

The Nutritional Value of Oat Forages for Dairy Cows

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by

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ABSTRACT

Three studies were conducted to evaluate the nutritional value of different oat (*Avena sativa*) forage cultivars (Assiniboia, Bell and Baler) that were newly emerged cultivars as a result of extensive oat growing conditions in western Canada. A total tract digestibility trial using 24 sheep (n=6) in a completely random design was conducted to assess apparent digestibility of dry matter (DM), organic matter (OM), crude protein (CP), crude fat (EE), acid detergent fiber (ADF), neutral detergent fiber (NDF), hemicellulose, non-structural carbohydrate, acid detergent lignin (ADL), soluble crude protein (SCP), non-protein nitrogen (NPN) and neutral detergent insoluble crude protein (NDICP) in Assiniboia silage, Bell hay, Baler hay and Rosser (barley- *Hordeum vulgare*) silage. Rumen *in situ* degradability characteristics of DM, OM, CP, ADF and NDF were determined on Assiniboia silage, Bell hay, Baler hay and Rosser silage at 96 to 0 h using a Holstein cow fitted with a rumen fistula. A dairy production trial using 8 multiparous Holstein cows at 90±20 DIM averaging 41 kg d⁻¹ milk yield, in a 2 × 3 switch-back design was conducted to compare the production response of the cows fed either 48 percent Assiniboia silage or Rosser silage (DM basis) in total mixed rations with the concentrate portion consisting mainly of rolled barley, canola meal and soy meal.

Digestibility of DM, OM, NDF, NPN, NDICP and EE were not different for Assiniboia and Rosser silages. Digestibility of DM, NDF and ADF were similar for Baler hay and Rosser silage. Digestibility of hemicellulose, NSC and ADL were similar for all forages. Sheep voluntary intakes of DM, OM, NDF, ADF and EE,

except CP were similar across the forages. Assiniboia silage provided more nutrients to the rumen than the hays due to the higher rumen disappearance and effective degradabilities of DM and CP, and lesser undegradable DM, CP, NDF and ADF ($P<0.05$). Estimated carbohydrate and protein fractions of Assiniboia and Rosser silages were similar. Assiniboia silage was typically comparable to Rosser silage whereas Baler hay was comparable to Bell hay which in contrast was chemically inferior to Baler hay in NDF and TDN content. An increase (8%, $P<0.05$) in milk fat percentage was observed in cows fed the Assiniboia diet. Milk protein and lactose percentages, and protein yield were higher ($P<0.05$) in the cows fed the Rosser diet. However, 3.5% fat corrected milk yields were similar. Milk fatty acids (FA) when Assiniboia diet was fed, showed a remarkable increase ($P<0.05$) in oleate percentage and yield while the others were not different. The increase in oleate content resulted in an increase ($P<0.05$) in unsaturated FA to saturated FA ratio. Therefore Assiniboia silage would be useful to increase unsaturated long chain milk fat content. It is concluded that Assiniboia silage could substitute for Rosser silage in dairy rations.

(Key words: Assiniboia, Rosser, cultivar, digestibility, total mixed ration, dairy, oats)

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LIST OF ABBREVIATIONS

<i>A</i>	readily available fraction of nutrient
ADC	apparent digestibility coefficient
ADF	acid detergent fiber
ADICP	acid detergent insoluble crude protein
ADL	acid detergent lignin
ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
ASOS	Assiniboia oat silage
Avg.	Average
<i>B</i>	potentially degradable fraction of nutrient
BAOH	Baler oat hay
BEOH	Bell oat hay
BU	blood urea
BUN	blood urea nitrogen
BW	body weight
<i>C</i>	unavailable fraction of nutrient
CA	<i>A</i> fraction of carbohydrates
CB1 and 2	<i>B</i> fractions of carbohydrates
CC	<i>C</i> fraction of carbohydrates
CCAC	Canadian Council of Animal Care
CLA	conjugated linoleic acid
CNCPS	Cornell Net Carbohydrate and Protein System
CP	crude protein
CPI	crude protein intake
CRD	complete randomized design
°C	degrees of Celsius
d	day
DE	digestible energy
DIM	days in milk

dl	deciliter
DM	dry matter
DMI	dry matter intake
<i>ED</i>	effective degradability
EE	ether extract
Est.	estimated
FA	fatty acid
FCM	3.5 % fat corrected milk
g	gram
GLC	gas liquid chromatography
H	hay
h	hour
IM	intra muscular
<i>K_d</i>	rate of degradation in the rumen (<i>c</i>)
kg	kilogram
<i>K_p</i>	flaw (passage) rate in the rumen
<i>L</i>	lag time
L	liter
LSD	least significant difference
MANOVA	multivariate analysis of variance
Mcal	mega calorie
ME	metabolizable energy
MF	milk fat
mg	milligram
ML	milk lactose
mm	millimeter
mmol	millimole
MP	milk protein
MP	milk proteins
NA	not available
ND	new diet

nd	not detected
NDF	neutral detergent fiber
NDICP	neutral detergent insoluble crude protein
NEm	net energy maintenance
NPN	non-protein nitrogen
NS	not significant
NSC	non-structural carbohydrates
OD	old diet
OM	organic matter
<i>P</i>	rumen disappearance at time <i>t</i>
PA	<i>A</i> fraction of proteins
PB1, 2 and 3	<i>B</i> fractions of protein
PC	<i>C</i> fraction of proteins
P-value	probability of significance
R ²	coefficient of correlation
ROBS	Rosser barley silage
SAS	Statistical Analysis System
SCC	somatic cell counts in milk
SCP	soluble crude protein
SD	standard deviation
SEM	standard error of the means
Sig.	significance
<i>t</i>	time in h for rumen degradability
TDN	total digestible nutrients
TMR	total mixed ration (diet)
TS	total solids
UV	ultra violet
VDMI	voluntary dry matter intake
VFI	voluntary feed intake

“Physiological experiment on animals is justifiable for real investigation, but not for mere damnable and detestable curiosity.”

Charles Darwin (1809 - 1882).

1. INTRODUCTION

Forages constitute the key feed component in dairy rations. Forages of varying quality support different levels of production. Forage is important in the sense of providing fiber to ruminants. Inadequate levels of dietary fiber are associated with low milk fat, rumen acidosis and dietary inefficiency. Forages provide rumen buffering and improve the fermentation efficiency of starchy grains. Forage also provides effective fiber in dairy rations where 75% of ration neutral detergent fiber should come from coarse forages. Cereal silages are often the preferred forage for dairy cattle in western Canada. Wheat (*Triticum aestivum*), corn (*Zea mays*) and barley (*Hordeum vulgare*) are used as cereal plant forages in North America and barley is the most popular forage in Saskatchewan. Oat (*Avena sativa L*) forage is being used in lesser extent. Silage is preferred to hay for total mixed rations used in a dairy enterprise. Research (Christensen *et al.*, 1977 and 1993) reveals that there is not much difference in compositions of cereal silages analyzed in Saskatchewan from 1976 to 1982, as influenced by the soil fertility, rather than by the species and variety.

Oat acreage in Saskatchewan continues to increase from the levels of the mid and late 1980's, when the planted area averaged some 320,000 hectares, to over 800,000 hectares in 1998. Saskatchewan became Canada's leading oat producing province in 1994 when the acreage surpassed that for Alberta by some 25%. By 1997 that differential increased to 40%. The Crop Development Centre varieties Calibre and Derby dominated production, although the newer varieties CDC Boyer, AC Assiniboia and AC Medallion began to make in-roads in 1998. Assiniboia which has good disease resistance, is well suited for the oat-growing areas of western Canada and in particular

the black soil zone of Manitoba and Saskatchewan. Assiniboia is also known for low lignin hulls (Thompson *et al.*, 2000). In addition, the CDC project, in collaboration with the Alberta and Saskatchewan Wheat Pools, in 1998 released CDC Bell, a specialty forage oat variety for greenfeed purposes. CDC Baler is another forage oat that results in higher yields. Around 2001 Saskatchewan started to move from grain to forage (greenfeed and silage) due to economic demands. This may be assisted by the trends related to Saskatchewan cereal forage varieties and growing conditions, with long days and low growing temperature to favour production of forages that attain higher nutritive value as they mature. Oat forage, for maximum nutritive value, should be harvested early-dough stage as it may lose feeding value with advancing maturity (Christensen, 1993).

Selection of a forage for a dairy ration is crucial in production terms as well as economic sustainability. Limitations of oat forages in Saskatchewan do demand improved cultivars. In this context there is a need to nutritionally evaluate newly developed oat cultivars for using as dairy forage in comparison to established forages such as barley. Assiniboia oat cultivar is one such newly developed variety. Rosser is one of the best varieties of barley extensively used as dairy forage in western Canada. The nutritional qualities of oat forage cultivars (Assiniboia, Bell and Baler) relative to Rosser were evaluated in three main aspects consisting of *in situ* rumen degradability, total tract digestibility and dairy production performance. Assiniboia silage (ASOS), Bell hay (BEOH), Baler hay (BAOH) and Rosser silage (ROBS) were the forages used in the studies. This information would be used to validate the accuracy of dairy and generally ruminant ration formulations under western Canadian conditions.

2. REVIEW OF LITERATURE

2.1 Introduction

Oat forage has a potential value as a dairy feed stuff and may be economically worthwhile, since oat has been grown extensively with high DM yield in western Canada. AC Assiniboia which is one such oat cultivar, is well suited for the oat-growing areas of western Canada and in particular the black soil zone of Manitoba and Saskatchewan and could be used as a forage (Brown *et al.*, 2001). Assiniboia is also known for low lignin hulls (Thompson *et al.*, 2000). CDC Baler and CDC Bell are other forage oats that result in higher yields. In order to obtain maximum nutritive value in ensiling and feeding, oat forage should be harvested early-dough stage (Christensen, 1993). Forage in dairy ration is important in the context of providing adequate amount of effective fiber to cow (Mertens, 1997). Barley silage which is the commonly used forage source for dairy rations in Saskatchewan, can be replaced by an alternative such as a comparable oat silage.

2.2 Whole Crop Silage and Hay as Forage

Forage is the key component in dairy rations (Van Soest *et al.*, 1994). The ruminant digestive system has evolved to utilize forage (Church, 1980). Forages of varying quality have elicited different level of production. Forage is important in providing fiber to ruminants. Inadequate levels of dietary fiber are associated with low milk fat, rumen acidosis and digestive inefficiency (Ørskov *et al.*, 1990). Forage also provides effective fiber in dairy rations where 75% of ration neutral detergent fiber

should come from coarse forages (Mertens, 1992). Because of climate and growing conditions cereal silages are often the preferred forage for dairy cattle in western Canada. Corn (*Zea mays*) and barley (*Hordeum vulgare*) are commonly used as cereal plant forages in North America with wheat (*Triticum aestivum*) and oat (*Avena sativa*) forages used less frequently. Barley is the most popular forage in Saskatchewan. Silage is preferred to hay for dairy total mixed rations. Differences in compositions of cereal silages analyzed in Saskatchewan from 1979 to 1982 were not great, but may have been influenced by the species and variety, or to lesser extent by the soil fertility.

2.3 Oat and Barley Forages

There are a number of varieties of barley extensively used as forage in dairy feeding while some varieties of oat are used to a lesser extent. Some oat varieties are used in the form of green feed or hay. It has been shown that oat produces more forage dry matter yield than most of the other cereal crops (Carr *et al.*, 2001) in most parts of North America. Some commonly used barley cultivars in Saskatchewan are AC Rosser, Brier, Stander, Virden, Westford and AC Lacombe. Some oat cultivars are AC Assiniboia, CDC Bell, CDC Baler, Foothills, Magnum, Royale, Derby and AC Mustang.

In previous studies conducted at the University of Saskatchewan, oat and barley silages have been consumed by beef steers at 1.5 to 2.2% of body weight daily on a dry matter basis (Christensen, 1993). Based on digestibility trials as well as milk production trials, it appears that cereal silage could provide sufficient energy for maintenance plus 10 to 15 kg of milk daily. Potential average productivity in

Saskatchewan is 40 kgd^{-1} for a 305 day lactation. Maximum energy utilized from forage reduces the amount of concentrate needed for the ration.

2.3.1 Assiniboia Oat Forage

The cultivar AC Assiniboia is a high-yielding, tan hulled oat cultivar possessing the crown rust resistance gene combination *Pc38*, *Pc39*, and *Pc68*, which was highly effective against the crown rust population on the Canadian prairies at the time of registration (Brown *et al.*, 2001). It has very good resistance to loose and covered smut, good resistance to crown rust (Chong *et al.*, 2000) stem rust, black stem (Cunfer *et al.*, 2000) and excellent tolerance to Barley Yellow Dwarf Virus (Brown *et al.*, 2001). Assiniboia has good kernel characteristics, including good protein and oil content. Low lignin level in Assiniboia oat hull compared to that of other oat cultivars, was reported by Thompson *et al.* (2000). Assiniboia is well suited for the oat-growing areas of western Canada and in particular the black soil zone of Manitoba and Saskatchewan.

2.3.2 Bell and Baler Oat Forages

CDC Bell was developed primarily for use by producers in western Canada who wish to grow an annual cereal crop for "green feed", oat hay (Rossnagel, 2001). Each year some 125,000 hectares of the western Canadian oat crop is destined for that end use. Bell is characterized by a long green period and very wide, long and thick leaves. It is tall, relatively late maturing and fast growing. It has good forage yield and better quality than standard grain oat cultivars. It is very susceptible to both stem and leaf rust, and because of this, should be grown only in the low risk areas of western

Canada. Bell was selected using a modified pedigree process with emphasis on forage yield and nutritional quality and was first identified based on its notably larger than normal leaf area and its long stay-green features.

CDC Baler is new forage oat that has a leaf 3.5 to 5.0 cm wide. Baler can deliver higher energy levels and protein levels compared to some other cultivars. It is 10 to 15% higher in forage yields compared to Foothills (<http://www.markertseeds.com>). Baler is characterised by a persistent green period and provides a lush growing forage oat with exceptional yield and good quality having consistently shown low ADF and NDF and high TDN. It is slightly taller than Foothills. Baler offers excellent lodging resistance, but is susceptible to stem and crown rust. Therefore Baler may be unsuitable for production in eastern Saskatchewan and Manitoba where prevalence of stem and crown rust is known.

2.3.3 Rosser Barley Forage

The cultivar AC Rosser was approved for release in western Canada in January 1997. Rosser is a six-row feed barley with high yield potential and broad adaptability to western Canadian conditions (Therrien *et al.*, 1998). It is mainly intended for on-farm use as cattle feed, serving the many cow-calf operations found commonly throughout the region. Rosser is similar to Brier in many respects, the main differences being higher yield, improved straw strength, and better disease-resistance. Rosser is widely adapted across western Canada. It is ideally suited for on-farm grain production for cattle. Rosser was the highest yielding barley cultivar in Manitoba in 1998, due, in part to its Spot Blotch resistance (Therrien, 2000). Rosser is distributed by the SeCan Association and has been commercially available since 2000. Rosser

silage has been used to feed the University of Saskatchewan dairy herd. Soita *et al.* (2002) showed that reducing theoretical cut length of Rosser silage increased DM intake and ruminal passage rate, and reduced mean ruminal retention time of particulates without affecting total tract digestibility of cell wall components in steer experiments.

2.4 Nutritive Value of Cereal Forages

Forage quality means the ability and the extent to which a forage has the potential to produce a desired animal response. Thus the quality reveals the level of nutrient (chemical) composition, palatability and intake, digestibility, anti-nutritional factors and animal production performance. Many factors influence forage quality. Some of them are forage cultivar, stage of maturity at harvest and storage method. Secondly environmental factors such as soil type and fertility, day length, temperature during plant growth are also important (Ball, 2000).

As ruminants are capable of digesting forage carbohydrates for the primary source of energy, carbohydrate characteristics have long been of interest as major factors in determining forage quality. Nutritive value implies not only the proportion of nutrients present in the plant, but also the intake and the digestibility by the animals (Ingalls *et al.*, 1965). Van Soest (1986) reported that forage intake is dependant upon the cell wall content, while forage digestibility is dependant on the cell wall (neutral detergent fiber) content and its availability determined by lignification and other factors.

The plant cells are composed of two major fractions; cell walls and cellular contents. The cellular contents which are vulnerable to rapid disappearance or digestion, consist of protein lipids, sugar and starch (Smith, 1973). The plant cell wall is the principal structure surrounding the protoplast and cell membrane and varies in digestibility.

Higher dry matter (DM) yield in forage production, higher intake by steers when fed as silage, similar digestibility and higher total digestible nutrients (TDN) for oat forages compared to barley and wheat forages (Table 2.1) were reported by Mtimuni and Christensen (1976). According to Christensen (1993) silage from oats cut at the early dough stage are equivalent to barley and wheat in nutritive value and digestibility (Table 2.2). Cereal silages as a feed source have demonstrated over time to be dependable and economic.

2.4.1 Chemical Composition of Cereal Forages

Several researchers reported narrow variation in chemical compounds measured by either wet chemistry or near infrared reflectance spectroscopy (NIRS) in cereal forages. Nutritional quality of forages including oat, barley and some others from several authors are summarized in Tables 2.1, 2.2, 2.3 and 2.4. Oat silage contains more DM (Table 2.3), acid detergent fiber (ADF) and neutral detergent fiber (NDF) compared to wheat silage; more soluble crude protein compared to wheat silage while rumen bypass protein percentage was similar to barley silage but lower than wheat silage (Nelson *et al.*, 1997).

Suleiman *et al.* (1997) concluded that the composition may be affected by geographical and environmental factors. Therefore western Canadian (Alberta) barley,

corn and oat silages were different in nutrient concentrations from similar forages reported by NRC (1984, 1989). McCartney *et al.* (1994) reported the nutritive values of barley, triticale and oat silage (Table 2.4) indicating similarities in DM, CP, NDF, ADF and lignin between barley and oats.

Table 2.1 Nutritive Values of Some Saskatchewan Cereal Silages and Intake by Steers (n=4).

Item (% DM basis)	Barley (Bonanza)	Wheat (Glenlea)	Oat (Fraser)
DM ¹ (%)	35.4	38.6	38.0
NDF ²	48.8	43.7	45.4
ADF ³	30.1	29.2	31.6
EE ⁴	2.6	2.4	4.4
CP ⁵	10.0	9.0	7.0
TDN ⁶	68.5	63.5	61.7
Intake (% BW)	2.1	2.2	2.3

¹ dry matter

² neutral detergent fiber

³ acid detergent fiber

⁴ ether extract

⁵ crude protein

⁶ total digestible nutrients.

(Mtimuni, 1976).

Table 2.2 Average Chemical Composition of Some Cereal Forages.

Item (% DM basis)	Barley silage (Bonanza)	Wheat silage (Lemhi)	Oat silage (Fraser)
NDF	58.2	53.7	57.1
ADF	30.4	35.1	31.2
Lignin	6.4	8.0	7.0
CP	13.1	13.1	11.0

Christensen, 1993).

Table 2.3 Nutrient Composition of Oat and Wheat Silages.

Item (% DM basis)	Wheat silages	Oat silage	Significance
NDF	48.9	64.8	S ²
ADF	38.8	46.8	NS ³
CP	10.3	13.5	S ²
SCP ¹ (% CP)	47.8	78.1	S ²

¹ soluble crude protein

² statistically significant at 5% level

³ statistically not significant at 5% level.

(Nelson *et al.*, 1997).

Table 2.4 Chemical Composition of Cereal Silages.

Item (% DM basis) (stage of maturity)	Barley (soft dough)	Triticale (soft dough)	Oat (milk stage)	Significance
DM	35.6	43.7	38.5	S ²
NDF	55.0	57.9	53.5	S ²
ADF	35.5	39.1	34.2	S ²
Hemicellulose	18.9	19.5	19.3	NS ³
Cellulose	25.2	30.2	27.1	S ²
Lignin	2.5	4.6	4.2	NS ³
CP	11.0	11.6	11.5	NS ³
ADICP ¹ (% of total CP)	3.9	5.9	4.5	S ²
Ash	17.3	14.6	14.9	NS ³
pH	4.32	4.42	4.46	NS ³

¹ acid detergent insoluble crude protein

² values for oat are significantly different at 5% level from that of one of the other

³ values for oat are not significantly different at 5% level from that of one of the others.

(McCartney *et al.*, 1994).

2.4.2 Cell Wall Components

Although variation in composition of cell walls from the same cell type found in different cultivars or species is small and appears to contribute little to any observed differences in whole plant digestibility, distinct and major differences are found in the composition of the walls of different cell types (Jung, 1993). Isolation of specific cell types has tended to center on plant storage organs where homogenous cell preparations can be obtained by simple dissection and on the cereal grains. The function of the cells that form the bulk of seed and storage organs differs from that of the cells forming the vegetative parts of the plant and this is often reflected in their composition. The cell walls of relatively few vegetative cell types have been examined in depth largely because of the difficulty in obtaining homogenous sample from forage plant in sufficient amounts to allow chemical analysis.

The plant cell wall is composed of three layers; the middle lamella, the primary cell wall and the secondary cell wall (Van Soest, 1994) with the relative proportions depending on cell type and maturity. The middle lamella is composed of pectic substances which are thought to function as inter-cellular cement. The primary cell wall is usually found in young undifferentiated cells that are still growing (Selvendran, 1987). This layer consists mainly of cellulose, hemicellulose and pectins, but may contain a small amount of protein, which is a glycoprotein rich in hydroxyproline, arabinose and galactose. In the Cornell Net Carbohydrate and Protein System (CNCPS; Sniffen et al., 1992) carbohydrate fractions *B* and *C* are cell wall (structural) components. Once the plant has reached inflorescence, the formation of the secondary cell wall begins to develop within the primary cell wall. Water content decreases

significantly as lignin replaces it. Lignification is initiated in the middle lamella and primary cell wall after cell expansion ceases, and proceeds throughout the secondary cell wall as cells age. The concentration of lignin is higher in the middle lamella or the primary cell wall than the secondary cell wall, but because of greater thickness the latter contains most of the lignin present in the plant (Jung, 1993). Deposition of hemicellulose and lignin increases within the secondary cell wall. Lignin precursors, the phenolic acids, crosslink hemicellulose and provide mechanical strength to the plant. As in the primary cell wall, cellulose is the most abundant substance in the secondary cell wall. The three layers often observed in the secondary cell wall (S₁, S₂ and S₃) represent different orientations of microfibrils. However Jung (1993) reported that these layers have not been shown to have any differences in digestion characteristics. The thick walled cells that lignify cause most of the low recovery of available energy from forage. The accessibility of carbohydrates to rumen microbes is limited by the chemistry of the cell wall and the structural arrangement of each cell type within a tissue by which influence physical breakdown of forage, and hence the rate of passage and intake of forage.

NDF has proven of value providing a robust measure of the cell wall content of forages and enables to distinguish cellular differences between forage and concentrates (Mertens, 1992). The NDF represents the insoluble matrix of the plant cell wall, substances covalently linked or so intimately associated through hydrogen bonding, crystallinity, or other intra-molecular association that are resistant to solutions within the range of physiological concentrations in rumen fluid. NDF is a valuable analysis that rank all feed stuffs in a continuum from feeds containing no

fiber, low fiber concentrates, to high fiber straws and cellulose. Although NDF recovers the indigestible components, unlike ADF (which does not include hemicellulose) or crude fiber (lignin and hemicellulose), its correlation with digestibility for ruminants is inferior to ADF.

Acid detergent fiber (ADF) mainly consists of the insoluble hemicellulose and the insoluble lignin and cellulose. ADF is widely used as a quick method for estimating fiber in feeds, often substituting for crude fiber as a part of a proximate analysis. ADF is relatively low in digestibility and hence ADF content can be used to predict the energy content of forage (Adams *et al.*, 1980 and Beauchemin *et al.*, 1996). According to these authors a robust attention and appreciation for the analytical variability and the limitations of predicting energy content from ADF is needed to interpret feed analysis reports in terms of animal performance. Generally a prediction of DM intake from NDF depends on number of factors, but NDF content of forage should be used in diet formulation to ensure adequate fiber. To maximize milk yield and milk fat content, both dietary NDF intake (as a percentage of body weight) and energy intake must be maximized. Diets for high producing dairy cows should be formulated to obtain the highest possible concentration of NDF from forage in the diet, while meeting the requirement for energy density. This can only be achieved by maximizing forage quality. According to NRC (2001) a minimum of 15% forage NDF should be included in dairy diet and dietary non fiber carbohydrate should not exceed 44%.

According to Mertens (2002) forages of differing qualities can result in equal performance if fed in rations that are formulated to contain similar NDF. Rather than

feeding a fixed forage concentrate ratio, it is recommended that dairy rations be balanced for NDF concentration to adjust for differences in forage quality. Optimum production of 3.5 or 4% fat corrected milk can be achieved when feeding a variety of forage sources by balancing rations to obtain an NDF intake of 1.1 to 1.3% of body weight of cow per day. But very high-quality forages and certain by-products may be associated up to 1.5% of body weight of cow. Mertens (2002) suggested that NDF can be used to quantitatively estimate the forage to concentrate ratio with minimum and maximum forage. This supported the NRC (2001) recommendations for NDF levels in formulated dairy diets. Chemical and physical characteristics of feed (forage) are important in formulating minimum or maximum forage rations. One of the main factors affecting the flux of NDF through the digestive tract is particle size. Differences in fiber characteristics among sources such as rate of digestion, digestibility and density can be important in fine tuning the system, but seldom do they exceed the effect of fiber concentration in establishing the optimal forage to concentrate ratio of the diet.

Table 2.5 Recommended Minimum Concentrations (% DM) of Total and Forage NDF and Recommended Minimum Concentrations (% DM) of Non Fiber Carbohydrates (NFC) for Diets of Lactating Cows, When the Diet is Fed as Total Mixed Ration.

Minimum Forage NDF	Minimum dietary NDF	Maximum NFC ^a	Minimum ADF
19	25	44	17
18	27	42	18
17	29	40	19
16	31	38	20
15	33	36	21

^a NFC is calculated by difference $100 - (\% \text{ NDF} + \% \text{ CP} + \% \text{ fat} + \% \text{ ash})$.
(National Research Council, 2001).

2.4.3 Agronomic Factors and Forage Quality

Most of the agronomic variation in forage quality is accounted for by plant maturity and response of the plant to environmental factors, which determine the rate of plant development and the distribution of synthetic resources in the plant. Another factor relevant to practical animal nutrition is the variation of quality (in terms of physical arrangement and chemical composition) expressed by individual forage species that may respond differently to environmental stimuli. Environmental effects on forage composition are complex, however, temperature, light and moisture in decreasing order are the dominant factors affecting the plant physical nature and composition chemistry (Van Soest, 1994).

It is generally assumed that cell wall (total fiber) and lignin content increase with plant age and both are negatively correlated with digestibility. However lignification is primarily dependant upon environmental temperature and plant maturity, with low temperatures overriding the effect of maturity by affecting photosynthesis, respiration, translocation of nutrients, carbon partitioning and cell wall formation, while cellulose and total cell wall are probably predisposed more by light patterns. Hence low temperatures influence the drive for increased stem diameter, plant height, leaf stem ratio, digestibility, decreased lignification and delayed maturity. Light and photoperiod promote photosynthesis and the production of sugars and metabolites that dilute the structural matter, hence a negative association between light and cell wall components (Van Soest *et al.*, 1978). Low moisture levels in soil delay plant maturity, decrease plant height, increase leaf stem ratio and can decrease NDF

percentage. Generally stress factors promote digestibility through retardation of plant development.

2.4.3.1 Stage of Plant Maturity

Stage of maturity at harvest is the most important factor determining the yield and quality of a cereal crop when used as forage. In both oat and barley, forage yield increases by 90 to 110% as maturity changes from the boot stage (head beginning to emerge from the leaf whorl) to the soft dough stage. At the same time, crude protein drops by 40 to 50%, ADF and NDF levels increase by only 15 to 25%. This results in only a modest decline in energy content of the forage as the cereals mature and indicates that maximum yield of energy per acre will occur when the cereal is at the soft dough stage of development (Werry, 1998). Mtimuni (1976) reported that the stage of maturity of cereal forages in western Canada affected neither the DM digestibility nor the organic matter digestibility. The stage of maturity does affect the content of structural polysaccharides and lignin; generally these increase in concentration with advancing stage of growth and the digestibility being related inversely to the composition of lignin carbohydrate complexes (Mtimuni, 1976). The decreased percentage of fibrous components with increasing maturity of the cereal forage mainly results from increasing dilution effect of the grain with increasing grain to leaf and stem ratio. However, it is not applicable to all forage plant species because age and the physiological maturity are not identical. Depending on growth conditions plant may reach physiological maturity at early or late chronological maturity (Steady, 1980).

Digestible protein and energy percentage is highest in the boot stage, but dry matter production per acre is low. When harvested at this stage of growth, small grain forage approaches mid to early bloom alfalfa in feed value. This stage also has higher protein level and about the same energy level as corn silage (Johnston, 1999). Forage harvested in the boot stage must be wilted to a desirable moisture content of the forage before ensiling. When harvested in the heading to flowering stage, small grain forage should be equal to or better than early cut grass forage. When growing conditions produce a tall straw, protein production per acre may be higher than other stages and digestible energy production will closely approach the maximum for a tall growing crop. Maturity affects chemical composition more than many other factors (Johnston, 1999).

Milk-stage silage is the least palatable to livestock, and usually produces slower and less efficient gains than dough-stage silage (Guyer, 1997). Dough-stage silage, although lowest in crude protein, produces the greatest forage yields and usually the greatest total digestible nutrient yield per acre. The exception is when plant growth is tall and grain yields are low, especially if the crop lodges and harvest is difficult. When varieties or weather conditions produce a short straw with low tonnage of forage, it is advisable to harvest at the early dough stage to take advantage of the grain produced (which is apt to provide a relatively high percentage of the total dry matter harvested). When the plant is tall, harvesting at the heading or flower stage of growth may have the greatest potential. The decline in digestibility and protein content of the stalk from heading to early dough may offset the increased dry matter production from the grain that would develop. Weather conditions that favor forage

growth are often less than optimum for high grain yields, thus spreading the grain-to-forage ratio even farther apart. Optimum harvest period is short for small grains compared to corn or sorghum (Guyer, 1997).

2.5 Methods of Forage Evaluation for Ruminants

In order to maximize the efficiency of forage utilization in ruminant feeding, estimation of forage nutritive values by reliable but simple methods is very important. Several techniques have been established to estimate the contribution of feed to the rumen in the process of efficient digestion and animal performance. Basically these techniques are comprised of chemical analysis and biological trials.

2.5.1 Analytical Procedures

The historical method of feed analysis is the proximate principles system. Since the mid 1800s this principle has been used to evaluate forage (Undersander *et al.*, 1995). The essential feature for this system is the partition of carbohydrate into crude fiber and nitrogen free extract (NFE). Besides having low precision, the crude fiber procedure does not recover all the fiber, resulting in large losses of hemicellulose and soluble lignin into the NFE fraction.

In the 1970s the proximate system of fiber analysis was replaced by the more meaningful detergent system which measures more basic components of plant structure and relates them to animal digestion and production according to their availability to both rumen microorganism and animal (Stern *et al.*, 1997). The system uses detergents to separate feed and forage dry matter into cell contents and various fiber (cell wall) fractions. The neutral detergent fiber (NDF) method (Van Soest *et al.*,

1991) dissolves soluble carbohydrate including pectic substances, protein, and other soluble components and provides a measure of the total cell wall material (cellulose, hemicellulose and lignin) as insoluble residue (Figure 2.1). The acid detergent fiber method dissolves only part of protein and hemicellulose, leaving cellulose, lignin and insoluble ash which is mainly silica (Van Soest et al., 1963). The difference between NDF and ADF values provides an estimate of hemicellulose. The lignin and cellulose contents may be determined gravimetrically from the ADF residues through removal of lignin by KMnO_4 oxidation, or removal of cellulose by acid hydrolysis (Goering and Van Soest, 1970).

Near infrared reflectance spectroscopy has proven to be a rapid, inexpensive, and fairly accurate and less laborious method for estimating nutrient composition (NDF, ADF and CP) of various feed stuffs (Stern *et al.*, 1997).

2.5.2 Biological Procedures

Biological feed evaluation the conventional method includes total tract digestibility trial which helps to understand the basic digestibility characteristics of feed. The method can be either total collection (direct), regression or marker based, depending on the situation (Given, 2000). For the quantitative description of digestive and metabolic process, appropriate biological data are required and can be obtained using *in vivo*, *in situ* and *in vitro* methods (Givens, 2000). *In vivo* digestibility trials are conducted with ruminally or intestinally cannulated animals. Instead of this large scale expensive feeding trails *in vitro* digestibility systems have been established (Tillery and Terry, 1963). In order to study degradability rate characteristics *in situ* or nylon bag technique were introduced (Lindenberg, 1983) though it requires surgically

fixed rumen fistulae. The *in sacco* intestinal mobile bag technique is the other alternative.

2.5.2.1 Total Collection Digestibility Trials

A digestion trial involves a record of nutrients consumed and of the amount voided in the feces. The proportion of a feed that is not excreted in the feces is assumed to have been absorbed by the animal, and this is defined as the apparent digestibility of the feed. In the case of herbivorous animals with their more complicated digestive tracts, total collection of feces is preferred (Horn *et al.*, 1954). Given *et al.* (1989) concluded the direct or total collection method had the smallest variability. In order to reduce individual animal variation an experiment should contain more (four to six or more) animals. Uniformly mixed feed is also important. Animals of similar body weights, age and sex are preferred to minimize variations. Mixing contamination and loss of feces can be avoided by using individual metabolism crates and harnessing collection bags to the animals. By using males, urine contamination of feces can be avoided. For most temperate forages the difference in digestibility between cattle and sheep was so small as to be no practical significance (Rymer *et al.*, 2000).

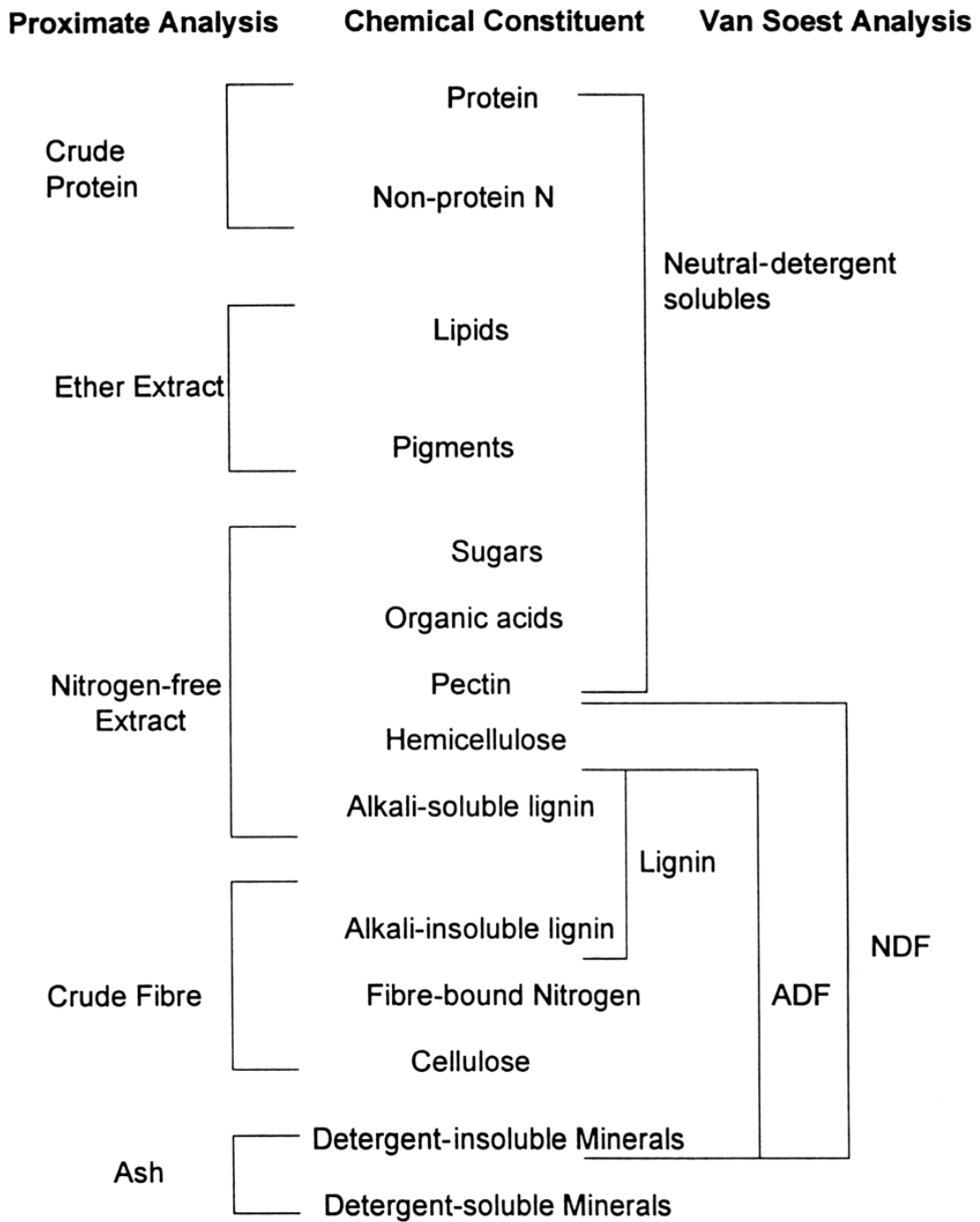


Figure 2.1 Contrast of Proximate and Detergent (Van Soest) Systems of Feed Analysis.

(Fisher *et al.*, 1995).

For the excreta of the experimental period (or collection period) to represent accurately the undigested residue of the feed, there must be a preliminary period of sufficient length to establish proper experimental conditions, such as animals becoming accustomed to the diet, to maintain uniform voluntary intake (VI), and to free the alimentary tract of residues of previous diet. This preliminary period may need to be 7 to 14 days or longer in length depending upon the feeds and the animals. With extreme ration changes in mature ruminants it may even be as long as three weeks. The length of collection period depends upon certain conditions, specially the rate of passage of digesta through the alimentary tract. It may be 5 to 20 days in ruminants (Horn *et al.*, 1954). Routine practice of feeding and collection once or twice a day would enhance the accuracy of values. Samples must be dried at temperature below 65 °C to avoid formation of artifacts, and if nitrogen balances are to be accurately measured (Van Soest, 1994).

2.5.2.2 Nylon Bag (*InSitu*) Technique

Measurements of degradation (digestion) rates of a feed in the rumen (*in situ*) using nylon bags with uniform pore size are used (Van Soest, 1994). An advantage of this technique is that the measurement of rumen digestion (or feed component disappearance) in relation to the time is strait forward and simple. Incubation of the sample for a series of time periods, defines the relationship between the extent of degradation or disappearance, and duration of time (Formula 3.12). Consequently the rate of degradation (or disappearance) and effective degradability of feed in rumen can be calculated (Ørskov and McDonald, 1979).

The suspension of feed material into the rumen allows intimate contact of the test feed with the ruminal environment (Nocek *et al.*, 1988). There is no better way to simulate the rumen environment within a given feeding regimen (temperature, pH, buffer substrate, enzymes), although in the ruminal environment, the feed is not subjected to the total ruminal experience: i.e., mastication, rumination, and digestive tract passage. Moreover the technique can be influenced by many inherent factors such as bag pore size, bag size or bag surface ratio, number of bags per incubation, sample size and sample particle size.

Effective degradability (*ED*) of nutrients is an estimate of the proportion of nutrients contained in the feed that can be degraded in the rumen, and was initially used for an estimation of the extent of protein degradation in the rumen (Ørskov and McDonald, 1979). This has since been expanded to apply to dry matter and other nutrients (Figure 2.2).

Where *P* is rumen disappearance at time *t* (h), *a* is soluble dry matter (DM) or nutrient (OM, CP, ADF and NDF) fraction (%), *b* is insoluble but degradable DM or nutrient fraction (%) and *c* is rate constant at which the *b* fraction is degraded (%h⁻¹). *L* (h) is lag phase that is particularly important for forages (Dhanoa *et al.*, 1988).

The importance of dry matter or nutrient effective degradability is acknowledged, especially for escape of true protein from the rumen (Van Soest *et al.*, 1987). Haj-Ayed (2000) reported the effective degradability of dry matter and protein for vetch-oat hays were 65.8 and 79.3% respectively. Khorasani (2000) reported effective degradability of dry matter for different Canadian barley grains from 73.8 to

89.0%. According to Mustafa *et al.* (2001), effective DM degradability of barley silage was lower than pea and alfalfa silages.

2.5.2.3 Production Trials

Dry matter intake, milk production and milk composition are influenced by dietary source of forage in total mixed rations. Undersander *et al.* (1995) developed a method for estimating milk per ton of forage dry matter as an index of forage quality. Greenfield (2001) concluded that in relation to feeding of corn silage in dairy rations increase in fiber component digestibility and improved nitrogen economy may combine to enhance dry matter intake and better support the nutritional demands of milk production for the high producing dairy cows. Lucas (1958) showed that the experiments with carry over effects such as dairy feeding and milk production trials can be carried out in change over (switch-back) experimental design minimizing the residual effects.

$$P = a + b [1 - e^{-c(t-L)}].$$

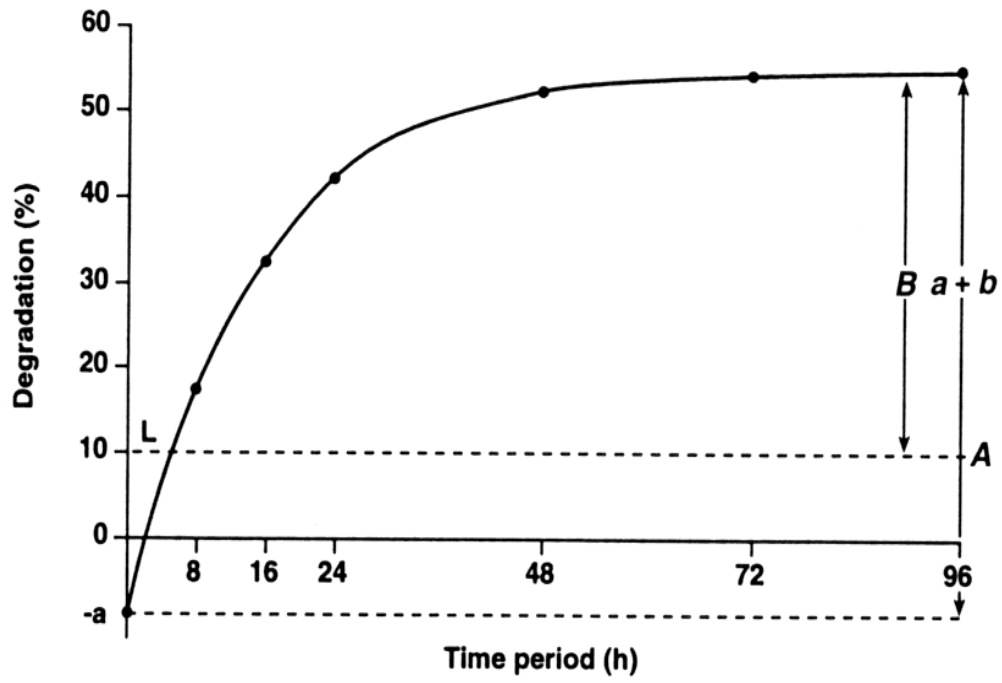


Figure 2.2 Degradation Rate and Extent of a Typical Forage.
(Ørskov, 2000).

2.6 Cereal Forage Digestibility by Ruminants

Several authors have discussed the cereal forage digestibility in ruminants indicating less favorable utilization of oat forage compared to barley forage. Barley has been recorded with more positive emphasis. According to Burgess *et al.* (1973) oat silage dry matter intake was not inferior to barley and corn silage. According to Oltjen *et al.* (1980), low intake by Hereford steers was reported with oat silage compared to barley and wheat silages. However in 1994 McCartney concluded that oat silage is comparable to barley silage in apparent digestibility for ruminants.

2.6.1 Dry Matter Digestibility

In general the chemical composition, and physical micro-structural arrangement of components of a forage are closely related to digestibility of the forage. The suggestion of a metabolic block by lignin on digestibility of other nutrients is sufficient to account for the lignin effect on digestibility of forage. Oltjen (1980) described a 9% decrease in DM digestibility of cereal forages from boot to dough stage of maturity. Christensen (1977) showed that dry matter, energy and crude protein digestibilities were similar among barley, wheat and oat silages in western Canada. Hingston and Christensen (1982) reported that oat silages had higher dry matter intakes in comparison to barley and wheat silages resulting in equal digestible energy intakes. However oat silages had significantly lower protein and energy digestibilities. Schroeder (1979) concluded that oat silages (Spear and Burnett cultivars) are not inferior to alfalfa brome hay in dry matter intake or production performance in dairy cattle. Oltjen and Bolsen (1980) did not find composition and

feeding performance differences in steers for barley, corn and wheat silages from different cultivars. McCartney *et al.* (1994) reported comparatively greater dry matter digestibility for Johnson barley silage over Calibre oat silage. However the oat silage performed better than Carmen triticale silage in dry matter digestibility. Mtimuni (1976) reported lower DM digestibility at mid dough stage than early and late dough stage for barley, oat and wheat silages.

Sileshi *et al.* (1998) showed DM intake and digestibility for oat hay with sheep to be $54.2 \pm 0.7 \text{ g/W}^{0.75} \text{ d}^{-1}$ and $58.8 \pm 0.6\%$ respectively. Soita *et al.* (2002) found that DM digestibility of Rosser barley silage when fed to steers, was affected by the particle size. The comparison of two particle sizes 4.7 mm theoretical cut and 18.8 mm theoretical cut of Rosser barley silage, revealed that the 4.7 mm was more digestible. To determine true digestibility directly the endogenous loss of the component must be zero or be measured by some method that can distinguish between endogenous component and digested feed component in feces (Mertens, 2002). Further he stated that true digestibility equals apparent digestibility for some components such as fiber or starch because they have no losses from intestinal secretions or microbial debris. However many important feed components such as crude proteins, ether extract, neutral detergent solutions and possibly soluble carbohydrates have associated endogenous secretions (Figure 2.3).

2.6.2 Crude Protein Digestibility

Higher crude protein (CP) digestibility was reported for oat forages by several workers (Table. 2.6). Lassiter (1958), Brundage (1973) and Christensen (1977) stated

that oat silage contains higher crude protein and higher percentage of digestible protein than some other cereal silages (Table 2.6 and 2.7).

Hingston *et al.* (1982) reported lower CP digestibility for oat silage relative to barley and wheat silages, having fed to steers. McCartney *et al.* (1994) concluded that there is no significant difference in CP digestibility of oat and triticale silages but higher CP digestibility in barley silage, with heifers.

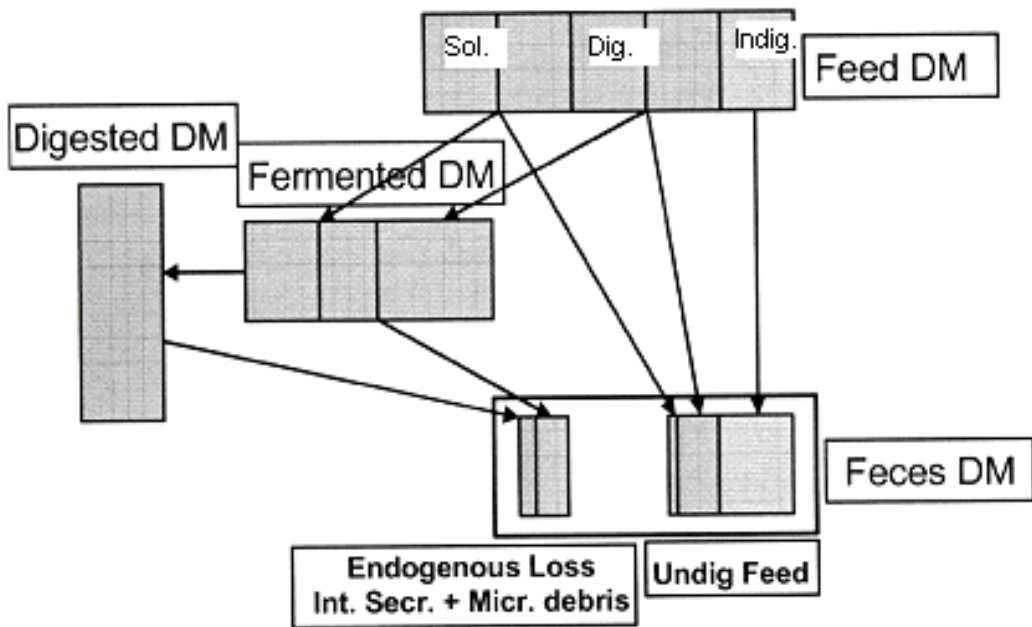


Figure 2.3 Components Involved in the Determination of Apparent and True Digestibility of Dry Matter.

Sol: soluble, Dig: potentially digestible, Indig: indigestible,
Int. Secr: intestinal secretions, Micr: microbial.

(Mertens, 2002).

Table 2.6 Apparent Digestibilities of Cereal Silages in Ruminants Reported in 3 Studies.

Digestibility (%)	Barley	Wheat	Corn	Oat	SE	Significance
DM	63.1	61.4	66.2	63.3	0.67	S ¹
Energy	63.2	63.2	66.7	63.2	1.4	S ¹
CP	70.1	67.0	59.4	69.3	0.22	NS ²

(Christensen *et al.*, 1977).

Digestibility (%)	Barley	Wheat	Oat	SE	Significance
DM	65.9	61.1	52.3	1.5	S ¹
Energy	64.4	62.9	52.3	1.5	S ¹
CP	70.2	66.3	61.4	1.7	S ¹

(Hingston *et al.*, 1982).

Digestibility (%)	Barley	Triticale	Oat	SE	Significance
DM	64.2	58.8	58.3	1.1	S ¹
Energy	63.5	62.3	57.6	1.1	S ¹
NDF	52.0	54.0	46.4	1.5	S ¹
CP	71.6	65.4	67.3	1.1	S ¹

(McCartney *et al.*, 1994).

¹ values for oat are significantly different at 5% level from that of one of the other
² values for oat are not significantly different at 5% level from that of one of the others.

Table 2.7 Dry Matter Intake and Apparent Digestibilities of Barley and Oat Silages in Saskatchewan.

Variable	Barley silage		Oat silage			
	Bonanza	Abee	Riel	Dumont	Cascade	Calibre
DMI (% BW)	2.41	1.92	2.19	2.05	2.20	1.70
DM (%)	69.0	65.2	60.1	59.2	60.4	61.1
OM	70.4	67.7	61.6	60.0	62.0	61.6
CP	73.0	70.4	72.9	70.5	70.9	74.2
NDF	55.1	54.6	43.6	46.3	52.1	52.6
ADF	51.2	48.5	40.4	41.2	49.7	49.3

(Christensen, 1993).

2.6.3 Neutral and Acid Detergent Fiber Digestibility

Dietary fiber as defined by nutritional concepts does not conform to a botanical definition of plant cell wall. The difference in definition occurs because non ruminants are limited to digestion of starch by secreted enzymes. As a result, such plant storage compounds as galactans and fructans are indigestible and hence defined as dietary fiber. In case of ruminants these storage compounds plus cell wall carbohydrates, such as extractable pectins and β glucans may be classified with soluble carbohydrates because they all will be fermented in the rumen (Van Soest, 1991). The nature of plant cell wall and the quality of NDF are variable because of variable lignification. However, NDF represents the insoluble coarse fiber from forage (Figure 2.1) and stimulates the rumination and rumen function, which are vital to maintain the rumen ecosystem and the process of rumen digestion. Unlike NDF, ADF is intended to isolate the components more resistance to digestion. These include pentosans, cellulose, lignin, cutin, and the acid detergent insoluble nitrogen (ADIN) fractions. Because of these recoveries, ADF trends to have the better correlations with organic matter digestibility of any of the feed fractions, more so than the NDF due to compositional interactions (Van Soest, 1991).

Traditionally, high fiber content has been considered a disadvantage because of the lower digestibility of high fiber feeds such as forages relative to concentrates. This does not seem to be true in all cases. It is well recognized that some measure of 'effective fiber' (eNDF) or physically effective fiber (peNDF) is required for ruminants to maintain normal rumen function and to ensure the normal milk fat percentage. Secondly eNDF stimulates mastication, salivation and rumination

processes. The source of NDF has a major impact on digestibility and cow response. Forage NDF has a slower passage rate and a higher rate of digestion than most non forage NDF (Mertens, 2002). Differences in the rate and extent of digestion of NDF and ruminal digestibility of NDF are related to volatile fatty acid production and ultimately the ability of feed to maintain ruminal pH (NRC, 2001). Particle size of the forage is also important in the sense of governing the passage rate. There should be sufficient time for rumen microbes to attach to feed and for fermentation to take place. Type I peNDF uses the NDF of forage materials retained on a 1.18 mm screen while Type II peNDF is based on the NDF content of three different particle size fractions using the Penn State Particle Separator. Kononoff (1998) found that 14% Type II peNDF in total mixed rations (diets) would support normal milk fat percentage. It has been suggested that diets should contain 6 to 10% of forage longer than 19 mm, 30 to 50% between 8 to 19 mm and 40 to 60% less than 8 mm. The density of the forage determines whether the forage particle sinks to the bottom of the rumen or floats in the fiber mat. Particles at the bottom may pass less digested from the rumen to the small intestines unless it is rapidly fermented. Higher digestibilities of NDF and ADF were reported for shorter (4.7 mm, theoretical cut) particle size Rosser barley silage (Soita *et al.*, 2002). McCartney *et al.* (1994) concluded that NDF digestibility of Caliber oat silage was lower than Johnson barley and Carmen triticale silages.

It is apparent that expressing the value of fiber or requirement as NDF is superior to ADF for many reasons. Factors that increase the NDF requirements would also increase the ADF requirements in ruminants because the two are correlated.

McCartney *et al.* (1994) concluded that ADF digestibility of Caliber oat silage was similar to Johnson barley and Carmen triticale silages.

2.6.4 Digestibility of Other Nutrients

Lignin is one component that negatively influences the digestibility of forage. According to Mtimuni (1996) lignin percentage decreased with increasing maturity of the cereal forage due to increasing grain to stem and leaf ratio. Late dough stage silage had lower lignin content than the early dough stage. However, increase in lignin concentration as plants mature varies with plant species. Stacy (1980) concluded that lignin increased with the maturity of brome, alfalfa and bailed forage due to leaf loss, and digestibility of lignin and organic matter in them decreased. According to McCartney *et al.* (1994) hemicellulose digestibility of oat silage was lower than barley and triticale silages. Cellulose digestibility of oat silage was lower than triticale silage, but similar to barley silage.

2.7 Rumen *In Situ* Degradation Characteristics of Forage

Some authors have used *in situ* degradability characteristics of DM, CP and NDF in terms of soluble, fermentable and undegradable fractions (*A*, *B* and *C*) and effective degradability (*ED*) in forages (Figures 2.2 and 2.4). Fraction *A* is soluble DM or nutrient (OM, CP, ADF and NDF), *B* is insoluble but degradable DM or nutrient fraction and *C* is undegradable DM or nutrient fraction. The values for *A*, *B* and *C* would be used by multiple regression to predict intake and digestibility (Ørskov, 2000). Under optimum rumen environment and function the rate of DM degradation is faster (Figure 2.4). Dewhurst *et al.* (1995) suggested that *in situ* technique may not

be as accurate for forages as for concentrates or protein supplements because the feed does not undergo effect of mastication. However, ADF content of the samples was greater than 25% of DM as in most forage, variations in degradability characteristics were less.

2.7.1 Dry Matter Degradability and Disappearance

Digestion in the rumen involves a sequential attack by ruminal microorganisms on feed (Cheng *et al.*, 1991). Fonseca *et al.* (1998) showed the relationship of digestible dry matter intake and *in situ* DM degradability characteristics. Sileshi *et al.* (1998) reported higher gas production for oat hay with sheep compared to other forage hays. Using Ørskov and McDonalds (1979) equations Sileshi (1998) reported the values of *A* (soluble), *B* (degradable) and effective degradability (*ED*) as 24, 45 and 53% (out flow rate: 2%h⁻¹) for oat hay. Hadjipanayiotou *et al.* (1996) reported that DM and CP effective degradabilities of barley and oat forages decreased with advancing stage of harvesting and an increase in CP degradability with increasing CP content of forages.

2.7.2 Crude Protein Degradability and Disappearance

The rate and extent of protein degradation in the rumen is very important, as it determines nitrogen and amino acids available to micro organisms, and amino acids passing into the small intestine available to the host animals (Stern *et al.*, 1997). The protein consumed by the animal should be partly degradable in the rumen, as peptides and amino acids derived from proteolysis are thought to stimulate microbial growth and rumen fermentation under certain conditions. It is, therefore, very important to

determine the degradability of feed ingredients (forage) which are grown and used in different regions, when for formulating rations using CPM Dairy, CNCPS and NRC Dairy 2001. Von Keyserlingk *et al.* (1996) concluded that *in situ* CP degradability characteristics in ruminants differed among forages.

Hadjipanayiotou *et al.* (1996) reported that *in situ* CP degradability was highly correlated with DM degradability of barley, oat forages (harvested at heading, milk stage and early maturity) and vetch. The difference between barley and oat forages was considerable in DM degradability but not in CP degradability. He also showed a shift in CP degradability with stage of maturity.

2.7.3 Degradability of Acid and Neutral Detergent Fiber

Particle size of forage as well as concentration of NDF in the diet has an impact on ruminal pH. Nonlinear models have been extensively used to predict rate and extent of degradation of NDF. Huhtanen *et al.* (1995) stated that some *in situ* NDF degradability values calculated using linear models can result in underestimation of NDF degradation. However he indicated that rumen *in situ* NDF degradability ranged from 70 to 95% of *in vivo* NDF digestibility. Spanghero *et al.* (2003) stated that animal to animal variability of *in situ* NDF degradability was low. In 1999 he reported that the rapidly degradable fraction (*A*) of NDF is 2.2% of total NDF on average. *In situ* degradability characteristics of NDF and ADF are shown in Table 2.9 for oat hull, straw and three different hays (Thompson *et al.*, 2000 and Spanghero *et al.*, 2003)

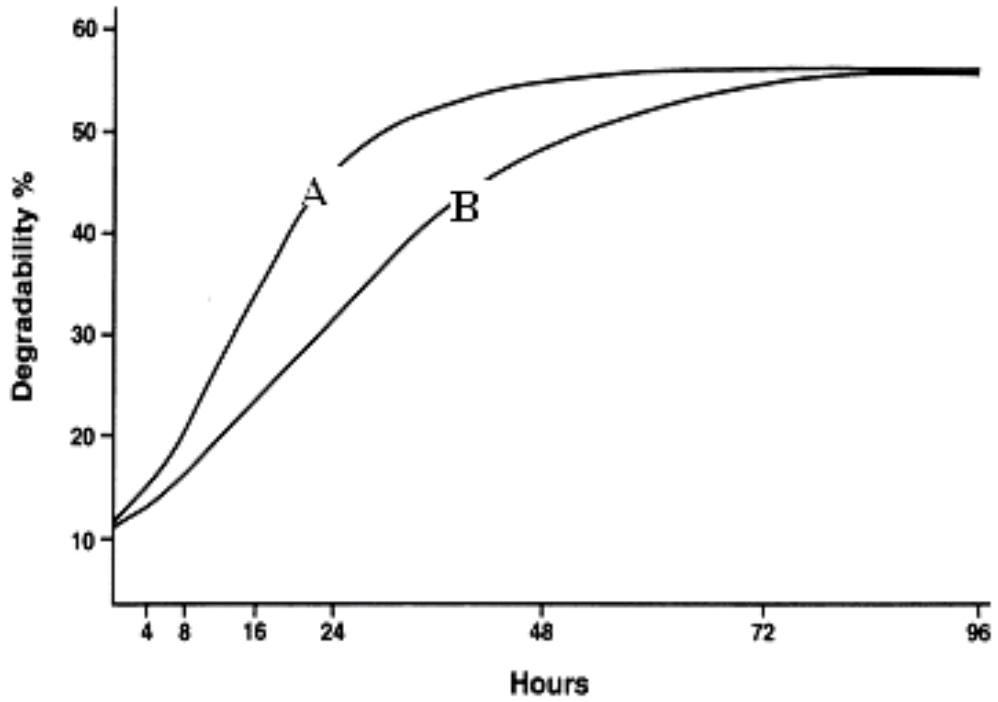


Figure 2.4 Rumen Degradation of a Forage when the Rumen Microbial Environment is Optimal (A) and Suboptimal (B). Note intercept and asymptote are similar.

(Ørskov, 2000).

Table 2.8 Rumen *In Situ* Degradation Characteristics and Effective Degradability of DM and CP in Some Roughages.

Variable	Barley straw ¹		Oat ¹			Vetch-oat hay ²		
	Corgi	Promise	Straw	Stem	Leaf	H1	H6	H12
Dry matter (DM)								
Soluble (% DM)	16.0	15.0	11.4	10.7	10.4	29.8	31.1	16.7
Degradable (% DM)	36.1	40.5	38.2	25.9	50.9	50.7	46.3	43.1
Undegradable (% DM)						19.5	22.6	17.9
Degradation rate (% h ⁻¹)	4.8	3.0	2.4	2.0	3.5	5.1	5.4	11.8
Effective degradability (%)						62.0	61.3	73.4
Crude protein (CP)								
Soluble (% CP)	NA ^a					40.3	47.3	41.8
Degradable (% CP)	NA ^a					42.8	38.6	49.5
Undegradable (% CP)	NA ^a					16.9	14.1	8.7
Degradation rate (% h ⁻¹)	NA ^a					23.1	11.2	17.7
Effective degradability (%)						78.3	78.0	84.1

Soluble: A, Degradable: B, Undegradable: C, Out flow rate (*Kp*): 3% h⁻¹.

H1, H6 and H12 were vetch-oat hay types.

^a not available

¹Ørskov, 2000

²Haj-Ayed *et al.*, 2000.

Table 2.9 Rumen *In Situ* Degradation Characteristics and Effective Degradability of NDF and ADF in Some Roughages.

Variable	Oat hull ¹		Oat straw ¹		Hay ²	
	Assiniboia	Calibre	Bell	H1	H2	H3
Neutral detergent fiber (NDF)						
Soluble (% NDF)	5.4	4.1	5.8	2.0	4.7	4.1
Degradable (% NDF)	85.4	39.1	55.0	61.7	65.6	79.8
Degradation rate (% h ⁻¹)	1.3	1.3	2.4	4.3	3.6	7.0
Effective degradability (%)	22.5	11.8	23.4	37.6	40.1	58.8
Acid detergent fiber (ADF)						
Soluble (% ADF)	6.3	5.2	5.3	NA ^a		
Degradable (% ADF)	84.0	42.5	55.5	NA ^a		
Degradation rate (% h ⁻¹)	1.2	1.1	2.3	NA ^a		
Effective degradability (%)	22.3	12.5	22.8	NA ^a		

Soluble: A, Degradable: B, Undegradable: C, Out flow rate (*Kp*): 3% h⁻¹.

H1, H2 and H3 were vetch-oat hay types.

^a not available

¹Thompson *et al.*, 2000

³Spanghero *et al.*, 2003.

2.8 Production Response to Type of Forage in Ration

A number of production studies have been carried out in North America to evaluate cereal forage quality. In general a negative correlation has been reported between NDF concentration and DM intake (Kennelly, 1995). No significant differences in actual and fat corrected milk yields were recorded by many authors, though there were some differences reported in milk and body weight changes (McCartney *et al.*, 1994) in the animals fed oat, barley, corn and wheat silages.

2.8.1 Milk Yield and Composition

Similar milk protein concentrations were reported by many authors for cows fed cereal silages. But milk fat concentrations reported were varied among the diets as well as among the experiments. Kennelly (1995) found barley forage was superior to oat forage in milk yield. Burgess *et al.* (1973) reported that actual milk yields were not different between cows fed oat silage and barley silage; but these authors found that cows fed corn and wheat silages had higher milk yields than the cows fed oat silages. However there was no difference in fat corrected milk yields. They noticed no difference in milk protein and solid non fat content, but marginally higher milk fat percentage was reported for the cows fed oat silages.

2.8.2 Feed Intake, Body Weight Change and Blood Urea

Lower DM intake with cows fed oat silage compared to barley and wheat silages were reported by several authors. But the effect of silage type on DM intake was less pronounced in mid lactation cows than in early lactation cows according to Kennelly (1995). However, higher DM intakes were reported with cows fed oat and

barley, but lower for cows fed corn silage although no difference in body weight change was observed by Burgess *et al.* (1973). However, interestingly higher rumen ammonia and blood urea nitrogen levels were recorded for the cows fed oat silage. McCartney *et al.* (1994) reported a higher final body weight and average daily gain for heifers fed barley silage; intermediate for heifers fed oat silage and lowest for heifers fed triticale silage. Oltjen *et al.* (1980) reported inferior production performance (DM intake and body weight gain) with steers fed oat silages compared to wheat and corn silages.

2.9 Summary of Literature Review

Forage is the key component in dairy rations. Cereal silages are often the preferred forage for dairy cattle in western Canada. Barley is a commonly used forage in Saskatchewan. But oats often yield more forage dry matter than most of the other cereal crops. AC Assiniboia is a high-yielding, tan coloured low lignin hull oat cultivar well suited for the oat-growing areas of western Canada. CDC Baler is a new forage oat which can deliver higher energy and protein levels. CDC Bell oat also showed good quality and yield. AC Rosser is a good barley forage with high yield potential and broad adaptability to western Canadian conditions.

Many factors influence forage quality. Some of them are forage cultivar, stage of maturity at harvest and storage method. Secondly, environmental factors such as soil type and fertility, day length, temperature during plant growth are also important. As ruminants are capable of digesting forage carbohydrates as a primary source of energy, composition of carbohydrate has long been of interest as a major factor in

determining forage quality. Nutritive value implies not only the proportion of nutrients present in the plant, but also the intake and the digestibility by the animals. Forage intake is dependant upon the cell wall content, while forage digestibility was dependant on the cell wall (neutral detergent fiber) content and its availability determined by lignification and other factors. The composition of forage may be affected by geographical and environmental factors. Chemical and physical characteristics of forage are important to formulate optimum forage rations.

NDF has proven of value (intake limited to 1.3% of BW) in ruminant nutrition, providing a robust measure of the cell wall content of forages able to distinguish between forage and concentrates. NDF is the only constituents that ranks all feed stuffs in a continuum from feeds containing no fiber, low fiber concentrates, to high fiber straws and cellulose. Although NDF includes the indigestible components, it is inferior to ADF in correlation with digestibility for ruminants.

Most of the variation in forage quality is accounted for by plant maturity and response of the plant to environmental factors, which determine the rate of plant development and the distribution of synthetic resources in the plant composition. The other factor relevant to practical animal nutrition is the variation of quality expressed by individual forage species that may respond differently to environmental stimuli. Temperature, light and moisture in decreasing order are the dominant factors affecting composition. Lignification is primarily dependant upon environmental temperature and plant maturity.

Total collection digestibility trial which explains digestibility of feed is a biological feed evaluation method. The *in situ* or nylon bag technique is preferred

method to evaluate the rumen degradation of feeds. Measurements of degradation rates of a feed in rumen (*in situ*) using nylon bags with controlled pore size are intended in the technique the rate of disappearance and effective degradability (*ED*) of feed in rumen can be calculated. *ED* of nutrients is an estimate of the proportion of nutrients contained in the feed that would be degraded in the rumen at a specific outflow rate. This has since been expanded to apply to dry matter and other nutrients.

Dry matter intake, digestibility, milk production and milk composition changes in response to dietary supplement of different forage in total mixed rations. DM and CP effective degradabilities of barley and oat forages decrease with advancing stage of harvesting. In general barley forage was considered as superior to old oat forages in DM intake, digestibility and milk production response. But milk composition data with different cereal silages are more inconsistent and complicating.

Agricultural statistics indicate that over a million hectares of oats are grown in western Canada. Some of these cultivars in Saskatchewan are bred for forage use. The hypothesis of the research carried out for this thesis is that similar digestibility and production performance could be observed in dairy cows fed either barley or oat (newly developed varieties) silages in total mixed rations (TMR). The objectives of this investigation are to determine the nutrient contents of the three oat cultivars, to evaluate degradability and digestibility of oat forages compared to Rosser barley silage and to determine the nutritional impact of Assiniboia oat silage based total mixed ration (diet) on dairy performance compared to Rosser silage.

3. MATERIALS AND METHODS

3.1 Introduction

Oat (*Avena sativa*) and barley (*Hordeum vulgare*) silages have been consumed by steers at 1.5 to 2.2% BW (DM basis) daily (Christensen, 1993). Based on digestibility studies as well as in milk production studies, it appears that cereal silage will provide sufficient energy for maintenance plus 10 to 15 kg of milk daily. Higher dry matter (DM) yield in forage production, higher intake for oat silage with steers and comparatively similar digestibility with barley and wheat having higher total digestible nutrients (TDN) were reported by Mtimuni and Christensen (1976). According to Christensen (1993) oat silage cut at the early dough stage is equivalent to barley and wheat in nutritive value and digestibility. Sileshi *et al.* (1998) reported DM intakes of $54.2 \text{ g/W}^{0.75} \text{ d}^{-1}$ and digestibility of 58.8% for oat hay with sheep respectively. McCartney *et al.* (1994) reported comparatively greater dry matter digestibility for Johnson barley silage over Calibre oat silage. This author further mentioned that NDF and hemicellulose digestibility of oat silage was lower, but ADF digestibility of oat silage was similar to barley silage.

Lassiter *et al.* (1958), Brundage *et al.* (1973) and Christensen *et al.* (1977) indicated that oat silage contains higher crude protein and higher percent digestible protein than those of some other cereal silages such as barley and wheat. However, Hingston *et al.* (1982) and McCartney *et al.* (1994) reported lower CP digestibility for oat silage compared to barley silage when fed to steers and heifers respectively. According to Mtimuni (1976) the effect of maturity of cereal silage plant was less relevance to ruminant performance than the effect of cultivar. Kennelly (1995)

described that barley silage was superior to oat silage in eliciting a milk production response.

AC Assiniboia is a forage oat cultivar which is well adapted to western Canadian soil (Brown *et al.*, 2001) with disease resistance (Chong *et al.*, 2000) and low lignin level in hull (Thompson *et al.*, 2002). CDC Bell and CDC Baler are forage oat cultivars for greenfeed purposes (Rossnagel, 1998).

The main objectives of the study were: (1) to determine the nutrient content of three oat cultivars (ASOS, BEOH, BAOH) and ROBS, (2) to evaluate *in situ* rumen degradability of oat forages compared to ROBS, (3) to evaluate total tract digestibility of the oat forages compared to ROBS, and (4) to determine the nutritional impact of ASOS based total mixed ration (TMR) on dairy performance compared to ROBS TMR.

3.1.1 Forage Samples and Preparations

Four forage cultivars grown in Saskatchewan, Canada were evaluated. These included Assiniboia, Bell and Baler oat (*Avena sativa*) forages and Rosser barley (*Hordeum vulgare*) forage. Assiniboia and Rosser were respectively harvested on July 18th and 27th, 2001. Bell and Baler were harvested on August 16th, 2001. Silage was prepared from Rosser and Assiniboia forage chopped to a 9 mm theoretical-cut and then respectively ensiled in a tower silo and in a polyethylene covered stack. Rosser was the routine silage used in the farm, hence it was ensiled in the tower. Hay was prepared from Bell and Baler. Oat forages were in the early dough stage but barley was in mid dough stage as at harvest.

In preparation for chemical analysis three composite samples of each forage were dried at 55°C for 48 h and then ground through a Christy & Norris (1 mm screen) mill. Samples for an *in situ* rumen degradability determination were dried at the same temperature and ground through a 2 mm screen. Hay from Bell and Baler for a sheep total tract digestibility was chopped using a Hay Buster (model H 10000) to pass through a 75 mm screen.

3.1.2 Chemical Analysis

Samples were analyzed according to the Association of Official Analytical Chemists (AOAC, 1990) following the methods of the Cornell Net Carbohydrate and Protein System (CNCPS) for dry matter (DM; method 930.15), ash (method 924.05), Kjeldahl nitrogen (CP; method 984.13) using a Kjeltex 1030 auto analyzer, crude fat (EE; method 920.39), acid detergent fiber (ADF; method 973.18) and acid detergent lignin (ADL; method 973.18). Neutral detergent fiber (NDF; method 930.15) was determined using heat stable amylase according to the procedure of Van Soest *et al.* (1991). An Ankom fiber analyzer was used for determination of ADF, NDF and ADL. Soluble crude protein (SCP) was determined according to the procedure described by Roe *et al.* (1990). Neutral detergent insoluble crude protein (NDICP), acid detergent insoluble crude protein (ADICP) and non-protein nitrogen (NPN) were determined according to the procedure of Licitra *et al.* (1996). Starch was determined by spectrophotometric (McCleary *et al.*, 1997) assay using α – amylase and amyloglucosidase (Megazyme, Ireland, UK). Forage fatty acids (longer than C₁₂) were analyzed using gas liquid chromatography (Folch *et al.*, 1957, as cited by Pritam *et al.*, 1998) in duplicate on Supelcowax – 2340, 60 m x 0.25 mm internal diameter, 0.2 μ m

column (Sigma Aldrich Ont. Canada) installed on a HP GC using a flame ionization detector with capillary injection system at a split ratio of 1:100. The oven temperature was set at 150⁰ C then raised to 200⁰ C at 1.5⁰ C/min then held for 10 min. Helium was used as a carrier gas, at a flow rate of 1.7 ml/min. Fatty acid identification was by comparison to retention times of known standards and amounts present were determined using an internal standard.

Carbohydrates (CHO) were classified according to degradation rate, into four fractions; **CA**, rapidly degradable sugars; **CB1**, intermediately degradable starch and pectin; **CB2**, slowly degradable cell wall; and **CC**, unavailable cell wall (Sniffen *et al.*, 1992). Based on the chemical analysis, the following formulas were used to calculate the CHO fractions of each the forage samples:

$$\text{Total carbohydrate (CHO, \%DM)} = 100 - \text{CP} - \text{EE} - \text{Ash} \quad (3.1)$$

$$\begin{aligned} \text{Non-structural carbohydrate} &= 100 - \{\text{NDF}(\%DM) \\ \text{(NSC, \%DM)} &= \text{NDF}(\%DM) - [\text{NDICP}(\%CP) * \text{CP}(\%DM)] \\ &+ \text{CP}(\%DM) + \text{EE}(\%DM) \\ &+ \text{Ash}(\%DM)\} \end{aligned} \quad (3.2)$$

$$\text{CA} (\%DM) = \text{NSC} (\%DM) - \text{B1} (\%DM) \quad (3.3)$$

$$\text{CB1} (\%DM) = \text{Starch} (\%NSC) * \text{NSC} (\%DM) \quad (3.4)$$

$$\text{CB2} (\%DM) = \text{NDF} (\%DM) - [\text{NDICP} (\%CP) \text{CP} (\%DM)] - \text{C} (\%DM) \quad (3.5)$$

$$\text{CC} (\%DM) = \text{NDF} (\%DM) * \text{NDL}(\%NDF) * 2.4 \quad (3.6)$$

Total crude protein was divided into five fractions; **PA**, non-protein nitrogen; **PB** (PB1, PB2 and PB3), true proteins; and **PC**, unavailable protein (Sniffen *et al.*, 1992). The following equations were used to calculate the true protein fractions.

$$\mathbf{PB1 (\%CP)} = \mathbf{SCP (\%CP) - NPN (\%CP)} \quad (3.7)$$

$$\mathbf{PB2 (\%CP)} = \mathbf{100 - A (\%CP) - B1 (\%CP) - B3 (\%CP) - C (\%CP)} \quad (3.8)$$

$$\mathbf{PB3 (\%CP)} = \mathbf{NDICP (\%CP) - ADICP (\%CP)} \quad (3.9)$$

3.2 Digestibility and Voluntary Intake of Forages

All four forages; Assiniboia silage (ASOS), Bell hay (BEOH), Baler hay (BAOH) and Rosser silage (ROBS) were evaluated in a total collection digestibility trial. Twenty-four male Suffolk sheep (lambs) with an average metabolic body weight of 14.4 ± 1.2 kg were used to assess apparent digestibility of dry matter (DM), organic matter (OM), crude protein (CP), crude fat (EE), acid detergent fiber (ADF), neutral detergent fiber (NDF), acid detergent lignin (ADL), hemicellulose, non-structural carbohydrate (NSC), non-protein nitrogen (NPN), soluble crude protein (SCP), neutral detergent insoluble crude protein (NDICP), acid detergent insoluble crude protein (ADICP), ash and energy in ASOS, BEOH, BAOH and ROBS. Sheep were randomly allocated to each of the four forage diets.

ASOS from the silage stack and ROBS from the tower silo were separately packed into 6 labelled 1 m diameter culverts (500 kg capacity) and sealed with 6 μ m plastic until they were used. BEOH and BAOH hay were chopped using a Hay Buster (model H 10000) with 75 mm screens a few days prior to feeding and stored in

labelled plastic barrels (200 kg capacity). The guidelines of the Canadian Council on Animal Care (CCAC, 1993) were followed in dealing with the animals.

3.2.1 Adaptation and Feeding

The digestibility trial consisted of a 19 d period of 3-step adaptation; 9 d of (3 day at each level) step wise (25, 50 and 75% of new forage) change over of diet, 6 d of *ad libitum* feeding period to estimate voluntary feed intake and 4 d of restricted feeding period at 80% of voluntary intake (Appendix: Table A2). During the 9 d diet adaptation period, animals were in four group pens; 6 sheep in each pen. With the start of *ad libitum* feeding of 100% forage diet, sheep were housed in individual metabolic crates.

The sheep were fed at 0800 and 1600 h throughout the trial. During the period of fecal sample collection (5 d), 80% of sheep voluntary intake feed was offered and zero orts was assured. Five grams of a standard sheep mineral mixture (Appendix: Table A1) and 3 g of feed grade salt (CO OP Saskatchewan) were added to the daily ration of each sheep. Fresh water was provided *ad libitum*.

3.2.2 Sample Collection, Chemical Analysis and Calculations

Total collection of fecal matter started at 0700 h for each of the 5 day experiment period (Appendix Table A2). Fecal collection bags were attached to sheep 7 d prior to the first day of fecal collection. Immediately after collection, all fecal samples were dried at 60 °C for 72 h. Dried fecal matter from each day was mixed proportionately on a DM weight basis to make individual sheep composite samples. The composite fecal samples were ground through 1 mm screen using a Christy &

Norris mill and stored at 4°C (cool room) until the chemical analysis was carried out as described above for forages. Feed and fecal samples were chemically analyzed for DM, OM, CP, EE, ADF, NDF, ADL, NPN, SCP, NDICP and ADICP (Section 3.1.2).

Digestibility (%) for DM and each nutrient was calculated by applying the following equation:

$$\text{Digestibility (\%)} = \frac{(\text{DM intake} - \text{Fecal DM output}) 100}{\text{DM intake}} \quad (3.10)$$

$$\text{Nutrient Digestibility (\%)} = \frac{(\text{Nutrient intake} - \text{Fecal nutrient output}) 100}{\text{Nutrient intake}} \quad (3.11)$$

Total digestible nutrients (TDN) were calculated using the digestibility of specific nutrients (CP, EE, crude fiber and nitrogen free extract). Digestible energy was calculated from TDN using 1 kg TDN equals 4.409 kcal DE.

3.3 Degradability of Forages

A non-lactating Holstein cow with a rumen fistula was used to determine degradability characteristics (DM, OM, CP, ADF, NDF) of ASOS, BEOH, BAOH and ROBS. The cow was fed a 48:52, barley silage: concentrate diet (DM basis) at 1.2% of body weight. The diet was introduced over a three-week adaptation period and was offered twice daily in equal portions at 0800 and 1600 h. Water was available *ad libitum*. The cow received appropriate health care and the experiment was conducted according to the guidelines of CCAC (1993).

3.3.1 Samples, Incubations, Chemical Analysis and Estimates

Five gram samples of each forage (DM) were weighed into nylon bags (9×21 cm, 41 µm average pore size). The number of bags (Appendix: Table A3) used for replication was selected to provide at least 7 g of DM residue of each forage from each incubation time.

The rumen incubations were performed according to the staged in and all out schedule. The nine incubation times were 96, 72, 60, 48, 36, 24, 12, 06 and 00 h. Incubations were performed in triplicate (n=3). Maximum number of bags incubated at one time was 40. Six incubations were carried out over total of 24 days.

Following the removal from the rumen, the bags were hand washed using cold tap water until wash water became clear. The washed bags were dried at 55°C for 48 h. Residues from each replicate bags were pooled according to the treatment forage and the incubation time, resulting 108 composite samples. Samples were ground through a 1 mm screen and chemically analyzed as described above. Rumen *in situ* disappearance of these nutrients was calculated as the difference between the amount in the original sample and in the residue. Ruminant, OM, CP, ADF and NDF disappearance data was used to estimate ruminal kinetic parameters using the equation of Ørskov and McDonald, (1979):

$$P = a + b [1 - e^{-c(t-L)}] \quad (3.12)$$

Where P is rumen disappearance at time t (h), a is soluble dry matter (DM) or nutrient (OM, CP, ADF and NDF) fraction (%), b is insoluble but degradable DM or nutrient fraction (%) and c is rate constant at which the b fraction is degraded (% h⁻¹). L (h) is lag phase particularly important for forages (Dhanao *et al.*, 1988).

The parameter a , b , and c were estimated according to Ørskov and McDonald, (1979), by means of an interactive least square method applying the nonlinear regression procedure of a newly updated curve fitting software (Origin 6.1, Version 6.1052 B 232) developed in 1995. Ruminant effective degradability (ED) of DM and nutrients at a rumen flow rate (k) of $4\% \text{ h}^{-1}$ was estimated using the equation:

$$ED = a + b * c / (c + k) \quad (3.13)$$

Where a , b and c were defined as above.

3.4 Dairy Production Trial

Eight multiparous Holstein cows at 90 ± 20 days in milk (DIM) averaging 41 kg daily milk yield, and housed in individual stalls were used in a 2×3 (28 d period) switch-back (Lucas *et al.*, 1956) experimental design to compare dry matter intake (DMI), change in body weight, milk yield and milk composition of cows fed either 48% ASOS or ROBS (DM basis) in total mixed rations (TMR). All cows received appropriate health care and the experiment was conducted according to the guidelines of the CCAC (1993).

3.4.1 Ration and Feeding

The total mixed ration consisted of 48:52 forage and concentrate (DM basis). TMR was well mixed in the individual feed boxes was fed *ad libitum* at 0800 and 1600 h maintaining a target minimum of 6% dailyorts. The first 6 d of each period were for a stepwise diet change (75:25, 50:50 and 25:75; previous forage: new forage) which occurred every 2 d. Water was freely available to each cow.

Table 3.1 Ingredient Composition of Concentrates Used in Total Mixed Rations (Diets).

Ingredient (DM %)	Assiniboia diet	Rosser diet
Barley grain	62.2	67.0
Canola meal	11.9	9.5
Soybean meal	11.8	9.4
Corn gluten meal	4.5	4.5
Wheat distillers grains	3.0	3.0
Molasses	1.0	1.0
Canola oil	0.5	0.5
Limestone	0.6	0.6
Cobalt iodized salt	0.6	0.6
Sodium bicarbonate	0.6	0.6
Dynamate ¹	0.3	0.3
Premix (mineral/vitamin mix.) ²	3.0	3.0

¹contained 22% S, 18% K and 11% Mg. (International Mineral and Chemical Corp., Mundelein, IL)

² contained 16.1% Ca, 8.5% P, 10.4% Cl, 6.3% Na, 3.3% Mn, 1.8% K, 1% S, and 1050 mg of Fe, 2100 mg of Zn, 1500 mg of Mn, 533 mg of Cu, 45 mg of I, 12 mg of Se, 15 mg of Co, 333,334 IU of vit. A, 60,000 IU vit. D3 and 1000 IU vit. E per kg.

3.4.2 Samples, Analysis and Calculations

Individual cow DM intake (DMI) was recorded daily. Cows were weighed on the 26th, 27th and 28th d of each period. Blood samples for blood urea were taken from the tail vein, 2 h *post-prandial* on the 27th and 28th d (the last 2 d) of every period. Daily milk yields were recorded and milk samples were collected at morning and afternoon milking on 3 consecutive days (d 26th, 27th and 28th). The period milk yield was based on the daily milk yields recorded on the last 10 days of each period for each cow. Morning and afternoon milk samples from each cow were pooled and stored at 4°C until analyzed. The milk samples were analysed (AOAC, 1990) in duplicate for total solids (TS; AOAC method 925.23), milk fat (MF; AOAC method 989.04) using the Babcock procedure, protein (MP; method 984.13) using the Kjeldahl procedure and lactose (ML; method 972.16) using infrared spectroscopy (O-Scan 605, Foss Food, Denmark). Milk urea was measured using a Beckman analyser (Beckman instruments, CA). Somatic cell count (SCC) was measured using a Fossomatic 360 (Foss Foods, Denmark) in which cells are dyed and then counted by means of a flow-cytometric fluoro-optoelectronic method. Milk fatty acids were analysed using the principle of gas liquid chromatography as described (Section 3.12).

Blood urea was analysed by a Roche/Hitachi analyser using the principle of enzymatic/kinetic UV assay absorbance. Feed samples were analysed as described above for forages.

Fat corrected milk (FCM, kg) was calculated applying the following equation:

$$3.5\% \text{ FCM} = (0.432 * \text{milk yield}) + (16.23 * \text{fat yield}) \quad (3.14)$$

3.5 Statistical Analysis

Analysis of variance (ANOVA) using the General Linear Model (GLM) and Proc Mixed procedures in the Statistical Analytical System (SAS) Institute, Inc (2001) were utilized with specific applications described in the following sections. Significant differences were declared when $P < 0.05$.

3.5.1 Statistical Analysis for Digestibility of Forages

The digestibility trial was set up in a completely random design (CRD) was used as the experimental design (Steel and Torrie, 1980). The digestibility data for 4 forages with 6 replicates (sheep) were subjected to analysis of variance (ANOVA) using the General GLM procedures in SAS Institute, Inc (1990). Orthogonal contrasts were carried out to distinguish differences in digestibilities' between Assiniboia oat silage and Rosser barley silage, between Bell oat hay and Baler oat hay, and between silages and hays.

3.5.2 Statistical Analysis for Degradability of Forages

A completely random design (CRD) was used as the experimental design (Steel and Torrie, 1980). The degradation characteristics (*a*, *b*, and *c*) and *ED* data for 4 forages with 3 replicates were subjected to ANOVA using the GLM procedures in the SAS Institute, Inc (2001). Means of the degradation characteristics and *ED* were

separated using orthogonal contrasts between Assiniboia oat silage and Rosser barley silage, between Bell oat hay and Baler oat hay, and between silages and hays.

Rumen disappearance rates at respective periods were subjected to multivariate analysis of variance (MANOVA) using the GLM procedures of SAS (2001). Student Newman Keuls (SNK) test procedure (Steel and Torrie, 1980) was used to differentiate means of raw data. Orthogonal contrasts were used to distinguish differences in disappearances between Assiniboia oat silage and Rosser barley silage, between Bell oat hay and Baler oat hay, and between silages and hays. Dry matter disappearances versus nutrient disappearances in the rumen were regressed to select the best suited model with minimum residual variability and higher coefficient of determination (R^2) or correlation coefficient (R).

3.5.3 Statistical Analysis for the Milk Production Trial

The statistical design in the trial was an incomplete Latin square (Lucas *et al.*, 1956). The milk constituents, production parameters and blood urea data for two silages with three periods were subjected to ANOVA using Proc Mixed (Cue, 2001) procedures in the SAS (2001). The means were separated using the t-test procedure and estimated mean differences in Proc Mixed analysis (Steel and Torrie, 1980). The model and random statements consisted of;

$$M = Grp Trt;$$

Cow(Grp) Prd; respectively. (*M*: dependant variable, production parameter, *Grp*: order of treatments during 3 periods, *Trt*: treatment diets and *Prd*: treatment period of 28 days).

Analysis of milk fatty acid data was performed only for the 3rd period of the experiment. The data were subjected to ANOVA using the GLM procedures in SAS (1990). Mean comparison was carried out according to LSD (Steel and Torrie, 1980).

4. RESULTS

4.1 Evaluation of Chemical Composition of Cereal Forages

The average composition of the four forages analyzed by wet chemistry is shown in Table 4.1. Physical characteristics of silages such as particle size and pH are shown in Table 4.2. Particle sizes of silages were comparable as they had undergone the same theoretical cut. Calculated protein and carbohydrate fractions of forages using the chemical composition data and formulas 3.1 to 3.9 (Section 3.1.2) are tabulated in Table 4.3. Forage fatty acids longer than C₁₂ were shown in Table 4.4. Although detailed statistical analyses were not done on these a few tendencies may be pointed out.

4.1.1 Nutrient Composition of Cereal Forages

The nutrient composition of Assiniboia oat and Rosser barley silages revealed similarity (Table 4.1) in many aspects. Bell and Baler oat hays were also similar in chemical content.

Structural carbohydrates such as neutral detergent fiber and acid detergent fiber in all four forages were comparable. Non-structural carbohydrates (23.5%), starch (25.7%) and ether extract (5.6%) were over 10% higher, and acid detergent lignin (7.7%) and acid detergent insoluble crude protein (3.1%) were over 10% lower in ASOS relative to ROBS. Crude protein and non-protein nitrogen were more than 20% higher in the silages than that of the hays. Total digestible nutrients (TDN) were in excess of 10% higher in the silages than that of the hays. Net energy for lactation

(NEI), calculated using TDN values ranged from 1.38 to 1.58 Mcal kg⁻¹ for the forages.

4.1.2 Carbohydrate and Protein Fractions

Cornell net carbohydrate and protein system fractions are shown in Table 4.3. Numerically lower unavailable (C) fractions (8.8% DM and 2.7% CP) and the higher rapid degradable fractions (A+B1) of both carbohydrate and protein could be observed in ASOS. It led to result 9% higher degradable and potentially degradable carbohydrate fractions and slightly (1%) lower degradable and potentially degradable protein fractions in ASOS than ROBS. Degradable carbohydrate and rapidly degradable protein fractions were 11% higher in the silages than the hays.

4.1.3 Fatty Acids in Forages

Fatty acids in the silages are shown in Table 4.4. Palmitic (C_{16:0}) in ROBS was 60% higher than that of ASOS. Oleic (C_{18:1}) and linoleic (C_{18:2}) were 15% and 10% higher in ASOS respectively.

Table 4.1 Nutrient Composition of Barley and Oat Forages (DM basis, n=4).

Nutrient	Barley		Oat					
	Rosser silage		Assiniboia silage		Bell hay		Baler hay	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DM	34.5	1.8	34.5	1.8	95.3	0.8	94.7	0.9
OM ¹ (% DM)	91.5	0.3	91.4	0.3	91.4	0.4	91.4	0.4
NDF ²	50.9	0.9	51.1	0.7	55.2	0.9	58.8	1.0
ADF ³	27.8	1.2	28.6	0.1	29.7	0.1	33.4	0.3
NSC ⁴	21.9	0.1	24.2	1.0	23.7	1.1	20.9	1.4
Starch	23.7	0.2	25.7	0.1	18.2	0.2	17.2	0.2
EE	5.1	0.4	5.6	0.6	3.5	0.1	3.0	0.1
Ash	8.6	0.3	8.5	0.3	8.6	0.4	8.7	0.4
CP	14.6	0.5	12.1	0.6	10.6	0.1	10.9	0.2
SCP ⁵ (% CP)	87.8	4.3	86.9	5.1	53.5	5.7	47.7	4.9
NPN ⁶ (% SCP)	79.5	1.5	75.6	2.9	52.2	3.1	47.8	2.4
NDICP ⁷	8.5	1.8	8.4	1.8	15.0	0.9	20.8	1.3
ADICP ⁸	3.5	0.5	2.7	0.6	4.1	0.6	3.4	0.3
ADL ⁹ (% NDF)	8.1	0.6	7.1	0.5	7.1	0.5	7.5	0.4
TDN ¹⁰	69.6	0.8	67.6	1.1	61.4	0.9	63.5	1.0
NEI ¹¹ (Mcal kg ⁻¹)	1.58	0.01	1.54	0.01	1.38	0.01	1.44	0.01

¹ organic matter

² neutral detergent fiber

³ acid detergent fiber

⁴ non-structural carbohydrates

⁵ soluble crude protein

⁶ non-protein nitrogen

⁷ neutral detergent insoluble crude protein

⁸ acid detergent insoluble crude protein

⁹ acid detergent lignin

¹⁰ total digestible nutrients

¹¹ net energy for lactation

TDN=tdNFC+tdCP+(tdFAx2.25)+td NDF-7; National Research Council (2001)

NFC: non fiber carbohydrates, td: truly digestible

NEI=(TDN×0.0245)-0.12: source: Weiss *et al.*, 1992.

Table 4.2 The Particle Size Distribution (%) and pH, of Assiniboia and Rosser Silages.

Variable	Silage (as fed basis, n=4)			
	Assiniboia	SD	Rosser	SD
Over 19 mm particle	6.9	0.01	6.9	0.01
Between 19 and 8 mm	49.8	1.11	51.3	1.05
Under 8 mm	43.3	1.07	41.8	1.06
Silage pH	4.3	0.03	4.2	0.01

Table 4.3 Cornell Net Carbohydrate and Protein System Fractions in Forages (n=4).

Fractions	Barley		Oat					
	Rosser Silage		Assiniboia Silage		Bell hay		Baler Hay	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Carbohydrates (% DM)								
CA (soluble)	0.1	0.0	0.1	0.0	4.8	0.3	2.8	0.2
CB1 (degradable)	23.7	0.2	25.9	0.3	18.9	0.6	18.2	0.9
CB2 (slow degradable)	39.8	0.7	41.4	0.5	44.2	0.7	46.0	0.4
CC (undegradable)	9.9	1.2	8.8	1.0	9.4	1.2	10.6	1.3
Proteins (% CP)								
PA (NPN)	69.8	4.2	65.7	5.3	27.9	3.8	22.7	2.8
PB1 (rapid degradable)	8.4	0.5	11.4	0.6	2.1	0.1	1.9	0.1
PB2 (degradable)	13.3	1.7	14.5	2.1	55.6	4.2	57.0	5.2
PB3 (slow degradable)	5.0	0.4	5.7	0.5	10.8	0.1	16.4	0.9
PC (undegradable)	3.5	0.3	2.7	0.2	4.1	0.4	3.4	0.3

Table 4.4 Fatty Acids C₁₂ and Longer than C₁₂ Detected in Forages (N=3).

	<u>Silage</u>		<u>Hay</u>	
	Rosser	Assiniboia	Bell	Baler
Ether Extract (%)	5.1	5.6	3.5	3.0
Fatty acid (mg g ⁻¹ of fat)				
Lauric (C _{12:0})	11.3	nd	nd	nd
Dedecenoic (C _{12:1})	34.7	nd	nd	nd
Myristic (C _{14:0})	17.4	nd	34.1	66.0
Palmitic (C _{16:0})	129.8	121.9	71.3	75.3
Palmitoleic (C _{16:1})	8.4	89.9	40.7	47.8
Oleic (C _{18:1})	173.2	209.9	207.7	238.7
Linoleic (C _{18:2})	294.0	324.7	244.9	257.3
Linolenic (C _{18:3})	241.9	216.6	70.4	59.9

nd: not detected.

4.2 Digestibility Evaluation

Voluntary DM and nutrient intakes, sheep body weights, chemical composition of sheep feces and apparent digestibility coefficients of forages are shown in Tables 4.5, 4.6, 4.7 and 4.8, respectively.

4.2.1 Voluntary Intake of Nutrients by Sheep

The voluntary dry matter intake was within the range of 1.95 to 2.25% of BW which is common for all forage diets, and was not affected ($P>0.05$) by diet. Organic matter intakes were similar ($P>0.05$) among the sheep and not affected ($P>0.05$) by diet. NDF and ADF intakes were not different ($P>0.05$). The crude fat (EE) intakes were higher ($P<0.05$) in sheep fed Assiniboia and Rosser silages than in sheep fed Bell and Baler hays. The lowest crude protein intake was shown in the sheep fed Baler hay and the highest CP intake was in the Rosser diet group. The voluntary intakes by sheep for all nutrients except CP and EE were equal ($P>0.05$) for Assiniboia and Rosser groups, and for Bell and Baler groups. Digestible energy intakes calculated from total digestible nutrients, were different ($P<0.05$). Rosser barley silage had higher (2.5 Mcal d^{-1}) DE intake compared to the others ($< 2.0 \text{ Mcal d}^{-1}$).

Table 4.5 Voluntary DM and Nutrient Intakes of Forages by Sheep.

Variable	Daily voluntary intake as % of BW ¹				SEM	Contrast		
	Silage		Hay			S/S	H/H	S/H
	Assiniboia	Rosser	Bell	Baler				
DM	2.02	2.25	2.06	1.95	0.053	NS	NS	NS
OM	1.84	2.06	1.87	1.78	0.048	NS	NS	*
NDF	1.04	1.16	1.15	1.16	0.028	NS	NS	*
ADF	0.58	0.64	0.61	0.65	0.015	NS	NS	NS
CP	0.24	0.32	0.22	0.18	0.012	***	***	**
EE	0.11	0.12	0.07	0.06	0.006	NS	NS	***
DE ² (Mcal d ⁻¹)	1.96	2.54	1.99	1.83	0.065	**	NS	**

¹ mean bodyweight of sheep: 34.9 ± 2.1 kg

² digestible energy.

S/S: contrast silage (Assiniboia) vs silage (Rosser)

H/H: contrast hay (Bell) vs hay (Baler)

S/H: contrast mean of silage vs mean of hay

*, **, *** P≤0.1, P<0.05 and P<0.01 respectively; NS: not significant (P>0.1).

4.2.1.1 Maintenance of Sheep Body Weights

The overall mean of body weights of the sheep was 34.9 (\pm 2.1) kg. Relatively lower average body weight (Table 4.6) was observed for the Assiniboia experimental diet group, though sheep were randomly assigned to experimental diets. The overall mean of metabolic body weights was 14.4 (\pm 0.6) kg. Pre, mid and post-experimental body weights of sheep were similar resulting in maintenance of constant body weight during the experimental period as expected.

4.2.1.2 Fecal Dry Matter and Chemical Composition

Fecal pellets of sheep fed Baler hay trended to be drier than those of sheep fed the silages and Bell hay (Table 4.7). The differences were small in chemical composition on a DM basis. Even on individual basis there were no outlier sheep with indigestion.

4.2.2 Total Collection Digestibility Determination

The apparent digestibility coefficient of DM was greater than 60% for all the forages (Table 4.8) and the variability among them was below 2% of the mean. Assiniboia and Rosser silages were equal ($P>0.05$) in apparent digestibility of DM, OM, NDF, NPN, NDICP and EE. Rosser silage was similar ($P>0.05$) to Bell hay in apparent digestibility of DM, NDF and ADF.

Table 4.6 Sheep Body Weights during the Digestibility Experiment (n=24).

Variable	<u>Silage</u>		<u>Hay</u>		SD
	Assiniboia	Rosser	Bell	Baler	
Pre-experimental BW (kg)	32.7	36.8	35.7	33.7	1.89
Mid-experimental BW	32.3	37.3	36.3	33.8	2.27
Post-experimental BW	32.8	37.2	36.8	33.6	2.21
Mean BW ^a	32.6	37.1	36.3	33.7	2.11
Mean BW ^{0.75} (kg)	13.6	15.0	14.8	14.0	0.65
DE ^b requirement (Mcal d ⁻¹)	1.91	2.11	2.08	1.97	0.09

^a body weight

^b digestible energy, (ME=82% DE, NEm=1.115-0.8971ME+0.6507ME²+0.1028ME³+0.005725ME⁴)
NEm= 63 kg^{0.75} d⁻¹ (National Research Council, 1985).

Table 4.7 Chemical Composition of Sheep Feces (DM basis, n=24).

Variable	<u>Silage</u>		<u>Hay</u>		SD
	Assiniboia	Rosser	Bell	Baler	
DM (%)	36.5	34.8	36.6	40.2	2.27
OM	80.9	81.9	85.0	82.3	1.75
NDF	60.0	64.4	68.6	64.8	3.55
ADF	40.7	39.3	41.8	42.1	1.26
ADL (% NDF)	18.7	23.4	18.1	22.9	2.78
CP	10.8	11.9	9.5	10.0	1.07
EE	3.9	4.2	3.3	2.9	0.61

Table 4.8 Apparent Digestibility of Forages.

Variable	Digestibility coefficient (%)				SEM	Contrast		
	Silage		Hay			S/S	H/H	S/H
	Assiniboia	Rosser	Bell	Baler				
DM	64.0	68.5	61.3	63.0	1.00	*	NS	**
OM	68.1	71.7	63.9	66.6	0.98	NS	NS	***
NDF	58.2	60.7	52.5	59.8	1.27	NS	**	NS
ADF	48.9	56.7	45.8	52.9	1.42	**	*	NS
Hemicellulose	69.9	65.6	60.4	68.1	1.69	NS	NS	NS
NSC	86.4	89.3	88.6	86.2	0.97	NS	NS	NS
ADL	8.9	3.5	2.7	2.3	1.84	NS	NS	NS
EE	73.9	73.2	63.3	64.8	1.27	NS	NS	***
CP	66.9	73.5	65.1	58.7	1.44	**	**	***
SCP	68.3	75.0	57.2	56.9	1.92	**	NS	***
NPN	69.1	76.5	56.7	60.7	1.99	*	NS	***
NDICP	17.7	27.0	29.4	42.2	2.81	NS	*	***
ADICP	0.0	4.3	0.0	0.0	0.77	*	NS	NS
Ash	21.3	35.4	35.2	27.1	2.09	**	NS	NS
DE (Mcal kg ⁻¹)	2.98	3.07	2.71	2.80	0.82	NS	NS	**

DE = TDN \times 0.4409

S/S: contrast silage (Assiniboia) vs silage (Rosser)

H/H: contrast hay (Bell) vs hay (Baler)

S/H: contrast mean of silage vs mean of hay.

*, **, *** P \leq 0.1, P<0.05 and P<0.01 respectively; NS: not significant (P>0.1).

Bell and Baler hays were equal ($P>0.05$) in apparent digestibility of all nutrients except for CP ($P<0.05$). Apparent digestibility of hemicellulose, NSC and ADL did not differ ($P>0.05$). Digestible energy values calculated using TDN were different ($P<0.05$). Energy digestibility for the hays was lower than the silages.

4.3 Degradability Evaluation

Rumen *in situ* degradation characteristics of forage, and the effective degradabilities (*ED*) of DM, CP, NDF and ADF respectively, are shown in Tables 4.9 and 4.10. The disappearance rates and the effective degradabilities ($P<0.05$) of the silages were higher than of that of the hays. This nature of fast disappearance was further supported by the less undegradable DM, CP, NDF and ADF ($P<0.05$).

4.3.1 Dry Matter Degradability

Assiniboia and Rosser silages provided more nutrients to the rumen than the hays because of the higher ($P<0.05$) soluble fractions, and lower ($P<0.05$) undegradable fractions. The degradation rates were not affected ($P>0.05$) by the forage cultivar. The rumen DM degradability characteristics were similar between Assiniboia and Rosser silages, and on the other hand some similarity in between Bell and Baler hays. The effective degradability of the silages which was higher ($P<0.05$) than that of the hays, was over 59% while the *ED* of the hays was under 49%. Similarly the soluble fraction of silages ($> 43\%$) was higher than that of the hays (32%).

4.3.2 Crude Protein Degradability

The crude protein of Assiniboia and Rosser silages disappeared faster ($P<0.05$) in the rumen than the crude protein of the hays (Table 4.9). The silages had higher soluble CP content and lower ($P<0.05$) undegradable content of CP than that of the hays. Consequently, the silages had a lower ($P<0.05$) slowly degradable fractions compared to the hays. Higher ($P<0.05$) effective degradabilities of CP were found with the silages. The rumen CP degradability characteristics were very similar between Assiniboia and Rosser silages. The variability of rumen CP degradation characteristics was higher and closer to 10% of the means. It indicated higher variability of CP disappearance among incubations.

4.3.3 Degradability of Acid and Neutral Detergent Fiber

The rumen *in situ* degradation characteristics and effective degradabilities of NDF and ADF of the forages revealed some similarity (Table 4.10). Effective degradabilities and rate of degradation (NDF and ADF) of the silages were higher ($P<0.05$) than those of the hays. There were differences in undegradable fractions where the silages had lower ($P<0.05$) undegradable NDF and ADF than the hays. The silages had higher soluble fractions when contrasted with hays.

Table 4.9 Rumen *In Situ* Degradation Characteristics and Effective Degradability of DM and CP.

Variable	Silage		Hay		SEM	Contrast		
	Assiniboia	Rosser	Bell	Baler		S/S	H/H	S/H
Dry matter (DM)								
Soluble (% of DM)	44.0	43.3	31.8	31.6	2.09	NS	NS	***
Degradable	40.6	42.8	43	40.1	0.76	NS	NS	NS
Undegradable	15.1	16.6	25.5	25.4	1.59	NS	*	***
Degradation rate (% h ⁻¹)	2.4	3.2	2.5	2.5	0.26	**	NS	NS
Effective degradability (%)	59	60.6	48.1	47.9	2.26	NS	NS	***
Crude protein (CP)								
Soluble (% of CP)	83.7	83.7	52.4	51.0	5.31	NS	NS	***
Degradable	10.2	9.1	27.8	29.4	3.16	NS	NS	***
Undegradable	6.5	7.5	19.8	19.7	2.36	NS	NS	***
Degradation rate (% h ⁻¹)	10	7.8	10	4.8	3.07	NS	NS	NS
Effective degradability (%)	87.0	87.9	72.2	67.0	3.09	NS	*	***

Passage rate (K_p) was assured 4% h⁻¹.

S/S: contrast silage (Assiniboia) vs silage (Rosser)

H/H: contrast hay (Bell) vs hay (Baler)

S/H: contrast mean of silage vs mean of hay.

*, **, *** P≤0.1, P<0.05 and P<0.01 respectively; NS: not significant (P>0.1).

Table 4.10 Rumen *In Situ* Degradation Characteristics and Effective Degradability of NDF and ADF.

Variable	<u>Silage</u>		<u>Hay</u>		SEM	<u>Contrast</u>		
	Assiniboia	Rosser	Bell	Baler		S/S	H/H	S/H
Neutral detergent fiber (NDF)								
Soluble (% of NDF)	10.0	10.1	2.9	2.0	2.4	NS	NS	**
Degradable	71.4	68.4	65.7	64.6	2.9	NS	NS	NS
Undegradable	18.6	22.4	31.1	33.4	2.3	**	NS	***
Degradation rate (% h ⁻¹)	2.0	2.9	2.0	2.1	0.3	**	NS	NS
Effective degradability (%)								
	35.1	39.0	24.9	24.1	3.0	NS	NS	***
Acid detergent fiber (ADF)								
Soluble (% of ADF)	8.3	9.2	0.0	0.1	3.2	NS	NS	***
Degradable	62.9	60.8	54.9	60.3	2.6	NS	NS	NS
Undegradable	25.8	23.7	45.1	39.6	3.1	NS	NS	***
Degradation rate (% h ⁻¹)	2.3	3.1	3.7	2.7	0.3	*	NS	NS
Effective degradability (%)								
	32.6	38.3	23.3	22.3	3.1	NS	NS	***

Passage rate (Kp) was assured 4% h⁻¹.

S/S: contrast silage (Assiniboia) vs silage (Rosser)

H/H: contrast hay (Bell) vs hay (Baler)

S/H: contrast mean of silage vs mean of hay.

*, **, *** P≤0.1, P<0.05 and P<0.01 respectively; NS: not significant (P>0.1).

4.4 Effect of Forage Type on Lactating Cows

Dairy production trial results were shown in Table 4.11, which consists of estimated means (in terms of a t-test in Proc Mixed) of milk yield and composition including milk urea.

4.4.1 Impact on Milk Yield and Composition

The 3.5% fat corrected milk yields (Table 4.11) were not different ($P>0.05$) in cows fed either Assiniboia silage based total mixed ration (ASOS diet) or Rosser silage based TMR (ROBS diet) though the actual milk yields were higher ($P<0.05$) for ROBS diet. Differences were observed in the percentages of milk protein, fat and lactose, and the milk protein yields. The milk fat percentage was higher ($P<0.05$) in the cows fed ASOS diet than the cows fed ROBS diet. The milk protein percentage and yield, and lactose percentages were higher ($P<0.05$) in cows fed ROBS diet. The milk fat yield was numerically higher in the cows fed ASOS diet. The total solids, somatic cell counts and milk urea levels were not affected ($P>0.05$) by silage type.

Table 4.11 Milk Yields and Composition of Lactating Cows Fed Assiniboia Oat Silage Total Mixed Ration (ASOS Diet) or Rosser Barley Silage Total Mixed Ration (ROBS Diet).

Variable	Silage based diets		SEM	P-value
	Assiniboia	Rosser		
Milk yield (kg d ⁻¹)	40.73 ^b	42.13 ^a	0.57	0.03
3.5% FCM ^x (kg d ⁻¹)	42.22	42.11	0.68	0.88
Milk protein (%)	3.05 ^b	3.12 ^a	0.03	0.05
Milk fat (%)	3.76 ^a	3.52 ^b	0.08	0.01
Milk protein yield (kg d ⁻¹)	1.24 ^b	1.31 ^a	0.02	0.01
Milk fat yield (kg d ⁻¹)	1.52	1.47	0.03	0.21
Total solids (%)	12.59	12.52	0.10	0.51
Milk lactose (%)	4.42 ^b	4.49 ^a	0.01	0.001
Milk urea (mmol L ⁻¹)	6.83	6.64	0.26	0.48
Somatic cell count (000 ml ⁻¹)	102	57	76	0.56

^{a,b} Proc mixed (t test) interpretation indicated a significant difference at 5% level

^x 3.5% fat corrected milk yield.

4.4.1.1 Effect on Milk Fatty Acids

Table 4.12 shows the fatty acid composition of milk fat. Milk fatty acids (FA) from cows fed ASOS diet, were higher ($P < 0.05$) in oleic acid ($C_{18:1}$) percentage and yield while the others fatty acids were not different ($P > 0.05$). The increase (29%) in $C_{18:1}$ resulted in an increase ($P < 0.05$) in unsaturated FA to saturated FA ratio. The least square differences has indicated a trend to an increase of stearic acid ($C_{18:0}$) percentage and yield in the cows fed ASOS diet. The saturated fatty acid concentrations and the yields were numerically higher in the cows fed ROBS diet. Unsaturated fat content increased ($P < 0.05$) 10% when cows were fed the ASOS diet. Total unsaturated fatty acids including conjugated linoleic acid (CLA), percentages as well as the yield were apparently higher in the cows fed ASOS diet. The fatty acids longer than C_{16} increased ($P < 0.05$) by over 30% when cows fed the ASOS.

4.4.2 Feed Intake, Body Weight and Blood Urea

Dry matter intake, body weight gain (change) and blood urea concentration (Table 4.14) were not different ($P > 0.05$) and not affected by the diets (ASOS or ROBS diet). DM intakes were above 24 kg per head or 3.8% DM body weight daily. However, there was a trend for an increase ($P = 0.09$) in dry mater intake (25.6 kg d^{-1}) by the cows fed the ASOS diet.

Daily intake of fatty acids longer than C_{12} from two silages is in Table 4.13. Daily intake of long chain fatty acids longer than C_{12} per cow from ASOS was over 30% higher than that from ROBS. Intake of unsaturated fatty acids from ASOS was over 40% higher than that from ROBS.

Table 4.12 Fatty Acid Content in Milk from Lactating Cows Fed Assiniboia Oat Silage (ASOS) Diet or Rosser Barley Silage (ROBS) Diet.

Variable	Silage based diet		SE	P-value
	Assiniboia	Rosser		
Milk Fat (%)	3.76 ^a	3.52 ^b	0.08	0.01
Milk fatty acid, % of total milk fat				
Lauric (C _{12:0})	4.75	5.40	0.27	0.10
Myristic (C _{14:0})	13.51	15.05	0.61	0.32
Myristoleic (C _{14:1})	2.54	3.95	0.54	0.33
Palmitic (C _{16:0})	32.79	37.93	1.55	0.16
Palmitoleic (C _{16:1})	2.63	2.58	0.15	0.88
Stearic (C _{18:0})	11.05	6.66	1.16	0.09
Oleic (C _{18:1})	22.42 ^a	18.71 ^b	0.75	0.002
Linoleic (C _{18:2})	2.13	2.23	0.08	0.79
Linolenic (C _{18:3})	0.89	0.94	0.04	0.69
Conjugated linoleic acid (CLA)	0.55	0.54	0.03	0.67
Below C ₁₄	24.4	27.6	0.97	0.12
Above C ₁₄	72.5	69.6	1.26	0.37
Below C ₁₆	59.8 ^b	68.2 ^a	2.25	0.05
Above C ₁₆	37.0 ^a	29.1 ^b	1.76	0.007
Saturated fatty acids	65.7	68.3	1.37	0.37
Unsaturated fatty acids	31.2 ^a	28.9 ^b	0.55	0.03
Milk fatty acid, yield (g d ⁻¹)				
Lauric (C _{12:0})	72.2	79.4	3.8	0.17
Myristic (C _{14:0})	205.4	221.2	8.5	0.49
Myristoleic (C _{14:1})	38.6	58.1	7.9	0.37
Palmitic (C _{16:0})	498.4	557.6	20.9	0.26
Palmitoleic (C _{16:1})	39.9	37.9	2.3	0.92
Stearic (C _{18:0})	167.9	97.9	18.1	0.07
Oleic (C _{18:1})	340.9 ^a	275.1 ^b	13.0	0.001
Linoleic (C _{18:2})	32.3	32.7	1.1	0.89
Linolenic (C _{18:3})	13.5	13.8	0.6	0.89
CLA	8.4	7.9	0.5	0.52
Below C ₁₆	908.8	1001.6	29.6	0.12
Above C ₁₆	563.0 ^a	427.4 ^b	29.1	0.004

^{a,b} - values with different letters are statistically different at 5% level.

Table 4.13 Average Intake of Fatty Acids C₁₂ and higher than C₁₂ from Silages.

Variable (g d ⁻¹)	Silage	
	Rosser	Assiniboia
Fatty acids intake (C ₁₂ and above)	517.7	663.8
Lauric (C _{12:0})	6.9	nd ^a
Dedecenoic (C _{12:1})	21.2	nd ^a
Myristic (C _{14:0})	10.7	nd ^a
Palmitic (C _{16:0})	79.3	84.0
Palmitoleic (C _{16:1})	15.1	52.0
Oleic (C _{18:1})	105.8	144.6
Linoleic (C _{18:2})	179.6	223.8
Linolenic (C _{18:3})	147.8	149.3

^a not detected.

Table 4.14 Dry Matter Intake, Body weight Change and Blood Urea Level of Lactating Cows Fed ASOS Diet or ROBS Diet.

Variable	Silage based diet		SEM	P-value
	Assiniboia	Rosser		
Dry matter intake (kg d ⁻¹)	25.61	24.98	0.34	0.09
Dry matter intake (% BW)	3.91	3.84	0.08	0.22
Weight change (g d ⁻¹)	106	13.0	225	0.68
Blood urea (mmol L ⁻¹)	7.70	7.28	0.35	0.24

^{a,b} Proc mixed (t test) interpretation indicated a significant difference at 5% level.

5. DISCUSSION

The nutrient compositions of Assiniboia oat silage and Rosser barley silage were similar while Bell and Baler oat hays were similar in chemical nature (Table 4.1). The apparent digestibility experiment results indicated the same sort of patterns revealing more similarities between the silages and certain similarities between the hays. Rumen degradability characteristics partially support and explain the digestibility results of the forages. The production responses of the cows were not affected by the diet validating the use of Assiniboia oat silage in total mixed rations.

Understandably, organic matter content was similar in all forages. Further the results showed that there was no difference in structural carbohydrates such as neutral (54.6±1.9%) and acid detergent fiber (30.0±1.1%). However, non-structural carbohydrates (23.5%), starch (25.7%) and ether extract (5.6%) were highest, and acid detergent lignin (7.7%) and acid detergent insoluble crude protein (3.1%) were lowest in Assiniboia silage. Crude protein (over 11%) and non-protein nitrogen (over 75% of SCP) were higher in the silages than the hays. There was a tendency to have higher total digestible nutrients (TDN) in silages than in hays, which led to higher NEI values. TDN, CP, NDF, ADF and lignin values of Assiniboia oat silage were in agreement with the range of values reported for oat silage by Christensen (1993). They also agreed with the values reported by Mtimuni (1976) related to the early mid dough stages of oat forages. The nutrient composition values of Bell and Baler hays were similar to the values given for oat hays in the CNCPS feed library (2000) and McCartney *et al.* (1994).

The voluntary dry matter intake (VDMI) of sheep was within the range of 1.95 to 2.25% which is acceptable for sole forage diets, and was not affected by diet. Physical structure and chemical nature of forages are the main factors that define the palatability and the voluntary intake (Mertens, 2000). Low intakes are frequently associated with low digestibility. Sheep fed the Rosser silage trended to have higher DM intake. The key factor for the lower palatability of the Assiniboia silage may be the growth of fungi which was more evident than with Rosser. The mould growth was likely due to increasing temperatures in April and May when the digestibility trial was conducted. Loose packing of Assiniboia silage in the stack may have a direct effect on faster growth of fungi, compared to Rosser silage which was packed well and ensiled in a tower silo. Numerically lower intakes were associated with Assiniboia silage as a result of these practical problems which likely led to low palatability related to storage and exposure to air and increased temperature. However, the effect was negligible and no statistical significance on intake data was seen.

The organic matter intakes of sheep were similar across the forages. The voluntary intakes for barley silage were in agreement with the values reported by Christensen (1993), but the values (over 2.0% BW d⁻¹) observed for oat forages were higher than those reported for some oat forages. The voluntary dry matter intake (54.2 g/W^{0.75} d⁻¹) of oat hay was not supported by Sileshi *et al.* (1998) since the observed values (averaging 2.0% BW d⁻¹ or 48.6 g/W^{0.75} d⁻¹) were lower. The NDF and ADF intakes (Table 4.5) were not different across the forages and agreed with Sileshi *et al.* (1998). The ether extract intakes were higher in the sheep fed Assiniboia and Rosser silages than the sheep fed Bell and Baler hays. The lowest crude protein intake was

with Baler hay and the highest was in the Rosser silage group. The voluntary intakes of all nutrients except CP and digestible energy were equal between the Assiniboia and Rosser groups, and between Bell and Baler groups. Daily digestible energy intakes (1.8 to 2.5 Mcal d⁻¹) agreed with the digestible energy requirements (DE=1.9 to 2.1 Mcal d⁻¹, NE_m=63 kg^{0.75} d⁻¹) at maintenance level for sheep (NRC, 1985). The lowest digestible energy intake was for Baler hay which had higher NDF and ADF contents. Though the digestible energy intake for Assiniboia and Rosser differed, digestible energy content was not different. The mixed forage NDF intake and digestibilities reported by Spanghero *et al.* (1999) ranged from 1.10 to 1.27% of BW d⁻¹ and 53 to 65% respectively. The observed results were in agreement with Spanghero *et al.* (1999). The above observations concurred with the dry matter intakes of lactating cows in this study when fed Assiniboia or Rosser silage total mixed ration. These intakes averaged over 3.8% DM body weight (DM basis). However, there was a trend for increase in dry matter intakes (Figure 5.16) by the cows fed Assiniboia silage diet.

Apparent DM digestibility coefficients observed in the sheep were over 60% and the variability among them was below 2% of the mean. Assiniboia and Rosser silages were similar in digestibility of DM, OM, NDF, NPN, NDICP, EE and energy. Digestible energy (3.0 Mcal kg⁻¹) of the silages was higher than that of the hays (2.8 Mcal kg⁻¹) which agreed with Christensen (1993). Digestibility of DM, NDF and ADF were similar for Bell hay and Rosser silage. Bell and Baler hays were not different in digestibility of all nutrients with the exception of CP (65 and 59%) and ADF (46 and

53% respectively). Digestibility of hemicellulose, NSC and ADL was equal for all the experiment diets.

Dry matter, CP, NDF and ADF digestibility of silages agreed with those reported by Christensen *et al.* (1977) and McCartney *et al.* (1994) but the digestibility of DM and CP (52 and 56%) for (Fraser) oat silage reported by Hingston *et al.* (1982) were lower than that repeated in the present trial. The observed DM digestibility of oat hay was higher than the values reported by Sileshi *et al.* (1998). The CP digestibility values of oat forages (58 to 67%) were low relative to barley (74%) and were not in agreement with Lassiter (1958), Brundage (1973) and Christensen (1977). However, the observed CP digestibility (lowest 59%) values were higher than the values (56%) reported by Hingston *et al.* (1982). The NDF digestibility of Bell oat hay was the lowest (53%) and agreed well with the values given for Cascade and Caliber oat silages by Christensen (1993). Though McCartney *et al.* (1994) had concluded that ADF digestibility of Caliber oat silage was similar to Johnson barley, ADF digestibility of Assiniboia oat silage was lower than Rosser barley silage. However, the observed ADF digestibility value (49%) for Assiniboia silage was similar to that of Cascade and Caliber oat silages reported by Christensen (1993). Hemicellulose digestibility was not different across the forages but it was also not in agreement with McCartney *et al.* (1994) who reported hemicelluloses digestibility of Calibre oat silage was 10% lower than that of Johnson barley silage.

The estimated carbohydrate and crude protein fractions (Table 4.3) for Assiniboia showed numerical tendencies for the lowest rumen unavailable fractions, and the highest degradable and potentially degradable fractions of both carbohydrate

and protein. Degradable carbohydrate and rapidly degradable protein fractions appeared to be higher in the silages than the hays. Soluble and degradable in silages may have increased with the process of ensiling and it was shown and suggested by the nutrient composition (Table 4.1) with high NPN and SCP. These estimations were supported by the observed results in the rumen *in situ* degradability trial. The disappearance rates of the silages were numerically higher than the hays. The effective degradabilities of DM, CP, NDF and ADF were higher for silages compared to hays. This observation was further supported by the lower undegradable DM, CP, NDF and ADF fractions. However, neither the silages nor the hays showed a robust difference in the rumen DM degradability patterns (Figure 5.1). The DM disappearance at zero hour was over 25% for all forages based on washing the samples. The DM disappearance of the silages was higher than the hays for each incubation time point from 0 to 96 h.

General DM disappearance pattern of the forages was typical of the results described by Ørskov (2000). The DM degradability and disappearance illustrated in Figure 5.1 and Table A4 supported the pattern shown by Ørskov, (2000) and the DM disappearances of the forages were correlated to each other, with 64% minimum degradability (Baler hay) and coefficient of determination (R^2) values of over 0.98. The trend lines were parallel and complete in degradation at 90 h. The variance of DM degradability was well within the values shown by Ørskov (1998). The DM degradability characteristics and the disappearance patterns of the silages were in agreement with Nikkhah (2002) who reported DM values of cereal silages to be 37 to 42% soluble, 33 to 38% degradable and effective degradability of 48 to 56%. The

disappearance at 6 h was mostly dependent on soluble fraction (A), whereas disappearance at 12 to 24 h fermentation period was more dependant on the balance between the rapidly degraded or soluble fraction (A) and slowly degraded or potentially degraded fraction (B). The disappearance after 24 h incubation was dependant on potential degradation (A+B) and degradation rate (Stern *et al.*, 1997). Assiniboia and Rosser silages provided more nutrients to the rumen than the hays because of the higher soluble fractions, and lower undegradable fractions (Figure 5.2 and Table 4.9). The DM degradation rates were not affected by the forage cultivar. This agreed with the findings of Ørskov (2000) which highlighted some similarities in DM degradation rates of roughage degradability in rumen. The rumen DM degradability characteristics showed a unique similarity between Assiniboia and Rosser silages, and also some similarity between Bell and Baler hays. The results of the rumen degradation characteristics and effective degradabilities of the hays were supported by Sileshi *et al.* (1998). The plotted patterns of DM disappearance of oat hays shown by Fonseca *et al.* (1998) agreed with the results shown in Figure 5.1 in terms of all aspects (i.e. 70% DM disappearance at 96 h).

Organic matter disappearance patterns (Figure 5.3 and Table A5) followed the DM disappearance patterns having R^2 values of 0.98. The plotted mean points and trend lines of Assiniboia and Rosser moved very similar, being higher than the hays at each incubation time point.

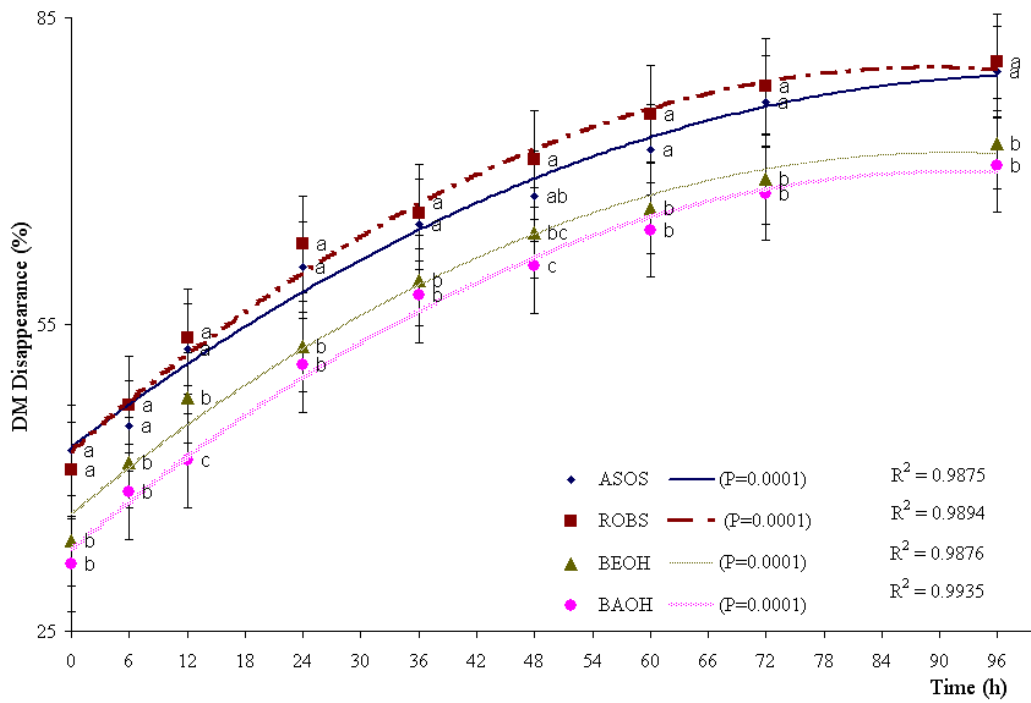


Figure 5.1 Rumen *In Situ* DM Degradability of Assiniboia Silage (ASOS), Rosser Silage (ROBS), Bell Hay (BEOH) and Baler Hay (BAOH), and Their Trend Lines;
 R^2 values and P values of trend lines followed forage order of the legend.
^{abc} – mean values at each incubation time, with similar letters are not statistically different at 5% level.

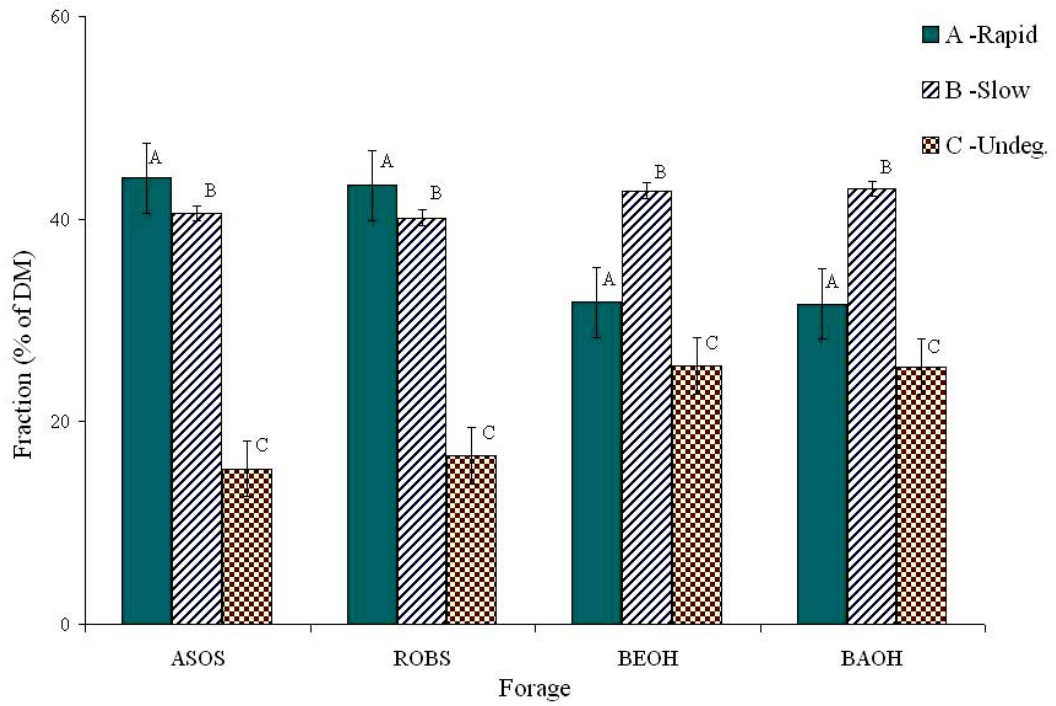


Figure 5.2 Rumen *In Situ* DM Degradability Characteristics of ASOS, ROBS, BEOH and BAOH.
 A: rapid degradable, B: slow degradable, C: undegradable.

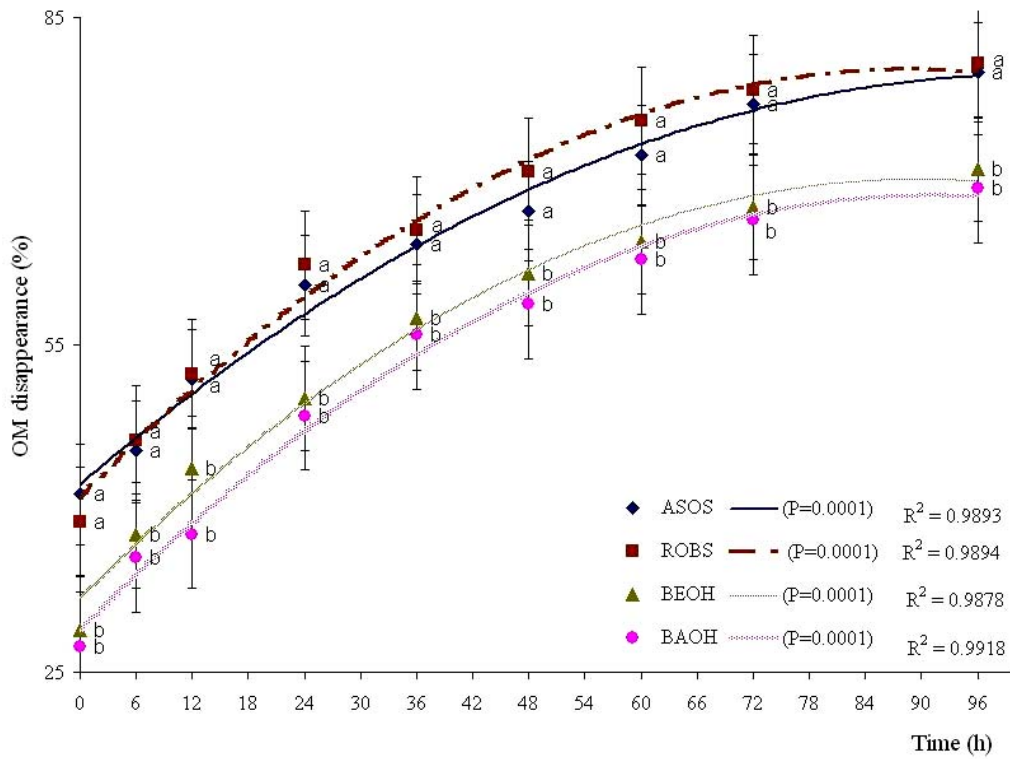


Figure 5.3 Rumen *In Situ* Organic Matter Degradability of ASOS, ROBS, BEOH and BAOH, and Their Trend Lines;
 R^2 values and P values of trend lines followed forage order of the legend.
^{abc} – mean values at each incubation time, with similar letters are not statistically different 5% level.

The crude protein of Assiniboia and Rosser silages disappeared faster in the rumen than that of the hays. Crude protein degradability characteristic values of cereal (barley) silages reported and the CP disappearance patterns plotted by Nikkhah (2002) were in agreement with results of this study. The soluble fraction (A) of proteins (81%) agreed with the values (78%) reported by Nelson *et al.* (1997) and were in agreement with his conclusions showing substantially a higher soluble crude protein fraction for oat silage than that of wheat and barley silages. However, the soluble fraction of proteins for Rosser barley silage was not different from that of Assiniboia oat silage. The silages had lower undegradable fraction (C) of protein than the hays. Consequently the silages had a lower slowly degradable protein fraction compared to the hays. However, degradation rate of CP was not affected by forage type. The CP degradability and disappearance showed (Figure 5.4 and Table A6) a substantial variability across the forages. This was in agreement with Von Keyserlingk *et al.* (1996). However, the higher effective degradabilities of CP were found with the silages. The R^2 values (0.72 to 0.84) were not high as for DM disappearance.

The rumen CP degradability characteristics were very similar between Assiniboia and Rosser silages (Figure 5.5 and Table 4.9). The variability of rumen CP degradation characteristics was higher and closer to 10% of the means. It may be a result of higher variability of CP disappearance among incubations. The relationship between DM disappearance and CP disappearance was shown in the Figure 5.6, which indicated curvilinearity in correlation with R^2 of 0.99 for all forages, and it illustrated similarity of CP disappearance between Assiniboia and Rosser. The best fitted trend lines with minimal residual variance when CP disappearance regressed over DM

disappearance showed different relationships in the hays and the silages. CP disappearance over DM disappearance was slow for the hays while that was rapid for the silages. The degradation of CP in the hays was maximised at 70% DM disappearance but that of the silages maximised at about 60% DM disappearance. During the first half of DM disappearance, CP disappearance was vigorous for silages and value wise at 20% DM disappearance CP disappearance for silages was over 50%. This agreed with the idea of more available and less unavailable CP fractions in the silages. The readily disappearing CP fractions would be NPN and rumen degradable or digestible CP. This information disclosed that there was a big gap between the silages and the hays in CP degradability. Therefore it urges the importance of combining a rapidly fermenting and available carbohydrate feed source in order to synchronise the CP and energy availability when formulating either Assiniboia or Rosser silage rations. In case of hay the demand to synchronise CP and energy may be slowly degradable carbohydrates. The above idea was also supported by rate of CP disappearance (Figure 5.4). Collectively the results were supported by the conclusions of Hadjipanayiotou *et al.* (1996). However Nocek *et al.* (1988) described the influence of microbial contamination in feed residues after ruminal suspension and reported higher contamination for forages than for concentrates. Nevertheless the nature of CP with regard to the intakes as well as the digestibility indicated a high variability across the forages.

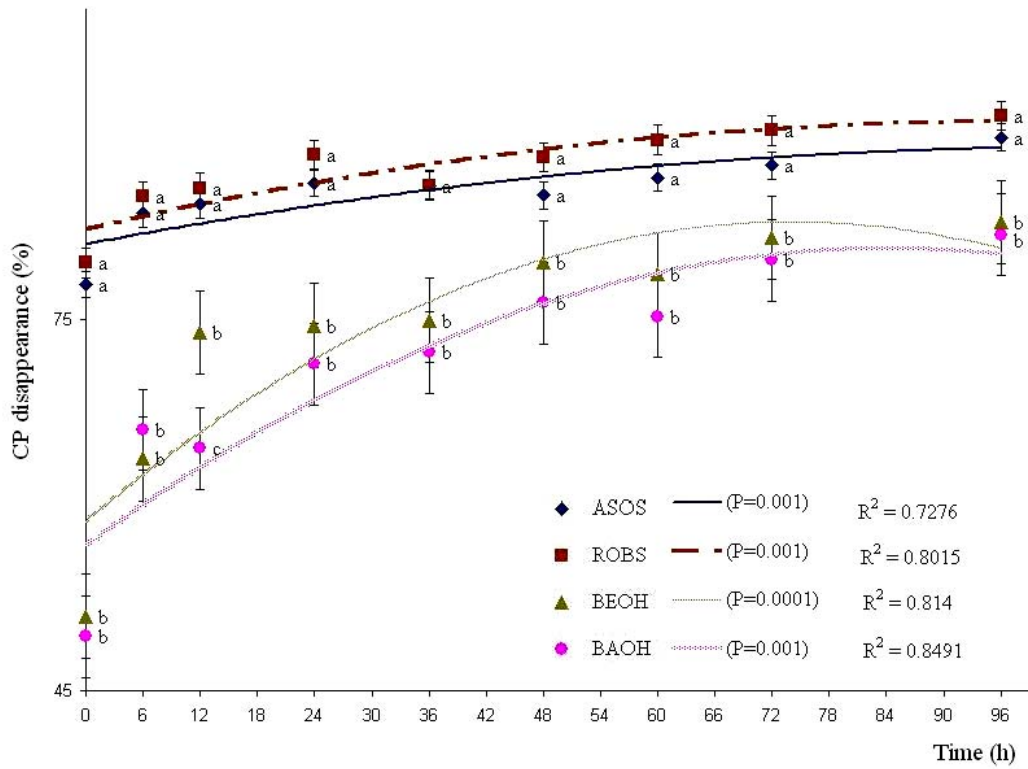


Figure 5.4 Rumen *In Situ* CP Degradability of ASOS, ROBS, BEOH and BAOH, and Their Trend Lines;
R² values and P values of trend lines followed forage order of the legend.
abc – mean values at each incubation time, with similar letters are not statistically different 5% level.

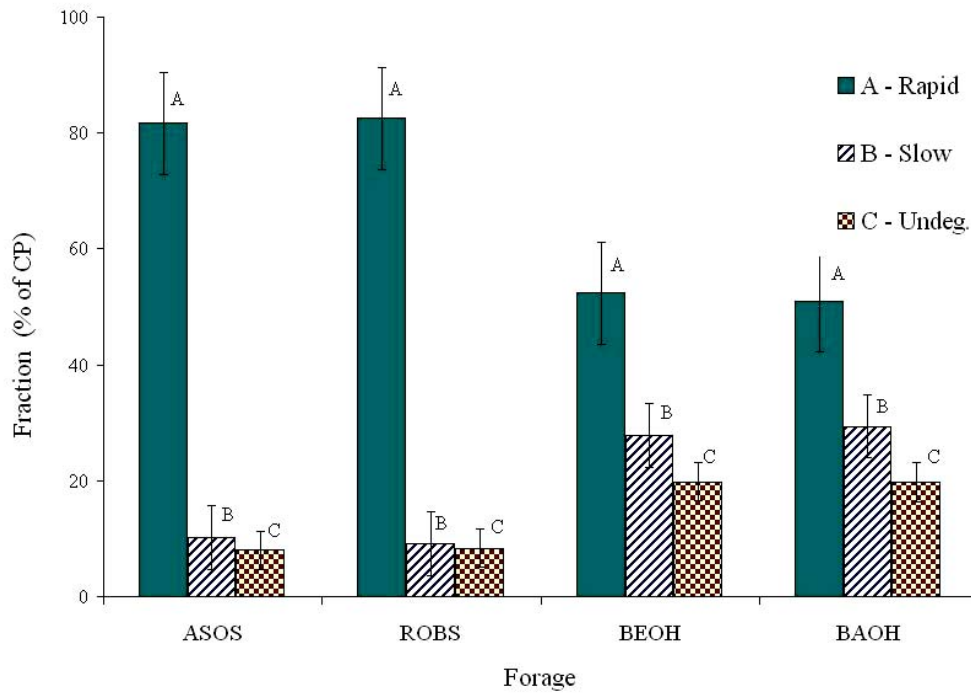


Figure 5.5 Rumen *In Situ* CP Degradability Characteristics of ASOS, ROBS, BEOH and BAOH.
 A: rapid degradable, B: slow degradable, C: undegradable.

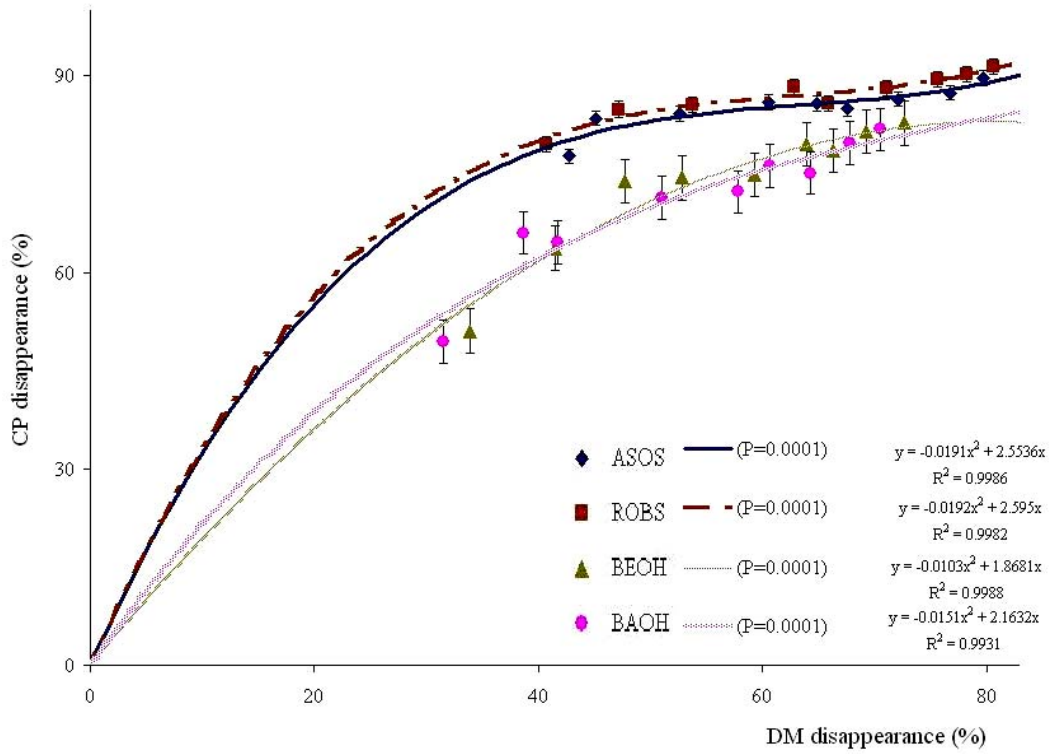


Figure 5.6 Rumen *In Situ* CP Disappearance Versus DM Disappearance of ASOS, ROBS, BEOH and BAOH; Equations and R² values followed forage order of the legend.

In general the ADF disappearance and degradation characteristics of the silages followed the pattern of NDF disappearance and degradation characteristics. Similarly the ADF disappearance and degradation characteristics of the hays followed the pattern of NDF disappearance and degradation characteristics (Figures 5.7 to 5.12, and Tables 4.10, A7 and A8). Rumen *in situ* degradation characteristics and effective degradabilities of NDF and ADF, of the forages were not different except for undegradable fractions where the silages had lower undegradable NDF and ADF than the hays. The silages showed higher soluble NDF and ADF fractions, and effective degradabilities when contrasted against those of hays (Table 4.10, Figures 5.7 and 5.8).

Although NDF and ADF are considered separate entities in an analytical scene, physically and chemically they are associated through covalent (hydrogen) bonds. As Huhtanen *et al.* (1995) noted, NDF *in situ* degradabilities values underestimated NDF degradation. The rumen *in situ* NDF degradability was lower than the expected 70 to 95% of NDF digestibility which in turn is not considered as a good indication of forage quality. NDF and ADF degradability values of Assiniboia silage were higher than the values of Assiniboia oat hulls reported by Thompson *et al.* (2000). In comparison of Figure 5.7 with observations of Kraus (1999), the NDF disappearance rates for cereal forages in this study were higher. The potential NDF degradable fraction of the silages (70%) was higher than the hay (65%). The rumen NDF degradability characteristics (potential NDF degradable fraction 65%) of oat hays (Figure 5.8 and Table 4.10) were in agreement with Spanhero *et al.* (2003). Among the chemical constituents of the forages NDF showed the highest influence on ruminal

degradation and effective degradability of dry matter. This agreed with Haj-Ayed *et al.* (2000). Figure 5.9 illustrated the relationship of NDF disappearance and DM disappearance with the best-fitted regressed trend lines with minimal residual variations. In general NDF disappearance was proportionate to DM disappearance but NDF disappeared slightly faster with increasing DM disappearance. Therefore there was a curvilinear relationship between NDF disappearance and DM disappearance with R^2 of over 0.98 for each forage. Silages showed a faster NDF degradability (Figure 5.7). The trend of NDF disappearance of Rosser in relation to DM disappearance (Figure 5.9) was similar to that of Assiniboia. The trend line of NDF disappearance versus DM disappearance for Bell hay (Figure 5.9) fitted with zero intercept and second order polynomial model hinted at faster NDF degradation. This was supported by Figure 5.8, 5.14 and 5.15 showing a trend of higher degradable NDF fractions, ED and Kd for Bell relative to Baler.

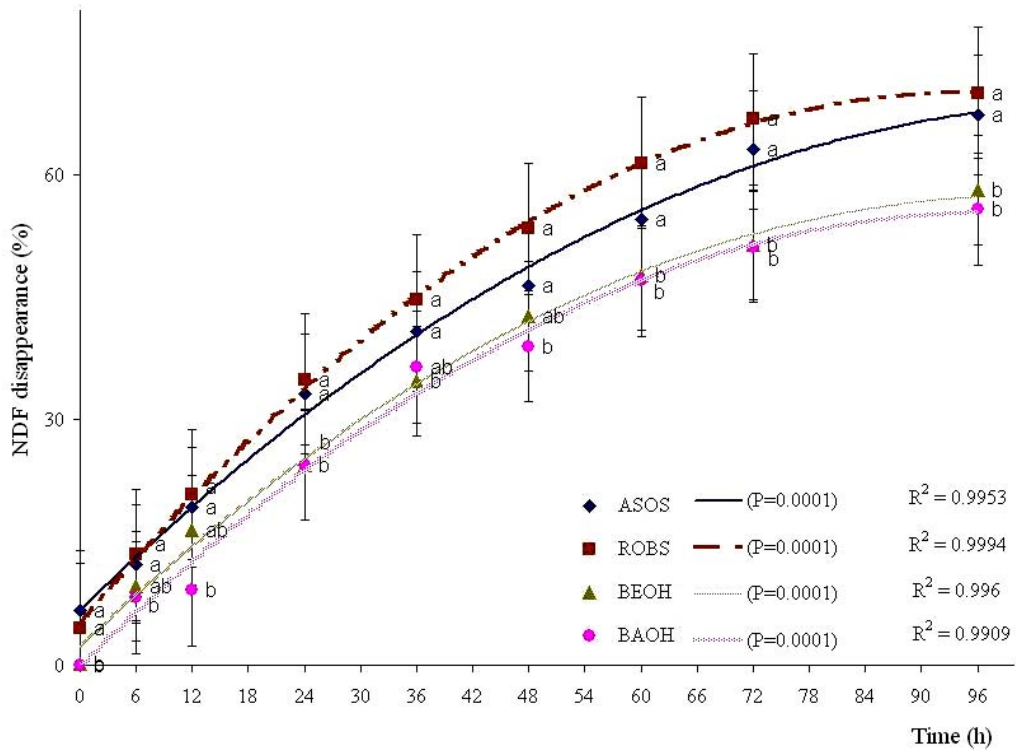


Figure 5.7 Rumen *In Situ* NDF Degradability of ASOS, ROBS, BEOH and BAOH, and Their Trend Lines;
 R² values and P values of trend lines followed forage order of the legend.
 abc – mean values at each incubation time, with similar letters are not statistically different at 5% level.

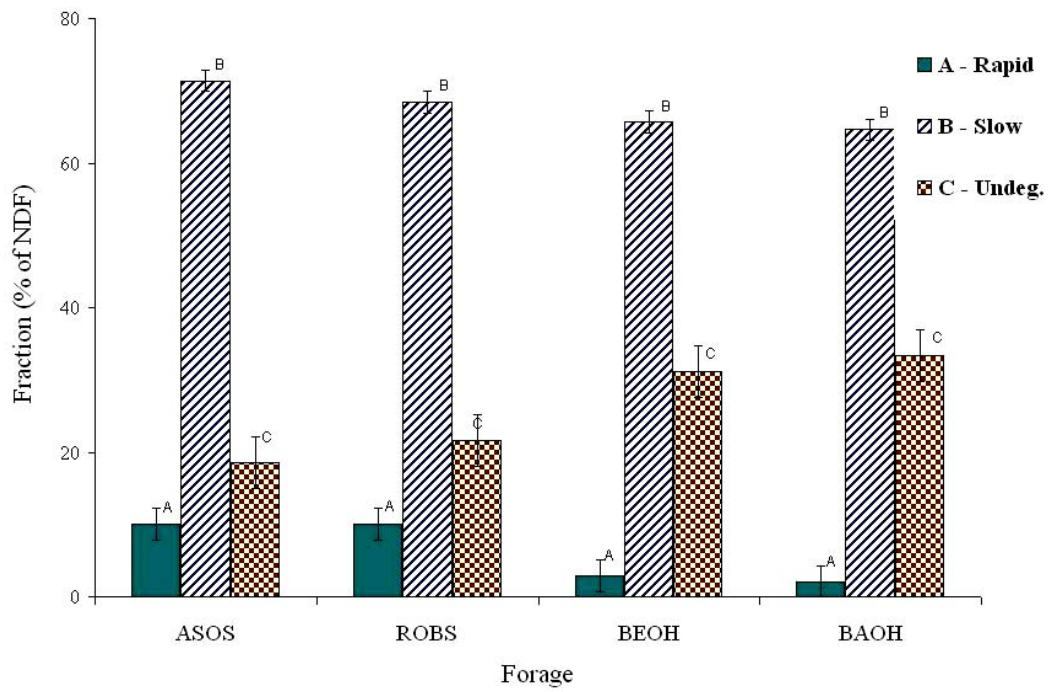


Figure 5.8 Rumen *In Situ* NDF degradability Characteristics of ASOS, ROBS, BEOH and BAOH.
 A: rapid degradable, B: slow degradable, C: undegradable.

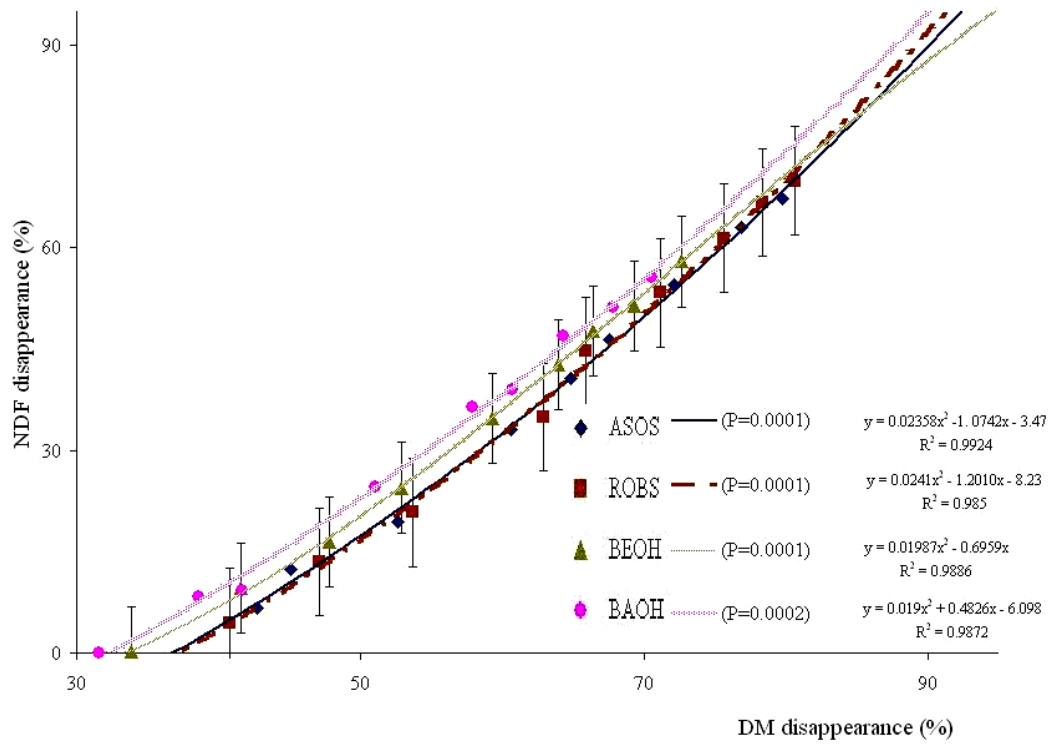


Figure 5.9 Rumen *In Situ* NDF Disappearance Versus DM Disappearance of ASOS, ROBS, BEOH and BAOH; The equations followed forage order of the legend.

ADF concentration was negatively correlated with the soluble fraction and the fractional degradation rate; and positively correlated with the slowly degradable fraction and undegradable fractions. ADF degradation over time (Figure 5.10) showed similar patterns for all forages with R^2 of over 0.98 though the trends of their rates were visually different with different regression formulas. Figure 5.12 showed the curvilinear relationship of ADF disappearance versus DM disappearances for the silages when regressed for the best fitted model (R^2 of over 0.96) with minimal residual variability and it somewhat resembled that of NDF. However, the hays had a more or less linear relationship (Figure 5.12) when regressed for the best fitted model with minimal residual variability and R^2 over 0.94. The trend of lower ADF degradability characteristics of Bell hay relative to the other three forages was visible in the Figure 5.11 and 5.12 having lower ADF disappearance over DM disappearance, less degradable ADF and more undegradable ADF fractions. Eventually this observation was supported by Figure 5.13, which showed a linear relationship of ADF disappearance and NDF disappearance for the best fitted regression trend lines with minimal residual variability and R^2 of over 0.96. The pattern of ADF and NDF disappearance agreed with the data for ADF and NDF digestion reported by Tamminga (1993). The trend of faster NDF disappearance of Bell hay may be relative the fact that it contained less degradable ADF compared to the other three forages. However it is contrary to the observation that Bell hay contained low ADF (29% of DM) relative to Baler but agreed with the lowest ADF digestibility (46%).

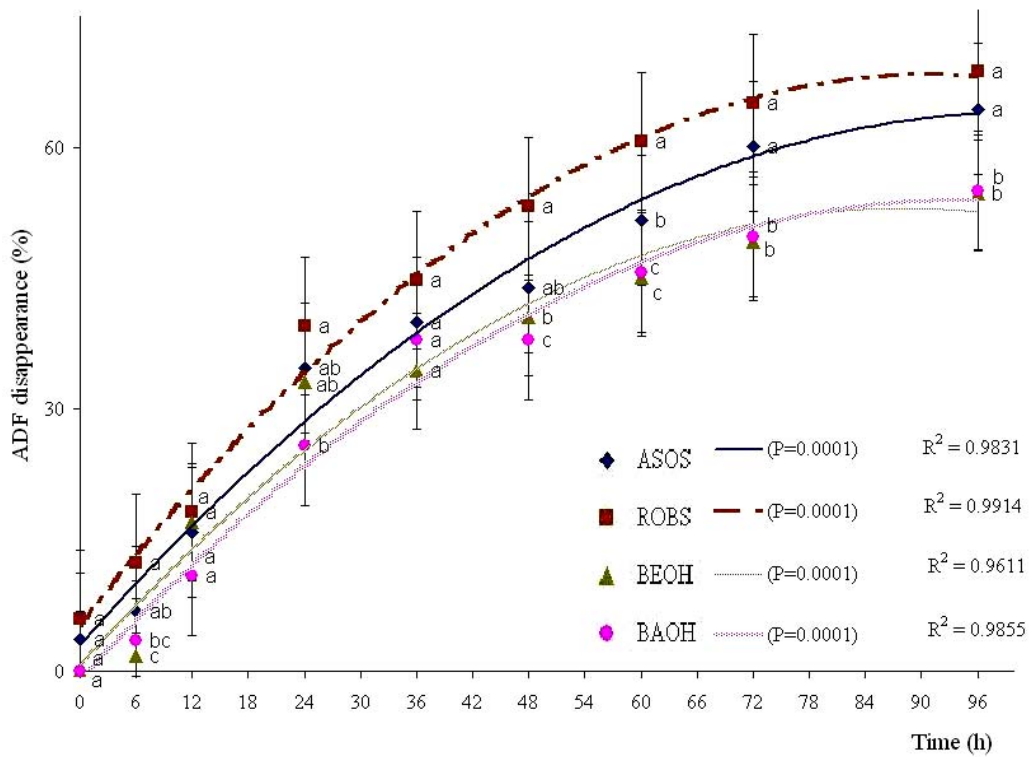


Figure 5.10 Rumen *In Situ* ADF Degradability of ASOS, ROBS, BEOH and BAOH, and Their Trend Lines;
R² values and P values of trend lines followed forage order of the legend.
^{abc} – mean values at each incubation time, with similar letters are not statistically different at 5% level.

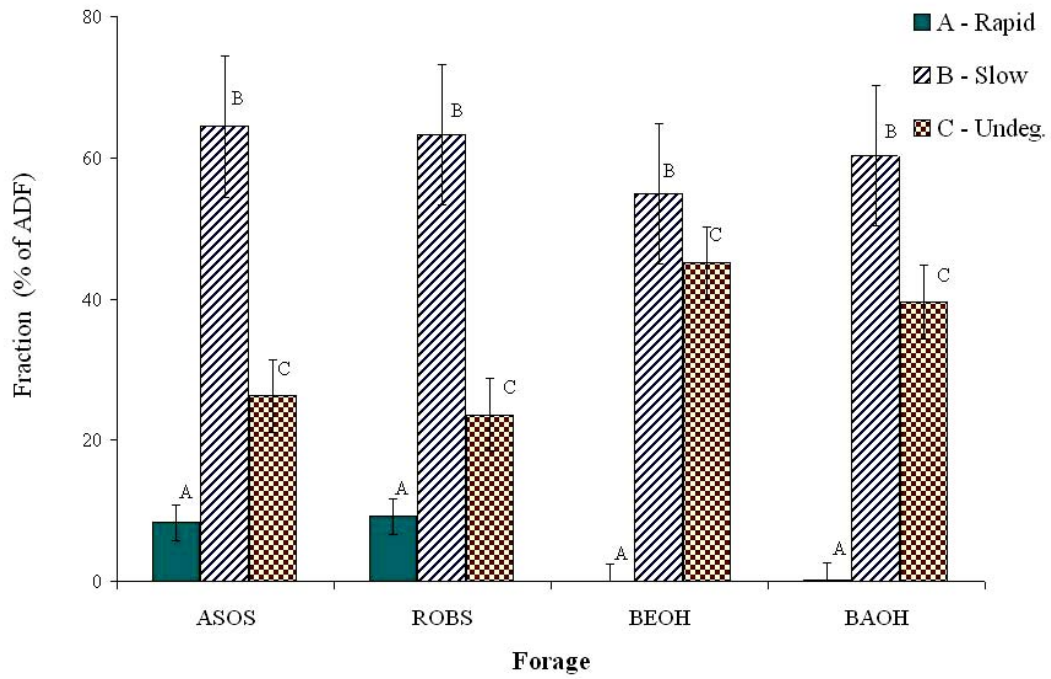


Figure 5.11 Rumen *In Situ* ADF degradability Characteristics of ASOS, ROBS, BEOH and BAOH.
 A: rapid degradable, B: slow degradable, C: undegradable.

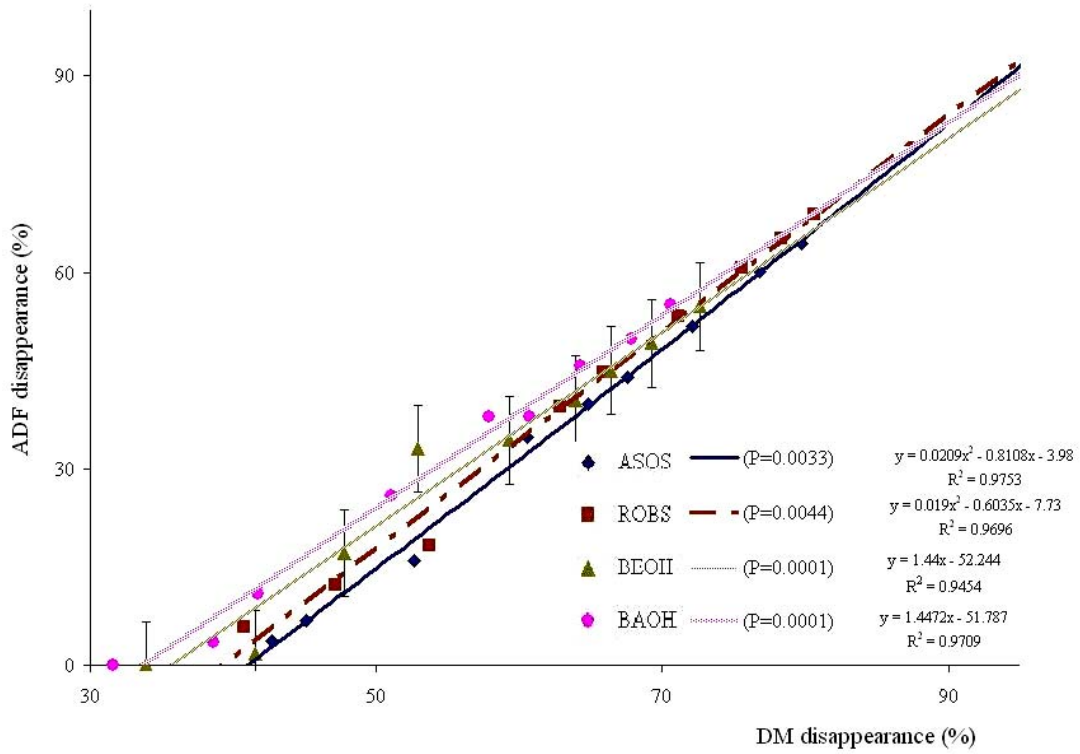


Figure 5.12 Rumen *In Situ* ADF Disappearance Versus DM Disappearance of ASOS, ROBS, BEOH and BAOH; Equations and R² values followed forage order of the legend.

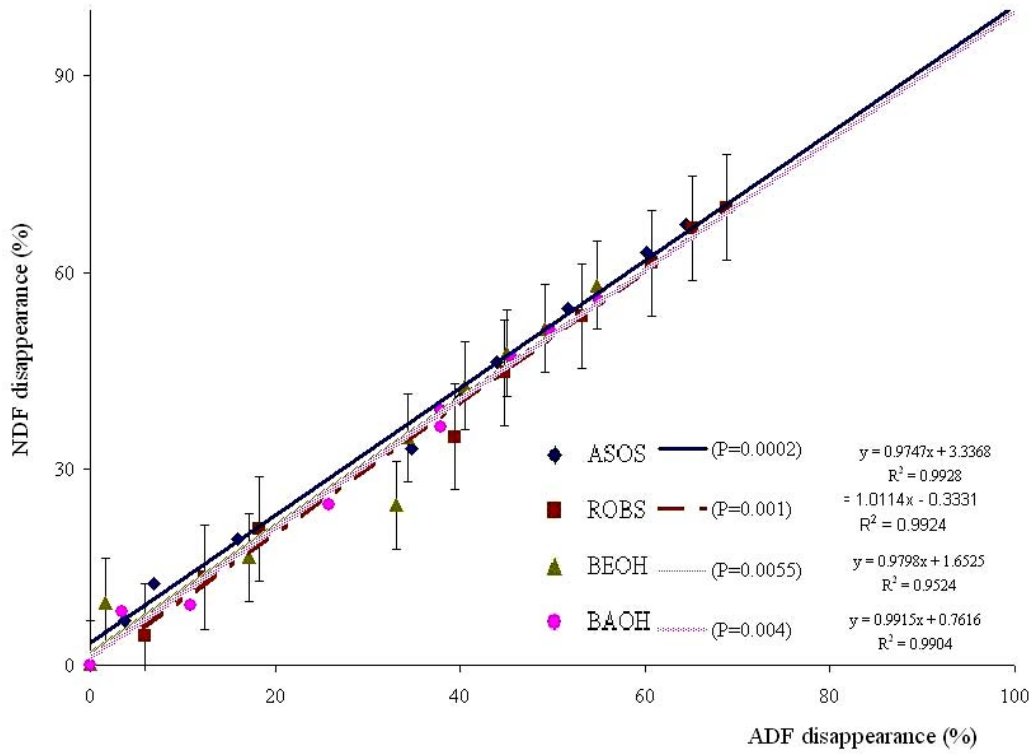


Figure 5.13 Rumen *In Situ* NDF Disappearance Versus ADF Disappearance of ASOS, ROBS, BEOH and BAOH; Equations and R² values followed forage order of the legend.

Effective degradability of DM, CP, NDF and ADF for the silages was higher than those of the hays (Figure 5.14). But the degradation rates did not follow the same trend. The trend for ADF degradation (passage, K_d) rate (Figure 5.15 and Table 4.10) was higher for the hays while Bell hay showed a tendency to behave similar to Assiniboia silage in DM, CP and NDF degradation rate. This was previously supported by these nutrient disappearances over time and over DM disappearance (Figure 5.1, 5.4, 5.6, 5.7 and 5.9). The observed values (2 to 3% h^{-1}) of DM degradation rates were supported by Haj-Ayed *et al.* (2000). NDF degradation rates of hay reported by Spanhero *et al.* (1999) were slightly lower than the observed values (2 to 3% h^{-1}) but similar to Fonseca *et al.* (1998). Although there was a tendency for lower DM degradability characteristics in Baler relative to those in Bell, the sheep DM digestibility of Baler was higher than that of Bell. This observation may provide some insight to the fact that chewing activity which is not generally associated with rumen *in situ* or *in vitro* trials, but with total collection digestibility trial, would have a considerable influence on the magnitude of digestion of a feed stuff. Baler appeared to be coarser may have initiated more chewing and salivation than Bell.

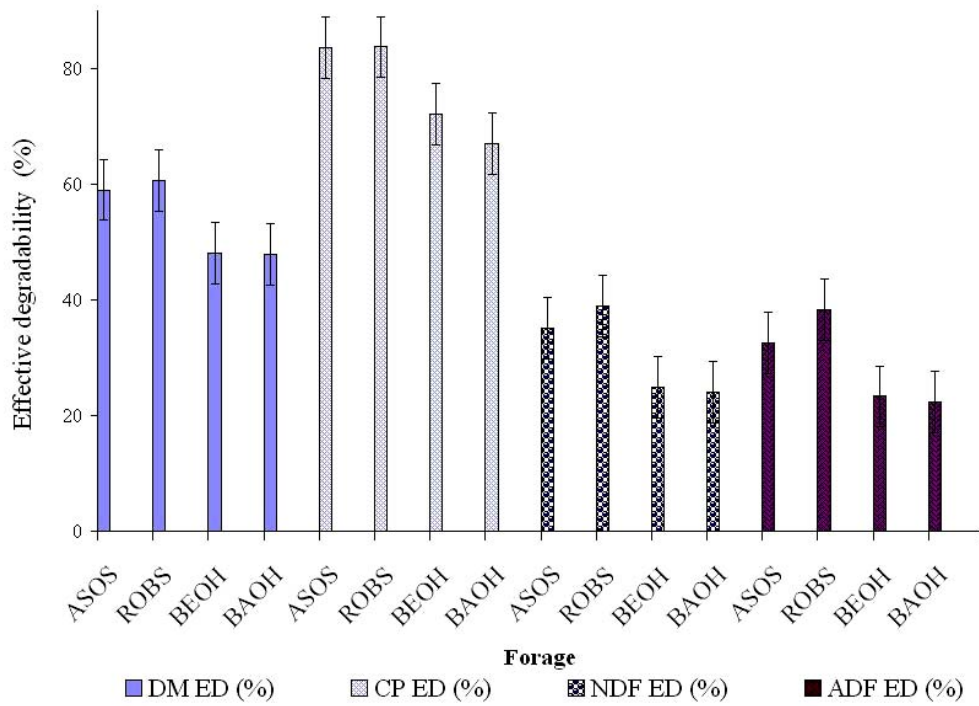


Figure 5.14 Rumen *In Situ* Effective Degradability (*ED*) of DM, CP, ADF and NDF in ASOS, ROBS, BEOH and BAOH.

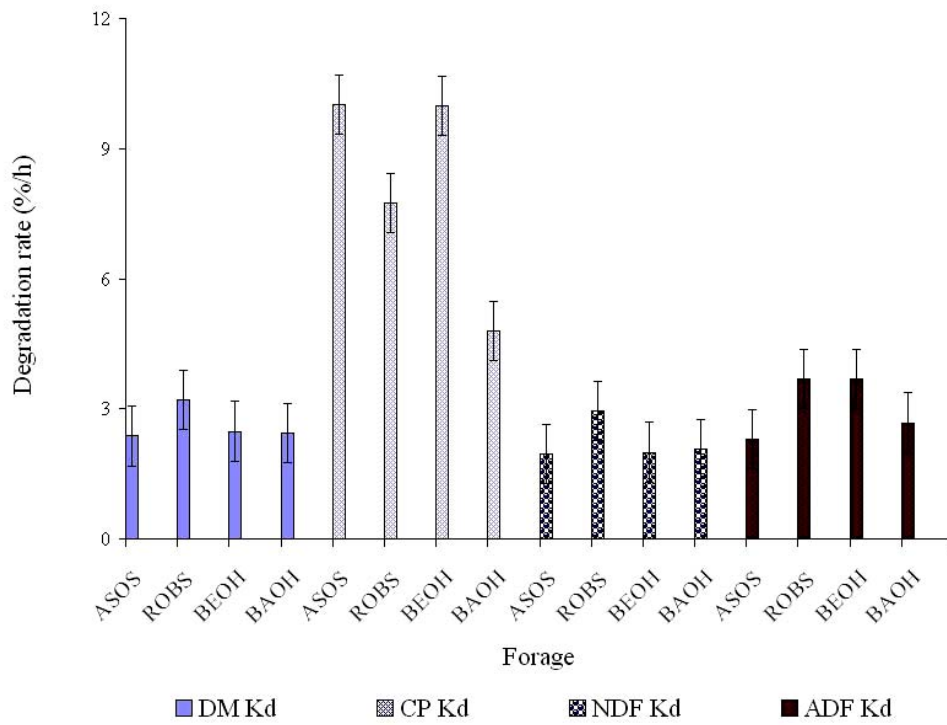


Figure 5.15 Rumen *In Situ* Degradation Rate (*Kd*) of DM, CP, ADF and NDF in ASOS, ROBS, BEOH and BAOH.

The 3.5% fat corrected milk yields were similar in cows fed either Assiniboia oat silage (ASOS) or Rosser barley silage (ROBS) based total mixed rations (diet) although the actual milk yields favored ($P < 0.05$) the ROBS diet (Figure 5.16). Milk composition was affected by the diets indicating differences in concentration (percentage) of milk protein, fat and lactose, and in milk protein yields. The milk fat percentage increased (Figure 5.17 and Table 4.11) in the cows fed ASOS diet relative to cows fed the ROBS diet. The milk protein percentage and yield, and lactose percentages increased in cows fed ROBS diet (Figures 5.17 and 5.18). The milk fat yield was numerically higher in the cows fed ASOS diet. The total solids, somatic cell counts and milk urea levels were not different between the diets. The milk composition data agreed with Burgess *et al.* (1973) in many ways (yield, FCM, CP and fat), and milk yields were similar for barley and oat silages. But these results disagreed with Kennelly (1995) who reported lower milk yields and proteins for oat silage relative to barley silages. Although Burgess *et al.* (1973) showed a marginal increase in milk fat content with cows fed oat silage diets, we observed a significant increase in fat content with the cows fed Assiniboia oat silage diet. West *et al.* (1999) concluded that increasing milk fat content resulted from increasing dietary NDF level. Chewing patterns may influence rumen digestibility (Soita *et al.*, 2002). Rumen digestion and volatile fatty acid production has an effect on milk fat content (Kononoff *et al.*, 1998) Although the particle sizes of the both silages were similar (Table 4.2) as they underwent the same theoretical cut, physical texture of ASOS appeared to be more coarse than that of ROBS. This physical coarseness of ASOS may influence, chewing, salivation and rumen digestibility, and may result in higher saliva

production, higher rumen pH, and higher volatile fatty acid production which would lead to increase milk fat content.

Oleic ($C_{18:1}$) percentage (22% of milk fat) and yield (341 g d^{-1}) increased markedly (Figure 5.18 and Table 4.12) for cows fed the ASOS diet. The observed increase in oleic ($C_{18:1}$) content with ASOS diet was 29%. The increase in oleic acid ($C_{18:1}$) and marginal increase of some others such as palmitoleic ($C_{16:1}$) resulted in an increase in unsaturated FA to saturated FA ratio for ASOS. There was a 30% increase of fatty acids longer than C_{16} in cows fed the ASOS diet compared to the ROBS diet. The fatty acids shorter than C_{16} were higher in cows fed the ROBS diet than the ASOS diet. This indicates the possibility of higher de novo fat synthesis associated with cows fed the ROBS diet than the ASOS diet. According to LaCount (2002) content of oleic acid (monounsaturated) in milk increased when increasing amounts of free fatty acids reached the abomasum. Therefore it is reasonable to expect that the ASOS diet provided more free fatty acids to the abomasum compared to ROBS diet. This idea was supported by the results of forage fatty acid analysis. Higher oleic ($C_{18:1}$) and palmitoleic ($C_{16:1}$) contents, and higher fatty acid intakes were noticeable (Tables 4.4, 4.13 and Figure 5.21) not only for ASOS but also for all oat forages relative to ROBS. The least square differences indicated a possible trend for increased stearic acid ($C_{18:0}$) percentage and yield in the cows fed ASOS diet.

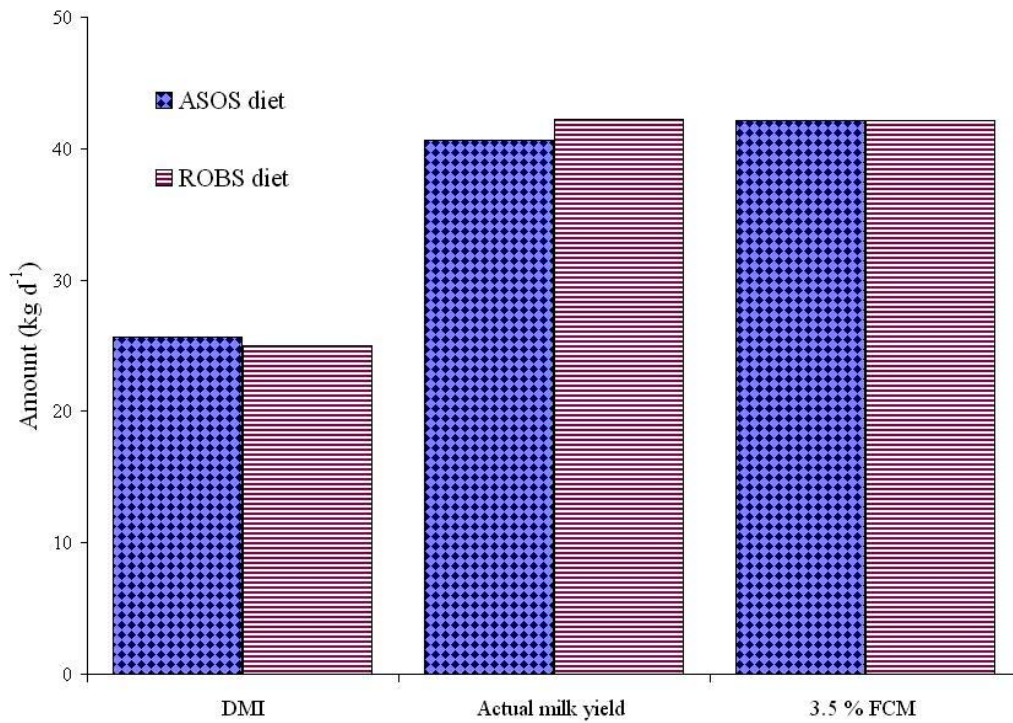


Figure 5.16 Dry Matter Intake (DMI), Actual Milk Yield and 3.5% Fat Corrected Milk Yield (FCM) of Cows Fed Assiniboia Oat Silage Total Mixed Ration (ASOS Diet) or Rosser Barley Silage Total Mixed Ration (ROBS Diet).

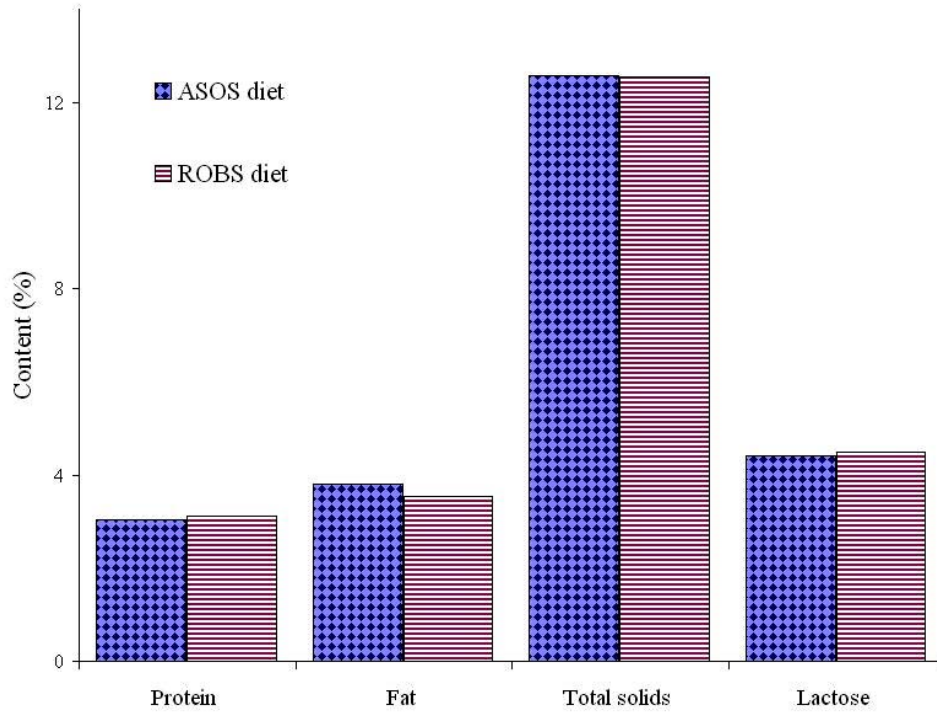


Figure 5.17 Milk Composition of Cows Fed ASOS Diet or ROBS Diet.

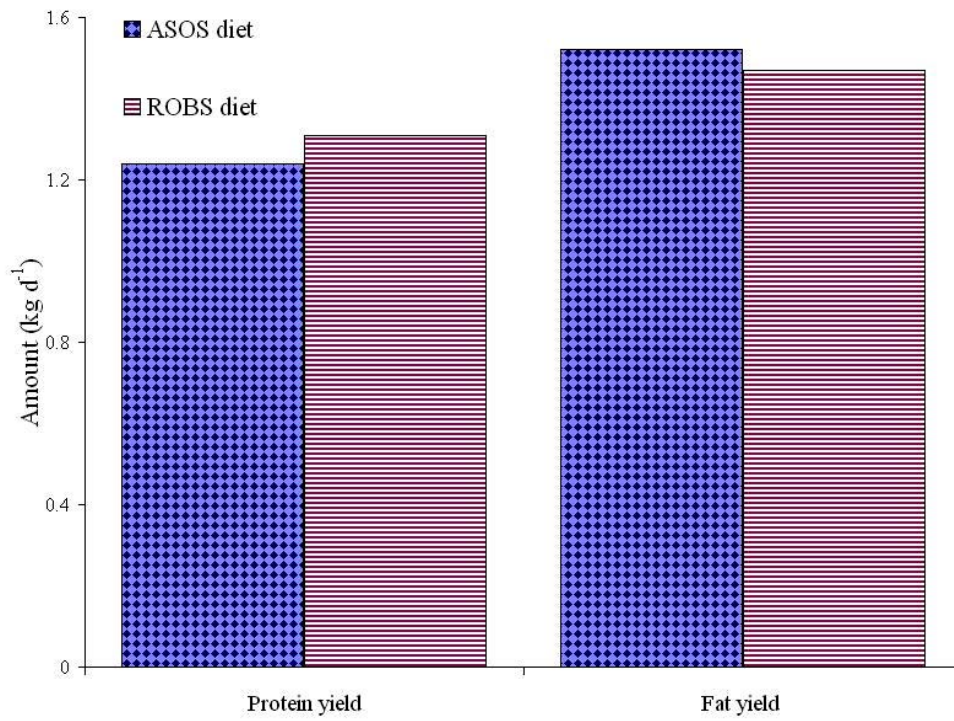


Figure 5.18 Milk Protein and Fat Yields of Cows Fed ASOS Diet or ROBS Diet.

The concentration as well as the yield of palmitic acid (C_{16:0}) was numerically higher (Figure 5.19) with the ROBS diet. The saturated fatty acid concentrations and the yields were numerically higher in the cows fed ROBS diet (Figure 5.20). This was supported by the results of forage fatty acid analysis and intakes (Tables 4.4, 4.13 and Figure 5.2) which indicated numerically higher palmitic (C_{16:0}) and other fatty acids below C₁₆ for ROBS relative to oat forages. Unsaturated fatty acid content increased 11% with ASOS diet. Long chain and long chain unsaturated fatty acids including conjugated linoleic acid (CLA) concentrations as well as the yield were higher in the cows fed ASOS diet. Griinari *et al.* (2000) described a trend for increased unsaturated fatty acids and CLA in milk of cows fed high fiber silage diets. French *et al.* (2000) concluded that high fiber diets decreased saturated intramuscular (IM) fat and increased unsaturated IM fat of steers fed to achieve similar carcass growth rates. Increased long chain unsaturated milk fat when fed oat based diets was reported by Martin *et al.* (1988). According to Richardson (1987) this milk property is more beneficial to the consumer in terms of reducing serum LDL and increasing HDL. This high unsaturated low saturated fat in milk property caused 10% reduction in saturated fat consumption. It is also important to enhance milk product quality (i.e. easy spreading quality in butter).

According to Jensen *et al.* (2001) and Gaynor *et al.* (1995), the glucogenic theory where increased hepatic glucose synthesis by means of increased propionate from the rumen associated with dietary changes could have occurred, may have likely played a role in decreasing fat contents in the cows fed Rosser silage besides having substantially higher rumen and total tract NDF digestion. The theory would be further

supported by the higher milk lactose contents in the cows fed Rosser silage. Increased lactose synthesis is usually associated with higher blood glucose and propionate levels in the presence of alpha-lactalbumin and β 1,4-galactosyltransferase according to Boston (1996). Propionate, glucose and insulin appear to repress fat mobilisation in ruminants. In fact the trend of higher non-structural carbohydrate digestibility (89%) and lower ether extract digestibility (73%) of Rosser silage relative to Assiniboia silage may have an influence for the observed increase in lactose which in turn led to increased milk yield by means of osmotic effects raising fluid volume in milk. Glucose which is the primary energy source of the mammary gland, indirectly plays a key role to increase (R=93%) milk yield as it is the precursor for lactose (Larson, 1985). Glucose is not directly incorporated into fatty acids. But it stimulates fatty acid synthesis from acetate. Acetate incorporates more than 70% to the synthesis fatty acids shorter than C₁₆ but less than 30% to synthesise fatty acids longer than C₁₆ in the mammary tissues. The rest of long chain fatty acids (longer than C₁₆) are absorbed from blood triglycerides (Larson, 1985). Fatty acids present in milk when fed Assiniboia diet was mainly long chain unsaturated. This may be associated with over 30% higher unsaturated and long chain fatty acid intake from Assiniboia diet as well as reduced endogenous fat [palmitic (C_{16:0})] synthesis, due to relatively lower acetate and glucose availability to the mammary gland of these cows compared to cows fed the Rosser diet.

Dry matter intake, body weight gain and blood urea level were similar across the diets. However, DM intakes by the cows fed the ASOS diet trended to be increased (Figure 5.16 and Table 4.14) compared to that of the cows fed ROBS diet. The silages

were opened for the production trial in the winter and the palatability was better than in the spring digestibility trial. The level of daily dry matter intake (25 kg DM) by the cows agreed with Burgess *et al.* (1973) and Christensen (1993). The body weight changes were not different in both the digestibility and milk production studies, and agreed with Burgess *et al.* (1973) but were not supported by McCartney *et al.* (1994) and Oltjen *et al.* (1980). However, there was a tendency with cows fed ASOS diet to gain slightly higher weight than cows fed the ROBS diet. These DM intakes and slight body weight gains suggested that the cows fed the ASOS diet may not be in negative energy balance.

Higher blood urea (nitrogen) levels were recorded for the cows fed oat silage by Burgess *et al.* (1973) but the current trial (milk urea, 6.9 and blood urea, 7.6 mmol L⁻¹) did not result higher blood or milk urea levels in ASOS fed cows. The reference value ranges for milk urea and blood urea reported by Jonker *et al.* (1997) and Merck's Veterinary Manual (1998) were respectively 3.5 to 10.6, and 2.8 to 8.8 urea mmol L⁻¹.

Although the biological aspects of the ASOS diet were comparable to ROBS diet according to the dairy production study results, the economic aspects which were based on Saskatchewan component price, June 2003, and calculated using average milk yield and composition, revealed lower revenues (Appendix: Table A9) for milk from cows fed the ASOS diet. The calculated milk value (\$ 64.18 per 100 kg) was 1.6% higher for the ASOS diet than for that of the ROBS diet. However, the milk revenues (\$ 26.14 per cow d⁻¹ and \$ 17.07 per kg of fat) were lower (1.7% and 4.8% respectively) for the ASOS diet than that of ROBS diet.

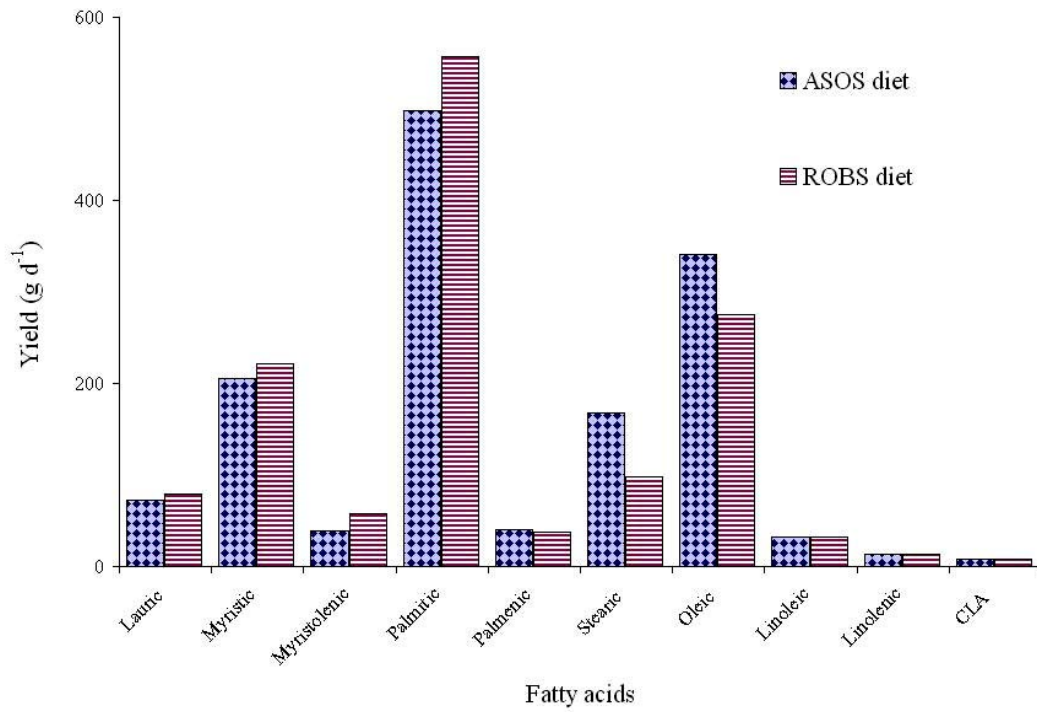


Figure 5.19 Milk Fatty Acid Yields of Cows Fed ASOS Diet or ROBS Diet.

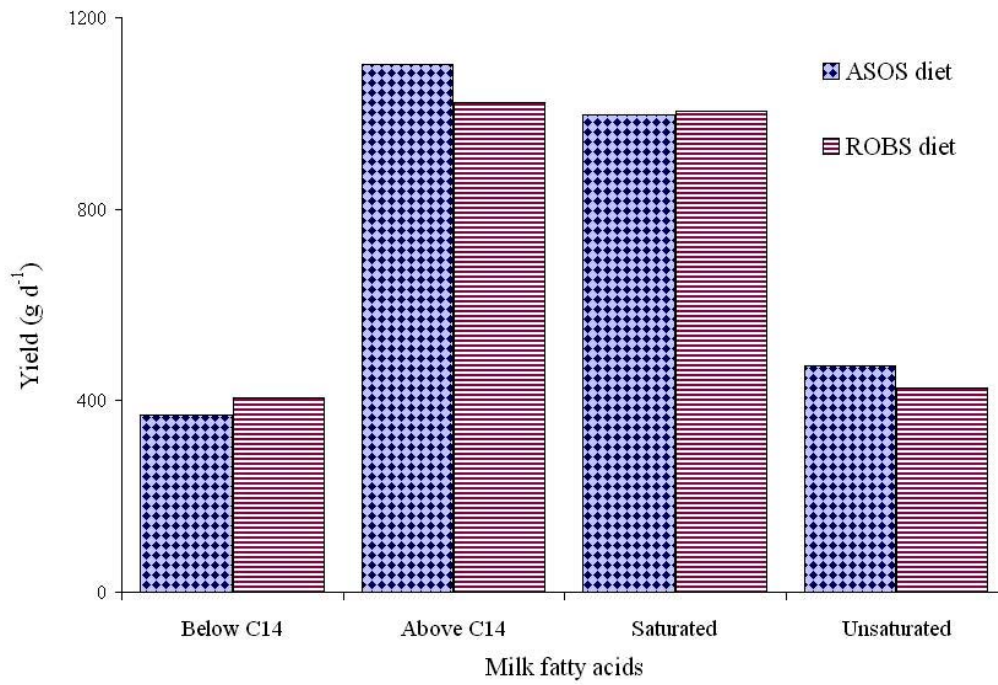


Figure 5.20 Milk Fatty Acid Yields According to Chain Length and Saturation, of Cows Fed ASOS Diet or ROBS Diet.

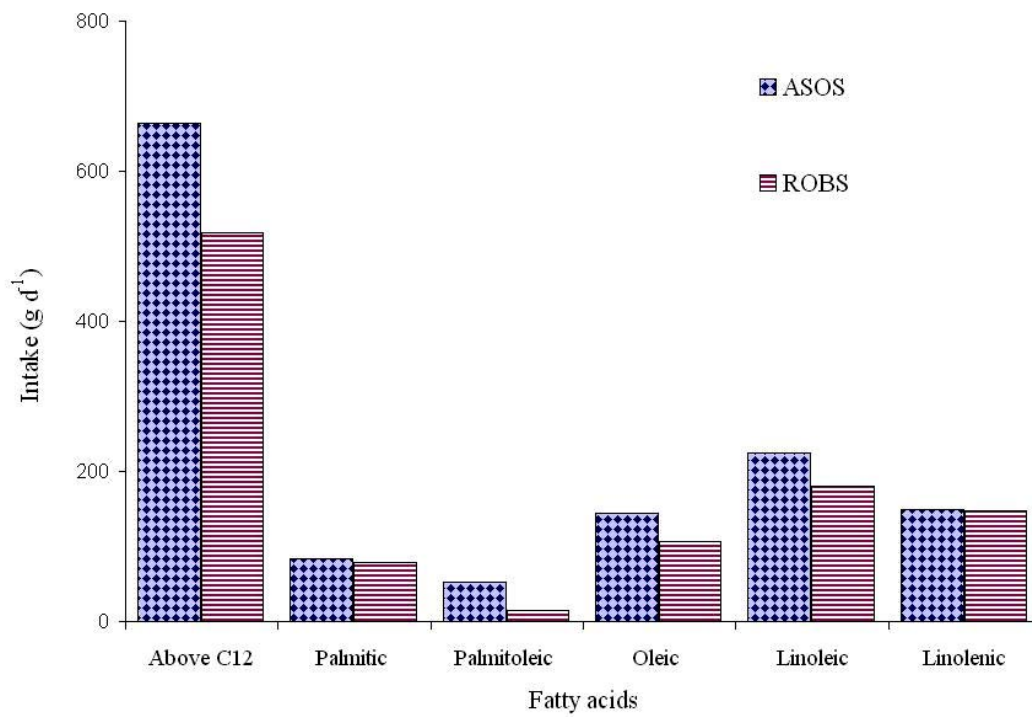


Figure 5.21 Daily Intakes of Fatty Acids Longer than C₁₂ from Assiniboia Oat Silage (ASOS) and Rosser Barley Silage (ROBS) per Cow.

6. CONCLUSIONS

Results from this project indicate that the nutritive quality of Assiniboia oat silage is comparable to Rosser barley silage in chemical, digestive characteristics and production aspects. Bell and Baler hays were not comparable to the silages in chemical and digestive characteristics, but comparable to each other in degradability characteristics. Bell hay was inferior in chemical and digestive features relative to Baler hay except in intake and rumen degradability.

Apparent digestibility coefficients of DM, OM, NDF, NPN, NDICP and EE for Assiniboia and Rosser silage were not different. Apparent digestibility coefficients of hemicellulose, NSC and ADL for all the forages were equal. Digestible energy in the silages was similar. Apparent digestibility coefficients of DM, NDF and ADF for Baler hay and Rosser silage were similar. Sheep voluntary intakes of DM, OM, NDF and ADF were similar for all the forages. EE intake was highest for Assiniboia. However CP intake was different, following the descending order as Rosser, Assiniboia, Bell and Baler.

The rumen degradability characteristics indicated a similarity between Assiniboia and Rosser silages, and on the other hand some similarity between Bell and Baler hays. There were higher disappearance rates and higher effective degradabilities for the silages than the hays. The silages provided more nutrients to the rumen than the hays due to the higher rumen disappearance and effective degradabilities of DM and CP, and lesser undegradable DM, CP, NDF and ADF. The rumen CP degradability characteristics were very similar between Assiniboia and Rosser silages. There was considerable variability of rumen CP degradation characteristics within and among the

forages based on higher variability of CP disappearance among incubations. Protein solubility was higher in the silages and consequently caused rapid protein disappearance in rumen. The estimated carbohydrate and protein fractions of Assiniboia and Rosser were similar. The rumen *in situ* degradation characteristics and effective degradabilities of NDF and ADF were similar among the silages, and were higher compared to the hays. The lowest ADF degradability was found for Bell. The silages had lower undegradable NDF and ADF fractions compared to the hays. The silages had higher degradable and potentially degradable NDF and ADF fractions.

Dry matter intake, body weight gain and blood urea levels were similar in cows fed either Assiniboia oat or Rosser barley silage based diet. There was a trend for increased dry matter intakes by the cows fed the Assiniboia diet. The body weight changes were not different in both digestibility and production studies. Blood and milk urea concentrations were not increased by the Assiniboia diet. The 3.5% fat corrected milk yields were similar for Assiniboia and Rosser diets, though the actual milk yields favoured Rosser. Milk fat content increased in the cows fed the Assiniboia diet. Milk protein and lactose contents increased in the cows fed the Rosser diet. Milk fatty acids when Assiniboia diet was fed, had 30 and 29% increases in fat acids longer than C₁₆ and oleic acid (C_{18:1}) content respectively. Stearic acid (C_{18:0}) content trended to be increased in cows fed the Assiniboia based diet. Unsaturated fatty acid to saturated FA ratio increased when cows were fed the Assiniboia diet. Saturated fatty acid contents trended to be increased when cows were fed the Rosser diet. Unsaturated fatty acids including conjugated linoleic acid (CLA, C_{18:2}) contents increased when fed Assiniboia diet because of higher intake and mammary incorporation of unsaturated

long chain fat. Therefore Assiniboia silage in addition to being nutritionally equivalent to good quality barley silage, would be useful as a forage source to increase unsaturated milk fat content. It was concluded that Assiniboia silage could substitute for Rosser silage in dairy rations; however, economic aspects should be counted and considered.

7. RECOMMENDATIONS

Baler oat cultivar conserved as silage should be further tested in a production experiment to evaluate the effects on production parameters and to compare with Assiniboia silage. Blood glucose, propionate and insulin should be determined in the production trial for further understanding of the changes in milk constituents such as lactose. Fatty acids in abomasal samples from cannulated cows should be analyzed to further understand the mechanism of action on milk fatty acids and other milk constituents.

Rumen *in situ* degradability of all cultivar silages should be carried out with more cows. It would be advisable to adopt incubation times covering 0, 2, 6 h and onwards to minimize the variability in the measurement of crude protein degradation characteristics. Further evaluation of regression equations in the study of nutrient disappearances versus dry matter disappearance is necessary before being accepted. Three variables (incubation time vs DM disappearance and nutrient disappearance) can be evaluated using best fitted models of regression analysis and three dimensional graphics illustrations can be created for better understanding of the process of rumen *in situ* degradability. Instead of calculating digestible energy (DE) using total digestible nutrient (TDN) values and nutrient digestibilities, DE should be determined based on gross energy analysis of the forages and fecal matter.

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APPENDIX

Table A1 CO OP Sheep Mineral Mixture Used in the Digestibility Trial.

Ingredient	Level	Quantity
Calcium (%)	Act. ²	16.00
Phosphorus (%)	Act. ²	16.00
Sodium (%) ¹	Act. ²	4.00
Zinc (mg/kg)	Act. ²	1,660
Iodine (mg/kg)	Act. ²	25
Iron (mg/kg)	Act. ²	4,000
Manganese (mg/kg)	Act. ²	800
Cobalt (mg/kg)	Act. ²	14
Fluorine (mg/kg)	Max. ³	3,000
Selenium (mg/kg)	Act. ²	7
Vitamin A (IU/kg)	Min. ⁴	202,400
Vitamin D ₃ (IU/kg)	Min. ⁴	33,300
Vitamin E (IU/kg)	Min. ⁴	400

¹ equivalent to approximately 10.0% salt.

² actual level

³ maximum level

⁴ minimum level.

Table A2 Schedule of Digestibility Trial.

Period	Diets	No. of days	Diet	Function
Diet adaptation (9)				
Step 1		3	ND ¹ 25% and OD ² 75%.	body weights
Step 2		3	ND ¹ 50% and OD ² 50%.	
Step 2		3	ND ¹ 75% and OD ² 25%.	
<i>Ad libitum</i> feeding		6	ND ¹ 100%	voluntary intakes transfer to met. ³ crates
Restricted feeding		4	ND ¹ 100%	intakes and body weights fix fecal collection bags
Experiment period		5		fecal sampling intakes and body weights

¹ new diet (silages or hays)

² old diet (alfalfa and concentrate pellets)

³ metabolic.

Table A3 Replication Schedule for Rumen *In Situ* Incubations.

Time (h)	0	6	12	24	36	48	60	72	96
Incubation 1: (4 steps – 16 d)									
Bags: 1. ASOS ¹	2	3	3	3	4	4	5	5	5
2. ROBS ²	2	3	3	3	4	4	5	5	5
3. BEOH ³	2	2	3	3	3	3	4	5	5
4. BAOH ⁴	2	2	3	3	3	3	4	5	5
Incubation 2: (4 d)									
Bags: 1. ASOS ¹	1	2	2	2	2	3	3	4	4
2. ROBS ²	1	2	2	2	3	3	4	4	4
Incubation 3: (4 d)									
Bags: 1. ASOS ¹	1	2	2	2	2	3	3	3	4
2. ROBS ²	1	2	2	2	3	3	3	4	4

Approximately 40 bags in two net sacs were inserted to the rumen at a single step of incubation.

¹ Assiniboia oat silage

² Rosser barley silage

³ Bell oat hay

Table A4 DM Disappearance of Forages (%).

Time (h)	Silage		Hay		SEM	Contrast		
	Assiniboia	Rosser	Bell	Baler		S/S	H/H	S/H
0	42.7 ^a	40.8 ^a	31.6 ^b	33.9 ^b	1.78	0.386	0.425	0.003
6	45.1 ^a	47.1 ^a	38.6 ^b	41.6 ^b	1.26	0.334	0.089	0.001
12	52.7 ^a	53.7 ^a	41.7 ^c	47.8 ^b	1.83	0.587	0.031	0.002
24	60.6 ^a	62.9 ^a	51.0 ^b	52.9 ^b	1.92	0.377	0.572	0.004
36	64.8 ^a	65.9 ^a	57.9 ^b	59.3 ^b	1.33	0.716	0.706	0.013
48	67.6 ^a	71.2 ^a	60.7 ^c	64.0 ^{bc}	1.51	0.135	0.278	0.002
60	72.1 ^b	75.6 ^a	64.3 ^c	66.4 ^c	1.73	0.003	0.108	0.001
72	76.8 ^a	78.3 ^a	67.8 ^b	69.3 ^b	1.75	0.338	0.468	0.001
96	79.7 ^a	80.6 ^a	70.6 ^b	72.7 ^b	1.68	0.591	0.364	0.001

^{abc} values with similar letters are not statistically different at 5% level

S/S: contrast silage (Assiniboia) vs silage (Rosser)

H/H: contrast hay (Bell) vs hay (Baler)

S/H: contrast mean of silage vs mean of hay.

Table A5 OM Disappearance of Forages (% DM basis).

Time (h)	Silage		Hay		SEM	Contrast		
	Assiniboia	Rosser	Bell	Baler		S/S	H/H	S/H
0	41.3 ^a	38.8 ^a	28.9 ^b	27.3 ^b	2.33	0.412	0.684	0.003
6	45.3 ^a	46.3 ^a	37.6 ^b	35.5 ^b	1.81	0.533	0.299	0.001
12	51.8 ^a	52.4 ^a	43.7 ^b	37.6 ^c	2.35	0.827	0.073	0.001
24	60.4 ^a	62.3 ^a	50.1 ^b	48.5 ^b	2.35	0.528	0.681	0.002
36	64.3 ^a	65.5 ^a	57.5 ^b	55.9 ^b	1.60	0.693	0.698	0.008
48	67.3 ^a	70.9 ^a	61.6 ^b	58.7 ^b	1.83	0.187	0.411	0.001
60	72.4 ^b	75.5 ^a	64.5 ^c	62.8 ^c	2.05	0.012	0.249	0.001
72	77.1 ^a	78.4 ^a	67.6 ^b	66.5 ^b	2.07	0.438	0.603	0.001
96	80.0 ^a	80.8 ^a	71.1 ^b	69.3 ^b	1.97	0.665	0.458	0.001

^{abc} values with similar letters are not statistically different at 5% level

S/S: contrast silage (Assiniboia) vs silage (Rosser)

H/H: contrast hay (Bell) vs hay (Baler)

S/H: contrast mean of silage vs mean of hay.

Table A6 CP Disappearance of Forages (% DM basis).

Time (h)	Silage		Hay		SEM	Contrast		
	Assiniboia	Rosser	Bell	Baler		S/S	H/H	S/H
0	77.8 ^a	79.6 ^a	51.0 ^b	49.4 ^b	5.49	0.637	0.729	0.001
6	83.5 ^a	84.9 ^a	63.7 ^c	76.0 ^b	3.74	0.241	0.001	0.001
12	84.2 ^a	85.6 ^a	73.9 ^b	64.6 ^c	3.28	0.435	0.008	0.001
24	86.0 ^a	88.3 ^a	74.5 ^b	71.4 ^b	2.78	0.195	0.164	0.001
36	85.8 ^a	85.8 ^a	74.9 ^b	72.3 ^b	2.38	0.999	0.378	0.001
48	85.0 ^a	88.1 ^a	79.6 ^b	76.3 ^b	1.76	0.111	0.179	0.001
60	86.4 ^b	89.5 ^a	78.6 ^c	75.2 ^c	2.22	0.045	0.075	0.001
72	87.4 ^a	90.2 ^a	81.5 ^b	79.7 ^b	1.64	0.152	0.464	0.001
96	89.7 ^a	91.4 ^a	82.8 ^b	81.8 ^b	1.61	0.275	0.623	0.001

^{abc} values with similar letters are not statistically different at 5% level

S/S: contrast silage (Assiniboia) vs silage (Rosser)

H/H: contrast hay (Bell) vs hay (Baler)

S/H: contrast mean of silage vs mean of hay.

Table A7 NDF Disappearance of Forages (% DM basis).

Time (h)	<u>Silage</u>		<u>Hay</u>		SEM	Contrast		
	Assiniboia	Rosser	Bell	Baler		S/S	H/H	S/H
0	6.7 ^a	4.5 ^a	0.1 ^b	0.0 ^b	1.11	0.651	0.837	0.061
6	12.4 ^a	13.5 ^a	9.6 ^{ab}	8.3 ^b	0.80	0.767	0.782	0.071
12	19.3 ^a	20.9 ^a	16.5 ^{ab}	9.2 ^b	1.73	0.743	0.235	0.071
24	33.1 ^a	34.9 ^a	24.5 ^b	24.5 ^b	1.85	0.399	0.994	0.030
36	40.7 ^a	44.7 ^a	34.8 ^b	36.4 ^{ab}	1.49	0.483	0.814	0.091
48	46.3 ^a	53.3 ^a	42.7 ^{ab}	39.0 ^b	2.04	0.134	0.528	0.028
60	54.5 ^b	61.4 ^a	47.7 ^c	46.9 ^c	2.26	0.014	0.739	0.001
72	63.0 ^a	66.8 ^a	51.4 ^b	51.1 ^b	2.67	0.159	0.929	0.001
96	67.3 ^a	69.9 ^a	58.0 ^b	55.7 ^b	2.31	0.372	0.550	0.003

^{abc} values with similar letters are not statistically different at 5% level

S/S: contrast silage (Assiniboia) vs silage (Rosser)

H/H: contrast hay (Bell) vs hay (Baler)

S/H: contrast mean of silage vs mean of hay.

Table A8 ADF Disappearance of Forages (% DM basis).

Time (h)	<u>Silage</u>		<u>Hay</u>		SEM	<u>Contrast</u>		
	Assiniboia	Rosser	Bell	Baler		S/S	H/H	S/H
0	3.7 ^a	5.9 ^a	0.0 ^a	0.0 ^a	0.97	0.772	0.775	0.094
6	6.9 ^{ab}	12.3 ^a	1.7 ^c	3.5 ^{bc}	1.56	0.157	0.562	0.024
12	15.9 ^a	18.2 ^a	17.1 ^a	10.9 ^a	1.08	0.648	0.343	0.457
24	34.7 ^{ab}	39.5 ^a	33.1 ^{ab}	25.8 ^b	1.89	0.335	0.247	0.067
36	39.9 ^a	44.8 ^a	34.4 ^a	37.9 ^a	1.46	0.351	0.601	0.156
48	44.0 ^{ab}	53.2 ^a	40.6 ^b	38.0 ^b	2.22	0.041	0.626	0.015
60	51.7 ^b	60.7 ^a	45.0 ^c	45.7 ^c	2.43	0.001	0.764	0.001
72	60.2 ^a	65.1 ^a	49.1 ^b	49.8 ^b	2.63	0.098	0.864	0.001
96	64.4 ^a	68.8 ^a	54.8 ^b	55.1 ^b	2.32	0.166	0.935	0.004

^{abc} values with similar letters are not statistically different at 5% level

S/S: contrast silage (Assiniboia) vs silage (Rosser)

H/H: contrast hay (Bell) vs hay (Baler)

S/H: contrast mean of silage vs mean of hay.

Table A9 Milk Value and Revenue Based on Saskatchewan Component Prize, June 30, 2003 for Milk from Assiniboia Oat Silage Total Mixed Ration (ASOS Diet) or Rosser Barley Silage Total Mixed Ration (ROBS Diet).

Variable	Silage based diets	
	Assiniboia	Rosser
Milk yield (kg d ⁻¹)	40.73	42.13
3.5% FCM ^x (kg d ⁻¹)	42.22	42.11
Milk protein (%)	3.05	3.12
Milk fat (%)	3.76	3.52
Total solids (%)	12.59	12.52
Milk value (per 100 kg)	64.18	63.16
Milk revenue (\$/cow d ⁻¹)	26.14	26.61
Milk revenue (\$/kg fat)	17.07	17.94

^x 3.5% fat corrected milk.