: the use of herbage utilization rates, short-term changes in animal live-weight, measurement of grazing behavior parameters as well as using reverse feeding standards to calculate intake based on energy retention and outputs and the metabolizable energy level of the diet (Coates and Penning 2000).

Accurate estimates of intake and their relationship to animal performance are crucial to the profitability of the cattle industry. In many cases where field studies and detailed measurements are impractical to obtain, researchers and producers have relied on prediction equations to estimate voluntary intake and resultant animal performance, based on known forage, animal and environmental factors. Examples of these prediction equations include the NRC model (National Research Council (NRC) 1996) from which the CowBytes beef ration balancer (Alberta Agriculture, Food and Rural Development) was developed, as well as the Cornell Net Carbohydrate and Protein System model (Fox et al. 2003). Data derived from models and prediction equations is only as accurate as the data entered into the equations. Thus, measured estimates of voluntary intake may be periodically needed to validate prediction equations and ensure that the models are still predicting relatively accurate results. Ultimately the method used to determine voluntary intake will depend on the resources and labor available as well as the desired level of accuracy.

2.6.3.1 Forage Utilization

The intake of grazed forage can be estimated from the difference in weight of forage before and after grazing. The accuracy of this technique depends a number of factors, including the error associated with the estimate of initial and final yields of available forage, the proportion of forage offered that is ingested, the growth of the forage that occurs over the duration of the experimental period and any losses of forage that occur due to forage senescence, trampling and insect activity. In extensively grazed pastures, cow intake has been shown to be overestimated as much as 8-16 kg dry matter per head per day using this method (Minson 1990). Minson (1990) indicated that the accuracy of this method improves greatly when pastures are strip grazed.

2.6.3.2 Grazing Behavior

Grazing behavior can be used to estimate forage intake as forage intake can be calculated from measurements of time spent grazing, the number of bites per minute and the average size of each bite (Allden and Whittaker 1970). This method requires estimation of the moisture level of the diet to enable dry matter intake to be calculated for individual species. This is of particular importance where dry matter content may vary between forage species and plant parts. This method also requires an accurate estimation of diet selection which provides a further source of error when estimating intake, especially in complex swards (Minson 1990).

Other methodologies utilized to measure grazing behavior in relation to forage intake have included the use of spectral analysis devices to record eating or chewing sounds (Laca and Wallis DeVries 2000) or vibracorders which record the characteristic jerk of the animal's head as it bites herbage from the sward (Castle et al. 1975). The use of these devices has produced simple and reliable measurements of time and duration of grazing.

2.6.3.3 Short-term Change in Animal Live-weight

Short-term change in live-weight can be used to determine the quantity of forage consumed over a short period of time (Allden and Whittaker 1970; Penning and Hooper 1985). To use this method, animals are weighed before and after grazing with corrections made for loss of body weight due to the excretion of feces, urine or insensible losses or gains in body weight due to water consumption (Minson 1990). Penning and Hooper (1985) fitted sheep with bags to prevent loss of feces and urine, weighed the sheep and then allowed the sheep to graze for approximately one hour before they were weighed again. Weight gains were adjusted for insensible weight losses and then the increase in live-weight was considered to be an estimate of fresh herbage intake. Minson (1990) suggested that a minimum five minute period is needed to determine forage intake using this method.

2.6.3.4 Reverse Feeding Standards

In order to use reverse feeding standards to estimate forage intake, animal production (ie. live-weight change) and output (ie. milk) needs to be known over a period of several weeks. This technique also requires the use of feeding standards to convert total production into metabolizable energy. Estimates of metabolizable energy concentration in the diet from pasture sample are also made so that herbage intake can be calculated (Coates and Penning 2000).

2.6.3.5 Prediction Models

The Cornell Net Carbohydrate and Protein System (CNCPS) (Cornell University, Ithaca, New York) was developed to predict requirements, feed utilization and nutrient excretion for beef and dairy cattle in a variety of production settings. The model combines knowledge of cattle requirements as influenced by breed type, body size, production level and environment with knowledge about feed composition, digestion and metabolism of nutrients to meet the animal's requirements. Included in the model are equations and coefficients that predict tissue requirements (maintenance, growth, pregnancy, lactation and tissue reserves) and the supply of nutrients needed to meet those requirements (including dry matter intake, carbohydrate and protein fractions, carbohydrate and protein digestion and passage rates, microbial growth, intestinal digestion and metabolism of absorbed nutrients). Like any model, the accuracy and reliability of the model is limited by the quality and availability of information about all components of the model and the amount of work and data needed to validate the model (Fox et al. 2003).

2.6.3.6 Estimation of Digestibility and Fecal Output

Using digestibility and fecal output estimates, intake is estimated according to the following equation:

Intake = Fecal output / (1 – Forage Digestibility) (Coates and Penning 2000).

There are a number of methods to estimate both forage digestibility and fecal output and the next sections will outline those methods.

2.6.3.6.1 Digestibility and Total Fecal Output Collection

The estimation of forage digestibility in conjunction with the estimation of total fecal collection is the oldest method for determining forage intake by livestock (Cordova et al. 1978). As outlined in a previous section (Section 2.5.4), there are a number of methods to determine forage digestibility. In brief, forage digestibility may be estimated in one of three ways: *in vivo*, *in situ* or *in vitro*. Estimates of forage digestibility in grazing situations are commonly determined using *in vitro* techniques as a large number of samples can be run with relative ease.

Digestibility may be estimated *in vitro* from hand-plucked forage samples or ingested extrusa from oesophageal fistulated animals. Based on forage alkane patterns, Dove et al. (1999) suggested that extrusa from oesophageal fistulated animals may provide representative herbage samples for *in vitro* digestibility estimates. As discussed previously, there are a number of concerns regarding the widespread accuracy of *in vitro* digestibility estimates because a single digestibility value is applied to all animals regardless of variations in individual animal intake, physiological status of the animal and interactions between dietary components and/or supplements (Dove and Mayes 1996). Digestibility can also be estimated using internal markers (*in vivo*), such as lignin (Fahey and Jung 1983) and AIA (Van Keulen and Young 1977), or *in situ* techniques (Adesogan et al. 2000).

The second part of the equation, fecal output, can be measured a number of ways. Total fecal collection is extremely time consuming, expensive and may be impractical under many situations. This method involves the constant changing, weighing and cleaning of fecal bags as well as the supervision and arranging of harnesses to prevent fecal loss. There is also concern that the fecal collection harnesses may alter grazing behavior and intake, place additional stress on experimental animals and have adverse effects on animal physiology and performance (Cordova et al. 1978). An alternative to total fecal collection is to use indigestible fecal markers such as chromic oxide or alkanes.

2.6.3.6.2 Indigestible Fecal Markers

A number of indigestible markers have been evaluated for their potential to estimate dry matter intake in grazing animals. Ideal markers should be chemically discrete and indigestible in the digestive tract (Dove and Mayes 1991). Kotb and Luckey (1972) and Faichney (1975) have reviewed characteristics of ideal markers in detail. Markers can be classified as either internal (endogenous) to the feedstuff or external (exogenous) to the feedstuff (ie. added to the feedstuff or dosed separately to the animal). Typically, external or dosed markers are used for the estimation of fecal output, while internal markers are used for the estimation of forage digestibility.

The use of indigestible markers calculates fecal output by relating the marker concentration in the feces to a known dose of the marker. The advantages of using markers to determine digestibility and intake include: minimal time and labor investment, digestibility prediction without the need to quantify feed intake and fecal output, and the ability to determine digestibility and intake based on a minimal number of feed and fecal samples (Van Keulen and Young 1977).

Problems associated with fecal markers include incomplete fecal recovery and diurnal variation. There may also be problems associated with obtaining representative forage and fecal samples as well as the discrete analysis of the marker compounds. These issues limit the precision and accuracy of which intake and digestibility estimates can be obtained (Mayes et al. 1986).

2.6.3.6.2.1 Chromic Oxide

Until recently, the most common procedure to estimate dry matter intake has been the use of chromic oxide (Cr_2O_3) as an external fecal marker in conjunction with some other method for estimating digestibility. This method uses two separate measurements to determine intake: the dilution of orally or ruminally administered Cr_2O_3 to estimate fecal output and *in vitro* or internal marker digestibility estimates.

Research has indicated complete chromium (Cr) recovery in samples from total fecal collections (Dove et al. 2000). As such, incomplete fecal recovery is not likely to be a source of error when estimating dry matter intake. The validity of rectal grab samples has been questioned when dosing and fecal sampling once or twice a day due to possible diurnal variation (Dove and Mayes 1991; Vulich et al. 1991). Development of a controlled release device (bolus) (Laby 1978) which releases Cr_2O_3 at a uniform daily rate is advantageous in grazing studies where there is a lack of confinement of grazing animals and minimal disturbance of normal grazing behavior is preferred. Caution must be exercised as the manufacturer's release rate could potentially be different than the actual release rate which may result in an over- or under-estimation of fecal output (Momont et al. 1994). Administration of Cr_2O_3 via a bolus has been shown to remove diurnal variation associated with once or twice-daily dosing (Ellis et al. 1981; Ferreira et al. 2004). This technique is still limited by the accuracy of the digestibility determination.

2.6.3.6.2.2 Alkanes

In 1965, Oro et al. (1965) reported the similarity between the pattern of alkanes (carbon lengths of C_{25}-C_{35}) in cattle feces and the pattern of alkanes in plants consumed. Grace and Body (1981) were the first to suggest that cuticular long-chain fatty acids were recovered in fecal material and may be used as an indigestible internal marker for nutritional studies. Alkanes were considered for forage intake studies because they are found in most plants, can be discretely analyzed and individual plant species had relatively unique alkane patterns (Dove and Mayes 1991; Dove et al. 1996).

Mayes et al. (1986) reported that naturally occurring odd-chained alkanes could be used as internal markers for digestibility estimates and dosed even-chained alkanes could be used as external markers for the determination of fecal output in ruminant animals. In contrast to the Cr_2O_3 technique, the alkane technique does not require an additional separate estimate of digestibility or the absolute recovery of the marker to measure intake (Vulich et al. 1991). Absolute fecal recovery of herbage alkanes is uncommon, but because fecal recoveries of dosed and natural alkanes of adjacent chain lengths are similar, ratios between the dosed and natural alkanes in feed and feces can be used to provide an unbiased estimate of individual animal intake (Mayes et al. 1986). When alkanes are of similar length (ie. C_{32} and C_{33}), the difference in recovery is negligible. Suitable alkanes to use as dosed markers include C_{28}, C_{32} and C_{36} as they are readily obtained in pure form at low cost and have relatively small concentrations in herbage (Mayes et al. 1986).

N-alkanes can be administered by pellets (Mayes et al. 1986), gelatin capsules (Dove et al. 1988; Vulich et al. 1991) or controlled release devices (Dove et al. 2002). Studies incorporating alkanes into dietary supplements have suggested that there may be limitations to this method for grazing studies; however, alkane CRD's have been shown to be reliable in sheep (Mayes et al. 1991) and are commercially available for sheep and growing and adult cattle (Captec Alkane™, Captec (N.Z.) Ltd, Auckland, New Zealand). Controlled release devices are advantageous for grazing studies as a constant release of marker minimizes diurnal variation and disturbance to animals, which has been a concern with either once or twice daily dosing of animals (Dillon and Stakelum 1989; Stakelum and Dillon 1990). It is suggested that in order to obtain accurate estimates of forage intake, a rumen fistulated animal should be used to validate the release rates for each grazing situation which increases the work-load and difficulty of this method.

The accuracy of forage intake estimates is strongly influenced by the representative sample of ingested forage and extent of variation of ingested forage. Since alkane concentrations may vary between plant parts and within a plant (Dove et al. 1996), there may be inaccuracies and variation between hand-plucked forage samples and actual forage consumption. Mayes and Dove (2000) reported these differences to be minimal. The task of estimating ingested material becomes much more difficult in complex swards and can lead to inaccurate forage intake estimates. Oesophageal fistulated animals may provide a better estimate of ingested herbage, particularly in complex swards; however, ingested herbage may be quite variable between oesophageal fistulated animals and a large number of samples may be required to validate the results.

Additional advantages of the alkane technique include: estimation of individual animal intake and accommodation of differences in individual diet digestibility instead of relying on a single *in vitro* estimate of digestibility; suitability across a number of physiological states; estimation of forage intake when animals are receiving feed supplementation; and a reduction in analytical error and bias as both plant and dosed markers can be determined at the same time (Mayes and Dove 2000).

2.7 Grazing Animal Responses

2.7.1 Animal Performance Measurements

2.7.1.1 Live-Weight Change

Change in animal live-weight can be used to accurately determine any change in animal biomass; however, the live-weight of the animal can vary over short periods of time and is dependent upon factors such as gut fill and changes in body water volume. To limit these sources of variation, it is suggested that researchers use shrunk body weights where animals are removed from feed and water for twelve hours prior to weighing. When facilities or conditions do not allow animals to be held without access to feed, an alternative method would be to weigh animals on two consecutive days at the same time each day in order to minimize between-day variation of body weights and reduce variation due to gut fill (Coates and Penning 2000). A limitation to this technique is the inability to determine the chemical composition of live-weight gain (ie. fat or protein) and changes that occur in the chemical composition of the entire animal. Corbett (1978) stated that there may be as much as a three-fold variation in energy value between unit gain made at low body weights by young, lean animals and unit gain of heavy, fat animals. Despite the variations in energy values per unit of weight, live-weights or shrunk body weights are important as they are measures of saleable product and reflect the economic returns of a grazing system.

2.7.1.2 Body Condition Scoring

In addition to changes in live-weight, animal performance can also be measured by changes in body composition through use of body condition scoring or ultrasound techniques. Both techniques can be used on live animals and are relatively quick to perform. These techniques are based on relationships between physical measurements of areas such as the thickness of fat over the eye muscle at the eleventh rib (Johnson and Charles 1976) or the rib-eye area as an indicator of muscling. Ultrasound can also be used to evaluate body composition in live animals. This involves ultrasound imaging to determine subcutaneous fat depth and eye muscle areas as indices of carcass composition (Coates and Penning 2000). These techniques may be advantageous in mature beef cattle where researchers want an indication of changes in body composition and condition over time in response to various management or feeding strategies (Waldron et al. 2006), or feeder cattle where these measures can be utilized to adjust for nutritional requirements and prediction of carcass traits (Loy et al. 1998).

3 General Materials and Methods

3.1 Introduction

During the summers of 2005 and 2006, a 2-year grazing study was conducted on 11.2 ha of seeded pastures near Lanigan, Saskatchewan (51°51´N; 105°02´W) at the Western Beef Development Center's Termuende Research Ranch. Topography at the study site (NW-22-33-21-W2) is gently to moderately rolling and the soils are a mixture of Oxbow Orthic Black and carbonated Oxbow with a loam texture.
The objective of this study was to evaluate forage yield and quality, steer performance and grazing capacity, individual animal intake, individual plant energy reserves and economic performance of five perennial grass species under grazed conditions.

3.2 Establishment of Grasses

In July of 1999, two 0.8 ha replicates each of meadow bromegrass cv. Paddock, smooth bromegrass cv. Carlton and hybrid bromegrass cv. AC Knowles were established. Prior to seeding, the site was sprayed with glyphosate at 2.0 kg ha^{-1} of active ingredient to facilitate weed control. Following herbicide application, the seedbed was prepared by cultivation with a light tandem disc. Seeding rates were 10 kg ha^{-1} for smooth bromegrass and 12 kg ha^{-1} for meadow bromegrass and hybrid bromegrass (differences in seeding rates were due to differences in seed size between species). Some overseeding was required on these paddocks in May 2000 due to patchy establishment. Post-seeding weed control included spot spraying of 1.1 kg ha^{-1} of active ingredient propyzamide for control of foxtail barley (*Hordeum jubatum* L.) in the fall of 2000. In the spring of 2001, 9.88 g ha^{-1} of active ingredient thifensulfuron methyl and 4.94 g ha^{-1} of active ingredient tribenuron methyl was applied for control of broadleaf weeds.

In 2003, two 0.8 ha replicates each of crested wheatgrass cv. AC Goliath, hybrid bromegrass cv. AC Knowles and tall fescue cv. Courtenay were established adjacent to the pastures established in 1999. Prior to seeding, glyphosate was applied at 0.879 kg ha^{-1} of active ingredient. The seed bed was prepared by two passes with a light tandem disc. Seeding rates were 10, 11.2 and 5 kg ha^{-1} for the crested wheatgrass, hybrid bromegrass and tall fescue, respectively. Fifty-six kg nitrogen (N) ha^{-1} was applied with the seed at seeding. Post-seeding weed control included 0.288 kg ha^{-1} of active ingredient fenoxaprop-p-ethyl, 0.334 kg ha^{-1} of active ingredient bromoxymil and 0.198 kg ha^{-1} of active ingredient tralkoxydim. Some overseeding was required on the tall fescue paddocks in 2004 due to variable establishment.

In addition and adjacent to the seeded pastures, two 0.8 ha paddocks of a long established crested wheatgrass stand (cultivar unknown) were sectioned to act as control pastures (Appendix Figure A1). Although the exact age of the control pastures is unknown, stand age is estimated to be at least 50 years old at the time of this study based on previous research trials. It is also important to note that there was a considerable amount of other species present in the sward, including quack grass (*Agropyron repens* (L.) Beauv.), Kentucky bluegrass (*Poa pratensis* L.) and smooth bromegrass (Appendix Table A8).

3.3 Pasture and Animal Management

Soil samples were taken in spring of 2005 and 2006 to determine soil N, phosphorus (P), potassium (K) and sulfur (S) levels (Appendix Table A1). Prior to grazing, all paddocks were fertilized with 79 kg actual N ha^{-1} and 23 kg actual P ha^{-1} in spring of 2005 (May 16) and 2006 (May 8) via coulter disc application according to soil test results.

Grazing of experimental pastures by cross-bred yearling steers commenced when available forage was approximately 20 cm high (4-5 leaf stage). With the exception of tall fescue, all paddocks had been previously grazed in 2004. In 2005 and 2006, crested wheatgrass paddocks were grazed by yearling steers in May due to the growth characteristics and early maturity of the species. The mid-season species were grazed June through July. Paddocks were not clipped or mowed following the first grazing period. In 2005, limited regrowth on pastures resulted in only one grazing period. Sufficient regrowth in 2006 allowed for a second grazing period in late July through early September on the 'AC Goliath' crested wheatgrass, hybrid bromegrass (both 1999 and 2003 established paddocks), smooth bromegrass and one replicate of the meadow bromegrass pastures. Grazing period dates are presented in Appendix Table A2. Prior to the start of trial and between grazing periods in 2006, steers were allowed to graze in common pastures which included crested wheatgrass, smooth bromegrass or Russian wild-rye..

Individual paddocks were separated with electric fencing and water was provided *ad libitum* to all paddocks in stock troughs through surface pipelines. Steers had *ad libitum* access to cobalt iodized salt and a 1:1 range mineral (Feed Rite, Division of Ridley, Inc.) (Appendix Table A3). Steers were implanted with RALGRO™ (36 mg zeranol; Schering Canada Inc.) in May 2005 and 2006 and given 30 mL of Megamectin™ (ivermectin; Novartis Animal Health Canada Inc.) for control of internal and external parasites. Steers were also vaccinated with Covexin™-8 (an 8-way modified live clostridial vaccine; Schering-Plough Animal Health Corp.) and STARVAC™ 4 Plus (a modified live BVD, PI3, IBR, BRSV vaccine; Novartis Animal Health Canada Inc.). All animals were handled according to the Guidelines of the Canadian Council on Animal Care (1993).

Steers were weighed on two consecutive days at the start and end of trial and every seven days throughout the course of the trial. For pastures established in 1999, the initial weights of tester animals averaged 338 ± 17, 305 ± 21 and 381 ± 27 kg (mean ± SD) for the 2005 grazing period, first and second grazing period in 2006, respectively. For the pastures established in 2003, the initial weights of tester animals averaged 336 ± 13, 311 ± 16 and 385 ± 21 kg in the 2005 grazing period, first and second grazing period in 2006, respectively. Steers were weighed at a consistent time each day, but were not fasted due to the lack of appropriate holding facilities. Paddocks were managed using a "put and take" grazing system with three randomly chosen tester steers per paddock (Mott and Lucas 1952). In a "put and take" grazing system, a variable number of homogeneous animals are used so that extra animals are added when forage growth is fast and forage production is high and extra animals are removed when forage growth rate is slow and forage production is low. Daily animal performance is based on that of designated tester steers (those that remain on the experimental pastures for the entire duration of the trial (Mott and Lucas 1952). In this experiment, "put and take" steers were added or removed from paddocks to maintain similar forage availability in each pasture type. Steers remained on each paddock until plants were grazed to a uniform level of approximately 8 cm above the soil surface.

3.4 Temperature and Precipitation Data

Long term average yearly precipitation data for the study area is 398 mm (1985-2006) according to Environment Canada's Climate Data Online (www.climate.weatheroffice.ec.gc.ca) for Esk, Saskatchewan which is approximately five kilometers south-east of the study site (51°48.000'N, 104°51.000'W). The long-term average rainfall for April 1 to September 30 is 289 millimeters. Daily precipitation data for 2005 and 2006 was obtained from Environment Canada for Esk, Saskatchewan. In 2005, the yearly precipitation was 442.2 mm, of which 355 mm fell between April 1 and September 30 (Appendix Table A4). April and July precipitation was reduced considerably in 2005 compared to the long-term average. In 2006, the yearly precipitation was 520.2 mm, of which 371 mm fell between April 1 and September 30 (Appendix Table A5). July and August monthly precipitation in 2006 was below that of the long-term average. Daily maximum and minimum temperatures were obtained from January 1, 2005 to August 21, 2006 from a weather station located on the Western Beef Development Center Termeunde Research Ranch (Appendix Tables A6 and A7). Temperature data is not available after August 21, 2006 due to equipment malfunction.

3.5 Statistical Analysis

For the purpose of statistical analysis, the study was analyzed as two separate experiments or study sites; the first experiment being the comparison of the pastures established in 1999 and control pastures, and the second experiment being the comparison of the pastures established in 2003 and the control pastures. Each experiment was a randomized complete block design with the four grass species as treatments with two pasture replicates (total of 8 experimental units per experiment). Year or grazing period was considered to be a random blocking effect. Statistical analysis was conducted using SAS Mixed procedure for analysis of variance and SAS Correlation procedure for simple correlation analysis (SAS Institute Inc. 2005). Where significant differences were indicated ($P<0.05$), means were separated at the 5% level of significance using Tukey's procedure (Steel et al. 1997).

4 Pasture Yield and Forage Quality of Five Perennial Forage Species Under Grazed Conditions

4.1 Introduction

Matching forage nutritive value and availability with livestock production goals is an integral part of managing forage resources. Pasture yield and forage quality are two important factors to consider when beef producers select grass species for summer grazing. When evaluating the potential of grass species or varieties for summer grazing, it is important to consider both forage yield and quality due to their inter-relationships and effect on nutrient digestibility, animal intake and overall animal performance. Beef producers require forage varieties that are high-yielding, of good nutritional value and have relatively long persistence under grazed conditions.

Historically, smooth bromegrass and crested wheatgrass have been the two most widely seeded perennial grasses across the prairies for both hay and pasture production. Smooth bromegrass is a sod-forming, drought-tolerant grass well-suited to hay production (Smoliak and Bjorge 1981), while crested wheatgrass is a drought-tolerant bunchgrass which provides excellent spring growth of high nutritional value (Vogel et al. 1993). More recently, meadow bromegrass has been identified as a good pasture grass, particularly in mixtures with alfalfa, but it prefers moister regions compared to smooth bromegrass and may not yield as high as smooth bromegrass (Knowles et al. 1993). In an attempt to find a grass suitable for both hay and pasture production, the Agriculture and Agri-Food Canada forage breeding program developed a hybrid bromegrass which shares characteristics of both the smooth bromegrass and meadow bromegrass parental lines (Coulman and Knowles 1995). There has also been interest from livestock producers to evaluate non-traditional grasses for the region, such as tall fescue. Tall fescue is a bunchgrass predominately found in the moist, humid areas of North America and is utilized very little on the Northern Great Plains. It is well suited to pasture production and produces tremendous growth under moist conditions and high fertility (Smoliak and Bjorge 1981). Choice of forage species and variety will influence both the yield and forage nutritional value of a pasture and ultimately animal production.

The objective of this experiment was to measure forage yield for the duration of the grazing season and evaluate forage quality, including crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF) and *in vitro* organic matter digestibility (IVOMD), at the start, middle and end of each grazing period for crested wheatgrass, smooth bromegrass, meadow bromegrass, hybrid bromegrass and tall fescue.

4.2 Materials and Methods

4.2.1 Forage Yield and Quality Sampling

Available forage (kg dry matter (DM) ha^{-1}) was measured at start of each grazing period by clipping three 0.25 m^2 quadrats to a stubble height of 2.5 centimeters. Cumulative dry matter yield (CDMY) was determined in each paddock using the cage comparison technique (Klingman et al. 1943). Each paddock had three randomly placed grazing exclusion cages allocated prior to grazing. On weekly sampling days, available forage was determined by clipping one 0.25 m^2 quadrat inside and one 0.25 m^2 quadrat outside each cage to a height of 2.5 centimeters. Broadleaf weeds were hand-separated and discarded at the time of clipping and were not included in CDMY measures as steers did not appear to eat these species. After clipping, cages were randomly repositioned within the paddock. Previously harvested areas were not re-harvested. Cumulative dry matter yield was determined for each paddock using the following formula:

CDMY = start of trial initial growth + (Week 1 inside cage clip – start of trial initial growth) + (Week 2 inside cage clip – Week 1 outside cage clip) + (Week 3 inside cage clip – Week 2 outside cage clip) + … (Thompson 2003).

The advantage of using this method to determine CDMY is that weekly regrowth occurring throughout the duration of the grazing period is added to the initial forage yield. Forage dry matter was determined by oven drying all samples in forced air oven at 55 °C until a constant weight was reached.

In 2006, clipped forage samples were hand-separated and weighed based on “seeded species” and “other species.” “Other species” included smooth bromegrass, quackgrass, Kentucky bluegrass and foxtail barley. These "other species" were not separated from one another as they were clipped and weighed, and they represent the total quantity of "other species" present. The control paddocks and paddocks established in 1999 had the greatest levels of "other species" present. Results of hand-separation (% composition based on a DM basis) are presented in Appendix Table A8.

4.2.2 Chemical Analysis

Forage quality laboratory analyses of the total available forage included CP, NDF, ADF and IVOMD at the start, end and middle of each grazing period according to calendar date (see Appendix Table A9 for clipping dates). Clippings from outside the exclusion cages were used for forage quality analyses. In preparation for forage quality analysis, all forage samples were ground through a Wiley mill and stored in sealed plastic bags. Samples which were separated into "seeded" and "other" species at clipping in 2006 were mixed together to obtain values that were representative of the total available forage to steers. Thus, the results of the forage quality analysis are if the total forage available to the steers (seeded and invasive species) and are not necessarily that of the pure forage variety.

Crude protein was analyzed using a Leco FP428 Nitrogen Analyser (Leco Corporation, St. Joseph, MI). Neutral detergent fiber and ADF were determined using an ANKOM 200 Fiber Digestor (ANKOM Technology, Fairport, NY). The IVOMD of available forage was determined using a modified Tilley and Terry (1963) technique (Troelsen and Hanel 1966). The artificial saliva composition used in the IVOMD analyses was that of Baumgardt et al. (1962). Fistulated steers used for the collection of rumen fluid were fed a standard bromegrass hay and cared for in accordance with the Canadian Council on Animal Care guidelines (CCAC 1993).

4.2.3 Statistical Analysis

Two experiments were conducted over two grazing seasons. In the first experiment, pastures established in 1999 were compared with long established crested wheatgrass control pastures. In the second experiment, pastures established in 2003 were also compared with long established crested wheatgrass control pastures. Pastures established in 1999 were not compared to pastures established in 2003 due to differences in stand age.

Each experiment was a randomized complete block design with four grass species as treatments and two replicates per grass species (individual grazing cages and forage clippings were considered to be sub-samples). Year or grazing period was considered to be a random blocking effect. Cumulative dry matter yield data for the first grazing period of 2005 and 2006 was averaged (because year was a random blocking effect) and analyzed for differences in means. Each grazing period was also analyzed separately for differences in means. Data collected in the second grazing period was not statistically analyzed because data was not collected on paddocks that were not grazed a second time. In addition, only one of the meadow bromegrass paddocks established in 1999 was grazed a second time and did not provide replication for analysis.

For forage quality, differences in means were analyzed separately at three points throughout the grazing periods; at the start, middle and end of each grazing period. The start, middle and end of trial dates were not consistent among species as steers were placed on and removed from paddocks in relation to grass growth as opposed to calendar date. Therefore, dates were chosen for analyses in relation to the duration that steers were on individual paddocks. Similar to the CDMY analysis, forage quality data was averaged for the first grazing periods of 2005 and 2006 and then grazing periods were analyzed separately. Data collected in the second grazing period was not analyzed statistically due to the previously stated reasons.

Cumulative dry matter yield and forage quality analyses were analyzed using the MIXED procedure of SAS for analysis of variance (SAS Institute Inc. 2005). Where significant differences were indicated ($P<0.05$), means were separated at the 5% level of significance using Tukey's procedure (Steel et al. 1997).

4.3 Results

4.3.1 Forage Yield

4.3.1.1 Pastures Established in 1999

Cumulative dry matter yields for the pastures established in 1999 are presented in Table 4.1. Mean CDMY for the first grazing periods of 2005 and 2006 was similar among all grass species ($P>0.05$). Cumulative dry matter yield measurements in 2005 and the first grazing period of 2006 (individual grazing periods) were similar among pasture types ($P>0.05$). Because the control pastures and one replication of meadow bromegrass were not grazed during the second grazing period of 2006, statistical analysis of the data was not performed.

4.3.1.2 Pastures Established in 2003

Cumulative dry matter yields for the pastures established in 2003 are presented in Table 4.2. Mean CDMY for the first grazing periods of 2005-2006 was similar among all grass species ($P>0.05$). In 2005, 'AC Goliath' produced greater forage yield than either hybrid bromegrass or the control pastures ($P<0.05$) but similar forage yield to tall fescue ($P>0.05$). Despite similar CDMY of all species during the first grazing period of 2006 ($P>0.05$), a lack of sufficient pasture regrowth for a second grazing period in the control and tall fescue pastures resulted in no additional grazing in 2006 for these species.

Table 4.1 Cumulative dry matter yield of three perennial pastures established in 1999 and long established crested wheatgrass (control) pastures.

		Cumulative Dry Matter Yield (kg ha^{-1})				
Year	**Grazing Period**[z]	**Control**	**Hybrid Bromegrass**	**Meadow Bromegrass**	**Smooth Bromegrass**	**SEM**[y]
2005-2006 Mean	1	3114	4875	4290	3538	813.6
2005	1	2485	4533	2868	3197	768.2
2006	1	3744	5217	5712	3879	668.2
	2[x]	-	1406	1427[w]	1377	-

[z]2005 Grazing period 1: control May 27-June9; hybrid, meadow & smooth bromegrass June 7-July 12.
2006 Grazing period 1: control June 2-July 6; hybrid & meadow bromegrass May 26-June 29; smooth bromegrass May 30-June 29.
2006 Grazing period 2: hybrid, meadow & smooth bromegrass August 23-September 7.
[y]Pooled standard error of the mean.
[x]Data not included in statistical analysis.
[w]N=1

Table 4.2 Cumulative dry matter yield of three perennial pastures established in 2003 and long established crested wheatgrass (control) pastures.

		Cumulative Dry Matter Yield (kg ha^{-1})				
Year	**Grazing Period[z]**	**Control**	**Crested Wheatgrass**	**Hybrid Bromegrass**	**Tall Fescue**	**SEM[y]**
2005-2006 Mean	1	3114	5404	3759	4410	821.1
2005	1	2485*b*	7515*a*	3136*b*	3932*ab*	727.4
2006	1	3744	3293	4381	4887	884.8
	2[x]	-	2504	2484	-	-

[z]2005 Grazing period 1: control May 27-June9; crested wheatgrass May 27-July 7; hybrid bromegrass June 6-July 14; tall fescue June 10-July 14.
2006 Grazing period 1: control June 2-July 6; crested wheatgrass May 17-June 21; hybrid bromegrass May 26-June 29; tall fescue June 2-July 13.
2006 Grazing period 2: crested wheatgrass July 28-August 23; hybrid bromegrass Aug 16-September 3.
[y]Pooled standard error of the mean.
[x]Data not included in statistical analysis.
a-b Least square means in the same row with different letters differ at *P*<0.05.

4.3.2 Forage Quality

Lab analysis of forage samples for CP, NDF, ADF and IVOMD at the start, middle and end of each grazing period are presented in Tables 4.3 through Table 4.10. Forage sampling dates used for forage quality analysis are presented in Table A9 in the Appendix. Samples collected during the second grazing period were not statistically analyzed.

4.3.2.1 Pastures Established in 1999

Start of Grazing Periods

For pastures established in 1999, CP (Table 4.3), NDF (Table 4.4) and ADF (Table 4.5) concentration was similar among all study pastures at the start of each grazing period ($P>0.05$). The pooled data for the first grazing periods indicate that CP concentration was similar among all bromegrass species ($P>0.05$), however hybrid bromegrass was the only species that had greater CP levels than the control pastures ($P<0.05$) (Table 4.3). No differences were observed in NDF or ADF levels at the start of the grazing periods between study species in this study ($P>0.05$).

In vitro organic matter digestibility was greater ($P<0.05$) for all bromegrass species in 2005 compared to the control pastures. In 2006, all forages had similar IVOMD in the first grazing period ($P>0.05$). The average IVOMD of hybrid and meadow bromegrass in the first grazing period of 2005 and 2006 was greater than the control pastures ($P>0.05$).

Middle of Grazing Periods

In the second grazing period of 2006, samples were not analyzed for forage quality at the middle of the grazing period due to the relatively short duration of the grazing period. In the middle of the first grazing periods for 2005 and 2006, the 2005 and 2006 pooled data indicates that all bromegrass species established in 1999 have similar CP (Table 4.3), NDF (Table 4.4) and ADF (Table 4.5) concentration ($P>0.05$).

Table 4.3 Crude protein concentration (DM basis) of available forage in pastures established in 1999 and long established crested wheatgrass (control) pastures.

Year	Grazing Period	Crude Protein (g kg^{-1})				
		Control	Hybrid Bromegrass	Meadow Bromegrass	Smooth Bromegrass	SEM[z]
Start of Grazing Period[y]						
2005-2006 Mean	1	150*b*	213*a*	189*ab*	199*a*	13.0
2005	1	129	222	175	205	18.3
2006	1	171	198	204	192	16.2
	2[x]	-	116	95[w]	117	-
Middle of Grazing Period						
2005-2006 Mean	1	109*b*	130*ab*	121*ab*	133*a*	8.9
2005	1	118	137	129	140	9.0
2006	1	100	124	112	127	8.6
End of Grazing Period						
2005-2006 Mean	1	105	99	102	116	11.9
2005	1	132	91	121	105	9.2
2006	1	78	107	84	127	8.8
	2	-	110	96[w]	103	-

[z]Pooled standard error of the mean.
[y]Start of grazing period: May 27-June 7 2005; May 26-June 2 2006; August 23 2006.
Middle of grazing period: June 2-June 20 2005; June 13-June 21 2006.
End of grazing period: June 9-July 12 2005; June 28-July 5 2006; September 7 2006.
[x]Data was not statistically analyzed.
[w]N=1.
a-b Least square means in the same row with different letters differ at $P<0.05$.

Table 4.4 Neutral detergent fiber concentration (DM basis) of available forage in pastures established in 1999 and long established crested wheatgrass (control) pastures.

		Neutral Detergent Fiber ($g\ kg^{-1}$)				
Year	**Grazing Period**	**Control**	**Hybrid Bromegrass**	**Meadow Bromegrass**	**Smooth Bromegrass**	**SEM[z]**
Start of Grazing Period[y]						
2005-2006 Mean	1	562	527	524	545	12.8
2005	1	593	527	528	543	17.0
2006	1	532	527	523	548	12.4
	2[x]	-	563	578[w]	551	-
Middle of Grazing Period						
2005-2006 Mean	1	619*a*	594*b*	586*b*	593*b*	4.4
2005	1	623*a*	587*b*	591*b*	588*b*	3.5
2006	1	615	601	581	598	6.8
End of Grazing Period						
2005-2006 Mean	1	602	618	593	624	8.2
2005	1	617*ab*	621*a*	579*b*	635*a*	7.0
2006	1	587	615	607	612	8.8
	2	-	578	598[w]	573	-

[z]Pooled standard error of the mean.
[y]Start of grazing period: May 27-June 7 2005; May 26-June 2 2006; August 23 2006.
Middle of grazing period: June 2-June 20 2005; June 13-June 21 2006.
End of grazing period: June 9-July 12 2005; June 28-July 5 2006; September 7 2006.
[x]Data was not statistically analyzed.
[w]N=1.
a-b Least square means in the same row with different letters differ at $P<0.05$.

Table 4.5 **Acid detergent fiber concentration (DM basis) of available forage in pastures established in 1999 and long established crested wheatgrass (control) pastures.**

Year	Grazing Period	Control	Hybrid Bromegrass	Meadow Bromegrass	Smooth Bromegrass	SEM[z]
		Acid Detergent Fiber (g kg^{-1})				
Start of Grazing Period[y]						
2005-2006 Mean	1	283	265	281	272	11.7
2005	1	275	274	290	271	14.6
2006	1	264	259	272	267	11.1
	2[x]	-	288	314[w]	275	-
Middle of Grazing Period						
2005-2006 Mean	1	322	309	310	310	5.8
2005	1	327*a*	300*b*	309*ab*	302*b*	4.0
2006	1	317	318	312	319	8.3
End of Grazing Period						
2005-2006 Mean	1	316*b*	339*ab*	329*ab*	343*a*	6.3
2005	1	320	343	314	349	7.2
2006	1	311*b*	335*ab*	345*a*	337*ab*	5.4
	2	-	296	327[w]	281	-

[z]Pooled standard error of the mean.
[y]Start of grazing period: May 27-June 7 2005; May 26-June 2 2006; August 23 2006.
Middle of grazing period: June 2-June 20 2005; June 13-June 21 2006.
End of grazing period: June 9-July 12 2005; June 28-July 5 2006; September 7 2006.
[x]Data was not statistically analyzed.
[w]N=1.
a-b Least square means in the same row with different letters differ at $P<0.05$.

Table 4.6 In vitro organic matter digestibility (DM basis) of available forage in pastures established in 1999 and long established crested wheatgrass (control) pastures.

		In Vitro Organic Matter Digestibility (g kg^{-1})				
Year	**Grazing Period**	**Control**	**Hybrid Bromegrass**	**Meadow Bromegrass**	**Smooth Bromegrass**	**SEM[z]**
Start of Grazing Period[y]						
2005-2006 Mean	1	608*b*	679*a*	676*a*	657*ab*	12.3
2005	1	576*b*	687*a*	673*a*	667*a*	14.0
2006	1	640	671	679	648	11.6
	2[x]	-	564	565[w]	585	-
Middle of Grazing Period						
2005-2006 Mean	1	551*b*	620*a*	619*a*	607*a*	15.6
2005	1	549*b*	642*a*	635*a*	628*a*	10.3
2006	1	553*b*	598*a*	604*a*	587*ab*	7.2
End of Grazing Period						
2005-2006 Mean	1	547*ab*	556*ab*	586*a*	546*b*	12.9
2005	1	540*b*	569*b*	619*a*	547*b*	5.9
2006	1	555	544	553	545	6.3
	2	-	545	549[w]	582	-

[z]Pooled standard error of the mean.
[y]Start of grazing period: May 27-June 7 2005; May 26-June 2 2006; August 23 2006.
Middle of grazing period: June 2-June 20 2005; June 13-June 21 2006.
End of grazing period: June 9-July 12 2005; June 28-July 5 2006; September 7 2006.
[x]Data was not statistically analyzed.
[w]N=1.
a-b Least square means in the same row with different letters differ at $P<0.05$.

Smooth bromegrass had greater CP concentration than the control pastures (P<0.05) but the control pasture protein levels were not significantly different than the hybrid bromegrass and meadow bromegrass pastures. In 2005, control pastures had greater NDF concentration than all bromegrass species (P<0.05) and greater ADF concentration than hybrid bromegrass and smooth bromegrass pastures (P<0.05). Crested wheatgrass control pasture samples had lower IVOMD compared to all bromegrasses during the middle of the grazing period (P<0.05); however, in 2006, only hybrid and meadow bromegrass had greater IVOMD than the control (P<0.05) (Table 4.6).

End of Grazing Periods

At the end of the first grazing periods in 2005 and 2006, there were no differences in CP concentration (P>0.05) (Table 4.3). During the 2005 grazing period, forage NDF levels of meadow bromegrass was less than hybrid bromegrass or smooth bromegrass (P<0.05) (Table 4.4). Pooled data from the end of grazing period one of 2005 and 2006 showed smooth bromegrass with a greater ADF concentration than the control pastures (P<0.05) (Table 4.5). Within individual grazing periods, significant differences in ADF concentration were only noted during the first grazing period of 2006, where meadow bromegrass had greater ADF concentration than the control pastures (P<0.05). At the end of the grazing period in 2005, meadow bromegrass had the greatest IVOMD (P<0.05), but these results were not observed in 2006 (Table 4.6). The pooled data from the first grazing periods of 2005 and 2006 indicate that smooth bromegrass was the only species to have significantly lower IVOMD than meadow bromegrass (P<0.05).

4.3.2.2 Pastures Established in 2003

Start of Grazing Periods

The 2005 and 2006 pooled quality data for the start of the first grazing periods of pastures established in 2003 indicates that ‘AC Goliath’ crested wheatgrass, hybrid bromegrass and tall fescue all had significantly greater CP concentration compared to the control pastures (P<0.05) (Table 4.7). In the 2005 grazing period, the control pastures

Table 4.7 **Crude protein concentration (DM basis) of available forage in pastures established in 2003 and long established crested wheatgrass (control) pastures.**

		Crude Protein (g kg^{-1})				
Year	**Grazing Period**	**Control**	**Crested Wheatgrass**	**Hybrid Bromegrass**	**Tall Fescue**	**SEM**[z]
Start of Grazing Period[y]						
2005-2006 Mean	1	150*b*	202*a*	208*a*	199*a*	11.1
2005	1	129*b*	216*a*	209*a*	222*a*	6.6
2006	1	171	191	208	177	12.1
	2[x]	-	110	109	-	-
Middle of Grazing Period						
2005-2006 Mean	1	109*c*	163*a*	121*bc*	136*b*	6.8
2005	1	118*b*	151*a*	112*b*	130*ab*	4.7
2006	1	100*b*	174*a*	130*ab*	141*ab*	8.1
End of Grazing Period						
2005-2006 Mean	1	105	122	100	103	13.1
2005	1	132	122	100	115	8.4
2006	1	78	122	100	91	16.1
	2	-	85	110	-	-

[z]Pooled standard error of the mean.
[y]Start of grazing period: May 27-June 10 2005; May 17-June 2 2006; July 28-August 16 2006.
Middle of grazing period: June 2-June 30 2005; May 31-June 21 2006.
End of grazing period: June 9-July 14 2005; June 21-July 12 2006; August 14-September 3 2006.
[x]Data was not statistically analyzed.
a-*c* Least square means in the same row with different letters differ at $P<0.05$.

Table 4.8 Neutral detergent fiber concentration (DM basis) of available forage in pastures established in 2003 and long established crested wheatgrass (control) pastures.

		Neutral Detergent Fiber (g kg^{-1})				
Year	**Grazing Period**	**Control**	**Crested Wheatgrass**	**Hybrid Bromegrass**	**Tall Fescue**	**SEM[z]**
Start of Grazing Period[y]						
2005-2006 Mean	1	563*a*	503*b*	528*ab*	498*b*	14.3
2005	1	593*a*	520*bc*	533*b*	475*c*	7.9
2006	1	532	486	512	520	10.1
	2[x]	-	583	574	-	-
Middle of Grazing Period						
2005-2006 Mean	1	619*a*	560*b*	601*ab*	576*b*	9.7
2005	1	623*a*	590*ab*	607*ab*	556*b*	8.9
2006	1	615*a*	547*b*	595*a*	596*a*	5.1
End of Grazing Period						
2005-2006 Mean	1	602	621	629	601	10.7
2005	1	617	594	632	589	9.0
2006	1	587*b*	648*a*	625*ab*	614*ab*	6.7
	2	-	614	597	-	-

[z]Pooled standard error of the mean.
[y]Start of grazing period: May 27-June 10 2005; May 17-June 2 2006; July 28-August 16 2006.
Middle of grazing period: June 2-June 30 2005; May 31-June 21 2006.
End of grazing period: June 9-July 14 2005; June 21-July 12 2006; August 14-September 3 2006.
[x]Data was not statistically analyzed.
a-c Least square means in the same row with different letters differ at $P<0.05$.

Table 4.9 **Acid detergent fiber concentration (DM basis) of available forage in pastures established in 2003 and long established crested wheatgrass (control) pastures.**

		Acid Detergent Fiber (g kg^{-1})				
Year	Grazing Period	Control	Crested Wheatgrass	Hybrid Bromegrass	Tall Fescue	SEM[z]
Start of Grazing Period[y]						
2005-2006 Mean	1	283*a*	251*b*	266*ab*	249*b*	8.8
2005	1	303*a*	258*bc*	273*ab*	241*c*	5.4
2006	1	264	244	259	257	7.7
	2[x]	-	316	314	-	-
Middle of Grazing Period						
2005-2006 Mean	1	322	297	318	303	8.9
2005	1	327*a*	317*ab*	329*a*	293*b*	4.5
2006	1	317*a*	276*b*	308*a*	313*a*	3.3
End of Grazing Period						
2005-2006 Mean	1	326*b*	345*ab*	350*a*	329*ab*	8.1
2005	1	320*b*	323*b*	359*a*	324*b*	5.9
2006	1	311*b*	368*a*	340*ab*	333*ab*	7.1
	2	-	342	311	-	-

[z]Pooled standard error of the mean.
[y]Start of grazing period: May 27-June 10 2005; May 17-June 2 2006; July 28-August 16 2006.
Middle of grazing period: June 2-June 30 2005; May 31-June 21 2006.
End of grazing period: June 9-July 14 2005; June 21-July 12 2006; August 14-September 3 2006.
[x]Data was not statistically analyzed.
a-c Least square means in the same row with different letters differ at $P<0.05$.

Table 4.10 ***In vitro*** **organic matter digestibility (DM basis) of available forage in pastures established in 2003 and long established crested wheatgrass (control) pastures.**

		In Vitro Organic Matter Digestibility (g kg^{-1})				
Year	**Grazing Period**	**Control**	**Crested Wheatgrass**	**Hybrid Bromegrass**	**Tall Fescue**	**SEM**[z]
Start of Grazing Period[y]						
2005-2006 Mean	1	608*b*	675*ab*	684*a*	691*a*	15.9
2005	1	576*b*	689*a*	687*a*	732*a*	8.7
2006	1	640*b*	660*ab*	681*a*	651*ab*	5.2
	2[x]	-	571	590	-	-
Middle of Grazing Period						
2005-2006 Mean	1	551*c*	665*a*	601*b*	613*b*	13.4
2005	1	549*c*	644*a*	599*b*	652*a*	8.7
2006	1	554*b*	687*a*	602*b*	584*b*	14.6
End of Grazing Period						
2005-2006 Mean	1	547	528	562	566	20.1
2005	1	540	531	567	599	40.8
2006	1	555	526	556	533	12.3
	2	-	513	574	-	-

[z]Pooled standard error of the mean.
[y]Start of grazing period: May 27-June 10 2005; May 17-June 2 2006; July 28-August 16 2006.
Middle of grazing period: June 2-June 30 2005; May 31-June 21 2006.
End of grazing period: June 9-July 14 2005; June 21-July 12 2006; August 14-September 3 2006.
[x]Data was not statistically analyzed.
a-c Least square means in the same row with different letters differ at $P<0.05$.

had lower CP concentration compared to the other study pastures (P<0.05). At the start of the first grazing periods of 2005 and 2006 (pooled data), the control pastures had greater NDF (Table 4.8) and ADF concentrations (Table 4.9) (P<0.05) than 'AC Goliath' crested wheatgrass or tall fescue but not the hybrid bromegrass pastures (P>0.05). In 2005, tall fescue and 'AC Goliath' crested wheatgrass had lower NDF and ADF levels at the start of the grazing period than the control pastures (P<0.05). Fiber content was similar among all species in 2006 (P>0.05).

In vitro organic matter digestibility was lowest for the control pastures at the start of the 2005 grazing period and the first grazing period of 2006, but it was not significantly different than 'AC Goliath' crested wheatgrass in the 2005 and 2006 pooled data or 'AC Goliath' and tall fescue in the first grazing period of 2006 (Table 4.10). At the start of each grazing period, digestibility was similar for 'AC Goliath', hybrid bromegrass and tall fescue (P>0.05).

Middle of Grazing Periods

In the second grazing period of 2006, samples were not analyzed for forage quality at the middle of the grazing period due to the relatively short duration of the grazing period. Pooled CP data at the middle of the first grazing periods of 2005 and 2006 indicated that 'AC Goliath' had the greatest CP concentration compared to tall fescue, hybrid bromegrass or the control pastures (P<0.05) (Table 4.7). When CP concentration was separated by individual grazing periods, 'AC Goliath' crested wheatgrass consistently had greater CP concentration compared to the crested wheatgrass control pastures (P<0.05). Crude protein concentration of 'AC Goliath' was similar to tall fescue in both years of the study (P>0.05).

In the pooled data for 2005 and 2006, NDF concentration was greater in the control pasture samples than 'AC Goliath' and tall fescue but not hybrid bromegrass (P<0.05) (Table 4.8). However, ADF concentration was similar among all species (P>0.05) (Table 4.9). In 2005, tall fescue was the only species that had significantly lower NDF concentration than the control pastures (P<0.05). In 2006, 'AC Goliath' crested wheatgrass had significantly lower NDF concentration than all other study species (P<0.05). In 2005, tall fescue had significantly lower ADF concentration than the hybrid bromegrass and control pastures (P<0.05). In 2006, 'AC Goliath' had the lowest ADF concentration (P<0.05). There were no significant differences in ADF concentration among the hybrid bromegrass, tall fescue or control pastures (P>0.05). At the middle of trial, the 2005 and 2006 pooled data indicates that 'AC Goliath' crested wheatgrass had the greatest IVOMD while the control pastures had the lowest IVOMD (P<0.05) (Table 4.10). Within individual grazing periods, the control pastures consistently had the lowest IVOMD values of all study species.

End of Grazing Periods

There were no differences in CP levels at the end of the first grazing periods (P>0.05) (Table 4.7). Pooled data showed that NDF concentration was similar among all pastures (P>0.05) (Table 4.8); however, hybrid bromegrass had significantly greater ADF concentration than the control pastures (P<0.05) (Table 4.9). In 2005, NDF concentration was similar for all species (P>0.05). Hybrid bromegrass had greater ADF concentration than other species in the trial (P<0.05). In 2006, 'AC Goliath' had greater NDF and ADF concentration than the control pastures during the first grazing period (P<0.05).

Despite 'AC Goliath' crested wheatgrass having the highest IVOMD during the middle of the grazing period, this trend was not observed at the end of trial (Table 4.10).

4.4 Discussion

4.4.1 Forage Yield

In both the pastures established in 1999 and 2003, there were large variations in forage yield, particularly when data from more than one grazing period was pooled. The rolling topography of the study area as well as the non-uniformity and variation in grazing behavior of the study animals likely contributed to high variability in forage yield measurements. In addition, the presence of invasive species in the study pastures may have contributed to variability in pasture yield estimates (Appendix Table A8). Percentages of other species, including quack grass, Kentucky bluegrass and foxtail barley, were greatest in the control pastures and pastures established in 1999. In one hybrid bromegrass paddock established in 1999, 50.3% of the yield was identified as other species. Poor establishment in some paddocks, small plot sizes and a low number of replications may also have contributed to high standard error terms observed in this study.

Despite the large variability of CDMY in this study, the CDMY of the crested wheatgrass control pastures was similar to yields reported by Thompson (2003). This suggests that the values for crested wheatgrass reported in this study may closely resemble the long term yield potential for crested wheatgrass when fertilized on a yearly basis.

Previous research has indicated that smooth bromegrass performs well in a one-cut system while meadow bromegrass and hybrid bromegrass perform well in multi-cut systems. This is likely due to the ability of meadow and hybrid bromegrass to elongate cut tillers, which contributes to faster and higher regrowth potential (Knowles 1987; Coulman 2004). In 2005, only one grazing period occurred which may explain why no differences were observed in CDMY between the bromegrass species. If an additional grazing period had occurred in the 2005 grazing season, meadow bromegrass and hybrid bromegrass may have yielded slightly higher than smooth bromegrass due to their greater regrowth potential. In 2006, a second grazing period did occur for all bromegrass pastures with the exception of one replicate of meadow bromegrass but yields were similar between bromegrass species. This may be due to the lengthy duration of the first grazing period which ranged from 30 to 41 days (Appendix Table A2). Some plant regrowth of meadow bromegrass and hybrid bromegrass likely occurred during the first grazing period and would have been accounted for in the CDMY estimate of the first grazing period. Jewiss (1972) and Davidson and Milthorpe (1966a) indicated that considerable regrowth may occur in as little as 7 to 8 days after defoliation in perennial ryegrass and orchardgrass, respectively.

The statistical model used did not allow year to be treated as a fixed effect for grass × year interactions; however, the data suggests that the 2006 conditions (increased April and June precipitation in 2006 compared to 2005; Appendix Table A4 and Table A5) favored meadow bromegrass production in the first grazing period more than the 2005 conditions relative to the other species included in the trial. It is generally accepted that meadow bromegrass is best adapted to the cooler, more moist areas within the wider adaptation region of smooth bromegrass (Knowles et al. 1993) so it was unexpected that one of the meadow bromegrass replicates did not have sufficient regrowth for a second grazing period in 2006. July and August precipitation in 2006 was lower than the 22-year average which may have limited meadow bromegrass regrowth. Thompson (2003) also noted that one pasture replication showed poor establishment and had lower than expected yields in the 2000 and 2001. It was also unexpected that the meadow and smooth bromegrass pastures had forage yield estimates similar to the control pastures. Because the control pastures had the same level of fertilizer applied in the two year study as the treatment bromegrass pastures, the fertilizer application may have masked some of the effects of stand age or varietal differences. In addition, the age of the bromegrass stands suggests that the pastures may no longer be producing at their peak production and results of this study may be indicative of the long term yield potential for these species. Forage yields measured in this study were similar to those of Thompson (2003) on the same study site.

The greater CDMY of 'AC Goliath' crested wheatgrass is attributed to the early spring growth habit of this species which allows it to utilize spring moisture and cooler temperatures in April, May and June (Appendix Table A4-A7). Crested wheatgrass is recommended for early spring grazing because of its early spring growth (Vogel et al. 1993) and the results of this study support that recommendation. Despite large numerical yield differences between the two crested wheatgrass pasture types in 2005, the difference was minimal in 2006. Apparent decreased yield of 'AC Goliath' in 2006 compared to 2005 and relative to the control may have been the result of animals being placed on these pastures 10 days earlier in 2006 than in 2005 and 15 days earlier than the control pastures in 2006. This study suggests that the new variety of crested wheatgrass, 'AC Goliath', has comparable if not superior yield compared to the older crested wheatgrass stand in this trial.

Hybrid bromegrass paddocks established in 2003 had similar CDMY to hybrid bromegrass pastures seeded in 1999; however, the hybrid bromegrass paddocks established in 1999 had an average of 40% of the dry matter contributed by "other species" such as quack grass, Kentucky bluegrass and foxtail barley. This may suggest that with a good fertility program under a non-continuous grazing system, hybrid bromegrass pastures may maintain a comparable level of productivity to newly established stands, but over time, the level of hybrid bromegrass in the stand may decline and be replaced by other grazing tolerant species. In newly established stands, this species appears to be well suited to a twice over grazing system (similar to the 'AC Goliath' crested wheatgrass and 'Paddock' meadow bromegrass). It is important to note that while this species does not necessarily produce the greatest forage biomass during the spring to early summer period, it may work well in a complementary grazing system that requires a suitable species for a second grazing period in the late summer to early fall.

Tall fescue yielded similar to all study species over both years suggesting that this species may be adapted to the climatic region at Lanigan, Saskatchewan; however, there is minimal forage yield data under grazed conditions available for tall fescue in the Dark Brown/Black soil zone of Saskatchewan. The lack of a second grazing period in both years of the study suggests that this species may have limited potential for regrowth despite a high initial yield during the first grazing period. Lardner et al. (2002) reported that of eight grasses grazed under irrigation at Outlook, Saskatchewan, tall fescue had the slowest leaf development rate at all stages of defoliation which may limit its ability for regrowth in pasture. Thus, this species may have limited use in the Dark Brown/Black soil zone. However, utilization of tall fescue in these soil zones would depend upon the producer's grazing systems and needs. In the United States, tall fescue has reported yields of 1961 to 2813 kg ha^{-1} in north-west Georgia (Hoveland et al. 1991) and 7007 to 8475 kg ha^{-1} in Missouri (Wen et al. 2002), demonstrating that there is a wide range of forage production dependent upon location and climate.

4.4.2 Forage Quality

The results of the CP, NDF, ADF and IVOMD analysis are reflective of total plant forage quality (similar to hay harvests) as forages clippings were harvested at a 2.5 cm height above the soil surface. It is likely that grazing animals would have ingested a higher quality diet than the clipping data suggests as cattle have the ability to select certain plant parts (ie. leaves) while avoiding other plant parts (ie. mature stems) (Collins and Fritz 2003).

In all established pastures, CP and IVOMD decreased and NDF and ADF concentration increased as the grazing season progressed. These results are similar to an earlier study which reported whole plant nutritive values for meadow bromegrass, smooth bromegrass and three cultivars of hybrid bromegrass at three stages of plant maturity – vegetative, heading and anthesis (Ferdinandez and Coulman 2001). At the vegetative stage of growth, Ferdinandez and Coulman (2001) reported that hybrid bromegrass had consistently lower NDF and ADF values than either meadow bromegrass or smooth bromegrass, but there was no consistent trend as these species matured. Other literature has suggested that meadow bromegrass has marginally lower forage quality than smooth bromegrass (Knowles et al. 1993), but this trend was less evident as the species matured.

With advancing plant maturity, changes occur to the chemical composition of plant parts and within the sward structure of grass pastures, causing the nutritive value to decrease (Collins and Fritz 2003). Kilcher and Troelsen (1973) showed that the decline in forage nutritive value with advancing maturity in irrigated smooth bromegrass resulted primarily from a decrease in the leaf:stem ratio, a decline in the CP concentration and an increase in the cell wall lignin concentration of the whole-plant. In addition, the leaf component maintained lower lignin content and higher CP, gross energy and *in vitro* digestible energy content throughout the growing season compared to the stem component. Kilcher and Troelsen (1973) also suggested that there was a two week harvesting period between pre-flowering and mid-bloom in which nutritive value and forage yield could be optimized. Thus, in short growing seasons, changes in nutritive value can occur very quickly and create challenges for managing forage resources. Baron et al. (2000) stated that during regrowth, much less variation in whole-plant forage nutritive value occurs because plants are largely composed of leaf blades. From this it can be inferred that forage nutritive value of regrowth may be superior to that of a mature plant. In these experiments, CP concentration, IVOMD and fiber concentration tended to be more favorable at the start of the second period in 2006 compared to the end of the first grazing period, likely due to an increased proportion of leaves to stems in the regrowth. Thus, management of pastures can be used to manipulate and optimize forage yield as well as forage quality.

Differences in forage quality may be a result of the leaf:stem ratio and the venation of the leaf blades. Ferdinandez and Coulman (2000) reported that meadow bromegrass had a lower leaf:stem ratio compared to smooth bromegrass and hybrid bromegrass. Meadow bromegrass may also have greater leaf fiber content due to greater leaf venation which could result in higher leaf blade lignin concentration compared to either smooth bromegrass or hybrid bromegrass (Ferdinandez and Coulman 2001). Similarly, Baron et al. (2000) also reported higher leaf ADF concentration in meadow bromegrass compared to either smooth bromegrass or a hybrid bromegrass cultivar, but the increased ADF concentration in the leaf may be offset by lower stem ADF concentration at later maturity and regrowth. On the contrary, Casler and Carpenter (1989) found that the digestibility of the whole plant was related more to stem digestibility than leaf digestibility.

To date, it does not appear that morphological and quality comparisons have occurred between ‘AC Knowles’ hybrid bromegrass, ‘Courtenay’ tall fescue and ‘AC Goliath’ crested wheatgrass due to the relative “newness” of these varieties to the region. At the start of the grazing period, CP concentration was similar among the 2003 established pastures; however, as the grazing period progressed, ‘AC Goliath’ crested wheatgrass maintained higher CP concentration relative to the other species in the trial. As the crested wheatgrass pasture was grazed much earlier in the summer compared to the other species, it is likely that the high CP content of crested wheatgrass at the middle of its grazing period was due to regrowth. ‘AC Goliath’ crested wheatgrass and hybrid bromegrass tended to have greater NDF concentration than tall fescue but these differences were not consistently significant. Also, there was no consistent ranking in ADF concentration or IVOMD between the pasture species established in 2003. Thus, it appears that all of the study species established in 2003 are of similar forage quality. Despite a lack of differences between forage species established in 2003, the results of this study suggest that they would provide superior forage nutritive value compared to long established crested wheatgrass pastures.

4.5 Conclusions

4.5.1 Forage Yield

Over the two years of this study, it was evident that the bromegrass pastures established in 1999 had the potential to provide greater forage yields compared to the long-established control pastures. When bromegrass pastures have good fertility and are managed for a twice-over grazing system, there appeared to be no differences in overall yield potential between the three bromegrass species evaluated in this study. Similarly, pastures established in 2003 also lacked significant differences in forage yield. When grazed early in the growing season (mid-May to late-June), the results of this study suggest that ‘AC Goliath” crested wheatgrass and ‘AC Knowles’ hybrid bromegrass may provide sufficient regrowth for a second grazing period. This is of particular importance for livestock producers who are looking for forage species to use in a twice-over grazing rotation or a grass species with good regrowth potential to establish with legumes. Although tall fescue provided excellent initial forage growth, it seems that its regrowth potential may be limited and this species may not be suitable as a mid-summer species for grazing in this region. Drought tolerance may be an issue for this species and limit regrowth potential.

4.5.2 Forage Quality

For the bromegrass pastures established in 1999, all species had similar CP, NDF, ADF and IVOMD levels. For the majority of the sampling dates, all bromegrass species had superior forage quality compared to the long established crested wheatgrass control pastures. Similarly, the pastures established in 2003 also showed superior forage quality compared to the long established crested wheatgrass pastures. However, there was not a consistent ranking observed between species in terms of CP, ADF and *in vitro* organic matter digestibility. Tall fescue tended to have a lower NDF concentration than either hybrid bromegrass or crested wheatgrass but this observation was not always significant. Hybrid bromegrass and ‘AC Goliath’ crested wheatgrass pastures tended to have mid to high fiber content which did not appear to lower *in vitro* organic matter digestibility.

The results of this study suggest that ‘AC Goliath’ crested wheatgrass may be a good option for producers looking for early spring grazing as it has good spring growth of excellent forage quality. Due to the early season growth of crested wheatgrass, steers were placed on ‘AC Goliath’ pastures one to two weeks before they were placed on either the bromegrass or tall fescue pastures. Also, steers were placed on ‘AC Goliath’ pastures sixteen days earlier in 2006 compared to the control crested wheatgrass pastures. Finally, as an example, if the cost of summer pasture is $0.80 per cow per day and the cost of over-wintering a cow is $1.78 per cow per day (Highmoor 2005b), savings to the producer may be as much as $15.68 per cow during that sixteen day period.

5 Etiolated Growth of Five Perennial Forage Species Under Grazed Conditions

5.1 Introduction

Forage production of perennial grasses is considered to be strongly influenced by the amount of energy reserves stored by the plant within the current growing season and during the previous growing period. Brown and Blaser (1965) suggested that energy reserves are pre-dominately non-structural carbohydrates but further research has indicated the importance of non-carbohydrate compounds, such as proteins, as substrates for plant growth (Davidson and Milthorpe 1966b; Richards and Caldwell 1985; Morvan-Bertrand et al. 1999). Other research has indicated that the leaf area and photosynthetic capacity of the plant following defoliation will ultimately influence subsequent herbage growth (Ward and Blaser 1961; Davidson and Milthorpe 1966b). Ward and Blaser (1961) suggested that tiller regrowth was affected by both energy reserves and leaf area. McKendrick and Sharp (1970) demonstrated that the weight of etiolated growth produced by plants prior to spring growth can be used as a measure of perennial plant energy reserves and growth potential. Etiolated growth represents the potential contribution of stored organic reserves to shoot regrowth by limiting the plant's access to sunlight. Etiolated growth is measured by removing above-ground growth and then covering plants with light-proof boxes so that the plant is unable to access sunlight.

An experiment measuring etiolated growth in the field was conducted during the spring and summer of 2006 and 2007 to determine if there were differences in energy reserves among several perennial grass species prior to grazing. Furthermore, a grazing treatment was imposed the previous grazing season to evaluate the effect of grazing on plant energy reserves the following spring compared to an ungrazed control. Evaluating the effect of grazing on plant energy reserves as well as seasonal changes in energy reserves may provide additional information for grazing management of perennial grass pastures.

5.2 Materials and Methods

A field study was conducted during the spring and summer of 2006 and 2007 to estimate stored energy reserves of grazed and non-grazed plants for five grass species after the 2005 and 2006 grazing seasons. Forage species included in the study were a long established stand of crested wheatgrass (control), meadow bromegrass cv. Paddock, smooth bromegrass cv. Carlton and hybrid bromegrass cv. AC Knowles paddocks established in 1999 and crested wheatgrass cv. AC Goliath, hybrid bromegrass cv. AC Knowles and tall fescue cv. Courtenay paddocks established in 2003.

Etiolated growth (Lardner et al. 2003) was measured during the spring and summer of 2006 and 2007 as an estimate of spring energy reserves in plants. During the 2005 and 2006 grazing seasons, a grazing exclusion cage was randomly placed in each pasture prior to grazing to obtain an area that would not be grazed by steers. In the spring of 2006 and 2007, 3 grazed and 3 non-grazed plants were randomly selected in each paddock for etiolated growth measurements.

In early spring (13 April 2006 and 14 April 2007), plants were identified, clipped to a 3 cm height (Matches 1969) and covered with metal cans (13.5 cm diameter, 25 cm height) painted white to reduce heating. There did not appear to be any new above-ground spring growth of the species prior to covering. Before plants were covered, basal tuft circumference was measured with a flexible meter tape to account for differences in etiolated growth and tuft size. Cans were pushed into the soil and secured with plastic strapping to reduce the possibility of tipping due to wind or animal activity.
Etiolated growth was first clipped 14 days after plants were covered and then every 7 and 14 days until etiolated growth ceased in 2006 and 2007, respectively. Final clipping dates each year were 16 July 2006 and 15 July 2007. At this time, etiolated growth had ceased under all remaining metal cans. In both years of the study, many plants had ceased to produce etiolated growth prior to the final clipping dates. Clipped etiolated growth of each species was dried in a forced air oven at 55°C until a constant weight was reached and then weighed. Etiolated growth was expressed as mg per cm^{-2} of basal tuft area.

For the purpose of statistical analysis, the study was analyzed as two separate experiments or study sites due to differences in stand age. The first experiment compared species established in 1999 and the second experiment compared species established in 2003. Experimental design was a 2 × 4 factorial in a completely randomized design. The two grazing treatments (grazed and ungrazed) and 4 species were considered to be fixed effects. There were two replicates of each pasture type and each covered plant was considered to be a subsample of the paddock. Treatment means were analyzed by analysis of variance using the SAS Mixed Model (SAS Institute Inc. 2005). Individual clipping dates in 2006 and 2007 were analyzed separately due to an inconsistent number of days between clipping dates over the two years of the study. Finally, year was treated as a random effect allowing total etiolated growth produced each year to be pooled and analyzed over the entire 2-year study. Where significant differences were observed ($P<0.05$), means were separated at the 5% level of significance using Tukey's procedure (Steel et al. 1997).

5.3 Results

5.3.1 Pastures Established in 1999

For the bromegrasses established in 1999, a species or grazing effect ($P>0.05$) did not exist for the pooled 2006 and 2007 data (Table 5.1). In 2006, all bromegrass species had similar total etiolated growth ($P>0.05$) while smooth bromegrass and hybrid bromegrass had greater ($P>0.05$) total etiolated growth compared to control pastures. In 2007, total etiolated growth for bromegrass pastures and control pastures was similar ($P>0.05$). At all clipping dates in 2006 and 2007, all species had similar etiolated growth ($P>0.05$).

In 2006, at 2 clipping dates, grazing treatment differences were observed in etiolated growth ($P<0.05$). On 27 April (14 d) and 22 June (70 d) grazed plants produced greater ($P<0.05$) etiolated growth than ungrazed plants. Total etiolated growth for grazed plants was greater ($P<0.05$) than ungrazed plants in 2006. However, total etiolated growth produced by grazed and ungrazed plants was similar in 2007 and for the 2006-2007 pooled data ($P>0.05$).

Table 5.1 **Spring etiolated growth (DM basis) of grass species established in 1999 with two grazing treatments.**

	Etiolated Growth (mg cm^{-2})							
	Grass Species					Grazing Treatment		
	Control	Hybrid Bromegrass	Meadow Bromegrass	Smooth Bromegrass	SEM[z]	Grazed	Ungrazed	SEM
2006								
April 27 (14d)	6.4	9.9	11.6	9.3	2.21	12.5*a*	6.1*b*	1.56
May 4 (21d)	2.3	5.8	7.0	7.7	1.54	6.4	5.1	1.09
May 11 (28d)	3.7	4.1	4.6	6.0	0.87	4.4	4.7	0.61
May 19 (36d)	4.1	5.6	5.4	9.5	1.20	6.3	6.1	0.85
May 25 (42d)	1.7	1.8	1.7	2.5	0.41	2.2	1.6	0.29
June 1 (49d)	1.0	1.7	1.2	1.7	0.29	1.5	1.3	0.21
June 8 (56d)	0.6	0.7	0.7	0.2	0.19	0.7	0.5	0.13
June 15 (63d)	0.3	1.0	0.5	4.2	2.56	2.7	0.3	1.81
June 22 (70d)	0.1	0.6	0.3	0.3	0.13	0.5*a*	0.1*b*	0.09
June 28 (76d)	0.1	0.2	0.1	0.2	0.07	0.2	0.1	0.05
July 5 (83d)	0.0	0.1	0.4	0.1	0.20	0.3	0.1	0.13
July 12 (90d)	0.0	0.1	0.1	0.1	0.05	0.1	0.0	0.04
July 16 (94d)	0.0	0.0	0.1	0.0	0.02	0.0	0.0	0.02
Total	20.2*b*	41.7*a*	32.8*ab*	40.3*a*	3.67	42.8*a*	24.8*b*	2.59
2007								
April 29 (15d)	5.0	4.1	5.7	5.0	0.56	4.9	5.5	0.40
May 6 (21d)	3.1	3.0	3.4	4.9	0.58	2.9	4.3	0.41
May 20 (35d)	4.2	3.7	3.6	8.6	1.94	3.5	6.6	1.37
June 3 (49d)	1.2	1.0	1.6	2.2	0.46	1.1	1.9	0.33
June 17 (63d)	0.1	0.5	0.8	0.9	0.30	0.3	0.8	0.21
July 1 (77d)	0.0	0.3	0.7	0.3	0.26	0.2	0.5	0.18
July 15 (91d)	0.0	0.1	0.5	0.0	0.13	0.1	0.2	0.09
Total	14.7	12.7	16.4	22.0	3.64	13.1	19.8	2.57
Mean 2006 & 2007 Total	17.5	24.7	25.1	31.2	8.89	26.7	22.5	8.42

[z]Pooled standard error of the mean.

a-b Least square means in the same row within treatment with different letters differ at $P<0.05$.

5.3.2 Pastures Established in 2003

For pastures established in 2003, pooled data for 2006 and 2007 indicates that the control pastures produced less (P<0.05) etiolated growth than 'AC Goliath' crested wheatgrass and 'AC Knowles' hybrid bromegrass (Table 5.2). The pooled 2006 and 2007 data indicates that 'AC Goliath' crested wheatgrass produced the greatest etiolated growth compared to tall fescue and the control, but was not significantly different than hybrid bromegrass (P>0.05). Hybrid bromegrass and tall fescue produced similar etiolated growth (P>0.05).

In 2006, 'AC Goliath' crested wheatgrass produced the greatest (P<0.05) amount of etiolated growth 14 d, 21 d and 28 d after covering the plants. In 2006, after 42 d 'AC Goliath' crested wheatgrass and hybrid bromegrass produced greater (P<0.05) etiolated growth than the control pastures. In 2006, total etiolated growth production was greatest for 'AC Goliath' crested wheatgrass and hybrid bromegrass, and lowest for the control pastures. Similar to the previous year, 'AC Goliath' crested wheatgrass produced the greatest amount of etiolated growth after 21 d in 2007 (P<0.05). However, by day 35 after covering, all species produced similar (P>0.05) etiolated growth (P>0.05). Overall, all species produced similar quantities of total etiolated growth in 2007.

A grazing treatment effect was observed in 2006, 70 and 76 days after covering plants, and in 2007, 15 days after covering plants. At each of these dates, grazed plants produced greater etiolated growth than ungrazed plants (P<0.05). Overall, total etiolated growth production was similar between grazed and ungrazed plants in 2006, 2007 and the pooled data (P>0.05).

5.4 Discussion

For those species established in 1999, meadow bromegrass produced numerically less etiolated growth than hybrid or smooth bromegrass (P>0.05) but still 60% more etiolated growth compared to control pastures (P>0.05). Lardner (1993), working with irrigated pasture, did not find any significant correlations between etiolated growth and

Table 5.2 **Spring etiolated growth (DM basis) of grass species established in 2003 with two grazing treatments.**

	Etiolated Growth (mg cm^{-2})							
	Grass Species					Grazing Treatment		
	Control	Crested Wheatgrass	Hybrid Bromegrass	Tall Fescue	SEM^z	Grazed	Ungrazed	SEM
2006								
April 27 (14d)	6.4*b*	33.4*a*	17.1*b*	13.2*b*	3.10	20.7	14.3	2.19
May 4 (21d)	2.3*b*	14.7*a*	7.2*b*	6.6*b*	1.22	7.7	7.7	0.86
May 11 (28d)	3.7*c*	11.1*a*	8.2*ab*	7.7*b*	0.74	7.6	7.8	0.52
May 19 (36d)	4.1	10.0	10.0	10.0	1.34	8.8	8.3	0.95
May 25 (42d)	1.7*b*	3.6*a*	4.0*a*	3.4*ab*	0.41	3.4	2.9	0.29
June 1 (49d)	1.0	1.8	2.1	2.5	0.40	1.9	1.8	0.28
June 8 (56d)	0.6	0.9	1.6	1.1	0.34	1.0	1.1	0.24
June 15 (63d)	0.3	0.8	0.6	1.1	0.35	0.6	0.7	0.25
June 22 (70d)	0.1	0.1	0.4	0.3	0.07	0.3*a*	0.1*b*	0.05
June 28 (76d)	0.1*b*	0.1*ab*	0.3*a*	0.1*ab*	0.05	0.2*a*	0.1*b*	0.04
July 5 (83d)	0.0*b*	0.1*ab*	0.2*a*	0.0*b*	0.04	0.1	0.0	0.03
July 12 (90d)	0.0	0.0	0.1	0.0	0.02	0.0	0.0	0.02
July 16 (94d)	0.0	0.0	0.1	0.0	0.02	0.0	0.0	0.01
Total	20.2*c*	78.2*a*	51.8*ab*	46.2*bc*	6.87	52.5	45.7	4.86
2007								
April 29 (15d)	6.0*b*	13.9*a*	7.6*b*	5.5*b*	0.91	10.0*a*	6.5*b*	0.65
May 6 (21d)	3.1*b*	6.5*a*	4.9*ab*	3.7*ab*	0.72	4.8	4.3	0.51
May 20 (35d)	4.2	5.7	5.9	4.3	1.72	4.2	5.9	1.22
June 3 (49d)	1.2	1.4	2.5	1.5	0.69	1.3	2.0	0.49
June 17 (63d)	0.1	0.5	0.7	0.4	0.26	0.4	0.5	0.18
July 1 (77d)	0.0	0.1	0.3	0.1	0.08	0.1	0.1	0.06
July 15 (91d)	0.0	0.0	0.2	0.0	0.07	0.1	0.0	0.05
Total	14.7	28.2	22.1	15.6	3.56	21.0	19.4	2.52
Mean 2006 & 2007 Total	17.5*c*	53.2*a*	37.0*ab*	30.9*bc*	1.50	36.7	32.5	1.47

^{z}Pooled standard error of the mean.
a-*c* Least square means in the same row within treatment with different letters differ at P<0.05.

CDMY or between etiolated growth and regrowth rates of eight irrigated perennial grasses in Saskatchewan. Richards and Caldwell (1985) suggested that current photosynthesis and leaf area could offset the effect of reduced energy reserves available for growth. Meadow bromegrass possesses basal leaf growth which may escape defoliation and continue to photosynthesize. Additionally, presence of basal meristems may provide some explanation as to why this grass has high regrowth potential despite low etiolated growth or energy reserves.

In crested wheatgrass, McKendrick and Sharp (1970) reported that etiolated growth per individual tiller did not show a good relationship to subsequent herbage yield; however, individual tiller weight appeared to reflect the previous year's grazing treatment. Locations that had been grazed the previous year had decreased etiolated growth compared to ungrazed locations. As the number of years without grazing increased, so did the etiolated growth weight (McKendrick and Sharp 1970). McKendrick and Sharp (1970) also reported that there was a high correlation (r=0.967) between etiolated growth per plant and subsequent herbage yield. In general, there is a seasonal pattern of TNC accumulation in the plant which can be altered by grazing. Typically, TNC levels are lowest during the periods of rapid growth when quantities of photosynthates are insufficient to initiate and sustain plant growth, and highest when plants are in a positive energy balance (photosynthetic supply exceeds growth and respiration demands) later in the growing season; however, once a plant is grazed the normal phenological development of the plant is disrupted (Trlica and Cook 1972).

In this study, no overall differences in total etiolated growth (pooled 2006 & 2007 data) were observed between bromegrass species. However, all plants in this study were clipped and covered prior to any spring growth occurring. Thus, differences may not have existed between bromegrass species in the spring because etiolated growth production would have been a result of energy reserves stored during the previous growing season. The last date that steers had access to the pastures in 2005 was July 14 (Appendix Table A2). Because livestock did not graze the pastures after mid-July, there would have been sufficient time for plants to replenish energy reserves prior to winter senescence. Reynolds and Smith (1962) used three cutting regimes to monitor change in total available carbohydrates in smooth bromegrass, timothy and alfalfa. Regardless if forages were defoliated twice (June 27 and July 29) or three times (June 3, July 18 and August 29) in their study, carbohydrate levels of defoliated plants in October exceeded the levels of non-defoliated plants. Forages able to maintain energy reserves while producing new plant growth may have an advantage in the next growing season (Lardner et al. 2003). Also, it is important to manage forage stands by avoiding defoliations that are too frequent or severe, as insufficient recovery time between defoliations may limit the ability of the plant to rebuild energy reserves.

In non-defoliated plants, Reynolds and Smith (1962) also reported a depression in total available carbohydrate reserves mid-August and then a slight replenishment of reserves in late-August through mid-September. However, the final total available carbohydrate levels never reached the same levels in October of plants that were defoliated twice. In the spring of 2006, grazed plants had greater etiolated growth than ungrazed plants. In 2005, it was observed that plants that were grazed in June through mid-July had a larger quantity of green, vegetative material that appeared to be actively growing in mid-August to mid-September compared to the ungrazed plants where the majority of these plants appeared to be mature and senesced. Thus, plants that had been grazed in 2005 may have been actively photosynthesizing and storing energy in the fall while the ungrazed plants may have had decreased rates of photosynthesis or may have already been using energy that was stored earlier in the growing season for normal plant metabolism.

In crested wheatgrass, Romo and Harrison (1999) reported that when plants were defoliated, they produced leaves more quickly than non-defoliated control plants. Increased photosynthesis resulting from increased leaf production may explain why the plants grazed in 2005 had almost twice the quantity of etiolated growth production in 2006 as did the ungrazed plants. In contrast, this difference was not observed for the total 2007 etiolated growth production or the pooled total etiolated growth production (2006 and 2007) for pastures established in 1999 or those established in 2003. Because there was a second grazing period in 2006, it is possible that some of the earlier grazed plants were grazed a second time in late-August through mid-September. Plants defoliated late in the growing season (at a later development stage) may produce less etiolated growth than plants defoliated early (plant growth is interrupted or can not continue after defoliation) (Romo and Harrison 1999). Reynolds and Smith (1962) suggested that the activity of basal buds at the time of defoliation may also contribute to the grass regrowth following defoliation. If buds have reduced activity at later stages of development or later in the growing season, it is possible that plants defoliated twice in 2006 were not able to store as much energy in the fall to produce similar quantities of etiolated re-growth in the spring of 2007 as they had in the spring of 2006.

In both years of the study, 'AC Goliath' crested wheatgrass produced greater etiolated growth early after plants were covered at 14 d in 2006 and at 15 d in 2007 compared to hybrid bromegrass, tall fescue and control pastures. When studying orchardgrass, Davidson and Milthorpe (1966a) found a positive relationship between the rate of leaf expansion and total soluble carbohydrate content, while Brown and Blaser (1965) suggested that carbohydrates have an important role in regrowth, initiation of spring growth and winter survival. This would suggest that 'AC Goliath' crested wheatgrass has greater potential to produce early spring growth compared to other species in this study. This may also reflect the level of winter dormancy of the species evaluated (crested wheatgrass may have greater dormancy compared to the other species evaluated). There was also a marked difference between 'AC Goliath' crested wheatgrass and the control pastures. Differences in the two stands of crested wheatgrass may be due to varietal differences or simply differences in stand age. In 2005, steers were placed on both types of crested wheatgrass pastures on the same date (May 27); however, in 2006 steers were placed on the control pastures 16 days (June 2) after the 'AC Goliath' pastures were stocked. Thus, there may be the potential for this new crested wheatgrass variety to provide earlier spring grazing compared to traditional crested wheatgrass varieties.

At only one harvest date in the 2-year study did hybrid bromegrass have greater etiolated growth production than tall fescue. Similar etiolated growth production observed for the two species would suggest that these grasses are ready for spring grazing at a similar time. In 2006, only hybrid bromegrass produced sufficient growth for a second grazing period. Thus, spring etiolated growth levels may not be a good indicator of potential regrowth following defoliation. For a more accurate measure of potential regrowth following defoliation for the species studied in this trial, it may be beneficial to measure etiolated growth at various stages of growth or phenological development throughout the growing season, particularly after a defoliation treatment.

5.5 Conclusions

Based on the results of the spring etiolated growth trial, there were no significant differences in energy reserves between meadow bromegrass, smooth bromegrass, hybrid bromegrass or the long established stands of crested wheatgrass. When the energy reserves of these plants were measured, pastures had been established for six years (1999) and stand age may have masked any species effect.

Of the species established in 2003, 'AC Goliath' crested wheatgrass had the greatest energy reserves which may account for the early spring growth of this species observed in this trial. The ranking of species in relation to energy reserves would place 'AC Goliath' crested wheatgrass first, followed by hybrid bromegrass, tall fescue and finally, the long established crested wheatgrass control pastures. This ranking was not significant in both years of the study; however, the 2006-2007 pooled data supports these rankings. Assuming that the amount of etiolated growth produced corresponds to energy reserves, 'AC Goliath' crested wheatgrass and hybrid bromegrass could potentially provide greater spring growth and greater winter hardiness than either tall fescue or long established stands of crested wheatgrass.

The results of this study do not provide conclusive evidence as to the effect of defoliation on plant energy reserves. While it is generally accepted that defoliation treatments decreases energy reserves, it appears that if a sufficient recovery period is provided after grazing, plants can replenish reserves to levels of ungrazed plants by the following spring. Thus, grazing management plans should consider not only the timing of defoliation in relation to energy reserves but also the intensity and frequency of defoliation and its effect on the plant's ability to photosynthesize, maintain and/or replenish energy reserves.

6 Animal Performance and Intake and Grazing Capacity of Five Perennial Forage Species Under Grazed Conditions

6.1 Introduction

Pasture forage is an important part of the long-term sustainability and profitability of beef production systems in Western Canada. Performance of grazing animals reflects a balance between its nutrient requirements and the nutrients it is able to consume. When choosing forage varieties, livestock producers must consider potential forage yield and quality, forage intake, factors which influence intake and how the animal will perform in response to intake of available forage. Thus, it is important to measure the following performance parameters: average daily gain (ADG), grazing days per hectare (AGD), beef production per hectare (TBP) and individual daily intake. In addition, examination of how these parameters can be influenced by forage species and/or forage variety should be determined.

Grazing animal intake is typically very difficult to measure as it can vary between individual animals and is affected by many factors including physiological status of the animal, plant species and maturity, diet composition and grazing behavior. In confined feeding trials, Lippke (1980) reported that animal performance or growth is more highly related to dry matter intake (DMI) than to digestibility and forage quality parameters. As direct measurements of individual animal intake are often difficult to obtain in a grazing system, the search for methodologies to estimate DMI has led to the development of techniques that rely on indigestible fecal markers to estimate fecal output and diet digestibility. Previously, the most extensively utilized markers to estimate individual intake were lignin or acid insoluble ash in conjunction with chromic oxide. As chromic oxide is no longer available, researchers have investigated other methodologies to estimate intake, such as the cuticular wax alkanes of pasture plants. Livestock producers need research on forages that evaluates animal intake, animal performance and overall livestock production in order to make management decisions and choose forage species that will best meet their grazing needs.

6.2 Materials and Methods

6.2.1 Experimental Animals and Grazing Management

Two separate experiments were included in this study. In 1999, two 0.8 ha replicates each of meadow bromegrass cv. Paddock, smooth bromegrass cv. Carlton and hybrid bromegrass cv. AC Knowles were established at the Termuende Research Ranch near Lanigan, Saskatchewan. In 2003, two 0.8 ha replicates each of crested wheatgrass cv. AC Goliath, hybrid bromegrass cv. AC Knowles and tall fescue. Courtenay were established adjacent to the pastures established in 1999. Central to the experimental pastures, two 0.8 ha paddocks of long established crested wheatgrass acted as control pastures.

In both years, grazing commenced when available forage was approximately 20 cm high (4-5 leaf stage). Crested wheatgrass pastures were grazed in May due to the growth characteristics and early maturity of the species (Appendix Table A2). The mid-season species were grazed June through July. Only one grazing period occurred in 2005, however, in 2006, a second grazing period occurred on both replicates of 'AC Goliath' crested wheatgrass pastures (mid-July to mid-August), both replicates of hybrid and smooth bromegrass and replicate of one meadow bromegrass (mid-August to early-September). Prior to the start of trial and between grazing periods, steers were allowed to graze a common grass pasture.

British × Continental steers were weighed and randomly allocated to one of 7 pasture types according to body weights. Steers were weighed over two consecutive days at the start and end of trial and every 7 d throughout the course of each grazing period. For pastures established in 1999, the initial weights of tester animals averaged 338 ± 17, 305 ± 21 and 381 ± 27 kg (mean ± SD) for the 2005 grazing period, first and second grazing period in 2006, respectively. For the pastures established in 2003, the initial weights of tester animals averaged 336 ± 13, 311 ± 16 and 385 ± 21 kg in the 2005 grazing period, first and second grazing period in 2006, respectively. Steers were weighed at a consistent time each day, but were not fasted due to the lack of appropriate holding facilities.

Pastures were managed using a "put and take" grazing system with three randomly chosen tester steers per paddock (Mott and Lucas 1952). Tester steers remained on their designated pastures for the duration of the grazing period while "put and take" steers were added or removed from pastures to maintain similar forage availability and maturity in each pasture type. Steers remained on each replicate paddock until plants were grazed to a uniform height of approximately 8 cm. Thus, steers were removed from pastures on varying calendar dates dependent upon forage availability. Pastures were allowed sufficient rest (minimum of 5 weeks) between grazing periods.

Average daily weight gain was determined using the average start and end of trial body weights of the three tester steers in each paddock. Animal grazing days per ha was determined using both tester and 'put and take' animals. Animal grazing days were calculated as:

$$AGD = \frac{\Sigma(\text{animal unit equivalents} \times \text{days on pasture})}{\text{pasture area}}$$

Total beef production per ha was calculated for each pasture as:

TBP = ADG of the tester steers × AGD (Mott and Lucas 1952).

6.2.2 Individual Animal Intake

Individual animal intake of grazing steers was estimated using Captec® alkane controlled-release device (CRD) (Nufarm Limited, Auckland, New Zealand) (Mayes et al. 1986; Dove and Mayes 2004) for two grazing periods in 2006. Two of the three tester steers in each paddock were dosed (d 0) with one alkane CRD at 0700 (two steers per treatment per replicate). Steers grazed on a crested wheatgrass-smooth bromegrass pasture adjacent to experimental paddocks for a minimum of 3 d prior to being dosed. After steers were dosed, they remained on the crested wheatgrass-smooth bromegrass pasture for an additional 4 d of grazing to ensure there would be sufficient available forage on the experimental paddocks for the duration of the sampling period. On d 4 after dosing with the CRD boluses, steers were placed on experimental paddocks. A 7 d period was allowed for marker release to achieve equilibrium and rectal grab sampling commenced on d 8 after dosing. From d 8 to d 23, fecal samples were collected once daily at 0700 by rectal grab sampling throughout the sampling period. All fecal samples were frozen immediately until they could be dried and ground for alkane analysis. Fecal samples were dried with a forced air oven at 55°C until a constant weight was reached and then ground through a 1 mm screen using a Retsch® grinder. Fecal samples were pooled by animal over the d 8 to d 16 collection period to produce one fecal sample per animal per grazing period for alkane analysis and determination of intake. Fecal samples from d 17 to d 23 were analyzed individually for alkane concentration and determination of the end-point of alkane release from the bolus.

A ruminally fistulated heifer (652 kg) was dosed with a single alkane CRD and placed on hybrid bromegrass pastures established in 2003 to graze along side the study animals. At set time intervals (d 0, 4, 8, 11, 15, 16, 17, 18, 19, 20), the CRD was removed from the rumen *per fistulum* and the length of remaining alkane bolus in the CRD was measured at two equidistant points around the circumference of the CRD using digital calipers. This was done to validate the manufacturer's reported daily release rate of 400 mg of n-dotriacontane (C_{32}) and 400 mg of n-hexatriacontane (C_{36}) daily. By knowing the starting length of the bolus, and the concentration of the alkanes in the bolus, we were able to determine the concentration of C32 that was released on a daily basis based on the length of the alkane bolus that disappeared between measurement intervals. Intake calculations reported in this study utilized the C_{32} measured release rate from the fistulated heifer. The measured release rate from the CRD was determined to be 378 mg of C_{32} daily.

Every 2 d throughout the fecal collection periods, forage samples were hand-plucked, separated by plant species and pooled within paddock. Forage samples were dried at 55 °C in a forced air oven until a constant weight was reached and then ground through a 1 mm screen in a Wiley mill. Forage and fecal samples were analyzed for alkane content following the procedure as described by Charmley et al. (2003). Due to the presence of invasive grass species in the study pastures and variable alkane concentrations between species, alkane content of available forage was calculated by accounting for species composition (by weight) according to forage yield clipping dates closest to the fecal sampling period and alkane profiles of individual species. Percent composition by weight was the average of 12-18 quadrats (2-3 clipping dates) per pasture. The calculation to determine the alkane profile of available forage in each pasture was as follows:

> Alkane content of available forage = (% composition $species_1$ x alkane content $species_1$) + (% composition $species_2$ x alkane content $species_2$) + … + (% composition $species_n$ x alkane content $species_n$).

This calculation was done for each individual alkane chain length (C_{24}-C_{36}).

Dry matter intake was estimated by the C_{31}:C_{32} and the C_{33}:C_{32} ratios in forage and feces according to the following calculation:

$$\text{DMI} = \frac{Dj}{(Fj/Fi) \times Hi - Hj}$$

Where Dj = daily dose of the external marker (C_{32}) (mg), Fi = concentration of internal marker (C_{31} or C_{33}) in the feces (mg kg DM^{-1}), Fj = concentration of C_{32} in the feces (mg kg DM^{-1}), Hi = concentration of endogenous C_{31} or C_{33} in the forage (mg kg DM^{-1}), Hj = concentration of endogenous C_{32} in the forage (mg kg DM^{-1}) (Dove and Mayes 2004). Since recovery of the dosed and natural alkanes was not known, it was not possible to account for variable recoveries in the calculation of forage intake.

In addition to DMI estimates using the alkane technique, DMI was also estimated using the Cornell Net Carbohydrate and Protein System (CNCPS version 5.0) (Cornell University, Ithaca, New York). Forage chemical composition parameters measured in this study (NDF, CP, ash content) were used in conjunction with the feed library in the CNCPS model to predict DMI for each pasture type. In the first grazing period, forage chemical composition values used were the average of the start and middle of the grazing period clippings as these dates corresponded closely to the fecal sampling period. The average chemical composition at the start and end of the grazing period was used for the second grazing period. Animal body weights that were entered in the CNCPS model were the average of 7 d steer weights that were the nearest (in calendar date) to the 8 d fecal sampling period. All other animal inputs were set to best reflect the animal and environmental conditions at the time of the fecal sampling period.

6.2.3 Statistical Analysis

Experimental design was a randomized complete block design with two replicates per treatment (pasture type). Year or grazing period was considered to be a random blocking effect. Tester steers and/or CRD dosed steers served as subsamples for average daily gain and animal intake. Initial steer weights were included in the model as a linear regression factor to account for differences in steer weights between grazing periods. Due to a possible confounding age effect, pastures established in 1999 were not compared to the pastures established in 2003; however, pastures established in 1999 and 2003 were compared to the long established control pastures. Data for ADG, AGD, TBP and animal DMI were analyzed using the Mixed Model procedure of SAS and means were compared using analysis of variance adjusted for Tukey's comparison (SAS Institute Inc. 2005). Treatment effects were considered significant when $P<0.05$.

The PROC CORR procedure of SAS (SAS Institute Inc. 2005) was used to determine correlations between DMI and ADG, AGD, TBP or forage quality factors in 2006. Due to the limited number of replications of each species, the correlation procedure was analyzed for the entire grazing period, not within individual pasture species.

6.3 Results and Discussion

6.3.1 Animal Performance, Grazing Capacity & Total Beef Production

For the pastures established in 1999 and 2003, animal performance data for 2005 and 2006 is presented in Table 6.1 and Table 6.2, respectively. Data from the second

Table 6.1 Steer performance, grazing capacity and total beef production of three perennial pastures established in 1999 and long established crested wheatgrass (control) pastures.

Year	Grazing Period	Control	Hybrid Bromegrass	Meadow Bromegrass	Smooth Bromegrass	SEM[z]
Average daily gain (kg d^{-1})						
2005	1	1.6	1.5	1.2	1.2	0.27
2006	1	1.3	1.4	1.2	1.1	0.20
	2[y]	-	0.7	0.6[x]	0.9	-
Animal grazing days (AUD ha^{-1})[w]						
Mean 2005-2006	Total[v]	113*b*	278*a*	268*a*	232*a*	28.6
Mean 2005-2006	1	113*b*	253*a*	256*a*	207*a*	17.0
2005	1	78*b*	252*a*	235*a*	221*a*	15.8
2006	1	148*b*	254*a*	277*a*	194*ab*	17.2
	2	-	49	49[x]	49	-
	Total	148*b*	303*a*	302*a*	243*ab*	22.3
Total beef production (kg ha^{-1})						
Mean 2005-2006	Total	177*b*	376*a*	319*a*	262*ab*	34.1
Mean 2005-2006	1	177*b*	359*a*	310*a*	241*ab*	30.9
2005	1	125	368	280	270	58.2
2006	1	230*b*	351*a*	340*a*	212*b*	8.0
	2	-	33	36[x]	41	-
	Total	230*b*	384*a*	358*a*	253*b*	14.7

[z]Pooled standard errorof the mean.
[y]Period 2 data not included in statistical analysis.
[x]N=1.
[w]AUD = animal unit day, based on one animal unit (or 455 kg animal).
[v]Yearly AUD ha^{-1}.
a-*b* Least square means in the same row with different letters differ at P<0.05.

Table 6.2 Steer performance, grazing capacity and total beef production of three perennial pastures established in 2003 and long established crested wheatgrass (control) pastures.

Year	Grazing Period	Control	Crested Wheatgrass	Hybrid Bromegrass	Tall Fescue	SEM[z]
Average daily gain (kg d^{-1})						
2005	1	1.7	1.7	0.7	1.3	0.39
2006	1	1.5	1.3	1.2	0.9	0.17
	2[y]	-	1.0	0.8	-	-
Animal grazing days (AUD ha^{-1})[x]						
Mean 2005-2006	Total[w]	113*b*	257*a*	272*a*	302*a*	49.3
Mean 2005-2006	1	113*c*	215*b*	233*ab*	302*a*	32.6
2005	1	78*b*	215*a*	232*a*	229*a*	10.4
2006	1	148*b*	215*b*	235*b*	375*a*	19.5
	2	-	84	78	-	-
	Total	148*b*	299*a*	313*a*	375*a*	24.1
Total beef production (kg ha^{-1})						
Mean 2005-2006	Total	177*b*	363*a*	279*ab*	322*ab*	49.9
Mean 2005-2006	1	177*b*	333*a*	235*ab*	322*a*	34.2
2005	1	125	351	190	316	43.1
2006	1	230	316	280	329	40.7
	2	-	58	89	-	-
	Total	230	374	369	329	49.0

[z]Pooled standard error of the mean.

[y]Period 2 data not included in statistical analysis.

[x] AUD = animal unit day, based on one animal unit (or 455 kg animal).

[w]Yearly AUD ha^{-1}

a-b Least square means in the same row with different letters differ at $P<0.05$.

grazing period was not included in the statistical analysis due to an incomplete data set. Average daily gain for each grazing period was analyzed separately due to significant differences in initial steer weights between grazing periods ($P<0.05$). Initial steer weight at the start of each grazing period was included in the model to adjust for individual steer weights, although the initial weight did not appear to have an effect on the average daily gain of steers within an individual grazing period ($P>0.05$).

Average Daily Gain

Average daily gain was similar for all species in 2005 and the first grazing period of 2006 ($P>0.05$) (Table 6.1 and Table 6.2). Steer performance was expected to be high for crested wheatgrass pastures as this species is known for very high forage quality in the spring (Hart et al. 1983a). Performance of grazing animals is dependent upon a number of factors, including forage quality and intake, with forage intake influenced by forage quality (Hart et al. 1983a). Therefore, grazing perennial grasses in the spring and early summer when forage quality is greatest (Section 4.3.2) and forage intake is not limiting, should result in high animal gains as observed in this study. Previously published ADG data for species included in the current study are presented in Table 6.3. The animal gain data shown in Table 6.3 are similar to the results observed in the present study.

Based on grazing trials at the Melfort Research Station (Melfort, Saskatchewan), Knowles et al. (1993) reported that animal gains were comparable between meadow and smooth bromegrass during the June through August time period, but were superior for meadow bromegrass during the August through October time period. More recent grazing trials at Lanigan, Saskatchewan, have also reported similar ADG between smooth bromegrass, meadow bromegrass and hybrid bromegrass during the summer grazing season (Thompson 2003). Average daily gains ranged from 0.53 to 1.25 kg d^{-1}, 0.78 to 1.36 kg d^{-1} and 0.74 to 1.62 kg d^{-1} for smooth bromegrass, meadow bromegrass and hybrid bromegrass, respectively (Thompson 2003).

Table 6.3 Animal performance of spring and summer grazed perennial grass pastures.

Species	Average daily gain ($kg\ d^{-1}$)	Reference
Crested wheatgrass	0.71-1.17	Hart et al. 1983b
	0.79	Hofmann et al. 1993
	0.89-0.96	Karn et al. 1999
	1.03-1.57	Thompson 2003
Hybrid bromegrass	0.74-1.62	Thompson 2003
Meadow bromegrass	0.72-0.86	Knowles et al. 1993
	0.78-1.36	Thompson 2003
Smooth bromegrass	0.86	Hofmann et al. 1993
	0.53-1.24	Thompson 2003
Tall fescue	0.76-1.03	Hoveland et al. 1991
	1.03	Hoveland et al. 1997
	0.65-0.73	Wen et al. 2002

Variation between the present study and previously reported data may be a result of differences in forage quality, environment or animal grazing characteristics. Additionally, a short grazing period combined with high forage quality and potential compensatory growth of the tester steers may have attributed to the high ADG observed in the present study.

The lack of observed significant differences in the ADG data of steers in this study may be a result of several factors. With only 2 replicates per pasture type and 3 tester steers in each replicate, the experimental design may not have been sensitive enough to detect differences in average daily gain. The steers used in the study were cross-bred animals with individual variation which may have had a greater effect on average daily gain rather than pasture type. Finally, based on the forage quality and yield data presented in Chapter 3, it could be assumed that all pasture species involved in the study provided similar levels of nutrition and available forage, which may explain the observed similar animal gains.

Animal Grazing Days

The grazing capacity data of each pasture type was converted to animal units equivalents (AUE) to account for differences in body weight (AUE = $BW^{0.75}/ 455^{0.75}$) and is expressed as AGD per hectare (animal unit days (AUD) ha^{-1}). In 2005, all bromegrass pastures established in 1999 had a significantly greater number of AGD than the control pastures ($P<0.05$) (Table 6.1). However, in the first grazing period of 2006, only meadow bromegrass and hybrid bromegrass had more AGD than the control pastures ($P<0.05$) (Table 6.1). In the second grazing period of 2006, control pastures and one replicate of meadow bromegrass did not produce sufficient forage for a second grazing period. Total AGD in 2006 was similar for all bromegrasses ($P>0.05$). However, hybrid bromegrass and meadow bromegrass produced a greater number of AGD compared to the control pastures ($P<0.05$).

In 2005, 'AC Goliath' crested wheatgrass, hybrid bromegrass and tall fescue pastures established in 2003 all had significantly greater AGD than the crested wheatgrass control pastures ($P<0.05$) (Table 6.2). In the first grazing period of 2006, tall fescue yielded the greatest number of AGD compared to the other species and control ($P<0.05$) (Table 6.2). In the second grazing period of 2006, there was insufficient regrowth on tall fescue paddocks to allow a second grazing period. When describing tall fescue, Balasko (1986) stated that "much of the increase of tall fescue in recent years has been related to its ability to provide more grazing days per year than other tall-growing cool season grasses." Balasko (1986) also indicated that this species may be well-suited to spring, fall and winter grazing as a lack of palatability may limit its use for summer pasture. Thus, the full potential of tall fescue may not have been illustrated in this study, as it is possible that it was under-utilized due to the timing of the grazing season; however, this species did not provide sufficient regrowth for a second grazing period which indicates that by mid-July, it may have produced all of it potential forage production for the year. As 'Courtenay' is an endophyte-free variety, it is possible that it lacks some drought and heat tolerance of the varieties that contain endophytes, as the endophytes typically improve plant persistence, heat and drought tolerance (Hoveland et al. 1997). Tall fescue may lack the drought tolerance of crested wheatgrass and bromegrass species.

In the second grazing period of 2006, hybrid bromegrass and 'AC Goliath' crested wheatgrass had similar animal grazing days. Overall in 2006, there were no significant differences detected in total number of AGD for 'AC Goliath' crested wheatgrass, hybrid bromegrass or tall fescue ($P<0.05$), however, all species had significantly greater AGD than the control pastures ($P<0.05$). This trend was also evident for total AGD produced by each species in the 2005 and 2006 pooled data.

Despite low AGD for the crested wheatgrass control pastures in the current study, Cohen et al. (2004) demonstrated that it is possible to obtain much higher AGD on crested wheatgrass when it is heavily fertilized (greater than 100 kg N ha^{-1}). In a long-term grazing study evaluating the effects of nitrogen fertilizer on performance of pregnant yearling heifers at Lanigan, Saskatchewan, ADG ranged from 0.34 to 1.23 kg d^{-1} while AGD ranged from 92 to 499 AUD ha^{-1} with higher AGD typically the result of timely precipitation and high nitrogen fertilization (Cohen et al. 2004). In the current study, it appears that 'AC Goliath' with moderate fertility (79 kg N ha^{-1}, 23 kg P ha^{-1}) has comparable animal production potential to the more highly fertilized, older established varieties of crested wheatgrass.

It was expected that over the 2-year study, all treatment pasture varieties established in 1999 and 2003 would produce greater AGD than the control pastures due to mainly stand age differences. Even though there were few significant differences in CDMY, there were large numerical differences between the control pastures and all other pasture types for CDMY (Tables 4.1 and 4.2). For the pooled 2005 and 2006 data, there was only 1113 kg ha^{-1} CDMY difference between the control pastures and smooth bromegrass pastures established in 1999. If an average 340 kg steer consumed 3% of its body weight (10.2 kg) of forage per day, it would be expected that a low yielding pasture (smooth bromegrass) could provide an additional 109 steer grazing days per hectare or 81 animal unit grazing days per hectare compared to the control pastures. Table 6.1 indicates that there is a difference of 119 AUD ha^{-1} between the control pastures and smooth bromegrass pastures, which may be the result of smaller steer size in the first grazing period of 2006 or intake and utilization levels that may be less than 3% of body weight.

Total Beef Production

In 2005, TBP was similar for all pasture types established in 1999 despite a large range of values (P>0.05). In the first grazing period of 2006, meadow bromegrass and hybrid bromegrass paddocks produced greater TBP compared to smooth bromegrass and control pastures (P<0.05). For the entire grazing season of 2006, meadow bromegrass and hybrid bromegrass produced TBP of 384 and 358 kg ha^{-1}, respectively (P<0.05). In grazing trials at the Melfort Research Station (Melfort, Saskatchewan), Knowles et al. (1993) reported TBP of meadow bromegrass and smooth bromegrass pastures to be 458 and 404 kg ha^{-1}, respectively. Thompson (2003) reported AGD and TBP to be similar among hybrid, meadow and smooth bromegrass species. Animal grazing days and TBP values for the current study are considerably higher than those reported by Thompson (2003) but not as high as those reported by Knowles et al. (1993). Differing results between the three studies may be a result of differences in environmental conditions prior to and during the grazing season as well as stand age differences.

In 2005, TBP was similar for all species established in 2003 despite a large numerical difference (P>0.05). In 2006, all pastures established in 2003 produced similar TBP (P>0.05), despite a lack of a second grazing period by the tall fescue and control pastures. Tall fescue produced the greatest TBP due to the large number of grazing days (375 AUD ha^{-1}) and a moderate ADG (0.9 kg d^{-1}) in the first grazing period. Because TBP is the result of both ADG and AGD, and there were a limited number of replications, the standard error of the mean for this parameter was quite large during both years of the study and in both sets of study pastures. In a 3-year grazing study evaluating endophyte-infected and endophyte-free tall fescue in central Georgia, Hoveland et al. (1997) reported TBP to be 99 and 285 kg ha^{-1} and 124 and 159 kg ha^{-1}, for spring and fall grazing periods, respectively. In one year of the study they were not able to obtain a fall (second) grazing period similar to the current study.

In the last 50 years, a number of scientists (Mott 1960; Peterson et al. 1965; Owen and Ridgman 1968; Conniffe et al. 1970; Jones 1974; Jones and Sandland 1974) have tried to model the relationship between stocking rate, animal daily gain and total beef production per hectare. Motts' (1960) first model ($Y_a = k - ab^x$, where Y_a=gain per animal, x= stocking rate, a and b are constants) indicated a curvilinear relationship between stocking rate and gain per animal and per hectare which resulted in a maximum gain per animal and per hectare at a critical (optimum) stocking rate. Further examination of the relationship by Jones and Sandland (1974) resulted in a model that suggested that the relationship between animal gain and stocking rate was linear ($Y_a=a-bx$), while the relationship between animal gain per hectare and stocking rate was quadratic ($Y_h=ax-bx^2$, where Y_h = gain per hectare). The result is a model that suggests that as stocking rate increases, gain per animal decreases and that there is an optimum stocking rate that will maximize total beef production per hectare. Using this model, ADG will be expected to be higher at low stocking rates than at high stocking rates. At either low or high stocking rates, TBP will be expected to be negatively impacted compared to a moderate (optimum) stocking rate.

In a put-and-take grazing system, such as the one used in this grazing trial, it is often difficult to determine a stocking rate (animals per ha) that will hold steady for the duration of the grazing period. However, a measure such as AGD will provide insight as to the carrying capacity of the pasture. For pastures established in 2003, stocking rates varied from 5 steers ha^{-1} for control pastures to 17.5 steers ha^{-1} for tall fescue paddocks throughout the first grazing period of 2006. The combined AGD for tester and put-and-take steers was 148 and 375 AUD ha^{-1} for control and tall fescue pastures, respectively. Although ADG was statistically similar for the two pasture types, there were large numeric differences in ADG between the two grasses (control 1.5 kg d^{-1}; tall fescue 0.9 kg d^{-1}). With higher stocking rates observed for the tall fescue paddocks, overall individual animal gain was decreased compared to the lower stocking rates observed for the control paddocks. However, overall TBP in tall fescue paddocks was much higher than in control paddocks. While this may be somewhat of an unfair comparison due to differences in pasture production and forage quality between the two species which may influence animal intake and overall animal gain, it does suggest that with increased stocking rates, individual animal gain is decreased.

In a similar study evaluating performance of animals grazing meadow foxtail (*Alopecurus pratensis* L.) and timothy (*Phleum pratense* L.), Rode and Pringle (1986) reported that even though timothy had fewer AGD than meadow foxtail, timothy was able to produce 28% greater TBP due to higher individual steer gains. Similarly, Jones and Sandland's (1974) model suggests that individual gain may be sacrificed at higher stocking rates but there is the potential to maximize overall animal gain on the pasture with an optimum stocking rate. Therefore, if one refers to Jones and Sandland's (1974) model, it is likely that the grass species in the current experiments would be consistent with the linear relationship between individual animal gain and stocking rate as well as the quadratic relationship between gain per hectare and stocking rate.

6.3.2 Animal Intake

Forage DMI for steers grazing 1999 established pastures is presented in Table 6.4. The CNCPS model predicted similar DMI between pasture species within grazing period one (P>0.05). In the first grazing period, the CNCPS model predicted the average DMI to be 6.8 kg DM d^{-1} (2.1% of body weight). In the second grazing period, the CNCPS model predicted the average DMI to be 7.7 kg DM d^{-1} (2.0% of body weight).

When DMI was estimated using the alkane method, the estimations of daily DMI were higher than the CNCPS model predictions. Using either the C_{31}:C_{32} or C_{33}:C_{32} ratios resulted in estimated intakes that were similar for all species in the first grazing period (P>0.05) (Table 6.4). For all pasture species included in this experiment, the C_{33}:C_{32} ratio estimated slightly higher DMI than the C_{31}:C_{32} ratio. In the first grazing period, the C_{31}:C_{32} ratio estimated the average DMI for all pasture species to be 8.3 kg DM d^{-1} (2.6% of body weight) while the C_{33}:C_{32} ratio estimated DMI to be 10.0 kg DM d^{-1} (3.2% of body weight). In the second grazing period, the C_{31}:C_{32} ratio estimated the average DMI to be 9.5 kg DM d^{-1} (2.5% of body weight) while the C_{33}:C_{32} ratio estimated DMI to be 11.9 kg DM d^{-1} (3.1% of body weight). Because the concentration of C_{33} alkanes were typically much lower than the concentration of C_{31} in the study grasses (Appendix Tables A10 and A11), a small variation between the concentration of forage C_{33} and concentration of fecal C_{33} tended to elicit a greater response in the equation than the same variation in concentration of C_{31} between the forage and the feces. It is possible that the recovery of C_{33} was slightly higher than the recovery of C_{31} or C_{32} which would also lead to higher DMI estimates than if the C_{32} had a greater recover than C_{33} or if the C_{31} alkanes had a greater recovery than C_{32}. Thus, the C_{33}:C_{32} ratio may have

Table 6.4 Comparison between predicted dry matter intake (DMI) using the Cornell Net Carbohydrate and Protein System (CNCPS) and two alkane ratios for steers grazing pastures established in 1999.

	CNCPS Predicted DMI		Alkane Predicted DMI			
			$C_{31}:C_{32}$		$C_{33}:C_{32}$	
	DMI ($kg\ d^{-1}$)	% of Body Weight	DMI ($kg\ d^{-1}$)	% of Body Weight	DMI ($kg\ d^{-1}$)	% of Body Weight
First Grazing Period						
Control	6.9	2.1	9.5	2.9	9.6	2.9
Hybrid Bromegrass	6.7	2.1	7.9	2.5	9.1	2.9
Meadow Bromegrass	6.7	2.1	6.8	2.1	9.3	3.0
Smooth Bromegrass	6.7	2.1	8.8	2.8	12.1	3.8
SEM[z]	0.09	0.01	0.82	0.25	1.04	0.34
p-value	0.48	0.21	0.25	0.28	0.27	0.31
Second Grazing Period[y]						
Control	--	--	--	--	--	--
Hybrid Bromegrass	7.9	2.0	10.0	2.6	11.8	3.0
Meadow Bromegrass[x]	7.4	2.0	8.7	2.3	11.8	3.1
Smooth Bromegrass	7.7	2.0	9.8	2.5	12.1	3.1

[z]Pooled standard error of the mean.
[y]Data was not statistically analyzed.
[x]N=1.

tended to over-predict DMI while the C_{31}:C_{32} ratio may have tended to under-predict dry matter intake.

The predicted DMI for 2003 established pastures is presented in Table 6.5. The CNCPS predicted similar DMI between all species in the first grazing period (average 6.8 kg DM d^{-1} or 2.1% of body weight) (P>0.05) and in the second grazing period (average 7.7 kg DM d^{-1} or 2.0% of body weight). When intake was estimated using either the C_{31}:C_{32} or C_{33}:C_{32} alkane ratios, DMI was again greater than the CNCPS predictions.

When DMI was estimated using the C_{31}:C_{32} ratio in the first grazing period of 2006, steers on the crested wheatgrass control pastures had greater DMI than steers on the 'AC Goliath' crested wheatgrass pastures (P<0.05). When the C_{33}:C_{32} ratio was used to estimate DMI in the first grazing period, control pastures and hybrid bromegrass pasture steers had similar DMI (P>0.05). However, both sets of animals had greater DMI than steers grazing either 'AC Goliath' crested wheatgrass or tall fescue pastures (P<0.05).

When the average C_{31}:C_{32} estimated intake is compared to the average C_{33}:C_{32} estimated intake in the first grazing period, the C_{31}:C_{32} ratio prediction was 7.3 kg DM d^{-1} (2.3% of body weight) while the average C_{33}:C_{32} ratio prediction was 1 kg greater at 8.3 kg DM d^{-1} (2.6% of body weight). In the second grazing period, the C_{31}:C_{32} ratio estimated the average DMI to be 10.7 kg DM d^{-1} (2.8% of body weight) while the C_{33}:C_{32} ratio estimated the average DMI to be 11.0 kg DM d^{-1} (2.9% of body weight). Both alkane ratios estimated greater DMI values than the CNCPS predictions. The lower DMI estimates using the CNCPS model may be a result of inaccurate descriptions of feedstuffs (ie. ruminal NDF, starch, CP and protein solubility pool sizes and digestion rates) or animal body composition (ie. percentage of fat) as these were not specifically measured in the current study (Fox et al. 1995).

The concentration of alkanes in the hand-plucked forage samples from the first and second grazing periods of 2006 are presented in Appendix Tables A10 and A11, respectively. The concentrations of natural alkanes observed in this study were relatively similar to alkane concentrations reported for cultivated grasses by Boadi et al. (2002). In general, C_{29} and C_{31} concentrations were greatest in the current study grasses and were the only alkanes that exceeded 50 mg kg DM^{-1} which was the minimum concentration of

Table 6.5 Comparison between predicted dry matter intake (DMI) based on the Cornell Net Carbohydrate and Protein System (CNCPS) and two alkane ratios for steers grazing pastures established in 2003.

	CNCPS Predicted DMI		Alkane Predicted DMI			
			$C_{31}:C_{32}$		$C_{33}:C_{32}$	
	DMI ($kg\ d^{-1}$)	% of Body Weight	DMI ($kg\ d^{-1}$)	% of Body Weight	DMI ($kg\ d^{-1}$)	% of Body Weight
First Grazing Period						
Control	6.9	2.1	9.5*a*	2.9	9.6*a*	2.9*ab*
Crested Wheatgrass	6.7	2.1	5.5*b*	1.8	6.8*b*	2.2*bc*
Hybrid Bromegrass	6.9	2.1	6.2*ab*	1.9	9.9*a*	3.0*a*
Tall Fescue	6.8	2.1	7.8*ab*	2.4	6.8*b*	2.1*c*
SEM[z]	0.08	0.01	0.66	0.21	0.42	0.14
p-value	0.39	0.22	0.04	0.05	0.01	0.02
Second Grazing Period[y]						
Control	--	--	--	--	--	--
Crested Wheatgrass	7.6	2.0	9.9	2.6	12.3	3.2
Hybrid Bromegrass	7.7	2.0	11.4	2.9	9.6	2.5
Tall Fescue	--	--	--	--	--	--

[z]Pooled standard error of the mean.

[y]Data was not statistically analyzed.

alkanes in the forage that Casson et al. (1990) considered to be necessary to obtain accurate estimates of forage intake using the alkane methodology. With the exception of tall fescue and 'AC Goliath' crested wheatgrass in the first grazing period, the concentration of C_{33} did not exceed 50 mg kg DM^{-1} in this trial. Thus, using the C_{33}:C_{32} ratio to estimate forage intake may result in erroneous intake estimations for the forages included in this study (Casson et al. 1990; Boadi et al. 2002). However, in a study by Moshtaghi Nia and Wittenberg (2002) which fed meadow bromegrass hay, alfalfa hay and barley grain to beef steers, it was reported that even though C_{33} concentration in the forage was less than 50 mg kg DM^{-1}, intake estimations using C_{33}:C_{32} were not significantly different than intake estimations using either total fecal collection or the C_{31}:C_{32} ratio, with the exception of the meadow bromegrass-barley grain diet.

Much of the early research which examined the potential for natural and dosed alkanes to estimate intake and digestibility in sheep indicated that fecal recovery of alkanes with adjacent chain lengths (ie. C_{31} and C_{32} or C_{32} and C_{33}) have similar recoveries (Mayes et al. 1986; Dove and Mayes 1991; Vulich et al. 1991; Dove et al. 2002). Hendricksen et al. (2002) found a strong correlation (R=0.96) between the variation in the recoveries of the alkane pairs used to estimated DMI and the variation in the accuracy of the estimate of dry matter intake. In a review of alkanes for the estimation of DMI and diet composition, Dove and Mayes (1996) reported that for every percentage unit difference in recovery between the alkane pair, there is a 1.25% difference in the DMI estimation. Thus, it is important that alkane pairs with similar recovery are used to estimate dry matter intake.

In Brahman-cross cattle fed buffelgrass (*Cenchrus ciliaris* L.) and alfalfa, Hendricksen et al. (2002) reported that alkane recovery was variable between animals, experiments and diet treatments. Similarly, in Holstein steers, Moshtaghi Nia and Wittenberg (2002) reported that the recovery of dosed and natural alkanes was incomplete and influenced by diet. Specifically, fecal recovery of the dosed alkane C_{32} was higher compared to either C_{31} or C_{33}, which resulted in lower estimates of dry matter intake using the alkane method compared to the total fecal collection method. In contrast, Unal and Garnsworthy (1999) reported that there was no significant effect of diet or cow on fecal recovery of C_{32}, C_{33} or C_{36} alkanes. Dove and Mayes (1991) indicated that the recovery of alkanes in sheep is higher and less variable compared to cattle Due to the extensive nature of the current grazing experiment, it was assumed that adjacent alkanes had similar fecal recovery but this assumed recovery may affect the overall accuracy of DMI estimates if the alkanes used to estimate DMI did not have similar fecal recovery. Therefore, this technique may have limitations for estimating DMI in grazing cattle.

In sheep, C_{33}:C_{32} has commonly been shown to give the most accurate estimate of dry matter intake (Mayes et al. 1986; Dove et al. 2000). Despite a small bias for C_{33}:C_{32} to overestimate DMI and C_{31}:C_{32} to underestimate DMI, Vulich et al. (1991) reported no significant differences between actual and estimated DMI values. In dairy cattle, DMI estimates using either C_{31}:C_{32} or C_{33}:C_{32} alkane ratios were similar to known DMI when measured release rates from a CRD were used to estimate dry matter intake (Ferreira et al. 2004). Unal and Garnsworhty (1999) also reported no significant differences between DMI estimated using C_{33}:C_{32} or C_{33}:C_{36} ratios and actual DMI, with C_{33}:C_{32} being slightly more accurate than C_{33}:C_{36}. Similarly, Charmley et al. (2003) reported DMI estimations derived using either C_{33}:C_{32} and C_{33}:C_{36} alkane ratios were similar to actual dry matter intake. In their study, C_{31}:C_{32} significantly under-estimated DMI while C_{33}:C_{32} gave the best estimate of intake (Charmley et al. 2003). These results are similar to the current study. The majority of studies already cited involved the use of confined pen feeding. For dairy cows grazing perennial ryegrass, Smit et al. (2005) recommended the use of C_{33}:C_{32} ratio to estimate dry matter intake instead of C_{31}:C_{32} because intake estimations were shown to be less variable with the former ratio. However, Smit et al. (2005) also indicated that alkane ratios tended to over-estimate forage intake compared with the energy requirements of the animals.

Based on the previously reviewed literature, both alkane ratios were used in this study for the determination of DMI as it does not appear that one ratio is consistently more accurate than the other ratio for intake determination in grazing cattle. Under grazing conditions, true forage intakes (actual intake) are extremely difficult to obtain because alternative methods for estimating intake and comparison purposes may be less reliable or possibly inferior (Dove and Mayes 1996), laborious (Smit et al. 2005) and time consuming to measure. Thus, it may be more useful to compare alkane DMI estimates to DMI estimates determined using prediction equations such as the CNCPS model.

The accuracy of the CNCPS model to predict intake is limited by the accuracy of input parameters, including both animal and feed characteristics (Fox et al. 2003). While many of the animal characteristics (ie. breed type, body size, maturity, expected body composition) will be very similar between study animals in this grazing trial, the accuracy to which the pasture types are described may be limited because laboratory analysis of the consumed forage did not fractionate the carbohydrate and protein components. In addition, there would have been differences between digestion and passage rates within grazing animals. Because a feed type in the CNCPS feed library (Pasture-Grass-Summer-Well Managed) was utilized as a base feed and only modified for CP, NDF and ash content without changing any other feed characteristics, it was expected that DMI predictions would be very similar between pasture types. In addition, all steers in the trial were of similar body weight, maturity, expected body composition and similar environment, which would have minimized any individual animal differences in the model. Thus, as the model was able to predict what appears to a realistic average DMI for the study animals, the measured chemical and biological characteristics of the available forage in each pasture do not appear to be detailed enough to elicit differential predictions in the model. Without further validation of the forage characteristics, it appears that this model is not sensitive enough to predict differences in DMI based on only CP, NDF and ash content. Therefore, despite a number of concerns regarding the ability of the alkane technique to accurately predict DMI in grazing cattle, it appears that the CNCPS model may not be able to provide any more accurate predictions without extensive validation work or more detailed forage nutritive input data.

Estimation of DMI by the CNCPS model includes body weight as a major factor in the prediction calculation. Since the study steers were of similar body weight in each grazing period, the CNCPS model predicted comparable intake for all treatments established in either 1999 or 2003 (Table 6.4 and Table 6.5, respectively). Similar to the results of this study, Chaves et al. (2006) found that the CNCPS model predicted similar DMI in heifers grazing either alfalfa or grass pastures even though there was a greater contrast in pasture type, chemical composition and digestibility between pasture types compared to the current study. Chaves et al. (2006) also reported higher DMI predictions using the CNCPS model compared to the alkane technique. However, the authors also concluded that the intake estimations produced using the CNCPS model as compared with the alkane intake estimations appeared more realistic, particularly in the alfalfa pastures.

Early work by Campling et al. (1961) which studied factors affecting the voluntary intake of food by cows, indicated that with less digestible roughages such as straw, DMI is decreased compared to more digestible roughages such as hay. Furthermore, decreased DMI associated with low quality roughages was suggested to be the result of increased retention time in the reticulo-rumen which is regulated by the rate of digestion. Based on this theory, the more digestible forages in this study should have greater DMI than less digestible forages. Horn et al. (1979) found evidence supporting this theory as forage intake of midland bermudagrass (*Cynodon dactylon* (L.) Pers.) was positively correlated with *in vitro* organic matter digestibility. This was not the case for the pastures evaluated in this study, as there were no significant relationships between intake and IVOMD for the pastures established in 1999 (Appendix Table A12). Additionally, the pastures established in 2003 indicated that there was an inverse relationship between intake and digestibility (Appendix Table A13). Intake data presented in Table 6.4 for pastures established in 1999 suggest that it is likely that those pastures were of similar digestibility and chemical composition (Table 4.3 - 4.6) and not likely to affect dry matter intake.

For the pastures established in 2003, there were significant negative correlations between DMI and IVOMD and DMI and crude protein. These results are in contrast to Milford and Minson (1965) who found that CP and DMI were not well correlated when CP concentration in the diet was above seven per cent. The results of the current study also indicate that there are significant positive correlations between DMI and NDF and DMI and ADF which may suggest that fiber content of the study grasses did not limit intake as some theories may suggest. Thus, the chemical composition of the forage, particularly the fiber content, may not be the primary regulator of DMI but intake is more likely a result of chemostatic regulation (Conrad 1966), metabolic factors (Illius and Jessop 1996) and energy balance in the animal (Ketelaars and Tolkamp 1992). Forbes

(1996) provided a review of the integration of regulatory signals which control forage intake in ruminants.

Van Soest (1965) suggested that there is difficulty in comparing DMI to chemical composition because animal individuality plays a large role. Evaluating West Virginia forages, Van Soest (1965) reported that there was a significant relationship between DMI and either chemical composition or digestibility in only four of seven species examined, with there being considerable differences between species. Overall, the correlation coefficients were highly significant for ADF (R=-0.53), NDF (R=-0.65), protein (R=0.54), cellulose (R=-0.59) and digestibility (R=0.66). Van Soest also suggested that cell-wall constituents (NDF fraction) may limit intake when their concentration increases to more than 55 to 60% of the dry matter due to the effects of rumen fill. For the pastures evaluated in the current study, NDF remained below 55% for all species at the start of the first grazing period and started to approach or exceed 55% at the middle of the first grazing period. Thus, it appears that the concentration of NDF may not have been great enough to limit intake. In the second grazing period of 2006, CP was the only parameter to be significantly correlated to dry matter intake ($P<0.05$). During this period, other factors such as herbage availability may have played a role in determining animal intake. Van Soest (1965) also suggests that it is difficult to decide what is the causative factor affecting intake when all chemical constituents are evaluated. Other factors affecting intake, such as palatability and digestible energy intake (Crampton 1957) will detract from the relationship between dry matter intake and digestibility (Van Soest 1965).

With the exception of the CNCPS model predictions of DMI for the pastures established in 1999, there does not appear to be a relationship between ADG and DMI for the pastures established in this grazing study ($P>0.05$). For both the pastures established in 1999 and 2003, there is a negative correlation between AGD and DMI with the exception of the C_{33}:C_{32} alkane ratio for predicting intake. Increased AGD may be associated with higher stocking rates and potentially less forage available for individual animals which may result in decreased DMI per individual animal (Vavra et al. 1973). Not including the correlation between DMI calculated using the C_{31}:C_{32} ratio in the 1999 pastures, there was a negative relationship between TBP and dry matter intake. With increased AGD (increased stocking rates), there is generally a decrease in individual animal weight gains which may be a result of decreased diet selection and overall decreased dry matter intake. However, an increase in AGD may also result in increased beef production per hectare (Vavra et al. 1973; Jones and Sandland 1974). Based on this theory, it was realistic to expect that there is a relationship between TBP and individual dry matter intake.

Recent studies by Basarab et al. (2003) and Nkrumah et al. (2006) which evaluated the performance of growing cattle have indicated that DMI may not be a useful indicator of feed efficiency and animal performance. They suggest that residual feed intake (RFI) may be a superior tool for selection of animals that are more energetically efficient without sacrificing animal gain. By definition, RFI is the difference between metabolizable energy intake and metabolizable energy required for gain and maintenance (Basarab et al. 2003). In other words, it is the difference between the animal's actual intake and its expected intake based on its body weight and growth rate over a period of time. Variation in RFI among animals of a similar phenotype is likely the result of differences in metabolizability (mainly digestibility and methane production), heat production and energy retention among animals (Nkrumah et al. 2006). Animals with a low or negative RFI are more efficient that those with a high or positive residual feed intake. Thus, the estimation of DMI of individual steers (as performed in the current study) may not be a true reflection of differences in DMI due to the effect of pasture species, as the confounding effect of individual animal variation may provide a significant source of error. In future studies, using animals that have similar RFI may minimize this source of error.

Finally, a lack of significant differences in this study is likely the result of minimal pasture and animal replication. Previous chapters have indicated uneven topography and variable establishment between pasture replicates. In addition, differences in botanical composition of the diet, grazing behavior, metabolism and utilization of ingested nutrients between animals may have been a factor. Finally, to detect significant differences between pasture types, more replication is needed.

6.4 Conclusions

From the results of this grazing study, it can be concluded that despite observed numerical differences in the data, there are no overall significant differences between the bromegrass species established in 1999 for steer ADG, AGD or total beef production produced per hectare. Similarly, there were no significant differences in ADG, AGD or TBP between 'AC Goliath' crested wheatgrass, hybrid bromegrass and tall fescue pastures established in 2003. Furthermore, it must be noted that tall fescue may have limited application in Western Canada as a summer pasture species, as pasture regrowth was minimal which limits the potential for a second grazing period. All study varieties showed greater potential for increased beef production compared to the long established crested wheatgrass pastures.

When DMI was estimated using either the alkane technique or the CNCPS model, intake was similar between the bromegrass pastures seeded in 1999 and the control pastures. When the same methods calculated DMI for pastures established in 2003, the alkane technique predicted higher intakes for control pastures and hybrid bromegrass pastures compared to 'AC Goliath' crested wheatgrass and tall fescue pastures in the first grazing period of 2006. Correlations between DMI and ADG, AGD, TBP, CP, NDF, ADF and IVOMD indicated that there were few consistent relationships with DMI in this study, particularly in the second grazing period of 2006. As the published literature suggests, there are a number of factors affecting intake and intake is not based primarily on one factor. The results of this study indicate there may be a relationship between chemical composition and intake, but it may not be limited to physical fill effects as earlier research would suggest. It also appears that as stocking rate increases on a pasture, there may potentially be less forage available per animal which could further impact individual intake and overall beef production. Without further validation of the intake data, it is difficult to measure the accuracy of these estimations. However, until a better technique is developed and is available for use, the alkane technique may be adequate for detecting large differences in intake between perennial grass pastures in Western Canada.

7 Economic Evaluation of Five Perennial Forage Species Under Grazed Conditions

7.1 Introduction

Pasture forage is an integral part of the beef sector in Western Canada. While forage production factors such as yield and quality are important for determining pasture carrying capacity and animal performance, it is also important to consider the economic costs and returns of these systems. Ultimately, producers need pastures to produce a saleable product. For most producers, that saleable product is kilograms of beef. Depending on the type of livestock operation producers manage, pasture production may be used as a feed source to maintain the pregnant beef cow or grow a weaned calf. In a survey of Saskatchewan beef producers in 2004, Highmoor (2005b) reported that the average direct cost of feeding and bedding cows was $1.00 per cow per day. In addition, the average yardage cost during the same winter-feeding period was $0.79 per cow per day. This total cost of $1.79 per cow per day was $1.00 more per cow per day than the average grazing cost of $0.80 per cow per day. Lang (2006b) reported that the average grazing cost ranged from $0.69 to $0.80 per cow per day for 2002 to 2005, compared to the direct cost of winter feed which ranged from $0.99 to $1.28 per cow per day.

In a traditional feedlot system, Highmoor (2005a) reported the cost per kg of gain to be $2.24 for 12 producers who fed on average 487 head gaining 0.6 kg per day for 156 days. Grazing systems may also be used to background feeder cattle as an alternative to the traditional feedlot system. Grazing perennial forages may be a more cost effective method to background animals than traditional drylot feeding systems.

With the abolishment of the Crow rate in 1995, there has been a shift for many producers to increase their perennial forage acreage and/or the number of livestock they own. When the Crow rate was abolished, freight rates increased and many grain farmers looked for ways to use their grain on-farm (ie. feed for livestock). However, for many producers this change has been limited by cash flow restrictions, lack of infrastructure or a lack of desire to raise livestock. Furthermore, if producers do not have significant land base to sustain a livestock operation or readily accessible water sources suitable for livestock, grazing may be not be a feasible option for producers. It is also important to note that the demand for commodities produced by annual cropping systems has increased for both human and animal consumption and more recently for the bioenergy industry (Saha and Trant 2008). Before a producer decides what is the best option for their farming operation it is important to consider alternative land uses and weigh the advantages, disadvantages and economics of all options.

This chapter will evaluate the economic returns of five perennial pasture species for grazing compared to the economic returns for annual cropping at Lanigan, Saskatchewan in the 2005 and 2006 growing season. The revenues, costs and net return to equity, labor and personal draw (take-home pay or cash available for withdrawal from a business to pay personal living expenses) were determined for pastures established in 1999 and 2003, along with the revenues, costs and returns which would have resulted had the land been annually cropped with spring wheat or feed barley. This work is an extension of research conducted at the Western Beef Development Center's Termuende Research Ranch in 2000 and 2001 (Thompson and Lardner 2002).

7.2 Materials and Methods

7.2.1 Grazing Systems

Pasture Management

Two separate experiments were included in this study. In 1999, two 0.8 ha replicates each of meadow bromegrass cv. Paddock, smooth bromegrass cv. Carlton and hybrid bromegrass cv. AC Knowles were established at the Termuende Research Ranch near Lanigan, Saskatchewan. In 2003, two 0.8 ha replicates each of crested wheatgrass cv. AC Goliath, hybrid bromegrass cv. AC Knowles and tall fescue cv. Courtenay were established adjacent to the pastures established in 1999. Pasture establishment details were previously described in Chapter 3. Central to the experimental pastures, two 0.8 ha paddocks of long established crested wheatgrass acted as control pastures.

In May of 2005 and 2006, all paddocks were fertilized with 79 kg actual N ha^{-1} and 23 kg actual P per hectare. In both years, grazing commenced when available forage was approximately 20 cm high (4-5 leaf stage). Crested wheatgrass pastures were grazed in May due to the growth characteristics and early maturity of this species (Appendix

Table A2). The mid-season species were grazed June through July. Only one grazing period occurred in 2005, however, in 2006, a second grazing period occurred on both replicates of 'AC Goliath' crested wheatgrass pastures (mid-July to mid-August) and on both replicates of hybrid and smooth bromegrass and one replicate of meadow bromegrass (mid-August through mid-September).

British × Continental steers were weighed and randomly allocated to one of 7 pasture types according to body weights. Steers were weighed over two consecutive days at the start and end of trial and every 7 d throughout the course of the grazing periods. For pastures established in 1999, the initial steer weights of tester animals averaged 338 ± 17, 305 ± 21 and 381 ± 27 kg (mean ± SD) for the 2005 grazing period, first and second grazing period in 2006, respectively. For the pastures established in 2003, the initial steer weights of tester animals averaged 336 ± 13, 311 ± 16 and 385 ± 21 kg in the 2005 grazing period, first and second grazing period in 2006, respectively. Steers were weighed at a consistent time each day, but were not fasted due to the lack of appropriate holding facilities.

Pastures were managed using a 'put and take' grazing system (Mott and Lucas 1952) with three tester steers per paddock to obtain grazing periods that were of minimum three week duration. Pastures were allowed sufficient rest (minimum of 5 weeks) between grazing periods.

Average daily gain (ADG) of tester steers and animal grazing days (AGD) were used to determine total beef production per hectare (TBP) (Chapter 6). Total beef production for each study variety was presented in Table 6.1 and Table 6.2 for pastures established in 1999 and 2003, respectively.

Revenue

Revenue generated in the perennial forage systems was the result of custom grassing feeder steers based on per kilogram of weight gain. In this study, the custom grassing rate was \$0.858 per kilogram of weight gain and then multiplied by TBP (kg ha^{-1}) to determine revenue generated in each paddock.

Costs

In the grazing system, variable or operating costs included supplemental feed and minerals, veterinary and medicine costs, fertilizer and custom work. Fixed costs in the grazing system included fence and water repair, fence and water depreciation and investment, insurance and licenses, grass establishment costs and land rent. Seed and grass establishment costs were not included for the long established stand of crested wheatgrass (control pastures) due to the excessive age of the stand. 'AC Goliath' crested wheatgrass was assumed to have a stand life of 20 years; therefore, all seed and grass established costs were amortized over 20 years even though producers would likely incur those costs in the first year establishment. The remaining tall fescue and bromegrass pastures were assumed to have a stand life of 12 years; costs were amortized over 12 years for those varieties.

Seeding rates for these pastures were based on recommended seeding rates by seed distributors and growers. Seeding rates for all study species were meadow bromegrass at 11.2 kg ha^{-1}, smooth bromegrass at 9 kg ha^{-1}, hybrid bromegrass at 11.2 kg ha^{-1}, crested wheatgrass at 10 kg ha^{-1} and tall fescue at 5 kg ha^{-1}. Pastures were seeded using disk press drills after areas were disked twice with tandem disks. Based on the herbicide application as described in Chapter 3, there were one-time weed control costs of \$109.84 ha^{-1} (herbicide costs) (Saskatchewan Ministry of Agriculture (SMA) 2004a) and \$12.15 ha^{-1} (application costs) (SMA 2004b). All field work was valued at the average custom rate per hectare (which included the power unit, implement and labour) from the *Farm Machinery Custom and Rental Rate Guide* (SMA 2004b). At time of seeding, 56 kg actual N ha^{-1} was placed with the seed. In following years, all pastures were fertilized with 79 kg actual N ha^{-1} and 22 kg actual P ha^{-1} of liquid fertilizer. All fertilizer prices and costs of custom application were based on spring quotes from Blair's Fertilizer Ltd., Lanigan, SK.

Supplemental salt and minerals was estimated to be \$8.08 ha^{-1} (Lardner 2004) and veterinary and medicine costs were estimated to be \$12.35 per hectare. Fence and water repair costs were estimated to be \$3.43 ha^{-1} $year^{-1}$ and fence and water depreciation and investment was estimated to be \$11.14 ha^{-1} $year^{-1}$ (SMA 2006a). In addition, insurance and licenses were estimated to cost \$4.69 ha^{-1} (SMA 2006a). Finally, the cost of land rent was assumed to be \$61.75 ha^{-1} in both years of the study.

7.2.2 Annual Cropping

Revenue

For comparison, revenue from the annual cropping systems was estimated if either spring wheat or feed barley had been grown on the same land base. Revenue was estimated by taking the average bushel yield per hectare for the Lanigan area (Rural Municipality 309) from the Saskatchewan Ministry of Agriculture web-site (www.agriculture.gov.sk.ca) for 2005 and 2006. The bushel yield was multiplied by the Canadian Wheat Board's final price for spring wheat (1 CWRS 13.5) or feed barley (1 CW Feed Barley) less the freight rate for Lanigan. Freight rate was not deducted for feed barley as it was assumed that it would be sold into a local market.

Costs

Estimation of the costs to annual crop the land was calculated by using Saskatchewan Ministry of Agriculture's 2005 and 2006 Crop Planning Guides for the Black Soil Zone. Costs were based on the crop being direct seeded into stubble. Variable costs included seed, chemical, fertilizer, machinery fuel and repairs, crop insurance premium, custom work, interest, utilities, office and miscellaneous expenses. Fixed costs included building repair, machinery and building depreciation and interest, insurance, licenses and land rent (SMA 2005; SMA 2006b).

7.2.3 Statistical Analysis

Revenue, variable costs, fixed costs, total costs and net return to labor, equity and personal draw were compared between pasture species established in 1999 or 2003 by analysis of variance using SAS Mixed Model (SAS Institute Inc. 2005). Year was considered to be a random blocking factor. Where significant differences were indicated ($P<0.05$), means were separated at the 5% level of significance using Tukey's procedure (Steel et al. 1997). Revenues, costs and net returns for the annual crops, spring wheat and feed barley, were not compared in the statistical analysis due to a lack of actual measured data and replication. The annual crops information were included in the study for discussion purposes only.

7.3 Results and Discussion

Pastures established in 1999

Based on TBP reported in Table 6.1, the average revenue for the 2005 and 2006 grazing seasons was \$151.87, \$322.18, \$273.49 and \$217.93 ha^{-1} for the control, hybrid bromegrass, meadow bromegrass and smooth bromegrass pastures, respectively (Table 7.1). When both years of data were pooled, hybrid bromegrass and meadow bromegrass pastures had greater revenue than the control pastures ($P<0.05$). In 2005, there was a wide variation in TBP between pasture replicates which resulted in high standard error of the means and a lack of significant differences in revenues between study species. In 2006, hybrid bromegrass and meadow bromegrass produced greater revenue than either the smooth bromegrass or control pastures ($p<0.05$).

Variable costs were similar between all species in both years of the study ($P<0.05$). A slight increase in the price of fertilizer between 2005 and 2006 increased the variable pasture costs minimally (\$0.66 ha^{-1}). Fixed costs were significantly different between pasture species ($P<0.05$), due to slight differences in the price of grass seed and seeding rates between species. Fixed costs were lowest for the control pastures ($P<0.05$) because there were no stand establishment costs included for those paddocks. Similarly, total costs were significantly different between species as this parameter mimicked the differences in fixed costs between species ($P<0.05$). Overall, the hybrid bromegrass pastures had the greatest total costs, followed by meadow bromegrass, smooth bromegrass and the control pastures at \$230.95, \$229.41, \$228.53 and \$206.19 ha^{-1}, respectively.

Overall, hybrid bromegrass generated the greatest net return to labor, equity and personal draw at \$91.24 per hectare which was significantly greater than the control pastures ($P<0.05$). The remaining species, meadow bromegrass (\$44.09 ha^{-1}) and smooth bromegrass (-\$10.59 ha^{-1}), generated net returns similar to the control pastures (-\$54.32 ha^{-1}) ($P>0.05$). The average net return for both years of the study was negative for

Table 7.1 Summary of revenue, costs and net returns associated with grazing perennial grasses established in 1999 at Lanigan, Saskatchewan.

	Grazing System					Annual Cropping	
	Control	Hybrid Bromegrass	Meadow Bromegrass	Smooth Bromegrass	SEM[z]	Spring Wheat	Feed Barley
2005-2006 Mean							
Revenue (\$ ha^{-1})	151.87*b*	322.18*a*	273.49*a*	217.93*ab*	28.76	371.84	375.43
Variable Costs (\$ ha^{-1})	125.17	125.17	125.17	125.17	0.04	253.20	238.15
Fixed Costs (\$ ha^{-1})	81.02*d*	105.77*a*	104.23*b*	103.35*c*	0.00	148.88	148.88
Total Costs (\$ ha^{-1})	206.19*d*	230.95*a*	229.41*b*	228.53*c*	0.04	402.07	387.03
Net Return to Labor, Equity & Personal Draw (\$ ha^{-1})	-54.32*b*	91.24*a*	44.09*ab*	-10.59*ab*	28.56	-30.23	-11.60
2005							
Revenue (\$ ha^{-1})	106.82	315.32	240.24	231.66	49.90	264.03	199.06
Variable Costs (\$ ha^{-1})	124.84	124.84	124.84	124.84	0.00	243.04	229.55
Fixed Costs (\$ ha^{-1})	81.02*d*	105.77*a*	104.23*b*	103.35*c*	0.00	148.47	148.47
Total Costs (\$ ha^{-1})	205.86*d*	230.62*a*	229.08*b*	228.02*c*	0.00	391.51	378.03
Net Return to Labor, Equity & Personal Draw (\$ ha^{-1})	-99.03	84.70	11.17	3.46	49.90	-127.48	-178.96
2006							
Revenue (\$ ha^{-1})	196.91*b*	329.05*a*	306.74*a*	204.21*b*	13.73	479.65	551.79
Variable Costs (\$ ha^{-1})	125.50	125.50	125.50	125.50	0.00	263.35	246.74
Fixed Costs (\$ ha^{-1})	81.02*d*	105.77*a*	104.23*b*	103.35*c*	0.00	149.28	149.28
Total Costs (\$ ha^{-1})	206.51*d*	231.27*a*	229.73*b*	228.85*c*	0.00	412.63	396.02
Net Return to Labor, Equity & Personal Draw (\$ ha^{-1})	-9.60*b*	97.78*a*	77.01*a*	-24.64*b*	13.73	67.02	155.77

[z]Pooled standard error of the mean.

a-c Least square means in the same row with different letters differ at $P<0.05$.

smooth bromegrass and the control pastures. Thus, it may be determined that smooth bromegrass is not best suited as a grazing species in this region. In 2005, a wide variation in total beef production and revenue was reflected by a large standard error of the means and resulted in similar net returns between all pasture species ($P>0.05$). In 2006, hybrid bromegrass and meadow bromegrass produced greater net returns compared to smooth bromegrass and the control pastures ($P<0.05$).

In a previous report of the production economics of the bromegrass species established on this site, Thompson and Lardner (2002) indicated that the average net return to labor, equity and personal draw was \$36.57, \$64.94, \$78.92 and \$71.80 ha^{-1} for the control pastures, meadow bromegrass, smooth bromegrass and hybrid bromegrass, respectively, in 2000 and 2001. In the current evaluation of economic returns from these pastures, hybrid bromegrass and meadow bromegrass were the only species that still maintained a positive net return in both years of the study. Thus, as the smooth bromegrass and long established crested wheatgrass stands mature, there may be a decrease in production that would lead to a decrease in overall net return. In addition, the previous study in 2000 and 2001 was based on revenue of \$0.88 per kilogram of gain whereas the current study was based on revenue of \$0.86 per kilogram of gain; therefore, it would be expected that returns would remain similar or slightly decrease due to the difference in the custom grazing rate.

Pastures established in 2003

For pastures established in 2003, the average revenue generated for 'AC Goliath' crested wheatgrass, hybrid bromegrass, tall fescue and the control pastures was \$311.03, \$239.39, \$276.27 and \$151.87 ha^{-1}, respectively (Table 7.2). 'AC Goliath' crested wheatgrass generated significantly greater revenue than the control pastures ($P<0.05$) but revenue was not significantly different than the hybrid bromegrass or tall fescue pastures ($P>0.05$). In the individual years of the study, there were no significant differences in revenues produced due to the large variation in TBP between replicates.

Variable costs were similar between all pastures species ($P>0.05$) and averaged \$125.17 ha^{-1} over the two years of the study. Fixed costs were different between species due to differences in grass establishment and seed costs ($P<0.05$). The 'AC Goliath'

Table 7.2 Summary of revenue, costs and net return associated with grazing perennial grasses established in 2003 at Lanigan, Saskatchewan.

	Grazing System					Annual Cropping	
	Control	Crested Wheatgrass	Hybrid Bromegrass	Tall Fescue	SEM[z]	Spring Wheat	Feed Barley
2005-2006 Mean							
Revenue (\$ ha^{-1})	151.87*b*	311.03*a*	239.39*ab*	276.27*ab*	42.82	371.84	375.43
Variable Costs (\$ ha^{-1})	125.17	125.17	125.17	125.17	0.04	253.20	238.15
Fixed Costs (\$ ha^{-1})	81.01*d*	93.36*c*	105.77*a*	101.78*b*	0.00	148.88	148.88
Total Costs (\$ ha^{-1})	206.18*d*	218.54*c*	230.94*a*	226.95*b*	0.33	402.07	387.03
Net Return to Labor, Equity & Personal Draw (\$ ha^{-1})	-54.32*b*	92.49*a*	8.44*ab*	49.33*ab*	42.56	-30.23	-11.60
2005							
Revenue (\$ ha^{-1})	106.82	301.16	162.60	270.70	37.00	264.03	199.06
Variable Costs (\$ ha^{-1})	124.84	124.84	124.84	124.84	0.00	243.04	229.55
Fixed Costs (\$ ha^{-1})	81.01*d*	93.36*c*	105.77*a*	101.78*b*	0.00	148.47	148.47
Total Costs (\$ ha^{-1})	205.85*d*	218.21*c*	230.61*a*	226.62*b*	0.00	391.51	378.03
Net Return to Labor, Equity & Personal Draw (\$ ha^{-1})	-99.03	82.95	-69.03	44.08	37.00	-127.48	-178.96
2006							
Revenue (\$ ha^{-1})	196.91	320.90	316.18	281.85	42.04	479.65	551.79
Variable Costs (\$ ha^{-1})	125.50	125.50	125.50	125.50	0.00	263.35	246.74
Fixed Costs (\$ ha^{-1})	81.01*d*	93.36*c*	105.77*a*	101.78*b*	0.00	149.28	149.28
Total Costs (\$ ha^{-1})	206.51*d*	218.86*c*	231.27*a*	227.28*b*	0.00	412.63	396.02
Net Return to Labor, Equity & Personal Draw (\$ ha^{-1})	-9.60	102.03	84.91	54.58	42.04	67.02	155.77

[z]Pooled standard error of the mean.

a-b Least square means in the same row with different letters differ at $P<0.05$.

crested wheatgrass pastures had seed and establishment costs amortized over 20 years while seed and establishment costs were amortized over 12 years to reflect differences in duration of productive years of the stand. Fixed costs ranged from \$81.01 ha^{-1} for the control pastures to \$105.77 ha^{-1} for the hybrid bromegrass pastures. Differences in total costs between pasture types were a result of the changes in fixed costs. Thus, total costs were significantly different between all pastures ($P<0.05$). Hybrid bromegrass had the greatest total costs (\$230.94 ha^{-1}), followed by tall fescue (\$226.95 ha^{-1}). 'AC Goliath' crested wheatgrass (\$218.54 ha^{-1}) and finally, the control pastures (\$206.18 ha^{-1}).

The overall net return to labor, equity and personal draw was greatest for the 'AC Goliath' crested wheatgrass at \$92.49 ha^{-1} ($P<0.05$). A slightly lower TBP for hybrid bromegrass and tall fescue pastures resulted in net returns that were numerically lower but statistically similar to 'AC Goliath" crested wheatgrass. Lastly, the control pastures generated negative margins (-\$54.32 ha^{-1}) which were statistically lower than the 'AC Goliath' crested wheatgrass pastures established in 2003 ($P<0.05$). Despite relatively constant costs between and within species, a wide variation in TBP and revenue produced per hectare, resulted in net returns within individual years that were not statistically different between species ($P<0.05$). Thus, it appears that 2 years of data may not be enough to predict net returns from grazing perennial pastures. It also appears that more tester steers and more pasture replications are needed to better evaluate ADG and total beef production per hectare.

Annual Cropping

In 2005, the average yield in the Lanigan area was 101 and 144 bu ha^{-1} for spring wheat and feed barley, respectively. The average crop price was \$2.62 and \$1.38 bu^{-1} for spring wheat and feed barley, respectively. This resulted in revenue for spring wheat at \$264.03 ha^{-1}, and revenue for feed barley at \$199.06 per hectare (Tables 7.1 and 7.2). In 2006, yields and revenues for both crops were slightly higher. Spring wheat yielded 105 bu ha^{-1} at \$4.58 bu^{-1} for revenue of \$479.65 ha^{-1} while feed barley yielded 173 bu ha^{-1} at \$3.19 bu^{-1} for revenue of \$551.79 per hectare. Thus, in the two years of the study, the average revenue generated by spring wheat and feed barley was \$371.84 and \$375.43 ha^{-1}, respectively.

It is suggested that the grain cycle is a ten-year cycle. From 1997 to 2006, the long term average yield was 85 and 125 bu ha^{-1} for spring wheat and feed barley, respectively (SMA web-site (www.agriculture.gov.sk.ca)). In addition, the average price per bushel for spring wheat and feed barley for the same time period was $4.20 and $2.90 bu^{-1}, which would generate revenues of $357.00 and $367.50 ha^{-1}, respectively.

In both years of the study, the variable costs for annual crops was nearly double that of the perennial pastures, averaging $253.20 and $238.15 ha^{-1} for spring wheat and feed barley, respectively. Similarly, fixed costs were also higher in the annual crops, averaging $148.88 ha^{-1} for both spring wheat and feed barley. The resulting total costs are much higher than would be incurred in the perennial pasture system. While the average total costs to generate an average revenue of $243.00 ha^{-1} for all pasture types was $222.21 ha^{-1} over the two years of the study, the average total costs needed to generate an average revenue of $316.08 and $375.43 ha^{-1} for spring wheat and feed barley was $402.07 and $387.03 ha^{-1}, respectively. Thus, in the two years of the current study, the potential to generate revenue was not as high in the pasture systems as in the annual crops, but neither was the yearly cash outlay (variable costs) or financial risk.

In 2005, both annual crops produced a negative return to labor, equity and personal draw. Stronger prices and slightly higher yields in 2006 resulted in net returns which appeared more promising than the previous year, particularly for feed barley ($155.77 ha^{-1}). If only the net returns for the three bromegrass pasture types established in 1999 are averaged over the two years of the study, the average net return is $41.58 ha^{-1}. If only the net returns for the 'AC Goliath' crested wheatgrass, hybrid bromegrass and tall fescue pastures established in 2003 are averaged over the two years of the study, the average net return for perennial pastures is $50.09 ha^{-1}. In comparison to the average net returns for spring wheat and feed barley of -$85.99 and -$11.60 ha^{-1}, respectively, recently established perennial pastures generated favorable net returns.

One advantage to custom grassing of yearling cattle is that it has the potential to provide a more consistent revenue source than annual cropping systems. As with growing annual crops, weather can be a major factor in determining potential revenue of pasture systems by either decreasing carrying capacity or total beef production. It may be likely in the Lanigan region for perennial pastures in good condition to withstand prolonged heat, late or early frosts much better than annual crops such as spring wheat or barley. Thus, if there are less potential risks to the overall revenue of perennial pasture systems, and the total costs are lower, it would be expected that custom grassing yearling steers on perennial pastures may be an economically sound business venture.

While this study assumed that the pasture forage was harvested by custom grazing steers, it is also a possibility that producers would be grazing their own cattle on the land. If producers were to buy feeder cattle for grassing or retain their own calves to grass, it is important that they determine their cost of gain. Similarly, if producers are custom grazing cattle based on weight gain, it is important that they determine what their cost of gain is to ensure that they will cover their costs and have a margin for labor, return to equity, personal draw and risk. Over the two years of the study, the cost per kilogram of gain (not including labor, return to equity, personal draw or risk) on the control pastures was \$1.16 per kilogram of gain. For the bromegrass pastures established in 1999, the cost of gain was \$0.61, \$0.72 and \$0.87 kg^{-1} for hybrid bromegrass, meadow bromegrass and smooth bromegrass, respectively. The cost of gain for 'AC Goliath' crested wheatgrass, hybrid bromegrass and tall fescue pastures established in 2003 was \$0.60, \$0.83 ad \$0.70 kg^{-1}, respectively. Thus, depending on the cost of gain in the feedlot, which will vary tremendously depending on the price of feedstuffs, labor and the scale of the feeding operation, grassing cattle on new forage varieties may be a relatively inexpensive method to put weight gain on cattle.

The current study used custom grazing of yearling steers to generate revenue from the perennial pasture systems; however, the likelihood that producers will be grazing cow-calf pairs is just as great. In a recent study by the Western Beef Development Center (2000-2005) evaluating the economics of Lorne Christopherson's (a mixed farmer near Weldon, Saskatchewan) conversion from 'grain to grass', rotational grazing of perennial pasture (meadow bromegrass-alfalfa) by cow-calf pairs provided greater net return (\$57.94 ha^{-1}) compared to annual cropping systems (\$28.80 ha^{-1}) (Lang 2006a). Thus, the current study is in agreement with the results of the Western Beef Development Center's producer evaluation (Lang 2006a); grazing perennial pastures can provide comparable, if not superior, net return compared to annual cropping systems.

7.4 Conclusions

In summary, it appears that while TBP can be extremely variable between pastures replicates and years, net returns generated by perennial pastures were similar, if not greater to net returns generated by annual crops such as spring wheat or feed barley over the 2 years of the current study. It is also important to note that when grazing long established crested wheatgrass pasture such as in this study, producers may be generating negative returns due to decreased beef production per hectare from these stands. Thus, it appears that younger stands of AC Goliath crested wheatgrass, Paddock meadow bromegrass, AC Knowles hybrid bromegrass and Courtney tall fescue, may provide greater returns than long established pastures. However, producers must determine their own potential costs, revenues and returns and choose species that will meet their own production and financial goals.

The price variability in annual cropping and high cash outlays associated with sowing the crop and owning the machinery may make forage based systems more favorable. However, the economic comparison in this study was done with the revenue coming from custom grazing stocker cattle. If the stockers been bought and sold, there are market forces that would come into play and likely affect revenue outcomes differently than a set custom grazing fee.

In addition, there has been strengthening of grain and oilseed prices with the growing bioenergy industry in North America. For example, the rising corn price due to corn-based ethanol production in the United States has also caused a rise in the price of Canadian spring wheat and barley. The Canadian Wheat Board's estimated final price for 2007-08 spring wheat (1 CWRS 13.5) is \$10.07 bu^{-1}. The 2007 average yield in the Lanigan area was 93.61 bu ha^{-1}. Once the cost of freight is deducted (\$1.11 bu^{-1}) in addition to the estimated expenses associated with growing the crop (\$400.93 ha^{-1}) (SMA 2007), the result was a net return of \$437.84 ha^{-1} which is considerably higher than the returns from either system in the current study. Thus, fluctuations in market conditions may drastically change net returns in a very short period of time.

It also must be considered that a rise in the cost of feed impacts a feedlot's operating margin and cost of gain. Consequently, feedlot owners will be looking to make up for lost margins by paying less for feeder cattle. Subsequently custom grazing rates will have to undergo a correction to reflect these increased feed costs being incurred by the feedlot. Either scenario could alter the returns that can be generated using perennial forage systems to graze feeder cattle.

8 General Conclusions

As rising input costs are shrinking margins in the agriculture industry, many producers are looking for methods to maximize their net return on their livestock operation. The reliance of the livestock industry on perennial forages as a cost-effective and sustainable source of feed means that new forage varieties will continue to be developed and will need to be evaluated for their grazing potential in western Canada. Two grazing studies were initiated at the Western Beef Development Center's Termuende Research Ranch near Lanigan, Saskatchewan to evaluate forage yield and quality, plant energy reserves, animal performance and intake and economic returns of five perennial grasses for grazing. Perennial grasses included in the studies were 'Carlton' smooth bromegrass, 'Paddock' meadow bromegrass, 'AC Knowles' hybrid bromegrass, 'AC Goliath' crested wheatgrass, 'Courtenay' tall fescue and a long established stand of crested wheatgrass.

In the first grazing study, no yield differences were observed between three bromegrass species seeded in 1999 and the long established crested wheatgrass (control) stand. Thus, when these cultivars were managed under a twice-over grazing system with good fertility in the Lanigan region, forage yield was similar. In the second study, the crested wheatgrass variety, AC Goliath yielded similarly to both AC Knowles hybrid bromegrass and Courtenay tall fescue. In addition, the variety AC Knowles had superior yield compared to the long established crested wheatgrass control. Although tall fescue produced excellent early growth, its regrowth potential was limited suggesting this species may not be suited for use as a mid-summer species for grazing in this region.

All the bromegrasses paddocks had similar crude protein, neutral detergent fiber, acid detergent fiber and *in vitro* organic matter digestibility levels. In previous research, it was suggested that meadow bromegrass had inferior forage quality to smooth bromegrass and that hybrid bromegrass would have forage quality intermediate to the parental lines. The results of this study suggest that forage quality is very similar among meadow, smooth and hybrid bromegrasses, and superior to long established crested wheatgrass stands.

‘AC Goliath’ crested wheatgrass, hybrid bromegrass and tall fescue also showed superior forage quality compared to the long established crested wheatgrass control pastures. The results for crude protein, acid detergent fiber and *in vitro* organic matter digestibility analysis did not show a consistent ranking among the study grasses; however, tall fescue tended to have lower neutral detergent fiber levels than either hybrid bromegrass or crested wheatgrass but this observation was not always significant. Higher fiber content in ‘AC Goliath’ and hybrid bromegrass pastures did not appear to lower *in vitro* organic matter digestibility, animal performance or animal intake.

Measurement of spring etiolated growth showed there were no differences in spring energy reserves between smooth, meadow and hybrid bromegrass species. ‘AC Goliath’ crested wheatgrass had the greatest etiolated growth over the 2-year study suggesting that it is well-suited for early spring grazing. On the contrary, tall fescue produced less etiolated growth than either ‘AC Goliath’ or hybrid bromegrass, with levels comparable to the control pastures. Thus, tall fescue and long established crested wheatgrass pastures may not be well suited for early summer pasture and there may be concerns with plant spring vigor and over-wintering potential.

Etiolated growth was greater in grazed plants compared to ungrazed plants in one year of this study. While it is generally accepted that defoliation events such as grazing decrease leaf material and overall energy status of the plants, the results of this study suggest that when cool season grasses are managed for a twice-over grazing system and plants are allowed sufficient rest before winter, grazing can increase spring energy reserves and potential spring vigor of the plants.

Livestock producers need perennial grasses that will produce high animal gains when used for summer pasture. Data from this study suggests that all five grass species evaluated will produce acceptable animal gains for grassing steers. Decreased forage availability during late summer or early fall will likely lead to decreased animal gains in a second grazing period as observed in the current studies. There were no statistical differences between animal grazing days and total beef production over the 2 years of the study for bromegrass species, suggesting that all three species can be utilized for summer pasture. However, over the 2 years of the study, hybrid and meadow bromegrass produced 144 and 122% numerically greater total beef production per hectare, respectively, than smooth bromegrass.

'AC Goliath' crested wheatgrass, hybrid bromegrass and tall fescue pastures established in 2003 also showed comparable average daily gain among grass species. Despite a lack of a second grazing period for tall fescue in 2006, it appears that this species can still produce many animal grazing days. Total beef production was also similar among species even though tall fescue was not grazed a second time. Thus, livestock producers must realize that even though tall fescue has tremendous animal production potential, the production may be very seasonal (early to mid summer) and there may be limitations as to when they can successfully graze this species. Grazing tall fescue may require more detailed grazing management to optimize its grazing potential in the Lanigan region.

Dry matter intake predictions were highest for the alkane C_{33}: C_{32} ratio, followed by the C_{31}: C_{32} ratio and lastly, the Cornell Net Carbohydrate and Protein System model. Intake predictions using the alkane methodology tended to be greater (% of body weight) in the second grazing period, likely a result of decreased forage quality and forage availability in the second grazing period.

Individual animal intake predictions were similar among bromegrass species regardless of the intake prediction method. Similar forage availability and quality among grass species likely contributed to this observation. Of the 2003 established pastures, 'AC Goliath' crested wheatgrass had the lowest dry matter intake which may be a result of the exceptional forage quality of the early spring growth. There was no consistent ranking between hybrid bromegrass and tall fescue using either alkane ratio which may suggest that the alkane profiles and recovery of adjacent alkanes is different between the two species.

Over the 2 years of the study, grazing steers on the study grasses provided comparable, if not superior, returns per hectare compared to growing spring wheat or feed barley during a similar period and location. Annual cash outlay and financial risk was much higher in the annual cropping systems compared to the perennial grass pastures; however, annual cropping systems also had the potential to produce higher gross revenue than the study pastures. Economic analysis of the pastures systems showed that producers who graze long established stands of crested wheatgrass may be generating negative returns due to the decreased beef production per hectare. Similarly, smooth bromegrass also generated negative returns over the two years of the study suggesting that other species such as AC Goliath crested wheatgrass, Paddock meadow bromegrass and Courtney tall fescue may be better options for summer grazing forages, as these all generated positive returns during the study. As the price of annual crops increases, future comparisons between grazing perennial grasses and annual cropping systems may favor annual crop production; however, if anuual crop prices are low, grazing systems may be more likely to generate positive returns.

Based on the results of this grazing study, beef producers can graze yearling steers on seeded perennial grass pastures during the summer grazing season and expect to maintain high levels of animal performance and pasture production. While this study did not span the entire summer grazing period, it has demonstrated that three bromegrasses, crested wheatgrass and tall fescue work well in a complementary grazing system while other seeded forages or native rangeland can fill the mid to late summer grazing period. However, more research needs to be done to evaluate the ability of these grasses to sustain animal production throughout the entire summer grazing season. In addition, future research needs to address the production potential of grass species in this study with perennial legumes. Not only would grass-legume stands decrease the reliance on commercial fertilizer application, but they could also increase animal performance and overall economic returns from summer pasture systems.

9 References

Adegbola, A. A. and McKell, C. M. 1966. Effect of nitrogen fertilization on the carbohydrate content of coastal Bermudagrass (*Cynodon dactylon*). Agron. J. **58**:60-64.

Adesogan, A. T., Givens, D. I. and Owen, E. 2000. Measuring chemical composition and nutritive value of forages. Pages 263-278 *in* Field and laboratory methods for grassland and animal production research. L. t'Mannetje and R. M. Jones (eds.). CAB International, Wallingford, UK.

Ahmed, J., Bonham, C. D. and Laycock, W. A. 1983. Comparison of techniques used for adjusting biomass estimates by double sampling. J. Range Manage. **36**: 217-221.

Akhter, S., Owen, E., Theodorou, M. K., Butler, E. A. and Minson, D. J. 1999. Bovine faeces as a source of microorganisms for the in vitro digestibility assay of forages. Grass Forage Sci.. **54**: 219-226.

Alberta Agriculture, Food and Rural Development. CowBytes Beef Ration Balancer Program. Version 4.

Allden, W. G. and Whittaker, I. A. McD. 1970. The determination of herbage intake by sheep: The interrelationship of factors influencing herbage intake and availability. Aust. J. Agr. Res. **21**: 755-766.

Allison, C. D. 1985. Factors affecting forage intake by range ruminants: A review. J. Range Manage. **38**: 305-311.

Bahrani, J., Beaty, E. R. and Tan, K. H. 1983. Relationship between carbohydrate, nitrogen contents, and regrowth of tall fescue tillers. J. Range Manage. **36**: 234-235.

Balasko, J. A. 1986. Tall fescue characteristics and management. Pages 185-191 *in* D. Smith, R. J. Bula and R. P. Walgenbach (eds). Forage Management, 5th ed. Kendall/Hunt Publishing Company, Dubuque, Iowa.

Baron, V. S., Dick, A. C. and King, J. R. 2000. Leaf and stem mass characteristics of cool-season grasses grown in the Canadian Parkland. Agron. J. **92:** 54-63.

Basarab, J. A., Price, M. A., Aalhus, J. L., Okine, E. K., Snelling, W. M. and Lyle, K. L. 2003. Residual feed intake and body composition in young growing cattle. Can. J. Anim. Sci. **83**: 189-204.

Baumgardt, B. R., Cason, J. L. and Taylor, M. W. 1962. Evaluation of forages in the laboratory. I. Comparative accuracy of several methods. J. Dairy Sci. **45:** 59-61.

Block, E., Kilmer, L. H. and Muller, L .D. 1981. Acid insoluble ash as a marker of digestibility for sheep fed corn plants or hay and for lactating dairy cattle fed hay. J. Anim. Sci. **52**: 1164-1169.

Boadi, D. A., Moshtaghi Nia, S. A., Wittenberg, K. M. and McCaughey, W. P. 2002. The n-alkane profile of some native and cultivated forages in Canada. **82**: 465-469.

Boschma, S. P., Scott, J. M., Hill, M. J., King, J. R. and Lutton, J. J. 2003. Plant reserves of perennial grasses subjected to drought and defoliation stresses on Northern Tablelands of New South Wales, Australia. Aust. J. Agric. Res. **54**: 819-828.

Bouton, J. H., Gates, R. N. and Hoveland, C. S. 2001. Selection for persistence in endophyte-free Kentucky 31 tall fescue. Crop Sci. **41**: 1026-1028.

Brown, R. H. and Blaser, R. E. 1965. Relationships between carbohydrate accumulation and growth rate on orchardgrass and tall fescue. Crop Sci. **5**: 577-582.

Buwai, M. and Trlica, M. J. 1977. Multiple defoliation effects on herbage yield, vigor and total nonstructural carbohydrates of five range species. J. Range Manage. **30**: 164-171.

Caldwell, M. M., Richards, J. H., Johnson, D. A. and Dzurec, R. S. 1981. Coping with herbivory: Photosynthetic capacity and resource allocation in two semiarid *Agropyron* bunchgrasses. Oecologia. 50: 14-24.

Campling, R. C. 1964. Factors affecting the voluntary intake of grass. Proc. Nutr. Soc. 23: 80-88.

Campling, R. C., Freer, M. and Balch, C. C. 1961. Factors affecting the voluntary intake of food by cows. 2. The relationship between the voluntary intake of roughages, the amount of digesta in the reticulo-rumen and the rate of disappearance of digesta from the alimentary tract. Brit. J. Nutr. **15**: 523-540.

Canadian Council on Animal Care (CCAC). 1993. Guide to the care and use of experimental animals. Vol. 1. CCAC, Ottawa, ON.

Carman, J. G. and Briske, D. D. 1982. Root initiation and root and leaf elongation of dependent little bluestem tillers following defoliation. Agron. J. **74**: 432-435.

Casler, M. D. and Carpenter, J. A. 1989. Morphological and chemical responses to selection for in vitro dry matter digestibility it smooth bromegrass. Crop Sci. **29**: 924-928.

Casson, T., Rowe, J. B., Thorn, C. W. and Harris, D. 1990. The use of natural n-alkanes in medic and clover as indigestible markers. Proc. Aust. Soc. Anim. Prod. **18**: 462-463.

Castle, M. E., Macdaid, E., Watson, J. N. 1975. The automatic recording of the grazing behaviour of dairy cows. Grass Forage Sci. **30**: 161-163.

Charmley, E., Ouellet, D., R., Viera, D. M., Michaud, R., Duynisveld, J. L. and Petit, H. V. 2003. Estimation of intake and digestibility of silage by beef steers using a controlled release capsule of n-alkanes. Can. J. Anim. Sci. **83**: 761-768.

Chaves, A. V., Thompson, L. C., Iwaasa, A. D., Scott, S. L., Olson, M. E., Benchaar, C., Veira, D. M. and McAllister, T. A. 2006. Effect of pasture type (alfalfa vs. grass) on methane and carbon dioxide production by yearling beef heifers. Can. J. Anim. Sci. **86**: 409-418.

Coates, D. B. and Penning, P. 2000. Measuring animal performance. Pages 353-402 *in* Field and laboratory methods for grassland and animal production research. L. t'Mannetje and R. M. Jones (eds.). CAB International, Wallingford, UK.

Cohen, R. D. H., Wright, S. B. M., Thomas, L. R., McCaughey, W. P. and Howard, M. D. 2004. Current and residual effects of nitrogen fertilizer applied to grass pasture on production of beef cattle in central Saskatchewan. Can. J. Anim. Sci. **84**: 91-104.

Collins, M. and Fritz, J. O. 2003. Forage Quality Pages 363-390 *in* Forages: An Introduction to Grassland Agriculture, 6th ed. Vol. 1. R. F. Barnes, C. J. Nelson, M. Collins and K. J. Moore (eds.). Iowa State Press, Ames, Iowa.

Conniffe, D., Browne, D. and Walshe, M. J. 1970. Experimental design for grazing trials. J. Agric. Sci. (Camb.). **74**: 339-342.

Conrad, H. R. 1966. Symposium on factors influencing the voluntary intake of herbage by ruminants: physiological and physical factors limiting feed intake. J. Anim. Sci. **25**: 227-235.

Cook, C. W. and Stubbendieck, J. 1986. Range research: Problems and techniques. Society for Range Management, Denver, CO.

Corbett, J. L. 1978. Measuring animal performance. Pages 163-231 *in* Measurement of grassland vegetation and animal production. Bulletin 52 Commonwealth

Bureau of Pastures and Field Crops. L. t'Mannetje (ed.). CAB, Farnham Royal, UK.

Cordova, F. J., Wallace, J. D. and Pieper, R. D. 1978. Forage intake by grazing livestock: A review. J. Range Manage. **31**: 430-438.

Coulman, B. 2004. Knowles hybrid bromegrass. Can. J. Plant Sci. **84**: 815-817.

Coulman, B. E. and Knowles, R. P. 1995. Hybrids between smooth and meadow bromegrass. Eastern Forage Improvement Conferenct. p. 49-50. Ottawa, ON.

Crampton, E. W. 1957. Interrelations between digestible nutrient and energy content, voluntary dry matter intake, and the overall feeding value of forages. J. Anim. Sci. **16**: 546-552.

Currie, P. O. and Peterson, G. 1966. Using growing-season precipitation to predict crested wheatgrass yields. J. Range Manage. **19**: 284-288.

Davidson, J. L. and Milthorpe, F. L. 1966a. Leaf growth in *Dactylis glomerata* following defoliation. Ann. of Bot. **30**: 173-184.

Davidson, J. L. and Milthorpe, F. L. 1966b. The effect of defoliation on the carbon balance in *Dactylis glomerata*. Ann. of Bot. **30**:185-198.

Dillon, P. and Stakelum, G. 1989. Herbage and dosed alkanes as a grass measurement technique for dairy cows. Irish J. Agric. Res. **28**: 104 (Abstract).

Douglas, J. T. and Crawford, C. E. 1994. An evaluation of the drop-disc technique for measurements of herbage production in ryegrass for silage. Grass Forage Sci. **49**: 252-255.

Dove, H. and Mayes, R. W. 1991. The use of plant wax alkanes as marker substances in studies of the nutrition of herbivores: A review. Aust. J. Agric. Res. **42**: 913-952.

Dove, H. and Mayes, R. W. 1996. Plant wax components: A new approach to estimating intake and diet composition in herbivores. J. Nutr. **126**: 13-26.

Dove, H., Freer, M. and Foot, J. Z. 1988. Alkane capsules for measuring pasture intake. Proc. Nutr. Soc. Aust. **13**: 131.

Dove, H., Freer, M. and Foot, J. Z. 2000. The nutrition of grazing ewes during pregnancy and lactation: a comparison of alkane-based and chromium/*in vitro* based estimates of herbage intake. Aust. J. Agric. Res. **51**: 765-777.

Dove, H., Mayes, R. W. and Freer, M. 1996. Effects of species, plant part, and plant age on the n-alkane concentrations in the cuticular wax of pasture plants. Aust. J. Agric. Res. **47**: 1333-1347.

Dove, H., Mayes, R. W., Lamb, C. S. and Ellis, K. J. 2002. Factors influencing the release rate of alkanes from an intra-ruminal, controlled-release device, and the resultant accuracy of intake estimation in sheep. Aust. J. Agric. Res. **53**: 681-696.

Dove, H., Wood, J. T., Simpson, R. J., Leury, B. J., Ciavarella, T. A., Gatford, K. L. and Siever-Kelly, C. 1999. Spray-topping annual grass pasture with glyphosate to delay loss of feeding value during summer. III. Quantitative basis of the alkane-based procedures for estimating diet selection and herbage intake by grazing sheep. Aust. J. Agric. Res. **50**: 475-485.

Dovrat, A., and Cohen, Y. 1970. Regrowth potential of Rhodes grass (*Chloris gayana* Kunth.) as affected by nitrogen and defoliation. Proc. 11th Int. Grassld. Congr. (Surfers Paradise). 552-554.

Dovrat, A., Deinum, B. and Dirven, J. G. P. 1972. The influence of defoliation and nitrogen on the regrowth of Rhodes grass (Chloris gayana Kunth.). 2. Etiolated growth and non-structural carbohydrate, total-N and nitrate-N content. Neth. J. Agric. Sci. **20**: 97-103.

Duncan, D. A. and Woodmansee, R. G. 1975. Forecasting forage yield from precipitation in California's annual rangeland. J. Range Manage. **28**: 327-329.

Edwards, P. J. 1964. The construction and use of light-proof boxes in grassland research work. Proc. IX Int. Grassl. Congr. pp. 45-48.

Ellis, K. J., Laby, R. H. and Burns, R. G. 1981. Continuous controlled-release administration of chromic oxide to sheep. Proc. Nutr. Soc. Aust. **6**: 145.

Fahey, Jr., G. C. and Jung, H. G. 1983. Lignin as a marker in digestion studies: A review. J. Anim. Sci. **57**: 220-225.

Faichney, G. J. 1975. The use of markers to partition digestion within the gastrointestinal tract of ruminants. Pages 277-291 *in* I. W. McDonald and A. C. I. Warner, eds. Digestion and metabolism in the ruminant. The University of New England Publishing Unit, Armidale, Australia.

Ferdinandez, Y. S. N. and Coulman, B. E. 2000. Characterization of meadow × smooth bromegrass hybrid populations using morphological characteristics. Can. J. Plant Sci. **80**: 551-557.

Ferdinandez, Y. S. N. and Coulman, B. E. 2001. Nutritive values of smooth bromegrass, meadow bromegrass, meadow × smooth bromegrass hybrids for different plant parts and growth stages. Crop Sci. **41**: 473-478.

Ferreira, L. M. M., Oliván, M., Rodrigues, M. A. M., Osoro, K., Dove, H. and Dias-Da-Silva, A. 2004. Estimation of feed intake by cattle using controlled-release capsules containing n-alkanes or chromium sesquioxide. J. Agric. Sci. **142**: 225-234.

Forbes, J. M. 1996. Integration of regulatory signals controlling forage intake in ruminants. J. Anim. Sci. **74**: 3029-3035.

Fox, D. G., Barry, M. C., Pitt, R. E., Roseler D. K. and Stone, W. C. 1995. Application of the Cornell Net Carbohydrate and Protein Model for cattle consuming forages. J. Anim. Sci. **73:** 267-277.

Gosselink, J. M. J., Dulphy, J. P., Poncet, C., Jailer, M., Tamminga, S. and Cone, J. W. 2004. Prediction of forage digestibility in ruminants using in situ and in vitro techniques. Anim. Feed Sci. Tech. **115**: 227-246.

Graber, L. F., Nelson, N. T., Leukel. W. A. and Albert, W. B. 1927. Organic food reserves in relation to the growth of alfalfa and other perennial herbaceous plants. Wisconsin Agr. Exp. Sta. Res. Bul. 80.

Grace, N. D. and Body, D. R. 1981. The possible use of long chain (C_{19}-C_{32}) fatty acids in herbage as an indigestible faecal marker. J. Agric. Sci. (Camb.). **97**: 743-745.

Hart, R.H., Abdalla, O.M., Clark, D.H., Marshall, M.B., Hamid, M.H.,Hager, J.A. and Waggoner, Jr., J.W. 1983a. Quality of forage and cattle diets on the Wyoming high plains. J. Range Manage. **36**: 46-51.

Hart, R.H., Balla, E.F. and Waggoner, Jr., J.W. 1983b. Gains of steers and calves grazing crested wheatgrass. J. Range Manage. **36**: 483-482.

Hendricksen, R. E., Reich, M. M., Roberton, R. F., Reid, D. J., Gazzola, C., Rideout, J. A. and Hill, R. A. 2002. Estimating the voluntary intake and digestibility of buffel-grass and lucerne hays offered to Brahman-cross cattle using n-alkanes. Anim. Sci. **74**: 756-577.

Highmoor, T. 2005a. 2003-2004 Saskatchewan backgrounding economics. Fact sheet #2005-05. Western Beef Development Centre, Humboldt, Saskatchewan.

Highmoor, T. 2005b. 2004 Saskatchewan cow-calf cost of production analysis. Western Beef Development Centre, Fact Sheet #2005-08.

Hofmann, L., Ries, R.E., Karn, J.F. and Frank, A.B. 1993. Comparison of seeded and native pastures grazed from mid-May through September. J. Range Manage. **46**: 251-254.

Hogg, E. H. and Lieffers, V. J. 1991a. Seasonal changes in shoot regrowth potential in *Calamagrostis canadensis*. Oecologia. **85**: 596-602.

Hogg, E. H. and Lieffers, V. J. 1991b. The relationship between seasonal changes in rhizome carbohydrate reserves and recovery following disturbance in *Calamagrostis canadensis*. Can. J. Bot. **69**: 641-646.

Horn, F. P., Telford, J. P., McCroskey, J. E., Stephens, D. F., Whiteman, J. V. and Totusek, R. 1979. Relationship of animal performance ad dry matter intake to chemical constituents of grazed forage. J. Anim. Sci. **49**: 1051-1058.

Hoveland, C. S., Hardin, D. R., Worley, P. C. and Worley, E. E. 1991. Steer performance on perennial vs. winter annual pastures in north Georgia. J. Prod. Agric. **4**: 24-28.

Hoveland, C. S., McCann, M. A. and Bouton, J. H. 1997. Influence of endophyte, alfalfa, and grazing pressure on steer performance and plant persistence of Jesup tall fescue. J. Prod. Agric. **10**: 546-550.

Hyder, D. N. 1972. Defoliation in relation to vegetative growth. Pages 304-317 *in* The biology and utilization of grasses. V. B. Younger and C. M. McKell (eds), Academic Press, New York, NY. 426 p.

Illius, A. W. and Jessop, N. S. 1996. Metabolic constraints on voluntary intake in ruminants. J. Anim. Sci. **74**: 3052-3062.

Jameson, D. A. 1962. Responses of individual plants to harvesting. Bot. Rev. 532-594.

Jewiss, O. R. 1972. Tillering in grasses – Its significance and control. J. Br. Grassld Soc. **27**: 65-82.

Johnson, E. R. and Charles, D. D. 1976. An evaluation of the Australian beef carcass appraisal system. Aust. Vet. J. **52**: 149-154.

Jones, R. J. 1974. The relation of animal and pasture production to stocking rate on legume based and nitrogen fertilized sub-tropical pastures. Proc. Aust. Soc. Anim. Prod. **10.**

Jones, R. J. and Sandland, R. L. 1974. The relation between animal gain and stocking rate: derivation of the relation from the results of grazing trials. J. Agric. Sci. (Camb.). **83**: 335-342.

Jordan, W. A., Lister, E. E., Wauthy, J. M. and Comeau, J. E. 1973. Voluntary roughage intake by non-pregnant and pregnant or lactating beef cows. Can. J. Anim. Sci. **53**: 733-738.

Karn, J.F., Ries, R.E. and Hofmann, L. 1999. Season-long grazing of seeded cool-season pastures in the Northern Great Plains. J. Range Manage. **52**: 235-240.

Ketelaars, J. J. M. H. and Tolkamp, B. J. 1992. Toward a new theory of feed intake regulation in ruminants. 1. Causes of differences in voluntary feed intake: critique of current view. Livestock Prod. Sci. **30**: 269-296.

Kilcher, M. R. and Troelsen, J. E. 1973. Contribution of stems and leaves to the composition and nutrient content of irrigated bromegrass at different stages of development. Can J. Plant Sci. **53**: 767-771.

Klingman, D. L., Miles, S. R. and Mott, G. O. 1943. The cage method for determining consumption and yield of pasture herbage. J. Am. Soc. Agron. **35**: 739-746.

Knowles, R. P. 1987. Productivity of grass species in the dark brown soil zone of Saskatchewan. Can. J. Plant Sci. **67**: 719-725.

Knowles, R. P., Baron, V. S. and McCartney, D. H. 1993. Meadow bromegrass. Agriculture Canada Publication 1889/E.

Knowles, R. P. and Baron, V. S. 1990. Performance of hybrids of smooth bromegrass (*Bromus inermis* Leyss.) and meadow bromegrass (*B. riparius* Rehm.). Can. J. Plant Sci. **70**: 330-331.

Kotb, A. R. and Luckey, T. D. 1972. Markers in nutrition. Nutr. Abs. Rev. **42**: 813-845.

Laby, R. H. 1978. Australian Patent Application No. 35908/78.

Laca, E. A. and WallisDeVries, M. F. 2000. Acoustic measurement of intake and grazing behaviour of cattle. Grass Forage Sci. **55**: 97-104.

Lang, K. 2006a. From grain to grass – 6-year analysis. Western Beef Development Centre, Humboldt, Saskatchewan.

Lang, K. 2006b. Saskatchewan cow-calf cost of production analysis 2001-2005. Fact sheet #2006-05. Western Beef Development Centre, Humboldt, Saskatchewan.

Lardner, H. A. 1999. Grass species for irrigated pastures. M. Sc. Thesis, University of Saskatchewan.

Lardner, H. A. 2004. Backgrounding calves on swathed corn & barley. Fact sheet #2004-02. Western Beef Development Centre, Humboldt, Saskatchewan.

Lardner, H. A., Wright, S. B. M. and Cohen, R. D. H. 2002. Leaf development of eight grass species following grazing. Can. J. Plant Sci. **82**: 747-750.

Lardner, H. A., Wright, S. B. M. and Cohen, R. D. H. 2003. Assessing eight grass species for pasture by measuring etiolated spring regrowth. Can. J. Plant Sci. **83:** 551-554.

Lippke, H. 1980. Forage characteristics related to intake, digestibility and gain by ruminants. J. Anim. Sci. **50**: 952-961.

Loy, D., Greiner, S., Rouse, G. and Maxwell, D. 1998. Evaluation of condition scoring of feeder calves as a tool for management and nutrition. 1998 Beef Research Report. Iowa State University, A. S. Leaflet R1538.

Matches, A. G. 1969. Influence of cutting height in darkness on measurement of energy reserves of tall fescue. Agron. J. **61**: 896-898.

Mayes, R. W. and Dove, H. 2000. Measurement of dietary nutrient intake in free-ranging mammalian herbivores. Nutr. Res. Rev. **13**: 107-138.

Mayes, R. W., Dove, H., Lamb, C. S. and Ellis, K. J. 1991. Evaluation of an intraruminal device for the controlled release of an alkane marker for intake estimation in sheep. Pages 456-457 *in* Proceedings of the 42nd Annual Meeting of the European Association of Animal Production, Vol. 1.

Mayes, R. W., Lamb, C. S. and Colgrove, P. M. 1986. The use of dosed and herbage n-alkanes as makers for the determination of herbage intake. J. Agric. Sci (Camb.) **107**: 161-170.

McCartney, D. H. and Bittman, S. 1994. Persistence of cool-season grasses under grazing using the mob-grazing technique. Can. J. Plant Sci. **74**: 723-728.

McKee, Jr., W. H., Brown, R. H. and Blaser, R. E. 1967. Effect of clipping and nitrogen fertilization on yield and stands of tall fescue. Crop Sci. **7**: 567: 570.

McKendrick, J. D. and Sharp, L. A. 1970. Relationship of organic reserves to herbage production in crested wheatgrass. J. Range Manage. **23**: 434-438.

McLean, A. and Wikeem, S. 1985. Rough fescue response to season and intensity of defoliation. J. Range Manage. **38**: 100-103.

McLeod, M. N. and Minson, D. J. 1978. The accuracy of the pepsin-cellulase technique for estimating the dry matter digestibility in vivo of grasses and legumes. Anim. Feed Sci. Tech. **3:** 277-297.

Menke, J. W. and Trlica, M. J. 1983. Effects of single and sequential defoliations on the carbohydrate reserves of four range species. J. Range Manage. **36**: 70-74.

Menke, K. H. and Steingass, H. 1988. Estimation of the energetic feed value obtained from chemical analysis and in vitro gas production using rumen fluid. Anim. Res. Dev. **29**: 7-55.

Milford R. and Minson D.J. 1965. Intake of tropical pasture species. Proc. 9th Int. Grassl. Cong., Sao Paulo, Brazil. pp. 815–822. (or 828?)

Minson, D. J. 1990. Forage in ruminant nutrition. Academic Press, Inc., San Diego, CA, pp. 483.

Mislevy, P., Washko, J. B. and Harrington, J. D. 1978. Plant maturity and cutting frequency effect on total nonstructural carbohydrate percentages in the stubble and crown of timothy and orchardgrass. Agron. J. **70**: 907-912.

Momont, P. A., Pruitt, R. J., Emerick, R. J. and Pritchard, R. H. 1994. Controlled release chromic oxide and alkaline peroxide lignin marker methods. J. Range Manage. **47**: 418-423.

Moore, K. J. 2003. Compendium of common forages. *In* Forage: An introduction to grassland agriculture, Vol. I., 6th Ed. R. F. Barnes, C. J. Nelson, M. Collins and K. J. Moore (eds.) Iowa State Press, Ames, Iowa.

Moriyama, M., Abe, J. and Yoshida, M. 2003. Etiolated growth in response to energy reserves and winter survival in three temperate grasses. Euphytica. **129**: 351-360.

Morvan-Bertrand, A., Boucaud, J. and Prud'homme, M. 1999. Influence of initial levels of carbohydrates, fructans, nitrogen, and soluble proteins on regrowth of *Lolium perenne* L. cv. Bravo following defoliation. J. Exp. Bot. **50**: 1817-1826.

Moshtaghi Nia, S. A. and Wittenberg, K. M. 2002. Evaluation of n-alkanes as markers for estimation of dry matter intake and digestibility in steers consuming all-forage or forage-concentrate diets. Can. J. Anim. Sci. **82**: 419-425.

Mott, G. O. 1960. Grazing pressure and the measurement of pasture production. Proc. 8th Int. Grassld. Cong. Reading. Pp. 606-611.

Mott, G.O. and Lucas, H.L. 1952. The design, conduct and interpretation of grazing trials on cultivated and improved pastures. Proc. VI Int. Grassld. Cong. pp. 1380-1385. State College, Pennsylvania.

National Research Council (NRC). 1996. Nutrient requirements of beef cattle. 7th revised edition. Washington, D. C., National Academy Press.

NRC. 1987. Predicting feed intake of food-production animals. Washington, D.C., National Academy Press.

NRC. 2000. Nutrient requirements of beef cattle, 7th revised ed. Update 2000**.** Washington, D. C., National Academy Press.

Nkrumah, J. D., Okine, E. K., Mathison, G. W., Schmid, K., Li, C., Basarab, J. A., Price, M. A., Wang, Z., and Moore, S. S. 2006. Relationships of feedlot feed efficiency, performance, and feeding behavior with metabolic rate, methane production, and energy partitioning in beef cattle. J. Anim. Sci. 2006. **84**:145–153.

Ogden, P. R., and Loomis, W. E. 1972. Carbohydrate reserves of intermediate wheatgrasses after clipping and etiolation treatments. J. Range Manage. **25**: 29-32.

Olson, B. E. and Richards, J. H. 1988. Tussock regrowth after grazing: intercalary meristem and axillary bud activity of tillers of *Agropyron desertorum*. Oikos. **51**: 374-382.

Oro, J., Nooner, D. W. and Wikström, S. A. 1965. Paraffinic hydrocarbons in pasture plants. Science. **147**: 870-873.

Owen, J. B. and Ridgman, W. J. 1968. The design and interpretation of experiments to study animal production from grazed pasture. J. Agric. Sci. (Camb.). **71**: 327-335.

Pechanec, J. F. and Pickford, G. D. 1937. A weight estimate method for determination of range or pasture production. J. Amer. Soc. Agron. **29**: 894-904.

Penning, P. D. and Hooper, G. E. 1985. An evaluation of the use of short-term weight changes in grazing sheep for estimating herbage intake. Grass Forage Sci. **40**: 79-84.

Peterson, R. G., Lucas, H. L. and Mott, G. O. 1965. Relationship between rate of stocking and per animal and per acre performance on pasture. Agron. J. **57**: 27-30.

Raese, J. T. and Decker, A. M. 1966. Yields, stand persistence, and carbohydrate reserves of perennial grasses as influenced by spring harvest stage, stubble height and nitrogen fertilization. Agron. J. **58**: 322-326.

Reece, P. E., Nichols, J. T., Brummer, J. E. and Engel, R. K. 1997. Technical note: Field measurement of etiolated growth of rhizomatous grasses. J. Range Manage. **50**: 175-177.

Reynolds, J. H. and Smith, D. 1962. Trend of carbohydrate reserves in alfalfa, smooth bromegrass, and timothy grown under various cutting schedules. Crop Sci. **2:** 333-336.

Richards, J. H. and Caldwell, M. M. 1985. Soluble carbohydrates, concurrent photosynthesis and efficiency in regrowth following defoliation: A field study with *Agropyron* species. J. Appl. Ecol. **22**: 907-920.

Rinne, M., Olt, A., Nousiainen, J., Seppälä, A., Tuori§, M., Paul, C., Fraser, M. D. and Huhtanen, P. 2006. Prediction of legume silage digestibility from various laboratory methods. Grass Forage Sci. **61**: 354-362.

Rode, L. M. and Pringle, W. L. 1986. Growth, digestibility and voluntary intake by yearling steers grazing timothy (*Phleum pratense*) or meadow foxtail (*Alopecurus pratensis*) pastures. Can. J. Anim. Sci. **66**: 463-472.

Rogler, G. A. and Lorenz, R. J. 1983. Crested wheatgrass – Early history in the United States. J. Range Manage. **36**: 91-93.

Romo, J. T. and Harrison, T. 1999. Regrowth of crested wheatgrass (*Agropyron cristatum* [L.] Gaertn.) following defoliation. Can. J. Plant Sci. **79**: 557-563.

Saha, B. and Trant, M. 2008. Canadian agriculture in 2007: Better farm prices and incomes as world demand for food increases in vista on the agri-food industry and the farm community. Statistics Canada. Website: www.statcan.gc.ca

Saskatchewan Ministry of Agriculture (SMA). 2004a. Guide to Crop Protection. Regina, Saskatchewan.

SMA. 2004b. Farm Machinery Custom and Rental Rate Guide 2004. Regina, Saskatchewan.

SMA. 2005. Crop Planning Guide 2005 – Black Soil Zone. Regina, Saskatchewan.

SMA. 2006a. Pasture Development Costs. Website: www.agriculture.gov.sk.ca

SMA. 2006b. Crop Planning Guide 2006 – Black Soil Zone. Regina, Saskatchewan.

SMA. 2007. Crop Planning Guide 2007 – Black Soil Zone. Regina, Saskatchewan.

SMA. 2008. Agricultural Statistics Fact Sheet. Regina, Saskatchewan.

Smit, H. J., Taweel, H. Z., Tas, B. M., Tamminga, S. and Elgersma, A. 2005. Comparison of techniques for estimating herbage intake of grazing dairy cows. J. Dairy Sci. **88**: 1827-1836.

Smith, D., Bula, R. J. and Walgenbach, R. P. 1986. Forage Management, 5th ed. Kendall/Hunt Publishing Company, Dubuque, Iowa.

Smith, D., Paulsen, G. M. and Raguse, C. A. 1964. Extraction of total available carbohydrates from grass and legume tissue. Plant Physiol. **39**: 960-962.

Smoliak, S. 1956. Influence of climatic conditions on forage production of shortgrass rangeland. J. Range Manage. **9**: 89-91.

Smoliak, S. and Bjorge, M. 1981. Hay and Pasture Crops. Pages 7-70 *in* Alberta Forage Manual. Alberta Agriculture, Food and Rural Development, Edmonton, Alberta.

Smoliak, S., Johnston, A. and Lodge, R. W. 1981. Management of crested wheatgrass pastures. Publication 1473/E. Agriculture Canada, Ottawa, ON. 19 pp.

Stakelum, G. and Dillon, P. 1990. Dosed and herbage alkanes as feed intake predictors with dairy cows: The effect of feeding level and frequency of perennial ryegrass. Proc. VII Eur. Grazing Workshop, Wageningen, The Netherlands, October 1990.

Steel, R.G.D, Torrie, J.H. and Dickey, D.A. 1997. Principles and procedures of statistics: A biometrical approach. 3rd Ed. McGraw-Hill Co. Inc., NewYork, New York.

t'Mannetje, L. 2000. Measuring biomass of grassland vegetation. Pages 151-177 in Field and laboratory methods for grassland and animal production research. L. t'Mannetje and R. M. Jones (eds.), CAB International, New York, NY.

Thompson, L. C. 2003. Forage Production and performance of beef yearlings grazing hybrid bromegrass. M. Sc. Thesis, University of Saskatchewan.

Thompson, L. and Lardner, H. A. 2002. The economics and production of establishing and grazing forages in the comparison to cereal crops in the Black Soil Zone of Saskatchewan – Final Report 2002 (Saskatchewan Agriculture Development Fund Project #9900122).

Thompson, L. C., Lardner, H. A., Cohen, R. D. H. and Coulman, B. E. 2003. Steer performance grazing hybrid bromegrass pastures. Can. J. Anim. Sci. **83**: 165-169.

Thonney, M. L., Duhaime, D. J., Moe, P. W. and Reid, J. T. 1979. Acid insoluble ash and permanganate lignin as indicators to determine digestibility of cattle rations. J. Anim. Sci. **49**: 1112-1116.

Thornton, R. F. and Minson, D. J. 1973. The relationship between apparent retention time in the rumen, voluntary intake, and apparent digestibility of legume and grass diets in sheep. Aust. J. Agric. Res. **24**: 889-898.

Tilley, J. M. A. and Terry, R. A. 1963. A two stage technique for the in vitro digestion of forage crops. J. Brit. Grassld. Soc. **18**: 104-111.

Trlica, M. J. and Cook, C. W. 1972. Carbohydrate reserves of crested wheatgrass and Russian wildrye as influenced by development and defoliation. J. Range Manage. **25**: 430-435.

Trlica, M. J., Buwai, M. and Menke, J. W. 1977. Effects of rest following defoliations on the recovery of several range species. J. Range Manage. **30**: 21-27.

Troelsen, J. E. and Hanel, D. J. 1966. Ruminant digestion in vitro as affected by inoculum donor, collection day, and fermentation time. Can. J. Anim. Sci. **46**: 149-156.

Troughton, A. 1957. The underground organs of herbage grasses. Commonwealth Agr. Bur. Farnham Royal, UK.

Turner, L. R., Donaghy, D. J., Lane, P. A., and Rawnsley, R. P. 2006. Effect of defoliation interval on water-soluble carbohydrate and nitrogen energy reserves, regrowth of leaves and roots, and tiller number of cocksfoot (*Dactylis glomerata* L.) plants. Aust. J. Agric. Res. **57**: 243-249.

Unal, Y. and Garnsworthy, P. C. 1999. Estimated of intake and digestibility of forage-based diets in group-fed dairy cows using alkanes as markers. J. Agric. Sci. (Camb.). **133**: 419-425.

Van Keulen, J. and Young, B. A. 1977. Evaluation of acid-insoluble ash as a natural marker in ruminant digestibility studies. J. Anim. Sci. **44**: 282-287.

Van Soest. P. J. 1965. Symposium on factors influencing the voluntary intake of herbage by ruminants: Voluntary intake in relation to chemical composition and digestibility. J. Anim. Sci. **23**: 834-843.

Van Soest, P. J. 1967. Development of a comprehensive system of feed analysis and its application to forages. J. Anim. Sci. **26**: 119-128.

Vavra, M., Rice, R. W. and Bement, R. E. 1973. Chemical composition of the diet, intake and gain of yearling cattle on different grazing intensities. J. Anim. Sci. **36**: 411-414.

Vogel, K. P., Gabrielsen, B. C., Ward, J. K., Anderson, B. E., Mayland, H. F. and Masters, R. A. 1993. Forage quality, mineral constituents, and performance of beef yearlings grazing two crested wheatgrasses. Agron. J. **85**: 584-590.

Volenec, J. J. 1986. Nonstructural carbohydrates in stem base components of tall fescue during regrowth. Crop Sci. **26**: 122-127.

Vulich, S. A., O'Riordan, E. G. and Hanrahan, J. P. 1991. Use of n-alkanes for the estimation of herbage intake in sheep: accuracy and precision of the estimates. J. Agric. Sci. (Camb.) **116**: 319-323.

Waldron, B. L., ZoBell, D. R., Olson, K. C. Jensen, K. B. and Snyder, D. L. 2006. Stockpiled forage kochia to maintain beef cows during winter. Rangeland Ecol. Manage. **59**: 275-284.

Ward, C. Y. and Blaser, R. E. 1961. Carbohydrate food reserves and leaf area in regrowth of orchardgrass. Crop Sci. 1:366-370

Weinmann, H., 1948. Underground development and reserves of grasses. J. Br. Grassld. Soc. **3**: 115-140.

Wen, L., Kallenbach, R. L., Williams, J. E., Roberts, C. A., Beuselinck, P. R., McGraw, R. L. and Benedict, H. R. 2002. Performance of steers grazing rhizomatous and nonrhizomatous birdsfoot trefoil in pure stands in tall fescue mixtures. J. Anim. Sci. **80**: 1970-1976.

White, L. M. 1973. Carbohydrate reserves of grasses: A review. J. Range Manage. **26**: 13-18.

Willms, W. D. 1991. Cutting frequency and cutting height effects on rough fescue and Parry oat grass yields. J. Rang Manage. **44:** 82-86.

Wilm, H. G., Costello, D. F. and Klipple, G. E. 1944. Estimating forage yield by the double-sampling method. J. Am. Soc. Agron. **36**: 194-203.

Wilson, D. B. 1966. Variability in herbage yields from caged areas in a pasture experiment. Can. J. Plant Sci. 46: 249-255.

10 Appendix A

Figure A1. Paddock and cultivar locations at Western Beef Development Center Termeunde Research Ranch at Lanigan, Saskatchewan.

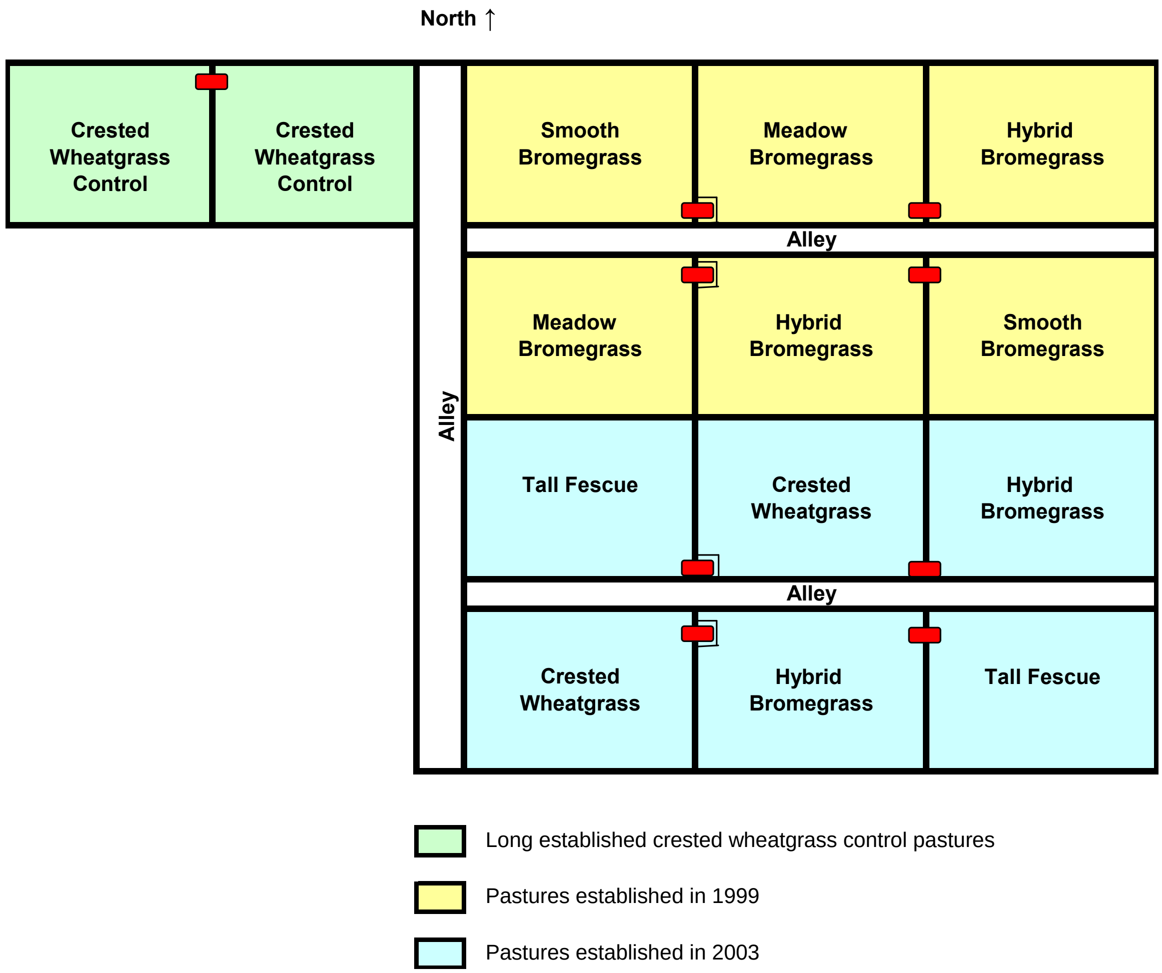

Table A1. Soil nitrogen (NO_3-N), phosphorus (PO_4-P), potassium (K_2O-K) and sulfur (SO_4-S) levels at a depth of 0-30 cm in grazed pastures during May 2005 and 2006.

Year/ Pasture Species	**NO_3-N**	**PO_4-P**	**K_2O-K**	**SO_4-S**
		Kg ha^{-1}		
2005				
Crested Wheatgrass Control	10	12	670	>45
Established in 1999				
Meadow Bromegrass	6	48	1025	11
Smooth Bromegrass	6	51	982	28
Hybrid Bromegrass	9	52	1220	11
Established in 2003				
Crested Wheatgrass	29	28	1027	>45
Tall Fescue	24	30	1097	>45
Hybrid Bromegrass	15	38	1177	40
2006				
Crested Wheatgrass Control	22	72	1873	35
Established in 1999				
Meadow Bromegrass	19	80	1972	109
Smooth Bromegrass	19	91	1873	117
Hybrid Bromegrass	20	96	2313	101
Established in 2003				
Crested Wheatgrass	28	74	2196	118
Tall Fescue	34	72	1947	77
Hybrid Bromegrass	19	76	2171	50

Table A2. Grazing period dates for study pastures during the 2005 and 2006 grazing seasons at Lanigan, Saskatchewan.

Paddock/Year	Start of Period	End of Period	# of Days
2005			
Crested Wheatgrass Control (rep1 & 2)[z]	May 27	June 9	13
Established in 1999			
Hybrid Bromegrass (rep1 & 2)	June 7	July 12	35
Meadow Bromegrass (rep1 & 2)	June 7	July 12	35
Smooth Bromegrass (rep 1 & 2)	June 7	July 12	35
Established in 2003			
Crested Wheatgrass (rep 1)	May 27	July 7	41
Crested Wheatgrass (rep 2)	May 27	June 30	34
Hybrid Bromegrass (rep1)	June 6	July 7	31
Hybrid Bromegrass (rep2)	June 6	July 14	37
Tall Fescue (rep1 & 2)	June 10	July 14	34
2006			
Grazing Period #1			
Crested Wheatgrass Control (rep1 & 2)	June 2	July 6	34
Established in 1999			
Hybrid Bromegrass (rep1 & 2)	May 26	June 29	34
Meadow Bromegrass (rep1 & 2)	May 26	June 29	34
Smooth Bromegrass (rep 1 & 2)	May 30	June 29	30
Established in 2003			
Crested Wheatgrass (rep 1 & 2)	May 17	June 21	35
Hybrid Bromegrass (rep1 & 2)	May 26	June 29	34
Tall Fescue (rep1 & 2)	June 2	July 13	41
Grazing Period #2			
Established in 1999			
Hybrid Bromegrass (rep1 & 2)	Aug 23	Sept 7	15
Meadow Bromegrass (rep 2)	Aug 23	Sept 7	15
Smooth Bromegrass (rep 1 & 2)	Aug 23	Sept 7	15
Established in 2003			
Crested Wheatgrass (rep 1)	Aug 5	Aug 23	18
Crested Wheatgrass (rep 2)	July 28	Aug 14	17
Hybrid Bromegrass (rep1 & 2)	Aug 16	Sept 3	18

[z]rep1 = replicate 1; rep2 = replicate 2.

Table A3. Composition of range mineral fed ad libitum to grazing steers (Feed-Rite Hi C-N-Z (1:1) Beef Mineral Premix with Weatherguard, Feed-Rite, Division of Ridley, Inc.).

Element	Concentration
Calcium	16.0%
Phosphorus	16.0%
Iron	450 mg kg^{-1}
Iodine	125 mg kg^{-1}
Manganese	5300 mg kg^{-1}
Copper	4000 mg kg^{-1}
Cobalt	40 mg kg^{-1}
Zinc	10 000 mg kg^{-1}
Fluorine	2000 mg kg^{-1}
Selenium	60 mg kg^{-1}
Vitamin A	200 000 IU kg^{-1}
Vitamin D	45 000 IU kg^{-1}
Vitamin E	40 IU kg^{-1}

Table A4. Precipitation (mm) for 2005 at Esk, Saskatchewan (Latitude 51°48.000' N. Longitude 105°51.000'W, Elevation 541.90 m) (Environment Canada – Climate Data Online).

Date	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1	2.6					17.4	T[z]	T		3.2	3.6	
2						4.2					2.0	
3						2.0	5.0					
4		3.0			T		13.4		4.0			
5		1.0	3.0						10.0			T
6	1.0	5.0	2.0		T							T
7	1.0					4.4				1.0		
8	3.0										9.0	T
9									6.0			
10									33.2			
11			1.0	T				2.0	T			
12	1.6			1.0				2.0	0.2	T		T
13					2.2		0.2		T			2.4
14		0.6	7.0			3.0			T			1.0
15						1.0			0.8			2.0
16			T							1.4		T
17		0.8	1.0	T	14.2	22.0	8.6	8.4				
18	T		5.0		15.4		T	0.6				
19	3.0							1.6		T		
20	T	1.0	1.0		T		8.0			7.6		
21			4.0		35.0	2.6					T	
22			T						2.6			
23	T							20.4				
24	1.8							2.4				
25					1.2	6.8		2.4				
26					2.0		5.0	T			T	
27				T	1.2						T	
28				1.0	T	1.2	2.4				1.0	T
29				1.0		7.6	1.0					T
30						7.2		53.6	T			
31					2.0			5.0		4.2		
Total	14.0	11.4	24.0	3.0	73.2	79.4	43.6	98.4	56.8	17.4	15.6	5.4
Average[y]	16.8	10.1	16.4	26.4	44.6	71.8	55.1	54.3	36.4	23.5	14.7	16.7

[z]Trace.
[y]Average monthly precipitation from 1984-2006 at Esk, Saskatchewan.

Table A5. Precipitation (mm) for 2006 at Esk, Saskatchewan (Latitude 51°48.000' N. Longitude 105°51.000'W, Elevation 541.90 m) (Environment Canada – Climate Data Online).

Date	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1		1.8	2.2		T[z]			6.0		2.6		1.0
2					5.0							1.0
3					1.0			6.4				1.0
4		1.6				T		0.2		T		
5		1.0										T
6			7.0							T		
7	0.6		1.0							4.6		
8			T		8.0	9.6						
9			3.5		14.0	10.4						
10	1.6		1.0	4.0		M[y]		T	T			
11	4.0		1.0	2.0		26.0	2.8	15.8				
12				1.6			13.8	T				
13							9.6		1.0			4.0
14	6.0					6.2			5.0			
15	9.0			8.6		13.0		T	34.0	8.0		3.5
16	T			18.6		2.0			51.2	7.0		4.0
17	T			4.0		7.4	1.8		2.4	6.0		
18		T						2.0		5.0		
19	T	1.0										
20	2.0	1.0			0.6	16.2			T			
21		T				2.2			11.0			
22								1.0				
23					1.0	T		1.0			4.0	
24					1.0		1.8					
25							T		2.0			
26		5.0	2.4		11.6		4.0					
27				2.2					1.0		7.0	
28	T	6.0			11.0		1.2			T	1.0	
29	0.6				2.8						5.0	
30	0.6									T	3.0	
31	T											
Total	24.4	17.4	18.1	41.0	56.0	93.0	35.0	38.0	107.6	33.2	42.0	14.5
Average[x]	16.8	10.1	16.4	26.4	44.6	71.8	55.1	54.3	36.4	23.5	14.7	16.7

[z]Trace.

[y]Missing data.

[x] Average monthly precipitation from 1984-2006 at Esk, Saskatchewan.

Table A6. Minimum (Min) and maximum (Max) temperature (°C) for January-June 2005 at the Western Beef Development Center Termuende Research Ranch, Lanigan, Saskatchewan.

Date	January		February		March		April		May		June	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	-18.7	-22.2	3.3	-8.1	-5.9	-20.5	6.4	-5.6	5.3	-8.1	16.5	9.1
2	-19.5	-29	5.6	-7.9	-4.3	-21	6.8	0	8	-11	19.3	9.3
3	-21.4	-31.6	1.3	-10.9	0.7	-14	7.8	-3.1	15.7	-7.6	21.5	11.5
4	-24.5	-35.9	-6	-18.2	4.5	-11.7	9.2	-0.4	21.1	0.1	15.7	9.2
5	-22	-34.4	-16.5	-20.2	6.1	-7.3	10.9	-0.5	21.5	-1.8	15.9	8.1
6	-10.9	-22.1	-20.2	-24.8	1.5	-8.7	17	-2.8	19.7	3.9	17.3	6.8
7	-12.2	-16.3	-16.6	-29.9	-5.7	-11.3	22.8	1	18	7.6	11.1	7.4
8	-14	-17.6	-13.5	-24.3	-1.1	-9.5	22.6	3.5	17.4	5.2	12.4	7.2
9	-16.7	-32.8	-1.5	-23.7	4.9	-5.7	18	6.3	19.8	-0.7	20.3	7.5
10	-23.3	-34.1	-2.3	-10.2	1.4	-4.2	8.3	2	7.4	-3.7	21	6.5
11	-21.1	-33.1	4.9	-9.1	0.3	-11	8.9	-3.1	12.3	-7.8	25	6.5
12	-21.4	-28	1.8	-13.3	-10.7	-17	4.7	0.2	14.9	-4.4	24.4	12.9
13	-25.9	-35.3	1.6	-11.7	-9.7	-18.4	14.8	0.9	6.8	-5.7	21.9	11.6
14	-28.1	-35.8	-3.5	-19.1	0.2	-18.3	22	2.2	12.3	-8	23	12.2
15	-26.7	-34.9	-11.7	-22.6	-12.8	-29.1	13.1	-0.8	19.8	-0.3	23.3	10.5
16	-26.2	-37.5	-10.8	-23.9	-9.7	-29.5	17.2	-4.5	24.4	3.7	24.5	7
17	-7.9	-30.5	-9.1	-26	-6.2	-14.1	25.1	6.8	22.3	9.4	24	14.3
18	-1.3	-20.6	-12.9	-25.1	-6.7	-11.3	15.3	0.1	13.8	7.8	22.7	13.8
19	-12.6	-21.3	-15.9	-28	-8.4	-17.6	12.9	-4.2	24.9	6	20.3	9.3
20	-14.2	-18.8	-10.2	-19.7	-4.4	-17.7	18.7	-2.2	24.7	5.2	21.5	8
21	-14	-32.1	-8.1	-16.6	-5.5	-8	16.3	0.9	13.1	10.4	26.6	9.2
22	-13.6	-34.5	-7.5	-	-2.7	-7.6	15.8	-4.6	23.9	8.2	32.1	16.1
23	-1.5	-15.1	-4.9	-17.6	-4.5	-16.9	21.4	0.9	20	8.6	20.9	10.8
24	0.4	-4.9	-5.7	-19	-7.1	-21.6	14.8	0.7	12.4	7.6	13.7	5.1
25	1.8	-16.7	-10.8	-22	-2	-19.9	11.1	-1.5	11.9	3.4	20.5	4.3
26	-11.1	-17.5	-4.8	-16.7	3.1	-15.4	7.2	-4.5	10.1	4.8	17	9.1
27	-2.7	-19.5	-7.5	-18.5	2	-5.6	5	-4.1	14.3	4	20.1	7.3
28	-2.9	-18.1	-5.5	-16.1	1.5	-2.7	1.4	-5.1	14	3.1	16.7	6.7
29	-3.8	-15.2			2.2	-0.3	0	-5.7	14.9	4.7	14.9	10.5
30	-2.5	-11.6			4.2	-0.8	2.1	-6.1	20.9	3.5	22.8	10.2
31	1.6	-6			4.7	-4.2			23.4	7.6		
Mean	-13.4	-24.6	-6.7	-18.6	-2.3	-12.9	12.6	1.1	16.4	1.8	20.2	9.3

Table A6. Minimum (Min) and maximum (Max) temperature (°C) for July-December 2005 at the Western Beef Development Center Termuende Research Ranch, Lanigan, Saskatchewan.

Date	July		August		September		October		November		December	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	26	10.9	32.7	11.5	21.1	2.4	10	3.8	7.3	-1.1	-12.3	-20.5
2	23.7	10.3	26.9	10.7	24.3	6.7	8.1	2.5	2.8	-1.9	-11.6	-17.9
3	20.1	12.6	23.1	8	26	9.8	4.2	-5	1.3	-4.4	-15.4	-21.6
4	22.5	8.5	25.9	7.9	23.5	10.2	7.1	-7.3	0.7	-0.9	-15.7	-28
5	27.5	10.6	30.1	9.2	16.5	9	7.3	-6.4	2	-0.6	-17.5	-24.5
6	29.5	13.3	29.5	8.9	20.5	4.9	9.6	-7.4	2	-6.5	-16	-25.4
7	24.5	11.9	30	11.2	24.6	3.7	12.4	0.6	-1.1	-8.8	-16.1	-26.1
8	30	10.6	22.9	6.9	27.3	10.5	14.8	-1.9	-0.1	-3.1	-5.5	-17.9
9	33.2	13.2	23.4	3.6	27.6	8.1	17.2	-1.2	-0.7	-5.3	5.9	-5.7
10	25.9	13.6	19.4	2.3	17.4	11.8	15.2	-2.5	5.5	-2.3	2.8	-2.2
11	28.9	13.4	17.2	6.7	16.8	8.8	15.6	1.8	5.4	-0.9	5.2	-5.1
12	31.6	-	16.4	4.1	15.5	6.6	15.2	-1.5	4.9	-4.7	-0.8	-9.6
13	33.2	-	18.7	1.2	13.4	2.7	18.1	0.9	-0.3	-10.7	-1.9	-7.5
14	24.4	9.9	21.1	6.8	10.8	3.2	14.4	-1.7	-2.7	-6.6	-7.1	-8.8
15	27.1	7.1	17.8	2.7	10.1	5.6	17	-2.2	-6.6	-26	-7.9	-15.1
16	28	14.5	15.1	5.9	12	7.5	12.6	-1.8	-10.2	-28	-15.1	-22
17	16.1	7.7	17.6	10.2	16.8	2.7	12.3	-5.8	0.6	-10.2	-20.3	-28
18	25.5	4.4	18.5	4	20.3	5.2	12.7	-4.3	4.7	-2.7	-15.4	-28.2
19	22.2	9.9	16.7	5.4	21.8	6	14.8	-4.2	6.2	-5.1	-8.1	-19.6
20	23.6	4.1	19.4	6.5	19.6	3.1	6.8	-1	10.3	-2.4	-8.3	-20.8
21	22	10.9	25	5.5	17.7	0.5	6	-4.1	0.9	-5.2	1.5	-20.2
22	26.3	7.2	30.3	13.1	18	-2.2	4.9	-6.6	9.3	-5.3	0.3	-7.9
23	27.2	14.6	17.3	12.5	11.6	-0.8	8.2	-5.6	4.9	-9.3	0.3	-8.2
24	18.4	3.9	19.4	10.2	16.5	-2.1	15.4	-1.6	-3	-9.1	1.2	-9.6
25	17.3	3	17.1	9.4	16.5	-0.4	13.4	-4.3	-4.2	-8.6	3.2	-6.2
26	20.8	3.4	18.2	8.2	20.9	3.5	15.7	-2.9	-2.1	-11.6	2.2	-5.7
27	17.8	4.7	26	6.4	11.8	2.6	11.8	-1.7	-4.5	-11	-2.3	-7.7
28	18.7	1	28.8	6.6	13.9	-6.7	5.5	1.8	-5.6	-10.4	-2.2	-3.3
29	25.9	8.5	29.9	10.7	18.8	4.8	13.4	-2.6	-9.5	-11.3	-2.3	-5.3
30	27.2	12.2	22.3	9.3	16.8	3.7	6.8	-5.4	-11	-18.6	-4.3	-6.6
31	33.3	10.4	13.2	4.1			8.1	-8.1			-2.2	-4.6
Mean	25.1	9.2	22.3	7.4	18.3	4.4	11.4	-2.8	0.2	-7.8	-6.0	14.2

Table A7. Minimum (Min) and maximum (Max) temperature (°C) for January-June 2006 at the Western Beef Development Center Termuende Research Ranch, Lanigan, Saskatchewan.

Date	January		February		March		April		May		June	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	-3.1	-4	-8.9	-19.3	-9.1	-12.7	10.2	-0.6	11.8	7.3	26.6	7.8
2	-1.3	-8.3	-9.4	-23.5	-10	-26.5	1.7	-9	10	2.1	30.6	12
3	-6.7	-13.4	-5.6	-21.9	-14.3	-27.3	4.4	-12.1	2.9	-0.6	25.8	13.8
4	-6.6	-15.1	-3.2	-14.2	-6.6	-16	11	-1.5	11.5	-4	25.3	8.8
5	-2.4	-18.7	-0.7	-5.3	-4.7	-10.3	3.5	0.6	19.8	7.4	21.2	9.6
6	1.2	-8.8	-4.4	-19.7	-2.6	-10.4	3.4	-3.9	25.9	8.2	23.7	9
7	-2.3	-9	-12.8	-	6.1	-3.6	6.8	-6.8	20.2	5.7	20.6	5.2
8	-3	-7.7	-4.2	-23.5	-0.9	-	9.7	1.6	21.4	3.1	13.5	9.5
9	-0.3	-7.6	-1.1	-6.4	2.4	-9.9	13.1	1.6	7.8	2.3	11.1	8.4
10	-3.1	-13.7	-6.1	-20.6	-1.8	-10.8	12.5	-	13	2	12.6	8.6
11	-2.3	-6.6	-5.8	-21.1	-6.3	-10.9	10.3	3.4	16	-0.1	14.3	7.5
12	-2.8	-11.8	0.6	-21.8	-10.9	-24.8	15.4	-0.9	17.2	1.7	15	7.8
13	-6.4	-11.6	2.9	-14.2	-10.1	-25.8	13.4	1.1	17.4	6.2	21.2	5.4
14	-4.7	-8.4	-2.5	-25.2	-15.5	-29	21.8	-0.2	15.1	5.7	23.4	10.2
15	-7.2	-12.4	-18	-29.7	-10.1	-22.3	21.6	2.1	21	2.4	24.6	14
16	-5.7	-10.9	-28.7	-36.3	-8.3	-16.6	17	6.5	24.9	8.9	20	12.7
17	-7.9	-15.7	-19.6	-34.4	-5.5	-12.1	11.9	1.8	25.1	4.1	18.5	11.4
18	-5.4	-13	-12.1	-29.9	-4.9	-14.5	8.8	3.2	27.7	10.8	22.4	13.1
19	-6.1	-25.3	-5.9	-12.5	-5	-12.1	12.8	2.5	24.8	8.3	24.3	10.8
20	-14.5	-26.5	-6.3	-18.7	-4.8	-14.6	18	-0.9	13.2	3.8	16.4	13.8
21	-15.7	-29.8	-7.8	-18.3	-4.2	-14	20.5	4	20.5	5.5	17.6	12.6
22	-6.8	-21.4	-11.8	-22.6	-2.6	-16.3	23.4	2.7	30.7	8.1	22.6	11.5
23	2.7	-10.1	-8.2	-26.4	-3	-20	9.8	-1.9	23.8	13.8	25.1	10.1
24	-3.9	-12.1	-14	-30.7	-2.2	-20.1	15	-3.7	18.4	8	24.9	12.4
25	1.9	-8.4	-11.8	-25	0.7	-10.9	18.3	-0.6	17.1	6	25.8	9.6
26	2.3	-7.5	-15.3	-29.7	0.7	-5.6	20.4	-0.3	11.7	7.1	23.7	11.1
27	-5.1	-20.5	-11.5	-16.6	5.6	-4	20.1	2.8	10.1	5.5	26.2	9.8
28	-4.3	-17	-8.2	-14.6	10	-5.6	22.1	4.5	9.7	6.9	29	12.7
29	-2.2	-15.4			2.2	-8.4	24.2	4.3	11.1	7.6	32.5	16.6
30	-0.9	-8.7			0.6	-9	14.6	5.4	19.9	6.6	24.5	13.1
31	-2.4	-19.1			3.4	-12.6			22.5	6		
Mean	-4.0	-13.5	-8.6	-21.6	-3.6	-14.6	13.9	0.2	17.5	5.4	22.1	10.6

Table A7. Minimum (Min) and maximum (Max) temperature (°C) for July-August 21, 2006 at the Western Beef Development Center Termuende Research Ranch, Lanigan, Saskatchewan.

Date	July		August		September		October		November		December	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	24.4	10.6	27.6	6.9								
2	24.2	9.8	23.7	7.1								
3	23.9	7.9	23.2	5.9								
4	26.6	11.1	24.3	11.5								
5	30.6	12.9	19.8	10.1								
6	30.4	14.6	24.3	7								
7	31.7	16.2	31.1	10								
8	22.3	10	30.1	13.4								
9	24.3	5.2	31.5	16.6								
10	31.9	13.3	30.7	16.6								
11	27.9	15.4	23.9	15								
12	33.3	14.7	18.3	8.8								
13	24.5	15.4	23.7	6.7								
14	24	13.7	28.4	5.1								
15	26.4	12	31.4	11.1								
16	23.6	10.6	22.6	10.3								
17	27.5	8.8	25.6	6.7								
18	24.5	13	28.6	6.1								
19	22.8	10.2	30	10.5								
20	28	9.4	23.7	7.5								
21	28.2	12	26.1	3.5								
22	30.4	13.2										
23	30.1	15.9										
24	29.3	13.3										
25	26.3	12.9										
26	30	10.6										
27	25.7	12.9										
28	19.6	9.6										
29	25.9	10.6										
30	27.7	13.7										
31	20.3	9.4										
Mean	26.7	11.9	26.1	9.4								

Table A8. Percentage of "other" species present in available forage throughout the 2006 grazing season (DM basis) based on hand separation at the time of clippings.

	Other Species (%)		
Grazing Period/ Species	**Replicate 1**	**Replicate 2**	**Average**
Grazing Period 1			
Crested Wheatgrass Control	43.9	33.6	38.8
Established in 1999			
Hybrid Bromegrass	50.3	29.7	40.0
Meadow Bromegrass	5.2	7.8	6.5
Smooth Bromegrass	9.9	22.9	16.4
Established in 2003			
Crested Wheatgrass	6.9	0	3.5
Hybrid Bromegrass	0.4	9.7	5.1
Tall Fescue	1.3	0.1	0.7
Grazing Period 2			
Established in 1999			
Hybrid Bromegrass	64.8	50.3	57.6
Meadow Bromegrass	-	0	0
Smooth Bromegrass	3.0	10.2	6.6
Established in 2003			
Crested Wheatgrass	12.2	0.8	6.5
Hybrid Bromegrass	0	31.5	15.6

[z]Other species include: quack grass (*Agropyron repens*), Kentucky bluegrass (*Poa pratensis*) and foxtail barley (*Hordeum jubatum*).

Table A9. Date of clippings for forage quality analysis for study pastures at Lanigan, Saskatchewan during the 2005 and 2006 grazing season.

Paddock/Year	Start of Trial	Middle of Trial	End of Trial
2005			
Crested Wheatgrass Control (rep1 & 2)[z]	May 27	June 2	June 9
Established in 1999			
Hybrid Bromegrass (rep1 & 2)	June 7	June 20	July 12
Meadow Bromegrass (rep1 & 2)	June 7	June 20	July 12
Smooth Bromegrass (rep 1 & 2)	June 7	June 20	July 12
Established in 2003			
Crested Wheatgrass (rep 1)	May 27	June 16	July 7
Crested Wheatgrass (rep 2)	May 27	June 16	June 30
Hybrid Bromegrass (rep1)	June 6	June 23	July 7
Hybrid Bromegrass (rep2)	June 6	June 23	July 14
Tall Fescue (rep1 & 2)	June 10	June 30	July 14
2006			
Grazing Period #1			
Crested Wheatgrass Control (rep1 & 2)	June 2	June 21	July 5
Established in 1999			
Hybrid Bromegrass (rep1 & 2)	May 26	June 13	June 28
Meadow Bromegrass (rep1 & 2)	May 26	June 13	June 28
Smooth Bromegrass (rep 1 & 2)	May 30	June 13	June 28
Established in 2003			
Crested Wheatgrass (rep 1 & 2)	May 17	May 31	June 21
Hybrid Bromegrass (rep1 & 2)	May 26	June 14	June 29
Tall Fescue (rep1 & 2)	June 2	June 21	July 12
Grazing Period #2			
Established in 1999			
Hybrid Bromegrass (rep1 & 2)	Aug 23	-	Sept 7
Meadow Bromegrass (rep1 & 2)	Aug 23	-	Sept 7
Smooth Bromegrass (rep 1 & 2)	Aug 23	-	Sept 7
Established in 2003			
Crested Wheatgrass (rep 1)	Aug 5	-	Aug 23
Crested Wheatgrass (rep 2)	July 28	-	Aug 14
Hybrid Bromegrass (rep1 & 2)	Aug 16	-	Sept 3

[z]rep1 = replicate 1; rep2 = replicate 2.

Table A10. The concentration of n-alkanes (mg kg^{-1} DM) in seeded perennial forages at Lanigan, Saskatchewan in the first grazing period of 2006.

	n-alkanes										
Species	**C_{24}**	**C_{25}**	**C_{26}**	**C_{27}**	**C_{28}**	**C_{29}**	**C_{30}**	**C_{31}**	**C_{32}**	**C_{33}**	**C_{36}**
Crested Wheatgrass Control	0.0	14.95	0.59	26.97	2.71	218.35	3.29	150.99	0.69	38.82	0.00
Pastures Established in 1999											
Hybrid Bromegrass	0.00	14.53	0.87	25.21	1.12	88.45	2.30	99.27	0.62	20.17	0.21
Meadow Bromegrass	1.62	19.07	2.16	58.54	5.63	170.79	6.00	128.51	1.10	32.40	0.23
Smooth Bromegrass	1.49	16.79	2.84	24.58	2.89	76.88	4.21	118.23	2.49	11.26	1.09
Pastures Established in 2003											
Crested Wheatgrass	0.00	10.30	0.42	42.49	2.77	376.55	2.33	167.26	0.55	50.87	0.04
Hybrid Bromegrass	1.04	16.57	3.61	31.43	3.68	106.05	3.67	121.77	0.49	18.95	0.00
Tall Fescue	0.00	8.56	2.38	18.40	4.94	127.41	9.10	209.92	3.44	63.64	0.00

Table A11. The concentration of n-alkanes (mg kg^{-1} DM) in seeded perennial forages at Lanigan, Saskatchewan in the second grazing period of 2006.

	n-alkanes										
Species	C_{24}	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}	C_{30}	C_{31}	C_{32}	C_{33}	C_{36}
Crested Wheatgrass Control	-	-	-	-	-	-	-	-	-	-	-
Pastures Established in 1999											
Hybrid Bromegrass	0.77	11.80	4.65	47.20	5.56	94.35	5.25	154.34	1.73	25.70	0.05
Meadow Bromegrass	2.83	7.38	5.85	82.33	5.88	106.99	5.40	167.93	1.45	29.97	0.03
Smooth Bromegrass	0.96	10.42	3.88	27.89	1.54	66.41	4.29	158.68	1.39	13.4	0.22
Pastures Established in 2003											
Crested Wheatgrass	2.64	11.71	6.01	34.08	7.76	303.70	6.64	174.68	1.66	20.18	0.00
Hybrid Bromegrass	6.10	13.04	9.83	44.31	7.37	78.90	6.23	148.89	2.34	26.87	0.43
Tall Fescue	-	-	-	-	-	-	-	-	-	-	-

Table A12. Pearson correlation coefficients between animal production or forage quality and dry matter intake of steers grazing perennial pastures established in 1999.

	Dry Matter Intake Estimate (kg d^{-1})		
	C_{31}:C_{32} Ratio	**C_{33}:C_{32} Ratio**	**CNCPS**
All Grazing Periods			
Average Daily Gain (kg d^{-1})	-0.139	-0.546	-0.811***
Animal Grazing Days (AUD ha^{-1})	-0.626*	-0.507	-0.897***
Total Beef Production (kg ha^{-1})	-0.539	-0.604*	-0.905***
Crude Protein (g kg^{-1} DM)	-0.216	-0.117	-0.811***
Neutral Detergent Fiber (g kg^{-1} DM)	0.084	0.345	0.273
Acid Detergent Fiber (g kg^{-1} DM)	-0.389	-0.295	-0.156
In Vitro Organic Matter Digestibility (g kg^{-1} DM)	0.253	0.375	-0.067
First Grazing Period			
Average Daily Gain (kg d^{-1})	0.526	-0.366	0.231
Animal Grazing Days (AUD ha^{-1})	-0.852**	-0.203	-0.632
Total Beef Production (kg ha^{-1})	-0.618	-0.541	-0.358
Crude Protein (g kg^{-1} DM)	-0.400	0.428	-0.407
Neutral Detergent Fiber (g kg^{-1} DM)	0.145	0.434	0.101
Acid Detergent Fiber (g kg^{-1} DM)	0.744	-0.163	-0.385
In Vitro Organic Matter Digestibility (g kg^{-1} DM)	0.407	0.567	0.225
Second Grazing Period			
Average Daily Gain (kg d^{-1})	0.316	-0.057	-0.658
Animal Grazing Days (AUD ha^{-1})			
Total Beef Production (kg ha^{-1})	0.329	-0.064	-0.638
Crude Protein (g kg^{-1} DM)	0.923*	0.910*	0.100
Neutral Detergent Fiber (g kg^{-1} DM)	-0.767	-0.595	-0.129
Acid Detergent Fiber (g kg^{-1} DM)	0.304	-0.492	-0.400
In Vitro Organic Matter Digestibility (g kg^{-1} DM)	0.531	0.561	-0.278

*, **, *** Significant at $P<0.05$, $P<0.01$, and $P<0.001$, respectively.

Table A13. Pearson correlation coefficients between animal production or forage quality and dry matter intake of steers grazing perennial pastures established in 2003.

	Dry Matter Intake Estimate (kg d^{-1})		
	C_{31}:C_{32} Ratio	C_{33}:C_{32} Ratio	CNCPS
All Grazing Periods			
Average Daily Gain (kg d^{-1})	-0.225	-0.421	-0.481
Animal Grazing Days (AUD ha^{-1})	-0.604*	-0.663*	-0.713**
Total Beef Production (kg ha^{-1})	-0.730**	-0.721**	-0.891***
Crude Protein (g kg^{-1} DM)	-0.807**	-0.669*	-0.878***
Neutral Detergent Fiber (g kg^{-1} DM)	0.788**	0.666*	0.791**
Acid Detergent Fiber (g kg^{-1} DM)	0.763**	0.714**	0.887***
In Vitro Organic Matter Digestibility (g kg^{-1} DM)	-0.742**	-0.702*	-0.759**
First Grazing Period			
Average Daily Gain (kg d^{-1})	0.028	0.309	-0.389
Animal Grazing Days (AUD ha^{-1})	-0.189	-0.581	-0.072
Total Beef Production (kg ha^{-1})	-0.458	-0.577	-0.427
Crude Protein (g kg^{-1} DM)	-0.886**	-0.494	-0.533
Neutral Detergent Fiber (g kg^{-1} DM)	0.797*	0.579	0.587
Acid Detergent Fiber (g kg^{-1} DM)	0.767*	0.594	0.593
In Vitro Organic Matter Digestibility (g kg^{-1} DM)	-0.831*	-0.387	-0.391
Second Grazing Period			
Average Daily Gain (kg d^{-1})	0.528	-0.824	0.567
Animal Grazing Days (AUD ha^{-1})	-0.390	-0.560	0.812
Total Beef Production (kg ha^{-1})	0.345	-0.894	0.747
Crude Protein (g kg^{-1} DM)	0.882	-0.401	0.114
Neutral Detergent Fiber (g kg^{-1} DM)	-0.791	0.322	0.089
Acid Detergent Fiber (g kg^{-1} DM)	-0.667	0.509	-0.115
In Vitro Organic Matter Digestibility (g kg^{-1} DM)	0.634	-0.742	0.447

*, **, *** Significant at $P<0.05$, $P<0.01$, and $P<0.001$, respectively.