BEEF COW-CALF PRODUCTION FROM FERTILIZED AND UNFERTILIZED ALFALFA-MEADOW BROMEGRASS AND MEADOW BROMEGRASS-ONLY PASTURES

A Thesis

Submitted to the Faculty

of

Graduate Studies

The University of Manitoba

by

Juanita Caye Kopp

In Partial Fulfilment of the

Requirements for the Degree

of

Doctor of Philosophy

Department of Animal Science

October 2002

0-612-79860-7

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

*****

COPYRIGHT PERMISSION PAGE

BEEF COW-CALF PRODUCTION FROM FERTILIZED AND UNFERTILIZED ALFALFA-MEADOW BROMEGRASS AND MEADOW BROMEGRASS-ONLY PASTURES

BY

JUANITA CAYE KOPP

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University

of Manitoba in partial fulfillment of the requirements of the degree

of

Doctor of Philosophy

ABSTRACT

Kopp, Juanita Caye. Ph.D., The University of Manitoba, May 2002. Beef Cow-Calf Production From Fertilized and Unfertilized Alfalfa-Meadow Bromegrass and Meadow Bromegrass-Only Pastures. Major Professor; Karin M. Wittenberg.

A four year (1995-1998) grazing experiment was conducted to determine the effect of pasture species (meadow bromegrass (*Bromus biebersteinii* Roem & Schult.)-only pastures and alfalfa (*Medicago sativa* L.)-meadow bromegrass mixed pastures) and fertilization on forage yield and quality and on cow-calf productivity. Four cow-calf pairs were assigned to four pasture treatments (T): alfalfa-grass fertilized (AF), alfalfa-grass unfertilized (AU), grass-only fertilized (GF) and grass-only unfertilized (GU). Each 3.7 ha pasture was sub-divided into five equally sized paddocks and rotationally stocked. Half of the cows in each pasture received a Rumensin® controlled release capsule (CRC). Suckling calf forage dry matter intake (FDMI) was estimated by determining the difference between net energy required for maintenance and gain, and energy provided by milk. Four year average forage production of AF, AU, GF and GU were 4.9, 4.1, 4.9 and 2.6 ± 0.24 t DM ha^{-1} and the average carrying capacities were 200.4, 163.9, 208.7 and 127.6 ± 3.3 cow grazing days (CGD) ha^{-1}, respectively. The percentage of alfalfa declined ($P < 0.05$) in the mixed pastures, from 75.4% and 84.1% in 1995 to 32.5 and 40.3% in 1998 for AF and AU pastures, respectively. Consumed forage quality declined as the grazing season progressed. Cow average daily gain (ADG, g d^{-1}) was affected by a pasture treatment by monensin interaction ($P < 0.05$), monensin use resulted in a higher cow ADG on GU and AU pastures and had no effect when cows grazed GF or AF pastures. Pasture treatment did not affect milk yield or milk

composition. Despite differences in nutrient profiles of the animal's diet, cow-calf productivity for AU, AF and GF were similar. The high dietary fibre content of cows grazing the GU pastures reduced calf ADG ($P < 0.05$). Calves pastured on the GU treatment had the greatest FDMI (5.3 ± 0.3 kg d^{-1}) followed by the GF pastures (4.1 ± 0.3 kg d^{-1}); calves on the AF and AU pastures had similar FDMI (3.5 ± 0.3 kg d^{-1}). Calves had the ability to select a diet that did not greatly compromise their ADG, even when forage quality was limiting. The AU pastures provided the most consistent results under a variety of environmental conditions. Fertilization improved DM yield of grass pastures by 39% and calf gain ha^{-1} by 37%, therefore, fertilization should be encouraged when precipitation is not limiting.

Dedicated to my parents, Edward and Regina Kopp, for all their unconditional love and support. Without you I would have quit my university career a long time ago. Thank you for all the financial and psychological reenforcement.

J.M.J.

ACKNOWLEDGMENTS

I wish to express my sincere appreciation for all the tireless effort, encouragement and practical advice I received from my supervisors Dr. Karin Wittenberg and Dr. Paul McCaughey. I would also like to thank the other members of my committee Drs. M. Rudstrom and K. Ominski for their helpful insight and encouragement. A special thank you to my external examiner Dr. R.D.H. Cohen for his advice and valuable editorial comments.

Thank you to the invaluable crew that I worked with at Agriculture Agri-Food Canada Research Centre in Brandon: Clayton Robins, Jim McGee, Rusty Mussbacher, Cindy Rose, Barb Kristjansson, Dave Corrigan and Dr. Av Singh.

Without Drs. L. Onischuk and G. Crow statistics would have no meaning in my life and I am forever grateful to them for their limitless patience and understanding.

I would also like to recognize the help I received from the nutrition lab staff, a special thanks to Janice Haines for her valuable assistance.

The financial assistance provided by Provel/Elanco and from the University of Manitoba's Graduate Fellowship Fund was greatly appreciated, many thanks.

Thanks to all my friends and fellow graduate students for helping me to maintain my sanity and sense of humor. Cheers!

TABLE OF CONTENTS

Page

LIST OF TABLES xi

LIST OF FIGURES xiii

LIST OF APPENDICES xiv

ABBREVIATIONS xvi

1.0 INTRODUCTION 1

2.0 LITERATURE REVIEW 4

2.1 Introduction 4

2.2 Forage Complementation and Suitability for the Northern Prairie Regions of North America (Arid vs. Sub-humid Regions) 4

2.2.1 Plant Establishment for Complementation and Suitability 6

2.2.1.1 Seed Characteristics Relative to Topography and Seeding Equipment 9

2.2.1.2 Seedling Emergence 9

2.2.1.3 Seedling Vigour 10

2.2.2 Forage Species Blends for the 'Ideal Pasture' 10

2.2.2.1 Characteristics of Successful Pasture Species Profiles 14

2.2.3 Extended Grazing 17

2.2.3.1 Forage Quality Characteristics versus Pasture Characteristics 18

2.3 Alfalfa Characteristics that Compliment an 'Ideal Pasture' 18

2.3.1 Forage Quality and Productivity 18

2.3.1.1 Meeting the Requirements of the Lactating Beef Cow and Growing Calf 20

2.3.2 Grazing Tolerance and Persistence 20

2.3.3 Bloat 23

2.3.4 Alfalfa in Mixed Species Pastures 24

2.3.4.1 Effect of Nitrogen Fixation on Grass Species 25

2.4 Meadow Bromegrass Characteristics that Compliment an 'Ideal Pasture'. . 26

2.4.1 Forage Quality and Productivity 26

2.4.1.1 Meeting the Requirements of Lactating Beef Cows and the Growing Calf 27

2.4.2 Grazing Tolerance 29

2.4.2.1 Regrowth and Growing Points 30

2.4.2.2 Resistence to Trampling 30

2.4.2.3 Effect of Drought and Heat Stress 30

2.4.3 Meadow Bromegrass in Mixed Pastures 31

2.4.3.1 Tillering Characteristics 31

2.5 Fertilization of Cultivated Pastures 32

2.5.1 Effect of Fertility on Quality and Productivity of Legumes and Grasses 32

2.5.2 Long-Term Effect on Botanical Composition of Legume-Mixed Pastures 34

2.5.3 Fertilization and Carrying Capacity or Length of Grazing Season . . 34

2.5.4 Sustainability of Fixed Nitrogen Versus Commercial Application . . . 35

2.5.4.1 Grass Versus Legume-grass Nitrogen Re-distribution 36

2.5.5 Economics of Fertilization 37

2.6 Rotational Stocking of Tame Forages 39

2.6.1 Rotational Stocking 39

2.6.2 Productivity and Regrowth of Rotationally Stocked Legume-grass Pastures 41

2.6.3 Effect of Rotational Stocking on Plant Persistence in Legume-grass Pastures 41

2.7 The Grazing Animal 42

2.7.1 Grazing Behaviour of Cow-calf Pairs 42

2.7.1.1 Trampling 43

2.7.1.2 Dirty Versus Clean Forages 43

2.8 Grazing Animal Productivity 44

2.9 Animal Performance and Monensin CRC 46

2.9.1 Cow-calf Responses to Monensin on Pasture or Forage Diets 46

2.10 Hypothesis 48

3.0 MANUSCRIPT 1: The use of fertilizer inputs versus legume incorporation for meadow bromegrass pastures 49

3.1 ABSTRACT 50

3.2 INTRODUCTION 52

3.3 MATERIALS AND METHODS 53

3.3.1 Experimental Pastures 53

3.3.2 Data Collection 54

3.3.3 Laboratory Analysis 56

3.3.4 Statistical Methods 56

3.4 RESULTS AND DISCUSSION 57

3.4.1 Fertilization 57

3.4.2 Forage Productivity 57

3.4.3 Carrying Capacity 60

3.4.4 Botanical Composition 61

3.4.5 Forage Quality 61

3.4.6 Cost Benefit Assessment of Fertilization 69

3.5 ACKNOWLEDGMENTS 71

4.0 MANUSCRIPT 2: Management strategies to improve cow-calf productivity on meadow bromegrass pastures 72

4.1 ABSTRACT 73

4.2 INTRODUCTION 75

4.3 MATERIALS AND METHODS 76

4.3.1 Description 76
4.3.2 Data Collection 78
4.3.3 Statistical Methods 80
4.4 RESULTS AND DISCUSSION 81
4.4.1 Consumed Forage Quality 81
4.4.2 Dry Matter Intake 88
4.4.3 Cow Productivity 88
4.4.4 Calf Productivity 91
4.4.5 Cost Benefit Assessment of Fertilization 94
4.5 CONCLUSION 96
4.6 ACKNOWLEDGMENTS 96
5.0 MANUSCRIPT 3: Forage and milk intake of suckling beef calves grazing alfalfa-meadow bromegrass and meadow brome grass-only pastures . . . 97
5.1 ABSTRACT 98
5.2 INTRODUCTION 100
5.3 MATERIALS AND METHODS 101
5.3.1 Description 101
5.3.2 Data Collection 102
5.3.3 Energy of Maintenance 102
5.3.4 Energy of Calf Tissue Gain 103
5.3.5 Energy of Milk 103
5.3.6 Energy of Forage 103
5.3.7 Calculations for Forage DM Intake 104
5.3.8 Statistical Methods 105
5.4 RESULTS AND DISCUSSION 105
5.4.1 Milk Energy and DMI 105
5.4.2 Forage Energy and DMI 107

5.4.3 Total DMI 113
5.5 ACKNOWLEDGMENTS 117
6.0 GENERAL DISCUSSION 118
6.1 FORAGE PRODUCTIVITY 118
6.2 FORAGE QUALITY 119
6.3 COW PRODUCTIVITY 121
6.4 CALF PRODUCTIVITY 122
6.5 CONCLUSION 123
7.0 LITERATURE CITED 125
8.0 APPENDIX 143

LIST OF TABLES

Table		Page
1	Forage characteristics of grass and legume species	15
2	Diet nutrient density requirements of beef cows and calves, and the nutrient composition of alfalfa and *bromus* species	21
3	Meadow Bromegrass yield (kg DM ha^{-1}), fertilization rate (kg ha^{-1}) and growing season and/or annual precipitation (mm)	28
4	Fertilizer recommendations and actual application rates (kg ha^{-1}) for meadow bromegrass and alfalfa-meadow bromegrass pastures during 1994-1998	55
5	Growing seasons precipitation and temperature data, Brandon, Manitoba, including a 92 year average	58
6	Carrying capacity (CGD ha^{-1}) of fertilized (F) and unfertilized (U) alfalfa-meadow bromegrass (A) and meadow bromegrass (G)-only pastures over four grazing seasons	59
7	Forage protein content, % DM basis, for alfalfa-meadow bromegrass (A) and meadow bromegrass (G) pastures in fertilized (AF, AG) and unfertilized (AU, GU) conditions over three pasture seasons	63
8	Forage neutral detergent fibre, % DM basis, for alfalfa-meadow bromegrass (A) and meadow bromegrass (G) pastures in fertilized (AF, GF) and unfertilized (AU, GU) conditions over three pasture seasons	66
9	Forage acid detergent fibre, % DM basis, for alfalfa-meadow bromegrass (A) and meadow bromegrass (G) pastures in fertilized (AF, GF) and unfertilized (AU, GU) conditions over three pasture seasons	68
10	Additional cow grazing days (CGD ha^{-1}) and fertilizer cost per additional CGD (\$ CGD^{-1}), comparing AF, AU and GF to GU over four grazing seasons	70
11	Cow breed, age, initial weights, milking dates, initial and final calf age and weights for the four year pasture study	77

12 Three year average (1995-1997) quality and *in vitro* organic matter digestibility (IVOMD) of forage consumed by esophageal fistulated animals for the alfalfa-meadow bromegrass (A) and meadow bromegrass (G) pastures in fertilized (AF, GF) and unfertilized (AU, GU) conditions 83

13 Effect of pasture treatment (T), monensin controlled release capsule (M) and sex of calf (S) on cow productivity during the grazing season 90

14 Effect of pasture treatment (T), monensin controlled release capsule (M) and sex of calf (S) on calf productivity during the grazing season 93

15 Additional calf gain (kg ha^{-1}) and cost per calf gain (\$ kg^{-1} ha^{-1}), comparing AF, AU and GF to GU over four grazing seasons 95

16 Initial age, initial weight, average daily gain, age at milking 1 and milking 2 and estimated energy requirements for maintenance and growth for suckling calves pastured from 1995 to 1997, means ± standard deviations 106

17 Effect of pasture treatment (T), monensin controlled release capsule (M) and sex of calf (S) on milk dry matter intake (DMI) and the contribution of milk to meet net energy of maintenance (NE_m) and gain (NE_g) during three grazing seasons (1995-1997) 108

18 Effect of pasture treatment (T), monensin controlled release capsule (M) and sex of calf (S) on the contribution of forage to meet net energy of maintenance and gain requirements and forage dry matter intake (DMI) during three grazing seasons (1995-1997) 111

19 Effect of pasture treatment (T), monensin controlled release capsule (M), and sex of calf (S) on calf total dry matter intake (forage plus milk DMI) during three grazing seasons (1995-1997) 115

LIST OF FIGURES

Figure		Page
1	Botanical composition of fertilized (AF) and unfertilized (AU) alfalfa-meadow bromegrass over a 4 year period	62
2	The effect of pasture treatment (T) at entry (I) and exit (O) from paddocks and of rotation (R) and I and O of paddock on the consumed forage NDF content (% DM basis) (SE = 1.55; RxI/O SE = 1.10) . . .	86
3	Forage quality of clipped (Clp, ▒) and consumed (Con, ■) forage for the alfalfa-meadow bromegrass (A) and meadow bromegrass (G) pastures in fertilized (AF, GF) and unfertilized (AU, GU) conditions (CP-clp SE = 0.22, CP-con SE = 0.51, NDF-clp SE = 0.28, NDF-con SE = 1.38, ADF-clp SE = 0.28, ADF-con SE = 0.99)	89
4	The effect of pasture treatment and monensin on cow ADG (SE = 65.8)	92
5	The effect of pasture treatment (T) by sex of calf (S) interaction on rotation two (R2) milk net energy of maintenance (NE_m, MJ d^{-1}) (n=12; SE = 1.05, P < 0.01)	109
6	The effect of pasture treatment (T) by sex of calf (S) interaction on rotation two (R2) forage net energy of maintenance (NE_m) intake (MJ d^{-1}) (n=12; SE = 1.01, P < 0.01)	112
7	The relationship between calf forage dry matter intake (FDMI) and milk dry matter intake (MDMI) as a percentage of calf body weight (%BW)	114

LIST OF APPENDICES

Appendix		Page
1	Precipitation data (mm) from Brandon, Manitoba 1995 to 1998, including a 92 year average	144
2	Temperature data (°C) from Brandon, Manitoba 1995 to 1998, including a 92 year average	145
3	The statistical models used to analyse the forage data. Manuscript 1.	146
4	Herbage biomass (kg DM ha^{-1}) 'In', clipped upon entering a paddock (1995-1998)	147
5	Herbage biomass (kg DM ha^{-1}) 'Out', clipped upon exiting a paddock (1995-1998)	149
6	Analysis of variance of cow grazing days and total forage production during four grazing seasons (1995 to 1998). Manuscript 1	151
7	Analysis of variance of yearly cow grazing days. Manuscript 1	152
8	Analysis of variance for percentage of alfalfa in the alfalfa-meadow bromegrass mixed pastures (AF, AU). Manuscript 1	153
9	Analysis of variance for forage quality factors (DM basis) three year average (1995 to1997). Manuscript 1	154
10	Analysis of variance for forage quality factors (DM basis). Manuscript 1	155
11	The statistical models used to analyse cow production data. Manuscript 2	156
12	Analysis of variance for calf ADG, total gain and gain per hectare. Manuscript 2	158
13	Energy concentration of consumed forage. Manuscript 3	159
14	Effect of year (Y), pasture treatment (T), monensin controlled release capsule (M) and sex of calf (S) on calf milk dry matter intake and the contribution of milk to meet net energy of maintenance and gain, analysis of variance results	160

15 Effect of year (Y), pasture treatment (T), monensin controlled release capsule (M) and sex of calf (S) on the contribution of forage to meet net energy of maintenance and gain requirements and calf forage dry matter intake, analysis of variance 161

16 Effect of year (Y), pasture treatment (T), monensin controlled release capsule (M) and sex of calf (S) on calf total dry matter intake (forage plus milk DMI), analysis of variance results 162

17 Clipped forage quality data for three grazing seasons (1995-1997) . . 163

18 Consumed forage quality data for three grazing seasons (1995-1997), collected from esophageally fistulated steers 169

19 The relationship between cow average daily gain (ADG) and serum urea nitrogen (SUN) levels of cows that grazed unfertilized meadow bromegrass pastures over three years (1995-1997 171

20 The relationship between cow average daily gain (ADG) and serum urea nitrogen (SUN) levels over three years (1995-1997) 172

ABBREVIATIONS

ADF	=	acid detergent fibre
ADG	=	average daily gain
AF	=	alfalfa-grass fertilized
AU	=	alfalfa-grass unfertilized
BW	=	body weight
c	=	specific combustion energy (MJ kg^{-1})
˚C	=	degree Celsius
Ca	=	calcium
CGD	=	cow grazing days
CP	=	crude protein
CRC	=	controlled release capsule
d	=	day
DE	=	digestible energy
DM	=	dry matter
DMI	=	dry matter intake
FDMI	=	forage dry matter intake
g	=	gram
GE	=	gross energy
GF	=	meadow bromegrass fertilized
GLM	=	general linear model
GU	=	meadow bromegrass unfertilized
h	=	hour
ha	=	hectare
I	=	*in*-sample taken upon entry into a paddock
IVOMD	=	*in vitro* organic matter digestibility

kg	=	kilogram
M	=	monensin
m	=	percent of mature weight
MDMI	=	milk dry matter intake
ME	=	metabolizable energy
N	=	nitrogen
MJ	=	mega joule
NDF	=	neutral detergent fibre
NE_m	=	net energy of maintenance
NE_g	=	net energy of gain
O	=	*out*-sample taken upon exiting a paddock
P	=	phosphorous
q	=	ME/GE
R1	=	rotation one
R2	=	rotation two
S	=	sex of calf
SCC	=	somatic cell count
SEM	=	standard error of the mean
SNF	=	solids non-fat
SUN	=	serum urea nitrogen
T	=	pasture treatment
t	=	metric tonne
Y	=	year

1.0 INTRODUCTION

The cow-calf industry in western Canada is very dependent on rangelands and grasslands to maintain a productive beef industry. Cattle producers rely on sound grassland management practises and adaptable forage species. Cultivated pastures have long been used in times of drought and to reclaim marginal crop-land to maintain environmental sustainability.

Grazing animal productivity is dependent on forage quality. To maintain pasture quality it is essential to keep pastures in the vegetative growth phase for as long as possible (Boyd et al. 2001), through utilization of rotational stocking practices (Christian 1987). The forage species used in the pasture can also affect forage yield and animal productivity. The most widely grown legume forage in Manitoba is undeniably alfalfa (*Medicago sativa* L.), since it is highly productive, fixes atmospheric nitrogen, has a high nutritive value that is well suited for cattle production and is adapted to many climatic and soil conditions (Van Keuren and Matches 1988). However, it is rare that high percentages of alfalfa are used in pastures grazed by cow-calf pairs. Many producers are reluctant to use alfalfa since it can cause bloat. It is recommended that alfalfa be grown with grass species to offset the potential for bloat. Currently, meadow bromegrass (*Bromus biebersteinii* Roem. & Schult.) has been identified as a good complement to alfalfa for use in pastures (Pearen and Baron 1996; Holt and Jefferson 1999).

Pasture productivity and longevity are also essential for an efficient and profitable beef operation. The majority of cow-calf production systems are based on unfertilized grass pastures. Pasture fertility is correlated to forage yield and quality which in turn will determine the productivity of grazing cattle. Managing pasture fertility can be accomplished by using inorganic fertilizers (Campbell et al. 1986; Ukrainetz and Campbell 1988), by including a legume in the forage stand (Walley et al. 1996; Tomm et al. 1995) or a combination of fertilizer and legume incorporation. These agronomic strategies may result in increased biomass production and increased protein concentrations.

Another strategy to help improve productivity is to enhance the performance of the grazing animals themselves. Improved forage utilization, by increased feed efficiency or plant protein utilization may be accomplished by treating grazing cows with an ionophore, such as monensin. Monensin administered to dairy cows has increased milk production (Beckett et al. 1998; Hayes et al. 1996) and reduced the percentages of milk fat and protein compared to the untreated cows, while increasing the daily production of fat and protein per cow (Ramanzin et al.1997). However, the effect of monensin on beef cow productivity, DMI, milk yield and composition is not well documented, especially when grazing alfalfa-meadow bromegrass and meadow bromegrass-only pastures under differing levels of fertility. In the past, grazing research in the Northern Great Plains region of North America has focussed on the performance of steers on legume-grass pastures (Popp et al. 1997a, 1997b, 1997c; Walton et al. 1981) and few studies have used cow-calf pairs (McCartney et al. 1999; Hart et al. 1993).

The objectives of this study were: 1) to evaluate the effect of forage species and fertilization on yield, quality and botanical composition of pastures under rotational stocking by cow-calf pairs over time; 2) to determine the effect of forage species, fertilization and use of ionophores on cow and calf performance while grazing fertilized and unfertilized alfalfa-meadow bromegrass and meadow bromegrass-only pastures; and 3) to use energy balance methodology to determine the effect of pasture system and dam milk supply on calf forage dry matter intake (FDMI).

2.0 LITERATURE REVIEW

2.1 Introduction

The cultivation of farmland has decreased soil organic matter and has made crop production areas more unstable. The rejuvenation of marginal crop land can be accomplished by planting perennial forages to increase soil organic matter (Campbell et al. 1990), reduce soil erosion (Stinner and House 1989) and improve overall soil structure and fertility (Mapfumo et al. 2000), while providing valuable grasslands for grazing or for hay production. Including forages in a crop rotation is an important part of sustainable agriculture.

To maintain sustainable pastures, proper management is needed which includes adequate fertility, adequate rest periods between grazing, good forage yields, adequate nutritional quality throughout the grazing season, an accurate evaluation of the grassland's condition and a proper calculation of the carrying capacity. The objective of this review is to evaluate the characteristics of an 'ideal pasture' by examining the scientific recommendations from the Northern Great Plains (where possible only publications from Alberta, Saskatchewan, Manitoba, and the northern United States including the states of Idaho, Montana, North Dakota, Minnesota and the northern regions of Wyoming and South Dakota were used).

2.2 Forage Complementation and Suitability for the Northern Prairie Regions of North America (Arid vs. Sub-humid Regions)

There are many forage species available for use in pastures and choosing the right specie(s) for grazing is dependent on a number of factors, such as climate, soil type, annual precipitation, topography, grazing intensity and length of grazing season required. Generally forage species are considered for their ability to survive in arid and sub-humid regions. Insufficient yearly precipitation in the Brown soils of the arid regions of Alberta and Saskatchewan limits the type of forage species used in cultivated pastures on these soils (Kilcher 1965). The arid grassland regions of southwestern Saskatchewan and southeastern Alberta receive approximately 250 mm of annual precipitation, whereas the Lake Manitoba plain of south central Manitoba, the warmest and most humid region of the Prairie Ecozone, receives slightly less than 700 mm of annual precipitation (Brandon average is 470 mm) (Environment Canada 2001). Thus winter-hardy and drought-tolerant grasses and legumes must be utilized in the arid regions (Lawrence 1977) and forages that grow well in areas of higher annual precipitation should be used in the humid regions of Manitoba. Therefore, environmental conditions must be considered before assessing the complementarity and suitability of a forage to different regions of the northern prairie region.

Although this literature review will focus on cultivated forages it should be stated that there are a number of studies that outline the use of complementary pasture-native range systems to extend the grazing season. Complementary cool season and warm season grasses grazed when they are actively growing, and the use of irrigation where possible, have the potential to increase production per unit of land, improve animal performance and can help to safeguard against drought conditions (Nichols 1989). Hart et al. (1988b) grazed cow-calf pairs on a combination of crested wheatgrass (*Agropyron desertorum* Fisch.), irrigated meadow bromegrass (*Bromus biebersteinii* Roem. and Schult.)-alfalfa (*Medicago sativa* L.) pastures (72% meadow bromegrass and 28% alfalfa, percent of DM yield) and mixed-grass prairie. The grazing season started on June 1 and the cow-calf pairs grazed the cultivated pastures for 42 days. Animals were put on the mixed grass prairie to graze for 112 days from July 13 to November 1. The objective of the study conducted by Hart et al. (1988b) was to determine the optimal stocking rate and the appropriate ratio of improved pasture area to rangeland area. The optimal stocking rate to maximize returns was dependent on range type, forage yield, grazing season, production costs and livestock prices (Hart et al. 1988a). Other studies have also identified level of management (Wilson et al. 1987) and marketing strategies (Ethridge et al 1987) as being important issues. The optimum combination of 1 ha of crested wheatgrass for every 3.94 ha of range per animal unit returned \$35.70 ha^{-1} (U.S.) to land, labour and management (Hart et al. 1988b).

2.2.1 Plant Establishment for Complementation and Suitability

There are a variety of forage establishment issues, for example the small seed size of most perennial forages makes accurate depth control at seeding essential (Waddington and Bittman 1983). Seedlings grow slowly and this can subject them to unfavourable hot weather, lack of moisture, poor seed bed environments, wind and water erosion and fierce weed competition (Waddington and Bittman 1983).

Forage establishment techniques should be based on the environmental constraints that will limit establishment success and the intended use of the crop during the seeding year (Curran et al. 1993). In semi-arid regions where the risk of erosion is elevated or where the complete loss of vegetation is undesirable, conventional pre-seeding cultivation of the seed bed is not recommended (Schellenberg et al. 1994b.). No-tillage seeding reduces the potential for erosion (Undersander et al. 2001; Casler et al. 1999; Wolf et al. 1985), increases water infiltration, maintains a firm seed-bed, reduces fuel and labour costs (Wolf et al. 1985), but requires the use of specialized seeders that increase input costs (Casler et al. 1999). As well, in sandy soils where moisture loss from the seed zone is rapid (Rehm et al. 1998) no-till planting systems could reduce the moisture loss and improve seedling emergence (Allen and Entz 1994). There are some limitations to no-till forage establishment. For example, heavy crop residue from previous crops can interfere with forage growth (Cochran et al. 1977), limiting the warming of the soil surface and reducing the seedling's ability to photosynthesize. As well, allelopathic chemicals released by the decay of previous crop residue can impede forage growth (Cochran et al. 1977). Allen and Entz (1994) found that meadow bromegrass (*Bromus biebersteinii* Roem. and Schult) was less adapted to no-till establishment compared to alfalfa when the previous crop was wheat (*Triticum aestivum* L.) especially under wet conditions with heavy wheat residue. However, in the year after establishment there was no effect of tillage system or preceding crop on forage dry matter yield (Allen and Entz 1994).

To sustain pastures in the semi-arid regions of the Northern Great Plains, forages should be planted in rows 30-cm apart (Jefferson and Kielly 1998). Vough et al. (1995) stated that to maximize forage yield, forages should be planted in narrow rows or broadcast seeding at high seedling density. Increased row spacing results in increased seed head density and a lower forage quality compared to vegetative growth (Jefferson and Kielly 1998). Narrow row-spacings and high plant density has the potential to reduce weed invasion and soil erosion (Jefferson and Kielly 1998).

The standard establishment procedures for legumes are as follows: prepare a firm seed bed, till in spring, seed in early May with row spacing of 15 cm and seed depth of 1.3 cm (Rehm et al. 1998). Many producers use companion crops to establish forages; generally small grain crops such as barley (*Hordeum vulgare* L.) and oats (*Avena sativa* L.) (seeded at half or less than half the normal seeding rate) are used for protection against soil erosion, to suppress weeds, to produce additional dry matter yield (Simmons et al. 1995) and for the production of a usable or saleable crop in the establishment year (economic benefit) (Jefferson and Zentner 1994). However, companion crops increase the competition between the plants and in the case of establishing alfalfa it is especially detrimental if the companion crop is prone to lodging (Lanini et al. 1991). On sandy soils, companion crops can increase the risk of stand failure with increased competition for moisture (Rehm et al 1998). Nielsen et al. (1981) reported that up to 90% of the alfalfa established in Minnesota is established with oats.

The forage establishment method may differ depending on the producer's resources. If a companion crop is used, a profitable use for the companion crop, such as a livestock enterprise or a market for the crop residue is needed (Hansen and Krueger 1973). Cover cropping is not recommended under dryland conditions in the Brown soil zone of western Canada due to competition for soil moisture (Saskatchewan Agriculture 1987). Establishment with herbicides to reduce weed infestation and improve the overall quality of the stand is recommended (Hansen and Krueger 1973). Alfalfa established without a companion crop or herbicide had 45% weeds in the first harvest, while the alfalfa established with the oat crop had less than 15% weeds (Hansen and Krueger 1973). The second year, alfalfa productivity in the above trial was not affected by the establishment methods used. Moyer et al. (1995) observed that Canadian prairie producers appear to favour the initial forage yield losses associated with companion crops over the detrimental effects of weed infestations, delayed economic returns and the potential for soil erosion when forages are seeded alone.

2.2.1.1 Seed Characteristics Relative to Topography and Seeding Equipment

Variation in seed size, morphology and seed weight requires that forage seeding equipment be adaptable to handle these seed differences plus a diversity of field topographies and soil structures. The use of semicircular seed boxes and auger agitators to properly meter out forage seed (Wiedemann and Cross 1981) are examples of the many engineering designs and technologies to improve seed placement. In dryland areas, forage establishment has been limited by the type of seeding equipment used. Often there are problems controlling the depth of seed placement as seeds are planted deeper than recommended (Lawrence and Dyck 1990). Lawrence and Dyck (1990) compared two types of furrow opener-depth control assemblies for forage seeding and found that a large-small double disk opener assembly with an adjustable rubber tire depth-gauge wheel (seeding at a depth of 2.5 cm) resulted in a superior forage crop emergence.

2.2.1.2 Seedling Emergence

The emerging seedling is dependant on the food stored in the seed until leaves develop, therefore, seeding depth is very important since many forage seeds are small and do not contain adequate food if planted too deep (Smoliak 1992). Alsike clover (*Trifolium hydridum* L.), birdsfoot trefoil (*Lotus corniculatus* L.) and timothy (*Phleum pratense* L.) have very small seeds and should not be seeded deeper than 1 cm, whereas, larger forage seeds can be seeded to a depth of 2 cm (Smoliak 1992). Seed quality is also important for the germination, emergence and subsequent establishment of cultivated forages (Hall and Wiesner 1990). Therefore, only certified forage seed should be purchased from reputable companies.

Soil temperature, season of seeding (spring vs. fall) and the amount of soil moisture affect the time required for the seedling to emerge (Hart and Dean 1986). In an establishment trial in the Central Great Plains region, Hart and Dean (1986) found that spring seeding of cool-season grasses and legumes produced a better forage stand than fall seeding.

2.2.1.3 Seedling Vigour

Upon emergence, competition from surrounding plants is the single most detrimental factor faced by seedlings. For example, the earlier emergence of grass seedlings prior to alfalfa can reduce the survival of the alfalfa seedlings (Bula and Massengale 1972 in Schellenberg et al. 1994a).

Drought conditions, weed and disease infestations can severely challenge forage seedlings. The severity of seedling damage is partially dependant on the seedling species. Waddington and Bittman (1983) found that during drought conditions (lack of precipitation, elevated temperatures and high evaporation rates), alfalfa seedlings were more susceptible to drought than smooth bromegrass seedlings. When each forage species was planted alone (no companion crop during establishment) there were more weeds in the alfalfa stands than in the bromegrass stands. Weed encroachment will over- shadow the fragile seedlings, reducing photosynthesis and retarding root growth making the plants more susceptible to drought conditions (Cooper 1967).

2.2.2 Forage Species Blends for the 'Ideal Pasture'

The ideal pasture/grazing system would be one in which high quality forage production matched the demand of grazing animals. An 'ideal pasture' may be characterised by the objectives set up for improved pastures. Reid and Jung (1982) stated that these objectives include: increasing forage DM production ha^{-1}, extending the period of high-forage-quality grazing, and providing uniform and adequate nutrition for the animals throughout the grazing season. Corbett (1987) stated that an 'ideal' temperate pasture would be one that is green, leafy and leguminous. This 'ideal' pasture would be preferentially eaten by grazing animals in larger amounts, compared to pastures that are composed of more dead and stemy plant material. It has been demonstrated that green foliage is more digestible than brown matured foliage and that legumes in general, tend to mature at a slower rate than grasses (Corbett 1987). Regrettably, the ideal 'green leafy and leguminous' pasture will often only last for a short period of time and is dependent on the climatic constraints (Corbett 1987). There is generally a low level of structural carbohydrates in plants that are highly digestible, therefore, they may be very susceptible to leaching, decay, desiccation, shatter (leaf loss) and wind loss. As well, if plants are mainly vegetative then their seed production may be low and propagation difficult (Corbett 1987).

Currently, the most popular forage mixtures are a combination of legume and grass species. Grasses and legumes are usually selected on the basis of their survival and seasonal DM production rather than on their nutritional qualities (Cooper 1973). To improve pastures or to develop an 'ideal' pasture a major problem is to alleviate the marked seasonality of pasture production and the resulting effects on animal productivity. This is especially true of the short growing season in the Northern Great Plains which is about 150 growing days in length (Reid and Jung 1982). Animal gains per head and pasture carrying capacity decline rapidly in late summer, but management systems based on the complementary use of cool season and warm season grasses and legumes have been developed (Matches et al. 1975).

Grazing of legume pastures has resulted in excellent animal performance, due to higher intakes, greater feed efficiency and a more efficient use of the forage nitrogen content (Christian 1987). Ulyatt (1981) reported that the live-weight gain of calves and sheep and dairy cow milk production are improved by use of legume pastures. In a similar fashion, the animal production advantages attributed to a grass-legume mix include increased rates of live-weight gain, increased DMI and increased feed efficiency compared to grass-only pastures (Thomson 1979).

Legumes grown with cool-season grasses can supply symbiotic N to the intermixed grasses (Farnham and George 1993) and can increase total forage yields (Nichols and Johnson 1969). In cultivated pastures, alfalfa (*Medicago sativa* L.) is commonly grown with smooth bromegrass (*Bromus inermis* Leyss.) and more recently with meadow bromegrass (*Bromus biebersteinii* Roem & Schult.) (Pearen and Baron 1996; Allen and Entz 1994; Smoliak 1992). However, there are many different forage combinations possible. The mixture of forage species used will depend on the field topography and the different micro-environments present. In a given field, there may be areas of low fertility (hill tops), to areas that are affected by salinity or excess moisture (valleys or slough areas). Within each zone an appropriate forage species in the mixture will grow to maintain forage productivity. For example, reed canarygrass (*Phlaris arundinacea* L.) does well in water-logged soils. In contrast crested wheatgrass (*Agropyron desertorum*, Fisch. ex [Link] Schult.) is a dryland forage that does not require a lot of moisture to be productive and is noted for its early spring growth. Similarly, Russian wild ryegrass (*Psathrostachys juncea* [Fisch.] Nevski.) will grow early in the spring and has a resurgence of growth in the fall to help extend the grazing season; it also maintains its quality well (Hart et al. 1988b).

The following is a list of commonly grown grass and legume species from a variety of studies conducted in the Northern Great Plains. Grass species include meadow bromegrass, smooth bromegrass, crested wheatgrass, reed canary grass, orchard grass (*Dactylis glomerata* L.), timothy (*Phleum pratense* L.), Russian wildrye grass, Altai wildrye grass (*Leymus angustus* [Trin.] Pilger), intermediate wheatgrass (*Elytrigia intermedia* [Host] Nevski), meadow foxtail (*Alopecurus pratensis* L.), Kentucky bluegrass (*Poa pratensis* L.) creeping red fescue (*Festuca rubra* L.). Legume species include alfalfa, white clover (*Trifolium repens* L.), red clover (*Trifolium pratense* L.), alsike clover (*Trifolium hybridum* L.), birdsfoot trefoil (*Lotus corniculatus* L.), cicer milkvetch (*Astragalus cicer* L.), sainfoin (*Onobrychis viciifolia* Scop.) and sweet clover (white flowers: *Melililotus alba* Desr.; yellow flowers: *Melililotus officinalis* L.).

Legume and grass forage species have been evaluated on the basis of re-growth potential, legume compatibility (with grass species), winter hardiness, ease of establishment, drought tolerance, flood tolerance, persistence and bloat incidence (legume species only). Each of the forage species have certain characteristics that stand out. Russian wild ryegrass is one of the most aggressively competitive grasses (Kilcher 1982), is tolerant of drought, saline soils and grazing, and is suitable for use as a fall pasture. However it is harder to establish compared to other grasses. Red clover and birdsfoot trefoil are both suitable for acidic soils; birdsfoot trefoil is a non-bloating legume, but it has poor seedling vigour (Sheaffer et al. 1993; Fairey 1991). Cicer milkvetch, which is non-bloating, is especially tolerant of drought conditions but has poor seedling vigour and does not compete well with other plants (Rehm 1998). The establishment vigour of alsike clover and its ability to enhance the growth of companion grasses is considerably lower than that of alfalfa (Fairey 1991). Crested wheatgrass is early growing and is very suitable for spring grazing, is drought resistant and grazing tolerant. Special characteristics of meadow foxtail include its ability to grow well in peat soils and in areas with a good moisture supply, and its early season growth (Tingle and van Adrichem 1974). Refer to Table 1 for an overview of the characteristics of the different forages.

2.2.2.1 Characteristics of Successful Pasture Species Profiles

To be classified as a successful pasture plant it is essential that the species be able to establish maximum ground cover as quickly as possible and survive adverse conditions including intensive grazing and mismanagement under a wide variety of environments. Without these characteristics, exceptional productivity under ideal conditions and high digestibilities are of little value (Christian 1987). However, many factors that allow plants to survive are negatively correlated to those factors that enhance nutritive value (Christian 1987). Hodgson (1981) indicated that plants that have a recumbent growth habit and those with large numbers of small tillers restrict damage to the meristematic tissues during grazing; but an upright growth promotes more efficient use of sunlight and facilitates animal intake. Stems of low fibre content and leaves generally have high digestibilities but are prone to decomposition and decay. Pasture plants need to be palatable to the grazing animals but not in excess of the other species grown in the pasture or it will not be able to survive overgrazing and die out of in the sward (Christian 1987).

A three year study conducted by McCaughey and Simons (1996) established that environmental conditions (soil type, yearly precipitation and weather) and pasture

Table 1. **Forage characteristics of grass and legume species**

Grasses	Legumes
Tolerant of Flooding	
Reed canary grass (*Phalaris arundinacea* L.) Meadow foxtail (*Alopecurus pratensis* L.) Creeping foxtail (*Alopecurus arundinaceus* Poir) Timothy (*Phleum pratense* L.) Meadow fescue (*Festuca elatior* L.)	Alsike clover (*Trifolium hydridum* L.) Birdsfoot trefoil (*Lotus corniculatus* L.)
Tolerant of Drought Conditions	
Crested wheatgrass (*Agropyron desertorum* (Fisch. Ex Link) Schult) Russian wild ryegrass (*Pasthyrotstachys juncea* (Fisch.) Nevski) Altai wild ryegrass (*Leymus angustus* Trin Pilger)	Alfalfa (*Medicago sativa* L.) Sweet clover (*Melilotus officinalis* L.) White clover (*Trifolium repens* L.) Cicer milkvetch (*Astragalus cicer* L.)
Tolerant of Saline Soils	
Tall wheatgrass (*Agropyron elongatum* (Host) Beauv.) Slender wheatgrass (*Agropyron trachycaulum* (Link) Malte) Russian wild ryegrass Altai wild ryegrass Creeping foxtail	Alfalfa Sweet clover
Tolerant of Acid Soils	
Timothy Creeping red fescue (*Festuca rubra* L.) Meadow foxtail Tall fescue (*Festuca aruninacea* Schreb.)	Red clover (*Trifolium pratense* L.)
Grazing Tolerant	
Kentucky bluegrass (*Poa pratensis* L.) Creeping red fescue Russian wild ryegrass Crested wheatgrass Altai wild ryegrass Meadow Bromegrass (*Bromus biebersteinii* Roem. and Schult.) Meadow fescue	Birdsfoot trefoil Sweet clover White clover Alfalfa

Table 1. Forage characteristics of grass and legume species

Grasses	Legumes
Excellent* to Good Ease of Establishment	
Crested wheatgrass*	Alfalfa
Tall fescue*	Alsike clover
Creeping red fescue	Sweet clover
Kentucky bluegrass	
Meadow bromegrass	
Orchard grass (*Dactylis glomerata* L.)	
Smooth bromegrass (*Bromus inermis* Leyss.)	
Timothy	
Fair to Poor† Regrowth Potential	
Kentucky bluegrass	Birdsfoot trefoil
Meadow foxtail	Sweet clover
Smooth bromegrass	Alsike clover†
Timothy	
Crested wheatgrass†	
Excellent* to Good Legume Compatibility	
Meadow bromegrass*	Not applicable
Timothy*	
Crested wheatgrass	
Orchard grass	
Smooth bromegrass	
Tall fescue	
Non-bloating Legumes	
Not applicable	Birdsfoot trefoil
	Sainfoin (*Onobrychis viciaefolia* Scop.)
	Cicer milkvetch
Fair to Poor† Persistence	
Orchard grass	Alsike clover†
Tall fescue	Sweet clover†
Timothy	Sainfoin†
Limited Winter Hardiness	
Orchard grass	Alsike clover
Tall fescue	White clover
	Red clover

(Adapted from Smoliak 1992; Joosse et al. 1996) management (harvest management and fertilization application) accounted for approximately 42% of the forage yield variations and forage species only accounted for 0.6% of the total variation. With this in mind, there is a greater emphasis on the management of semi-arid pastures than on the species grown for pasture production.

2.2.3 Extended Grazing

The grazing season can be extended through the use of crop residues such as corn stover and sowing annual grasses (Reid and Jung 1982). Annual cereal crops such as oats, barley, fall rye, winter wheat, winter triticale and Italian ryegrass can all be used to extend the grazing season for cow-calf and backgrounding operations (McCartney 1998). These annuals may also be used to supplement perennial pastures or to increase the carrying capacity. Spring seeding of winter cereals will only produce vegetative material in the year of seeding because the crop has not gone through a cold period (vernalization) which promotes seed production (McCartney 1998).

Annual forages may allow for a more stable forage supply during drought conditions. They can add value to the perennial forage-livestock system when used appropriately to aid in weed control, decrease winter feed costs and improve the efficiency of land use (Baron and Entz 2000). Annuals can be used to complement perennials and increase the flexibility for land use, labor and time (Baron and Entz 2000).

Swath grazing of late seeded cereal crops such as oats and barley have also been used to extend the grazing season for dry cows well into the winter months (early January). Annual cereals are seeded in late June and then swathed at the soft dough stage in mid-September, just before or right after the first killing frost (McCartney 1998).

2.2.3.1 Forage Characteristics Versus Pasture Characteristics

Productivity of grazing animals is mainly limited by the seasonality of pasture production within and between years (Christian 1987). Objectives of pasture research should include: minimizing the effect of climatic variations on available feed and feed requirements; facilitating a reasonable and stable farm income; and avoiding frequent and often costly changes in livestock numbers (Christian 1987). Increased forage production will have a positive outcome if pasture quality is improved; grazing animals may experience metabolic disease, low dry matter intake and insufficiencies in protein and trace element intake when pasture quality is low (Christian 1987). Grazing animal productivity and pasture management may be improved or stabilized by the incorporation a legume into grass-based pastures, fertilization or a combination of theses strategies.

2.3 Alfalfa Characteristics that Complement an 'Ideal Pasture'

Alfalfa is one of the most energy efficient crops grown, it provides an important source of protein. In temperate climates, alfalfa has the potential to yield up to two tonnes of protein per hectare (Barnes et al. 1988). The merits of alfalfa include the ability to increase animal performance, elevate pasture yield and crude protein content; improve palatability and digestibility (Popp et al. 2000; Van Keuren and Matches 1988).

2.3.1 Forage Quality and Productivity

Cultivation of alfalfa has decreased the need for producers to purchase feed supplements for their livestock and has decreased the potential of N and P accumulation in the soil (Cherney et al. 1994). Alfalfa is a very productive, nutritious, nitrogen-fixing legume that is often referred to as the 'Queen of the forages'. Alfalfa also has the ability to adapt to a variety of climate and soil conditions (Van Keuren and Matches 1988). However, cool growing seasons of about 110 d, harsh winters and plant competition often reduce alfalfa persistence and yield (Pearen et al. 1995). The inclusion of alfalfa can help to increase forage production in the semi-arid regions of the Northern Great Plains, however, the proportion of alfalfa in the stand can decrease due to drought, overgrazing and episodic winter kill (Schellenberg et al. 1994a).

Drought conditions during alfalfa's pre-flowering stage results in a reduced shoot length, increased leaf-to-stem ratio and delayed maturity (Halim et al. 1989). However, if the drought occurs after the stems are fully elongated (reproductive stage), the leaf-to-stem ratio is reduced due to substantial leaf death and accelerated plant maturation (Carter and Sheaffer 1983, Halim et al. 1989). In general, alfalfa will decrease shoot length, leaf area and its shoot-to-root ratio when it is under water stress (Halim et al. 1989; Brown and Tanner 1983).

The use of alfalfa in legume-grass mixtures can result in a substantial increase in productivity. Berdahl et al. (2001) found that with no supplemental N, the total yield for a two-cut alfalfa-grass mixture, averaged over two years, was 223% greater than the grass mono-cultures. Based on a number of studies, the average productivity of alfalfa-bromegrass pastures is 4,102 kg DM ha^{-1} in the Northern Great Plains (Bittman et al. 1991; Walley et al. 1996; Berdahl et al, 2001; Nuttall et al. 1980; Holt and Zentner 1985). Of these studies, the highest alfalfa-bromegrass yield was, 10,500 kg DM ha^{-1}, when the stands were fertilized (44 and 436 kg ha^{-1} of P and K_2O, respectively) and irrigated to field capacity (Walley et al. 1996). The lowest production was 1,020 kg DM ha^{-1}, without fertilization and sown on a grey-wooded Luvisolic loam soil (Bittman et al. 1991). When the pastures were fertilized

(17.7 and 82.3 kg ha^{-1} of N and P) in that study the maximum productivity was 3,310 kg DM ha^{-1}, 3.2 times the lowest production level (30% alfalfa in the unfertilized treatment and 44 % in the fertilized pastures, respectively).

2.3.1.1 Meeting the Requirements of the Lactating Beef Cow and Growing Calf

The productivity of grazing animals is dependent on the daily intake of nutrients from the pasture (Hodgson et al. 1994). Alfalfa is a high quality forage that is very digestible. With improved forage digestibility there is an increase in forage consumption. Higher voluntary intake of alfalfa compared to grasses, leads to an increased rate of digestion and passage of the neutral detergent fibre fraction (Poppi et al. 1981).

The nutrient requirements of beef cattle are outlined in the National Research Council (NRC) (1996) publication. A brief summary of the beef cow and calf requirements from this source can be found in Table 2. Alfalfa is a high quality forage that can easily meet all the requirements of the beef cow. If the cow's nutrient requirements are met, then it is easier for her to produce milk for her calf and meet the calf's requirements. For example, NRC (1996) estimates that in the fifth month after calving (represented as July in the Table 2) the cow's DMI is 12.0 kg d^{-1}. If the cow consumed only fresh late vegetative alfalfa, she would consume 18.12 Mcal NE_m, 2.66 kg CP, 0.21 kg Ca and 0.04 kg P, all of which exceed the cow's requirements.

2.3.2 Grazing Tolerance and Persistence

Grazing tolerance is the ability of a plant to withstand defoliation from different livestock species. Frequent defoliation by intensive grazing and competition from grasses planted in the mixture can reduce alfalfa's longevity (Pearen and Baron 1996) or persistence.

Table 2. Diet nutrient density requirements of beef cows and calves, and the nutrient composition of alfalfa and *bromus* species

	May	June	Jul.	Aug.	Sept.	Oct.	Grazing Season Average
Requirements for a 544 kg beef cow, calving in February, peak milk production of 9 kg							
NE_m, Mcal kg^{-1} DM	1.26	1.21	1.17	1.12	0.82	0.84	1.07
CP, % DM	9.92	9.25	8.54	7.92	5.99	6.18	7.97
Ca, % DM	0.29	0.26	0.24	0.22	0.15	0.15	0.22
P, % DM	0.19	0.18	0.17	0.15	0.12	0.12	0.16
DMI, kg d^{-1}	12.9	12.4	12.0	11.7	11.0	10.9	11.8
Growing Calf Requirements	NEm, Mcal kg^{-1}	NEg, Mcal kg^{-1}	ADG, kg d^{-1}	CP, % DM	Ca, % DM	P, % DM	DMI, kg d^{-1}
250 kg Calf	1.35	0.77	0.80	9.80	0.36	0.19	7.3
Forage Nutrient Profiles							
Forages	NE_m, Mcal kg^{-1}	NE_g, Mcal kg^{-1}	CP, % DM	Ca, % DM	P, % DM	NDF, %	
Alfalfa, fresh late vegetative[1]	1.51	0.92	22.2	1.71	0.3	30.9	
Alfalfa, fresh full bloom[1]	0.97	0.42	19.3	1.19	0.26	38.6	
Alfalfa average[1]	1.29	0.71	20.1	1.4	0.27	38.9	
Bromegrass, fresh immature[2]	1.57	0.97	17.1	0.59	0.37	57.7	
Bromegrass hay, pre-bloom, sun-cured[2]	1.28	0.71	10.5	0.32	0.37	68	
Bromegrass hay, mature, sun-cured[2]	1.02	0.47	6.6	0.43	0.09	70.5	
Bromegrass Average[2]	1.29	0.72	11.4	0.45	0.28	65.4	

[1]Based on NRC Nutrient Requirements of Beef Cattle, 1996

[2]Bromegrass (*Bromus* spp) nutrient composition from the International Feedstuffs Institute, College of Agriculture, Utah State University, Feed Composition Data Bank, National Library, USDA, Beltsville, MD.

Persistence is the survival of plant material even though it has been challenged by specific stresses in the environment (Smith and Kretschmer 1989). The persistence of alfalfa in pastures depends on its response to grazing, the effect of grazing on the other forage species in the stand and overall competitive relationships between all the plants in the stand (Curll and Jones 1989). Other factors that affect the persistence or the longevity of alfalfa in a stand include drought, diseases and pest infestations. Winter droughts are more stressful to alfalfa since there is no snow to insulate the plant's crown and winter kill becomes more evident (Bolton 1962).

The physiological and morphological survival responses of alfalfa to grazing have been reviewed in the Ph.D. thesis by Singh (2000) in which maintenance of root carbohydrate reserves, maintenance of residual leaf area, decumbent growth habits, stem density, crown characteristics, basal ground cover are considered. These important characteristics also reduce the accessibility of the grazing animal to alfalfa's growing points (meristematic tissues in the crowns). Morphologically, the characteristics include deep-set crowns, plants with decumbent growth habits and creeping rooted varieties (Smith et al. 2000).

The persistence of alfalfa can also be reduced by disease infestation. The main diseases that affect alfalfa in the western provinces of Canada include bacterial and verticillium wilt which occur most frequently under irrigation, snow mold, winter crown rot and crown root rot (*Fusarium* and *Rhizoctonia* spp.) (Goplen et al. 1983). Insects can have a negative impact on alfalfa. These include the pea aphid, alfalfa weevil, but the most widespread insect pests are grasshoppers (Goplen et al. 1983). There are also much bigger pests, such as the pocket gopher which feeds on both the above and below ground parts of alfalfa. Damage to the root system is the most detrimental to plant survival (Townsend 1982).

2.3.3 Bloat

The main reason that producers resist using alfalfa in grazing systems is that it can cause frothy bloat and result in animal losses on pasture (Coulman et al. 2000). Bloat is a digestive problem characterized by an atypical distension of the abdomen (Berg et al. 2000; Popp et al. 2000). Under normal digestion, gas produced by rumen fermentation is released by the process of eructation. When conditions are favorable for bloat, a stable foam is produced that prevents cattle from eructating and gases accumulate in the rumen (Berg et al. 2000). The gas pressure in the rumen negatively affects the circulatory and respiratory systems and, if the animal is not treated, it may die.

Contrary to belief, alfalfa is safe to graze if proper grazing practices are followed. Majak et al. (1995) outlined the guidelines for the reduction of bloat when grazing legume-based pastures. Coulman et al. (2000) reported on the development of a bloat-reduced alfalfa cultivar in which the development of AC Grazeland B^r was reviewed. As well, Berg et al. (2000) reviewed the use of low initial rate of digestion (LIRD) alfalfa to reduce the incidence of bloat in grazing beef cattle. However, the effectiveness of these "bloat-reduced" alfalfa varieties varies with grazing management practices, plant maturity and the season of use (Berg et al. 2000).

The use of low-bloating alfalfa cultivars does not allow producers to become lax in their management practices; currently there is no method to guarantee zero incidence of pasture bloat. However, a combination of methods to reduce the risk or incidence of bloat is recommended. These may include use of low-bloating alfalfa cultivars, effective grazing management practices, alfalfa-grass or alfalfa-non-bloating legume mixtures and bloat controlling products such as pluronic detergents and Rumensin (Berg et al. 2000). Plant breeders have the potential to make alfalfa non-bloating but this would greatly compromise digestibility or cause the addition of anti-nutritional factors (Berg et al. 2000). The non-bloating legumes contain condensed tannins and McMahon et al. (2000) have reviewed the effect of condensed tannins on ruminal fermentation and bloat in grazing cattle. There is the potential to modify alfalfa to incorporate condensed tannins to reduce the incidence of bloat (McMahon et al. 2000).

2.3.4 Alfalfa in Mixed Species Pastures

Climate, environment and management conditions determine which grass specie is best grown with alfalfa in a mixed pasture. Planting grass with alfalfa can help prevent bloat, reduce thinning of the forage stand, increase soil coverage and help protect alfalfa from winter kill.

There is competition between legume and grass species when planted together, as they compete for light, water and nutrients for growth (Donald 1963). Seasonal growth rates, tillering characteristics and the number of times the forage is cut or grazed will have an effect on the competition of legume-grass mixtures (Haynes 1980). In arid areas, it is important to select a hardy alfalfa cultivar that exhibits a significant amount of fall dormancy and spreading growth characteristics. The legume should be planted with a grass species that is not overly competitive (Kilcher and Heinrichs 1966a; Dubbs 1971). Berdahl et al. (2001) found that alfalfa-intermediate wheatgrass, alfalfa-crested wheatgrass and alfalfa-smooth bromegrass mixtures are suited for dryland hay production in most subhumid to semiarid areas of the

Northern Great Plains. These mixtures can be grazed with some success, but mixtures with a less invasive grass species like meadow bromegrass may be better as it is not as competitive as smooth bromegrass and has better regrowth potential (Pearen and Baron 1996).

Fairey (1991) found that smooth bromegrass, meadow bromegrass, timothy and meadow foxtail were more productive when grown with alfalfa than when grown individually, or when grown with either alsike clover or birdsfoot trefoil. Alfalfa grown as the companion legume increased the yield of meadow bromegrass and meadow foxtail by 1.5 times, smooth bromegrass by 3.1 times and timothy by 4.4 times compared to grasses grown alone or grown with the other legumes (Fairey 1991). Elliott et al. (1961) found that grass-legume mixtures produced about twice as much forage as unfertilized grasses grown alone in Northern Alberta. As well, it was indicated that these northern pastures provided adequate grazing at a stocking rate of about 1.5 animal units (AU) ha^{-1} for a 100 to 120 day growing season (Elliott 1969).

Legumes maintain a higher proportion of leaf to stem ratio with advancing maturity compared with grass species and legume leaves are more digestible than grass leaves of the same stage of maturity (Hodgson 1990). If environmental conditions are favorable (adequate moisture throughout the growing season) alfalfa has the ability to maintain active growth for a longer period of time (Bell 1993). Alfalfa will constantly produce new shoots and leaves which will enhance the nutritive quality of legume-grass pastures.

2.3.4.1 Effect of Nitrogen Fixation on Grass Species

To maximize forage quality and yield when inorganic N fertilizer is not used, the most appropriate legume to seed in a binary mixture (legume-grass pasture) is alfalfa (Fairey 1991).

Alfalfa can fix N and any surplus N can potentially be transferred to grass species. However, the N cycle is not that simple, it is a dynamic system in which there is a bi-directional flow (Tomm et al. 1995; Tomm et al. 1994). Soil fertility level, plant litter, harvest loss, nodule fixation of N_2 and the decomposition of all plant parts are factors in the N cycle. Grass species provide a limited amount of N in litter loss and root decomposition, but this is readily used for growth. Depending on the competition from the alfalfa plants, grasses can receive N fixed by a legume for growth.

In the northern region of Alberta (Peace River region, black clay loam soil, 55°12'N, 119° 23'W) Rice and Hoyt (1980) found that, in pure stands, alfalfa fixed more atmospheric N than either alsike clover or birdsfoot trefoil (171 vs. 152 and 145 kg ha^{-1} N for alfalfa, alsike clover and birdsfoot trefoil, respectively).

2.4 Meadow Bromegrass Characteristics that Complement an 'Ideal Pasture'

In 1949, meadow bromegrass was introduced to North America from Turkey (Smoliak 1992). Meadow bromegrass is a long-lived perennial bunchgrass that grows well under drought conditions and can survive cold North American winters (Malik 1991). Meadow bromegrass is harder to establish than smooth bromegrass. It also has the potential for late summer and fall regrowth to improve and extend the grazing season (Knowles and Sonmor 1985).

2.4.1 Forage Quality and Productivity

As with most forages, meadow bromegrass decreases in quality as the growing season progresses and as plants are allowed to mature. However, meadow bromegrass is very palatable and in a six year plot study conducted in Montana (harvested once at 10% bloom) the average dry matter digestibility (DMD) of meadow bromegrass was 63% (White and Wight 1984). Dry matter digestibility is inversely proportional to forage yield. As forage yield increased by 1000 kg ha^{-1}, the DMD decrease averaged 1.7 percentage units for meadow bromegrass (White and Wight 1984).

Meadow bromegrass yield data is presented in Table 3. Productivity of meadow bromegrass was improved 2.2 times by fertilizing with 112 kg ha^{-1} N in the brown soil zone of Saskatchewan (Table 3, Knowles 1987). With as little as 45 kg ha^{-1} N, the forage yield was doubled compared to the unfertilized treatments (the annual precipitation values were similar in 1987 and 1989) (Malik 1991). However, regardless of the amount of fertilizer used or of soil fertility levels, meadow bromegrass productivity will drop off significantly if moisture levels are low as demonstrated by White and Wight (1984). When precipitation was 60 % of the long-term average, forage yield was 6 times lower than for an average moisture year (Table 3).

2.4.1.1 Meeting the Requirements of Lactating Beef Cows and the Growing Calf

As previously stated, cow and calf nutrient requirements are shown in Table 2. If the same cow as described in the alfalfa example were to consume fresh immature bromegrass (12.9 kg DMI) she would easily meet all her nutritional requirements since the immature bromegrass has a similar nutrient profile as alfalfa. Even late in the grazing season, during September with a forage quality comparable to the mature bromegrass hay, the cow's requirements are met, but with little room to spare. It is estimated that seven months after calving the cow will consume 11 kg DM d^{-1}, and will require 9.02 Mcal NE_m, 0.66 kg CP, 0.02 kg Ca, and 0.01 kg P. The mature bromegrass supplies 11.2 Mcal NE_m, 0.73 kg CP,

Table 3. Meadow Bromegrass yield (kg DM ha^{-1}), fertilization rate (kg ha^{-1}) and growing season and/or annual precipitation (mm)

Reference	Year(s)	Location/Soil Type	Fertilization	Precipitation	Yield	Comments
Knowles 1987	1981-1983	Saskatoon, SK Dark Brown Chernozem	0	267 / 381	838	Growing season precipitation measured from April to August (267 and 381 mm, respectively)
	1984	Saskatoon, SK Dark Brown Chernozem	112	138 / 310	1850	Fertilizer applied in October, 1983
Malik 1991	1986	Melfort, SK Silty clay loam (fine-silty, mixed Typic Croyoboroll)	8 N, 18 P	264 / 391	2208	Growing season precipitation measured from May to September (264 and 391 mm, respectively). Seed bed preparation occurred in 1985, with broadcasting and discing of fertilizers. 'Regar' meadow bromegrass sown with a precision seed drill (8 kg ha^{-1} at a depth of 1.3 cm).
	1987		45 N, 11 P	221 / 348	4796	Fertilizer application to all the experimental plots.
	1988		0	198 / 315	2796	
	1989		0	259 / 378	2342	
White and Wight 1984	1975-1981	Sidney, Montana, sandy range, Fine-loamy, mixed Typyic Argiborolls	Tilled range, provided an estimated 135 to 180 kg N ha^{-1} in 1975 and 1976	346	200 - 1200	No inorganic fertilizer used. The lowest yield of meadow bromegrass was in 1980 (200 kg DM ha^{-1}) when they received 60% less annual precipitation than the 30 year average; highest yield occurred in the year after establishment (1200 kg DM ha^{-1}).

0.05 Ca and 0.01 kg P, thereby meeting the estimated daily requirements.

If the calf was totally reliant on bromegrass at seven months of age (in September) there may be a deficiency in protein. A calf gaining 0.8 kg d^{-1} requires about 0.71 kg of CP and the mature bromegrass only provides 0.48 kg of CP (DMI is 7.3 kg d^{-1} for a 250 kg calf). However, if the calf has not been weaned and the cow is still producing some milk, the calf's protein needs may still be met. Overall, meadow bromegrass has a good nutrient profile, especially early in the grazing season. Nutritional deficiencies associated with its use can be avoided through animal and grazing management.

2.4.2 Grazing Tolerance

Forages that are suitable for grazing must have certain characteristics, these include: rapid regrowth, ability to withstand trampling, low growing points and adequate longevity (Smoliak 1992). In grass productivity trials conducted by Knowles (1987), meadow bromegrass and western wheat grass performed the best out of 9 grasses when multiple clips (2 to 3 clips per year) where performed to mimic grazing.

Meadow bromegrass starts to grow early in the spring but should not be grazed before it reaches a height of 20 to 30 cm (Smoliak 1992). It has rapid tiller development or regrowth rate (Van Esbroeck et al. 1995), it partitions DM into its leaf blades, for each unit of blade extension it produced 50% more leaf weight than smooth bromegrass (Van Esbroeck et al. 1995). This characteristic of high specific leaf weight seems to be advantageous under short growing seasons and as such it has been proposed that specific leaf weight has promise as a selection standard for high regrowth potential in *Bromus* species (Van Esbroeck et al. 1995).

2.4.2.1 Regrowth and Growing Points

Meadow bromegrass exhibits better regrowth and has a more uniform growth pattern compared to smooth bromegrass (Van Esbroeck et al. 1995; McCaughey and Simons 1996), which makes it more adaptive and in some instances more productive than smooth bromegrass with rotational stocking (Pearen and Baron 1996). Smooth bromegrass tillers elongate during regrowth and growing points may be removed under heavy grazing or defoliation (Van Esbroeck et al. 1995). Under these conditions smooth bromegrass plants have to grow from buds initiated below the ground (Carlson and Newall 1985) which in turn increases the amount of time needed for tiller development. Meadow bromegrass regrows from many existing tillers (Van Esbroeck et al. 1995). Pearen and Baron (1996) found that the superior regrowth of meadow bromegrass mixtures was due to higher tiller density, and that growth from points below the cutting or grazing height ensures that regrowth is less sensitive to frequent defoliation.

2.4.2.2 Resistence to Trampling

In general, legumes are less resistant to treading than are grass species (Matches 1992). Meadow bromegrass has low growing points to avoid defoliation and the plant sends up many tillers in the spring which elongate quickly following cutting or grazing (Knowles and Sonmor 1985). The creeping root system and the abundant basal leaves (Knowles 1990) help to protect the stand from trampling damage.

2.4.2.3 Effect of Drought and Heat Stress

Under severe drought conditions, meadow bromegrass goes dormant earlier than smooth bromegrass (Knowles 1987), however, meadow brome recovers quickly after precipitation is received. During the summer months when temperatures are at their highest, the pasture plants tend to have higher fiber levels and lower protein levels, the reverse occurs when temperatures are cool (Marshall et al. 1998a). Under varying environmental conditions meadow bromegrass exhibits good longevity and can control weeds effectively (Knowles 1987).

2.4.3 Meadow Bromegrass in Mixed Pastures

Meadow bromegrass has shorter rhizomes than smooth bromegrass, therefore, it is considered to be less invasive (Pearen and Baron 1996) and would complement alfalfa well. In a study by Pearen et al. (1995), it was found that when alfalfa was grown with meadow bromegrass instead of smooth bromegrass, the alfalfa growth was 97 to 197% higher. Alfalfa productivity was the same when grown in binary mixtures with smooth bromegrass or meadow bromegrass, even though the meadow bromegrass was higher yielding (Pearen and Baron 1996). This clearly indicates how well meadow bromegrass complements alfalfa. It is possible that the uniform seasonal yield of meadow bromegrass-alfalfa pastures could improve cattle productivity during summer and fall when grazing conditions are often poor in central Alberta (Pearen and Baron 1996). Over time, forage yields will decrease and good fertility management is needed for all pastures to remain viable.

2.4.3.1 Tillering Characteristics

Meadow bromegrass grows from many tillers close to the ground which helps the plant survive defoliation (Pearen and Baron 1996). The tillers regrow rapidly after they have been cut or grazed, therefore, seasonal growth of meadow bromegrass is more uniform than smooth bromegrass (Knowles and Sonmor 1985). A pasture of meadow bromegrass should be allowed to regrow for a three to four week period after defoliation to maintain a maximum productivity and longevity of the stand (Smoliak 1992).

2.5 Fertilization of Cultivated Pastures

Fairey (1991) grew smooth bromegrass, meadow bromegrass, timothy and meadow foxtail individually or in combination with alfalfa, alsike clover or birdsfoot trefoil and found that when these pastures were cut more than twice per year, there was a substantial decrease in the productivity of smooth bromegrass, followed by meadow bromegrass, timothy while meadow foxtail was virtually unaffected. A similar effect was observed at Brandon in grass plots (McCaughey and Simons 1996). The yield of smooth bromegrass was almost halved. Without fertilization, alfalfa proved to be the most suitable companion legume to enhance the performance of grasses (Fairey 1991). When N was not limiting (fertilized treatments) the grasses responded to cutting management or cutting frequency. With N fertilizer and two cuts per year, the bromegrass stands (yields for smooth bromegrass-legume mixes ranged from 2.8 to 3.5 t ha^{-1}; meadow bromegrass-legume mixes ranged from 3.7 to 3.9 t ha^{-1}) were superior to the other grass-legume stands (Fairey 1991).

2.5.1 Effect of Fertility on Quality and Productivity of Legumes and Grasses

Application of moderate levels of N fertilizer on alfalfa has no effect on forage digestibility, NDF, ADF and lignin, however, CP content can be affected (Cherney et al. 1994) when high levels of inorganic N are applied. When the application of inorganic N exceeds 224 kg ha^{-1}, much of the increased N content of alfalfa is nitrate-N (NO_3-N) (Lee and Smith 1972). The high concentration of N in the alfalfa can lower the amount of energy available to ruminants by altering rumen fermentation and VFA profiles, typified by a higher molar percentage of propionate and lower total VFA production (Cherney et al. 1994). One should test the NO_3 level of forages if the protein levels are 24% or higher (Cherney et al. 1994). Most beef cattle producers would rarely fertilize with such high levels of inorganic fertilizer, however, these conditions could occur if pastures were fertilized heavily with livestock manure.

Nitrogen fertilization of grass pastures will increase the CP concentration in grass plants. In a study by White (1985b), western wheatgrass was fertilized over a 10 year period. Fertilization increased the CP yield by 0.87 kg ha^{-1} kg^{-1} N applied and increased the 10 year accumulated forage yield by 4.35 kg CP ha^{-1} kg^{-1} of N applied. The application of 100 kg N ha^{-1} increased the digestibility by 0.1 percentage units, however, that was not as significant an effect on forage quality as harvest date. As harvest date is delayed, vegetative western wheatgrass tiller digestibility decreased by 0.25 percentage units per day (White 1983). The increased CP content of fertilized western wheatgrass would only slightly improve the forage digestible energy and this would not translate into any significant increase in animal productivity (White 1985b) unless initial CP levels were deficient.

The average herbage N content of grass-legume pastures is controlled by the frequency of harvesting (Fairey 1991). In the 2 cuts per season-fertilized treatment, the N content ranged from 24 to 30 g N kg^{-1} DM (15 to 19% CP); for the 4 cuts per season-fertilized treatment the N content was 32 to 40 g N kg^{-1} DM (20 to 25% CP). Fairey (1991) concluded that herbage yield and quality were influenced more by management practises (harvest frequency and fertilization) than by the species composition of the pastures, especially when N was not limiting.

Generally, in semi-arid regions, the primary and secondary factors that influence forage production is water availability and N availability (Reuss and Innis 1977). Limited soil water may decrease forage production in the range of 30 to 50%, depending on the forage species and fertilization rate (Stout et al. 1986, 1988; Stout 1992). Another important factor to consider when evaluating the effectiveness of fertilization is the N-use efficiency, important in terms of productivity measurements and for environmental sustainability (Stout et al. 1995). For cool season grasses the N-use efficiency has a low average value of about 27 % (Staley et al. 1991).

2.5.2 Long-Term Effect on Botanical Composition of Legume-Mixed Pastures

A considerable amount of research has been carried out on the effect of fertilization of grass-legume mixtures and generally they all draw the same conclusion; N fertilization favours the grass component in the stand and the amount of legume declines over time (Nuttall et al. 1980). Ledgard and Steele (1992) found that when the level of soil mineral nitrogen is low, for example when forage stands are first established, legumes can dominate the stand for several years. Over time, however, as nitrogen builds up in the soil, the proportion of legume in the stand will decrease dramatically. The increased concentration of mineral nitrogen in the soil inhibits the legume's ability to fix nitrogen. Drought conditions can also limit nitrogen fixation by alfalfa plants and thus decrease their proportion in mixed stands (Wery et al. 1986).

2.5.3 Fertilization and Carrying Capacity or Length of Grazing Season

Fairey (1991) cut fertilized grass-only and grass-legume pastures four times during the growing season to simulate rotational stocking and recorded the following yield ranking from most productive to least productive: meadow bromegrass > timothy = meadow foxtail > smooth bromegrass. These results need to be tested in an actual grazing trial since frequent mechanical cutting/harvesting does not trample the forage in a similar manner to grazing animals which deposit wastes or selectively harvest the more preferred plants.

McCartney et al. (1999) found that on average the rotationally stocked-fertilized treatments doubled the forage DM yield over the continuously stocked-unfertilized treatments. The grazing season was extended by two weeks in rotationally stocked treatments, divided equally between the spring and fall grazing periods. Forage and cow-calf production were improved and year-to year variation was reduced.

2.5.4 Sustainability of Fixed Nitrogen Versus Commercial Application

A major environmental concern is the contamination of surface and subsurface water supplies with NO_3-N (Owens et al. 1994). An alternative to the use of inorganic fertilizers, that can easily accumulate in the soil and water sheds, is the use of legumes. When alfalfa was used to replace the inorganic N source in a study conducted in eastern Ohio, the NO_3 concentration levels decreased to 30 % of the earlier levels (Owens et al. 1994). Whereas, by using inorganic fertilizers at 224 kg ha^{-1}, over a two year period, the NO_3 concentration was above the drinking water standards (Owens et al. 1994).

The use of farmyard manure as a source of N, P, K and micronutrients versus the application of inorganic fertilizer (N and P) to grass, alfalfa and grass-legume pastures was examined by Holt and Zentner (1985). They found that manure was more likely to meet the lower P requirements of the forages than the primary N requirements.

2.5.4.1 Grass Versus Legume-grass Nitrogen Re-distribution

Under hayfield conditions, the transfer of fixed nitrogen from alfalfa to meadow bromegrass is primarily through net N mineralization of below ground plant components or likely through the decomposition of plant roots (Walley et al. 1996). The estimated amount of N that is transferred between legumes and non-legumes is variable. There are reports of N transfer between alfalfa and grasses that are from 1 to 13 kg ha^{-1} yr^{-1} during the seeding year (Ta and Faris 1987b; Heichel and Henjum 1991) and up to 53 kg ha^{-1} yr^{-1} once the forage stand has been totally established (Heichel and Henjum 1991). In an alfalfa-meadow bromegrass stand the level of N_2 fixation was 68 to 217 kg ha^{-1} yr^{-1} and the estimated amount of N that was transferred was 14 to 18 kg ha^{-1} yr^{-1} (Walley et al. 1996).

The direction of N transfer is not always from the legume to the non-legume, as indicated by Tomm et al. (1994) who found that N is transferred within species and between species. Therefore, the N cycle is more complex than legumes donating N to grasses (Tomm et al. 1995). Legumes may make a net N contribution to grasses in a mixed stand (Ta and Faris 1987a) however, the amount of N contributed depends on how much N the legume requires, thus limiting the actual transfer of N to the grass. Tomm et al. (1995) showed that although alfalfa provided a net source of N, the alfalfa plants were strongly competitive in a bi-directional system of transferred and recycled N. When considering N cycling through litter-fall and harvest losses, in some instances the amount of N provided by alfalfa equalled the amount used by the alfalfa plants and there was no net transfer to the grass (Tomm et al. 1995). However, decomposition of roots in a mixed sward remains a likely mechanism of net N transfer to grass.

The above N-transfer studies were mainly conducted under hayfield conditions and not under grazing. The nitrogen cycle can be significantly influenced by incorporating a grazing animal. Grazing livestock return nutrients to the soil in the form of excreta (dung and urine). This is a valuable recyclable source of soil nutrients because about 60-90% of the plant nutrients consumed by the animals is returned to the pasture (Haynes and Williams 1993). In a grazing study using cow-calf pairs, Chen et al. (2001) found that alfalfa-grass pastures can increase soil mineral N supply through alfalfa's ability to fix atmospheric N. In the top 7.5 cm of soil, total mineral N (mg N kg^{-1} soil) was greater for the alfalfa-grass pastures (16.9 mg N kg^{-1} soil) than for the grass-only pastures (6.4 mg N kg^{-1} soil), N content increased by 38% in the alfalfa-grass pastures (Chen et al. 2001). When the alfalfa-grass pastures were fertilized, total plant N uptake was 35 kg N ha^{-1} greater than the unfertilized alfalfa-grass pastures (Chen et al. 2001). Alfalfa in the alfalfa-grass pastures fixed an average of 74 kg N ha^{-1} yr^{-1} (Chen unpublished data). For every tonne of forage DM produced, alfalfa fixed 27 kg N (Chen unpublished data). The amount of nitrogen retained in animal gain was only 4% of the total external N inputs and 9% of the total animal N intake (Chen unpublished data). This study demonstrated that rotational grazing can evenly distribute animal excreta and enhance the uniformity of soil nutrient redistribution.

2.5.5 Economics of Fertilization

The decision to fertilize cultivated tame pastures is primarily an economical decision, but in some cases producers may fertilizer to maintain forage production on a limited land base. Generally, nitrogen fertilization of grasses is uneconomical when moisture is limiting in areas such as southwestern Saskatchewan in the Brown soils zone (Campbell et al. 1986).

This may not be the case in areas where annual precipitation is greater, therefore, appropriate application of fertilizers can increase forage yields by greater than 300% (Ukrainetz and Campbell 1988). The fertilization rate of 90 kg ha^{-1} N and 20 kg ha^{-1} P resulted in the largest economic return, with an average production increase of 74% for smooth bromegrass-alfalfa pasture, grown on a silty-clay black chernozemic soil (Nuttall et al. 1980). The range of N tested was from 0 to180 kg ha^{-1}. Increased forage production was reported for three years after fertilizer application (Nuttall et al. 1980).

Holt and Zentner (1985) compared the economic returns of using inorganic fertilizers to farmyard manure application on the heavy clay soils of Indian Head, Saskatchewan. The net returns were affected by forage type (alfalfa, smooth bromegrass and crested wheatgrass) and level of fertility. They found that stands that included alfalfa had greater returns than stands that consisted of only grasses. When averaged over fertility levels, applications of inorganic fertilizer to bromegrass and to alfalfa-bromegrass stands were more profitable than using farmyard manure on the same forage treatments ($125 CND ha^{-1} more with inorganic fertilizer compared to farmyard manure on the bromegrass only treatments and $81 ha^{-1} higher for bromegrass-alfalfa treatments). The combination of 110 kg ha^{-1} N and 24 kg ha^{-1} P produced the greatest economic returns for all the forage types (Holt and Zentner 1985). The farmyard manure was applied at the rate of 11 and 22 t ha^{-1}. When the manure value was set to zero but the application costs were maintained, this increased the net returns by $63 and $126 ha^{-1} for 11 and 22 t ha^{-1}, respectively. If the farmyard manure was valued at $10 t^{-1} of DM it was not competitive with inorganic fertilizer application on all forage treatments. The breakeven value of farmyard manure was between $0 and $6 t^{-1} of DM.

2.6 Rotational Stocking of Tame Forages

Plant response to grazing was reviewed in a series of papers in the in the Journal of Production Agriculture (Matches 1992, Coleman 1992, Russelle 1992, Hoveland 1992). The factors that influence the animal-plant interaction include, trampling, method of prehension, deposition of animal wastes, species of grazing animal, timing of grazing, frequency and severity of grazing (Matches 1992).

The two main benefits of rotational stocking are that it affects the patterns of defoliation and the composition of the plant community can be improved with planned rest periods or extended periods of rest for plant rejuvenation (Walker 1995).

2.6.1 Rotational Stocking

The definition of rotational stocking by the Forage and Grazing Terminology Committee (1992) is as follows: "A *grazing method* that utilizes recurring periods of grazing and rest among two or more paddocks in a *grazing management unit* throughout the period when grazing is allowed".

The objective of optimizing grazing management is not to maximize the yield of the pasture but maximize the intake of digestible organic matter. For this to occur, it is essential to keep the pasture in a constant condition with vigorous growth for as long as possible (Christian 1987, Boyd et al. 2001). Rotational stocking, to be effective, involves strategic and sequential movement of animals through a paddock system to optimize the use or intake of available forages (Boyd et al. 2001). The main method of achieving this is through subdivision of the pastures to regulate pasture growth (Christian 1987), in other words through the use of rotational stocking. Rotational stocking may be of most value in providing rest periods to allow the accumulation of adequate leaf area and root systems for optimum growth (Christian 1987).

In cultivated pastures in the Aspen Parkland region of Alberta, forage yield and cow-calf productivity were improved, and year- to- year variation in herbage yield and animal gains were reduced when rotational stocking was used compared to continuous stocking (McCartney et al. 1999). Hart et al. (1993) have stated that intensive rotational stocking systems are unlikely to enhance animal performance unless pasture size is reduced and the distance to water is decreased to reduce the travel distance and increase the uniformity of grazing. They found that reducing pasture size from 207 to 24 ha usually produced noticeable improvements in cow and calf gains regardless of the grazing system. Cow-calf gains were increased under the rotational stocking study because of reduced pasture size resulting in reduced distance travelled and more uniform grazing, not because of rotational stocking *per se* (Hart et al. 1993), similar conclusions have also been stated by Irving et al. (1995).

Steers grazing alfalfa-grass pastures were used to compare two grazing systems (rotational vs. continuous stocking) and two levels of stocking rates (light: 1.1 steers ha^{-1} vs. heavy: 2.2 steers ha^{-1}) (Popp et al. 1997a,b,c). Popp et al. (1997 a,c) found that forage DM yield tended to be lower when heavy stocking rates were used, but forage yield was not affected by the grazing system used. Grazing season length was shorter one year out of four for the continuous stocked pastures compared to the rotational stocked pastures ($P < 0.05$). The grazing season was shorter in two of four years ($P < 0.05$) compared to the rotational pasture systems, when continuous pastures were heavily stocked, (Popp et al. 1997c). The quality of the consumed forage was not affected by either pasture system or stocking rate (Popp et al. 1997a).

The main factor that optimized individual animal performance or gain per hectare for alfalfa-grass pastures, was stocking rate (Popp et al. 1997c). The lightly stocked pastures produced 121.8 kg steer gain ha^{-1} less than the heavily stocked pastures in the final year of the experiment (Popp et al. 1997c). The highest steer ADG (kg d^{-1}) was on the continuous-lightly stocked pastures (1.49 kg d^{-1}) and the lowest level of ADG was on the continuous-heavily stocked pastures (1.07 kg d^{-1}).

2.6.2 Productivity and Regrowth of Rotationally Stocked Legume-grass Pastures

Casler et al. (1999) stated that to maximize pasture productivity, management should be intensified. Management may be intensified by increasing the fertility of the pasture, increasing stocking rates, changing from continuous stocking to rotational stocking practices (Casler et al. 1999) and ensuring adequate pasture rest and recovery between stocking periods (Undersander et al. 2001). Poorly managed pastures are characterized by low forage production, influx of weedy species, (Shaeffer et al. 1990) and influx of less palatable forage species (Falkner and Casler 1998).

2.6.3 Effect of Rotational Stocking on Plant Persistence in Legume-grass Pastures

Since rotational stocking by definition allows for extended or appropriate rest periods, it helps encourage plant persistence when compared to pastures that are heavily stocked and continuous grazed. Walton et al. (1981) found that the persistence of alfalfa was encouraged by rotational stocking, in fact, the percentage of alfalfa in the alfalfa-smooth bromegrass-creeping red fescue pastures increased from 32 to 47% over a period of two years. Although this response may have been due to the variation in annual precipitation.

2.7 The Grazing Animal

2.7.1 Dry Matter Intake of Grazing Cow-calf Pairs

Four factors of grazing management have an effect on the cow-calf dry matter intake (DMI). The four factors are: timing of grazing, distribution of animals and how they defoliate the plants, kind and class of grazing animals and, stocking rate (Walker 1995). Stocking rate is the most important factor, if the stocking rate improper then the other three factors are unimportant. Calculating the proper stocking rate for a given pasture is hindered by the difficulty in determining carrying capacity as it varies over time (Walker 1995). The Standing Committee on Agriculture, Ruminant Subcommittee (1990) reported that DMI of cattle declines slightly when forage DM availability is less than 2 t ha^{-1} but a more rapid decline in DMI occurs when forage DM availability is below 1 t ha^{-1}. Intake of cow-calf pairs generally increases as the grazing season progresses and decreased forage availability may limit DMI late in the season at which time cow-calf intake demand is greatest (Marshall et al. 1998b).

Based on forage productivity estimates and cow gains, daily forage disappearance averaged 3.7% of the cow body weight in a study conducted by McCartney et al. (1999). If the weight of the calf was included in their calculation (during the grazing period), forage disappearance averaged 2.8% of the cow-calf weight. McCartney et al. (1999) based cow intake on clippings taken before and after grazing, which will over estimate intake values of the animal. For more accurate values of cow dry matter intake, intake can be estimated using external marker techniques (Merchen 1993).

2.7.1.1 Trampling

Trampling of pasture plants inevitably occurs when animals graze pastures. Trampling or treading of plant tissue can destroy photosynthetic material, damage growth points and can potentially increase soil compaction (Wilkins and Garwood 1986). Soil compaction can limit root growth and this can result in the reduction of water and nutrient uptake (Murphy 1987).

The extent of damage or impact placed on the soil or pasture sward is dependent on the original bulk density, moisture content and soil organic matter and sward strength (Scholefield and Hall 1985). For short duration grazing, hoof action or trampling did not have a major impact on crested wheatgrass, when 92 Angus heifers were used to graze for 2 day intervals (Balph et al. 1989). However, if grazing pressure or duration of grazing increased and if the vegetation was dry, trampling had a negative impact on the crested wheatgrass pasture. Severe trampling of this kind occurs near mineral-salt feeders and water sources where animals tend to congregate and usage is very high. Continuously grazed pastures (one herd-one pasture system) were compared to short duration mob grazing (which is one herd rapidly rotated through several paddocks of one pasture), the short duration grazing stocking rates may be up to 90 times that of the continuous stocked pasture and increased incidence of trampling occurs (Savory and Parsons 1980). Short duration stocking results in pastures being rested for extended periods of time, which contrasts the continuously stocked pastures; rest periods allow plant to recover from defoliation at similar stocking rates.

2.7.1.2 Dirty Versus Clean Forages

A cow may defecate 12 times and urinate 8 times per day, each defecation covers an area of 0.09 m^2 and each urination covers an average area of 0.28 m^2 (Peterson et al. 1956).

The approximate daily manure production (solids plus liquids) of a 544 kg beef cow is 0.05 m^3 or 47 *l* (Ensminger and Perry 1997). However, losses of manure weight can be as high as 60% when exposed to pasture conditions (Ensminger and Perry 1997). Cattle are reluctant to graze over or near dung pats, this leads to rank herbage of low quality (Wolton 1979) especially under continuously stocked pastures. Cattle may refuse to graze these areas for some time. Rotational stocking results in better distribution of manure compared to continuously stocked pastures which helps to recycle valuable nutrients back into the soil to enhance pasture productivity (Peterson and Gerrish 1995).

2.8 Grazing Animal Productivity

Many factors determine grazing animal performance. These include: forage availability, forage quality (Popp et al. 2000), stocking rate, proper grazing management, even livestock distribution, uniform forage utilization, distance to water source (Hart et al. 1993) and type of grazing system utilized (rotational versus continuous stocking) (McCartney et al. 1999). As well, the animal's production potential has an effect on overall performance on pasture (Adams et al.1993).

Although forage quality is very important in terms of animal productivity, DM availability is fundamental to maximize animal performance on alfalfa-based pastures (Popp et al. 2000). Individual animal gains (grazing steers) are maximized when forage utilization is less than 70%. Beef production can be as high as 1946 kg ha^{-1} on irrigated pastures to 107 kg ha^{-1} on dryland pastures under these conditions (Popp et al., 2000).

Hart et al. (1993) conducted a five year grazing study on native range (Cheyenne, Wyoming) using cow-calf pairs, dry cows and heifers to evaluate the effect of pasture size on animal gains and grazing behaviour. They found that by reducing pasture size from 207 ha to 24 ha, while grazing the same native range, improved cow and calf gains by 0.18 and 0.09 kg d^{-1}, respectively. As well, when the distance to water was greater than 3 km the gains of nursing cows and calves was reduced due to poor forage utilization (heavy grazing around the water source and little grazing of forage further away from the water), increased travel and grazing time (Hart et al. 1993).

In another cow-calf grazing study by Hart et al. (1988b), the optimum grazing pressure was calculated based on animal unit days per tonne of DM. In the early part of the grazing season cows utilized crested wheatgrass, mid-summer native range and then later in the grazing season cows used a mixture of alfalfa and meadow bromegrass, with the legume-grass pastures having the highest carrying capacity of the three pasture types. For crested wheatgrass pastures a cow grazing pressure of 40.2 AUD t^{-1} DM was the upper limit (cows gaining 1.27 kg d^{-1} but only for a short duration at the beginning of the grazing season, gain then declined to 0.52 kg d^{-1} when the cows were put on the native range pastures) and if a larger value of AUD t^{-1} DM was used then profitability and productivity would decline rapidly. The optimal grazing pressure value was much lower (18.9 AUD t^{-1}) for cows on the native rangeland.

In Montana, a grazing trial was conducted to determine the effect of grazing seeded rangeland compared to native rangeland for beef cows that were high milk producers versus cows that were low milk producers (Adams et al. 1993). The net weight gain of high producing cows was 2.5 kg over the 158 days of grazing compared to 29.2 kg for the low milk producing cows. Overall, the seeded and native rangeland treatments provided the same level of nutrition for both the high and low milk producing cows (no effect of pasture type and no pasture by animal type interaction). As well, the calf net weight gain over the grazing season was not affected by pasture type (157.5 versus 112.9 kg for the calves of the high and low producing cows, respectively). Generally, there were no interactions with cow type and pasture type on calf gain (Adams et al. 1993). They concluded that the productivity of cow-calf pairs was similar for the pasture treatments and that these treatments would not support the lactation and maintenance of high milk producing cows during late summer. The availability of crude protein seemed to be the limiting factor in this study (Adams et al. 1993).

2.9 Animal Performance and Monensin CRC

2.9.1 Cow-calf Responses to Monensin on Pasture or Forage Diets

In 1975, monensin, a carboxylic polyether antibiotic ($C_{36}H_{61}O_{11}Na$) was first registered for use in animal feeds. Initially, the ionophore was added to poultry diets and acted as an anti-coccidial agent (Bergen and Bates 1984). Many of the early trials involved the direct application of monensin to feeder cattle diets with very few studies using grazing cattle and beef cows. Intra-ruminal delivery devices or controlled-release capsules (CRC) were developed and permitted internal administration of the ionophore for use in grazing cattle. For a review of the effects of ionophores (monensin and lasalocid) on beef cow production refer to Sprott et al. (1988).

Bergen and Bates (1984) reported that ionophores do not suppress intake for cattle on forage based diets (high cellulose levels), at least not to the extent of concentrate or grain based diets. Lemenager et al (1978) evaluated the effect of monensin on DMI, cow productivity and on milk production and composition of beef cows grazing native winter range. Monensin was administered at 0, 50 or 200 mg d^{-1} in a soybean meal-based supplement. Forage DMI was depressed from 9.6 kg DM for the control cows to 8.3 and 7.7 kg DM for the 50 and 200 mg treatments, respectively. Although forage DMI was reduced with monensin administration, cow productivity was not compromised; cow feed efficiency was improved with monensin (Lemenager et al. 1978). This result has also been noted in later studies (Baile et al. 1982; Walker et al. 1980). Milk yield and composition were not affected by monensin treatment (Lemenager et al. 1978). In dairy cow studies, monensin has had variable results on milk fat content, some studies show little or no effect (Hayes et al. 1996) and some show a reduction in milk fat (Van Der Werf et al. 1998; Abe et al. 1994).

There are a number of metabolic effects associated with the administration of monensin and these are outlined in Bergen and Bates (1984). Some of the most often stated effects include, a shift from acetate production to propionate, decrease in ruminal protein breakdown and deamination (lower amount of ammonia-N in the rumen) and reduced methane production.

To observe the potential amino acid sparing effect that monensin could have on the protein fraction of a diet, two fistulated cows were fed timothy and alfalfa hay (Lana and Russell 1997). Monensin had no effect on total ruminal ammonia when timothy hay was present in the diet but increased with monensin supplementation when cows were fed the 100% alfalfa hay diet. Monensin was observed to spare amino acids by decreasing the specific activity of deamination and increasing the amount of bacterial protein (20% increase) in all combinations of timothy and alfalfa hay. Bacterial protein elevation may be explained by monensin-dependent increases in total volatile fatty acids (20% increase) (Lana and Russell

1997).

2.10 Hypothesis

Most cow-calf operations are based on unfertilized grass pastures. There are a number of strategies that can help improve the productivity of these operations. Inorganic fertilizers can be applied to improve grass-based pastures by increasing forage yield and improving plant protein concentrations. Incorporation of a legume into grass-based pastures can increase forage yield, improve forage protein concentrations and extend the period of active plant growth. A combination of both fertilization and legume incorporation can be used to try to maximize the productivity of the grazing system. In addition to the agronomic strategies, animal productivity can be enhanced by using ionophores to improve forage utilization via improved feed efficiency and improved plant protein utilization. These strategies have not been tested for cow-calf grazing systems and need to be evaluated to determine the extent of their effectiveness.

In the Northern Great Plains region, few grazing studies have been conducted using cow-calf pairs. Most grazing studies will present animal performance data, but will not address calf dry matter intake. The effect of pasture management (inorganic fertilizer application, incorporation of a legume and a combination of fertilizer and incorporation of a legume into grass-based pastures) and dam milk supply on calf forage dry matter intake is not known.

3.0 Manuscript 1: The use of fertilizer inputs versus legume incorporation for meadow bromegrass pastures

J.C. Kopp[1], W.P. McCaughey[2] and K.M. Wittenberg[1]

[1]Department of Animal Science, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2. [2]Agriculture and Agri-Food Canada, Brandon, Manitoba, Canada R7A 5Y3

3.1 ABSTRACT

A four-year grazing experiment was conducted using 32 'tester' cow-calf pairs and additional 'put and take' cow-calf pairs to rotationally stock eight, 3.7 ha pastures sown to meadow bromegrass (*Bromus biebersteinii* Roem & Schult.) and alfalfa (*Medicago sativa* L.)-meadow bromegrass. The effects of forage type and fertilization on pasture productivity (t DM ha^{-1}), number of cow grazing days (CGD ha^{-1}), forage quality (CP, NDF and ADF) and persistence of alfalfa (% alfalfa, DM basis) under four pasture treatments (alfalfa-grass fertilized (AF), alfalfa-grass unfertilized (AU), grass-only fertilized (GF) and grass-only unfertilized (GU)) were studied. Four year average (1995-1998) forage production of AF, AU, GF and GU pasture treatments were 4.9, 4.1, 4.9 and 2.6 ± .24 t DM ha^{-1} and average carrying capacities were 200.4, 163.9, 208.7 and 127.6 ± 3.29 CGD ha^{-1}, respectively. Alfalfa declined ($P < 0.05$) over the four years from 75.4% and 84.1% in 1995 to 32.5% and 40.3% in 1998 for AF and AU pastures, respectively. Application of fertilizer (GF) and incorporation of a legume (AU) both increased ($P < 0.05$) DM yield and forage quality compared to GU pastures. Fertilizing the grass-based pastures increased productivity ($\bar{x}$ ± SD) by 81.8 ± 43.1 CGD ha^{-1}, while the incorporation of a legume into grass-based pastures resulted in an increase of 37.2 ± 38.8 CGD ha^{-1}. Incorporation of a legume, coupled with fertilization increased pasture productivity by 74.0 ± 72.3 CGD ha^{-1}. The variability in increased productivity was smallest for the AU pasture treatment. Fertilization of grass pastures consistently improved forage quality, as determined from crude protein, neutral detergent fibre and acid detergent fibre. Improvements in forage quality were greater for alfalfa-grass pastures than for fertilized grass pastures.

Abbreviations: **AF**, alfalfa-grass fertilized; **AU**, alfalfa-grass unfertilized; **GF**, grass-only fertilized; **GU**, grass-only unfertilized, **R1**, rotation one; **R2**, rotation two; **CGD**, cow grazing days

Key Words: Alfalfa, Meadow Bromegrass, Productivity, Forage Quality, Grazing

3.2 INTRODUCTION

Meadow bromegrass (*Bromus biebersteinii* Roem & Schult.) has shorter rhizomes and, therefore, does not overwhelm alfalfa as quickly as other grasses such as smooth bromegrass (*Bomus inermis* Leyss.) (Pearon and Baron 1996). Meadow brome maintains a higher density of small vegetative tillers that regrow quickly from growing points that are located below the grazing height, thus making it less vulnerable to frequent defoliation (Pearon and Baron 1996; Van Esbroeck et al. 1995; Knowles et al. 1993). When Malhi et al. (1998) fertilized meadow bromegrass with a variety of N fertilizers (100 kg N ha^{-1}) the average increase in forage yield was 56% more than unfertilized plots. McCaughey and Simons (1996) reported a 43% average increase in meadow bromegrass yield when sandy loam sites were fertilized at 120 kg N ha^{-1}.

Legumes can be a very important part of grazing systems. The advantages of legume-grass mixtures include increased soil and water conservation, enhanced control of weedy species, minimized loss of production from thinning legume stands and reduced risk of bloat in grazing animals (Casler and Walgenbach 1990). However, many grass species are very competitive when planted with alfalfa (*Medicago sativa* L.) (Hoveland et al. 1995; Pearen and Baron 1996) and as legume persistence declines, a loss of nutritive value occurs compared to pure alfalfa stands (Smith et al. 1992). Fertilization of mixed species pastures can increase competitiveness of grasses causing the persistence of legumes to decline (Russelle 1992; Pearen and Baron 1996).

Alfalfa is a valued pasture plant as it yields well, fixes atmospheric N, has a high nutritive value that is well suited for cattle production and is adapted to many climatic and soil conditions (Van Keuren and Matches 1988). However, when planted in mixtures, grass competition and frequent defoliation may decrease alfalfa longevity (Pearen and Baron 1996). Grasses are generally more tolerant than alfalfa to frequent cutting (Hoveland et al. 1995). There are a number of agronomic strategies that can improve the productivity of cultivated grass pastures. The application of inorganic fertilizers to grass-based pastures can improve forage yield and increase plant protein concentrations. The incorporation of a legume into grass-based pastures will also improve forage yield, increase protein concentration and extend the period of active plant growth. To optimize the production potential grass pastures, a combination of fertilizers and legumes could be used. The objective of this study was to determine the effect of forage species and fertilization on yield, quality and botanical composition of pastures over time.

3.3 MATERIALS AND METHODS

3.3.1 Experimental Pastures

A four year trial was conducted east of Brandon, Manitoba, Canada (49° 52' N; 99° 59' W; 363 m above sea level) on an orthic black chernozemic soil rated as a class five Souris fine sandy loam soil (Ehrlich et al. 1957). Eight, 3.7 ha experimental pastures were randomly assigned to one of four treatments, alfalfa-meadow bromegrass fertilized (AF), alfalfa-meadow bromegrass unfertilized (AU), meadow bromegrass fertilized (GF) and meadow bromegrass unfertilized (GU). Each pasture treatment combination was replicated twice. In the spring of 1994, four 3.7 ha pastures were sown to meadow bromegrass (cv. 'Paddock'; 10 kg ha^{-1}) and four-3.7 ha pastures were sown to a mixture of alfalfa (cv. 'Spredor II'; 3 kg

ha^{-1}) and meadow bromegrass (cv.'Paddock'; 6 kg ha^{-1}) to produce alfalfa dominated pastures. After seeding, two of the grass pastures and two of the alfalfa-grass pastures were fertilized with nitrogen (N), phosphorous (P), potassium (K) and sulfur (S) at Manitoba soil test recommended levels (Table 4, Loewen-Rudgers et al.1977) and the remaining four pastures were left unfertilized. The AF and GF pastures were fertilized once each year in early spring on the basis of results from soil tests collected the previous fall.

Grazing started in 1995. On each pasture, four 'tester' cow-calf pairs were used to collect animal performance data and additional 'put and take' cow-calf pairs were used to maintain equal herbage availability. This ensured the same length of grazing season for all treatments and all the animals were rotated between paddocks at the same time. Each 3.7 ha pasture was equally divided into five paddocks using portable electric fencing and all cow-calf pairs were rotationally stocked.

3.3.2 Data Collection

Pasture productivity was assessed through direct measurement of forage biomass (t DM ha^{-1}) at entry and exit from each paddock, and indirectly by calculation of carrying capacity (cow grazing days per hectare, CGD ha^{-1}). The latter was calculated by multiplying the number of cows in the paddock by the number of days spent grazing the paddock and dividing by pasture area. Paddock biomass was calculated by hand-clipping 8 randomly selected 0.25 m^2 areas per paddock at ground level and drying the clipped herbage in a 50°C forced-air oven for 48 hours to determine dry matter content. Four of the dried samples collected from each pasture when cattle entered the paddock were hand-separated into different forage species and re-weighed to determine pasture botanical composition. The

Table 4. Fertilizer recommendations and actual application rates (kg ha^{-1}) for meadow bromegrass and alfalfa-meadow bromegrass pastures during 1994-1998

	Meadow Bromegrass				Alfalfa-Meadow Bromegrass			
	N	P_2O_5	K_2O	S	N	P_2O_5	K_2O	S
Recommended Fertility[y]								
New Stand	0	30	70	0	0	60	70	30
Established Stand	120	30	70	0	0	60	70	30
Actual Application Rates								
1994	0	0	50	0	11	50	77	0
1995	95	4	0	30	29	20	0	30
1996	110	22	0	0	9	43	0	0
1997	110	10	0	0	5	22	0	0
1998	68	22	21	0	44	31	16	10

[y]Manitoba Department of Agriculture (1978)

remaining four samples collected when cattle entered the paddock were composited, ground to pass through a 1 mm steel sieve using a Wiley Mill and stored in air- tight containers until submitted for forage quality analysis.

3.3.3 Laboratory Analysis

Clipped herbage samples were analyzed for acid detergent fiber (ADF; Association of Official Analytical Chemists 1990; method no. 973.18), and neutral detergent fiber (NDF; Van Soest et al. 1991) using the Tecator Fibertec System M 1020 Hot Extractor (Herndon, Virginia, U.S.A), as well as crude protein (CP) via Kjeldahl digestion (Association of Official Analytical Chemists 1990; method no. 984.13) to determine the nitrogen content of the sample, which was then multiplied by 6.25 to estimate the CP content of the forage sample. Results of all laboratory analyses were expressed on a dry matter basis (DM; Association of Official Analytical Chemists 1990; method no. 934.01).

3.3.4 Statistical Methods

Annual forage quality (CP, NDF and ADF), botanical composition, forage yield and carrying capacity (CGD) data were analyzed as a randomized complete block, blocked by year. Pasture treatment was in the main plot and time of sampling was in the sub-plot using the general linear model procedure of SAS (1990). Forage quality parameters also were analyzed for the three years of data collection (1995 to 1997) and forage yield and total CGD ha^{-1} were analyzed for the four years of data collection (1995 to1998). The statistical model included year and pasture treatment in the main plot and time of sampling and rotation in the sub-plot. Forage quality, yield and botanical composition data was analyzed by grazing rotation (rotation 1 (R1) and rotation 2 (R2)). In R1, the cattle grazed initial plant growth during which meadow bromegrass can enter into the reproductive stage of growth. In R2, the cattle grazed plant regrowth during which meadow bromegrass is not expected to advance to the reproductive state. Differences between treatment means were determined by linear contrasts (t-tests) when $P < 0.05$.

3.4 RESULTS AND DISCUSSION

The year effect ($P < 0.05$) observed for all parameters, reflects the variation in growing conditions, animal type and date that cattle were placed on pasture (Table 5). Grazing season precipitation was the lowest in 1995 (206.0 mm) and highest in 1998 (464.9 mm) with 1996 and 1997 precipitation at 263.0 and 219.4 mm. During 1995, the average grazing season temperature was 16.1 °C, 1.1 °C higher than the long-term average of 15.0 °C. The 1996, 1997 and 1998 grazing season average temperatures were 0.1, 1.1 and 0.9 °C higher than the long-term average.

3.4.1 Fertilization

The GF pastures received on average 57 kg ha^{-1} more N than the AF pastures each year for the period representing time of pasture establishment to the end of the trial (Table 4). The AF pastures received 21 kg ha^{-1} more P and 22 kg ha^{-1} more S than the GF pastures in that time frame.

3.4.2 Forage Productivity

The four year average forage production of AF, AU, GF and GU was 4.9, 4.1, 4.9 and 2.6 ± 0.24 t DM ha^{-1}, respectively (Table 6). Treatment ($P < 0.01$) and year ($P = 0.01$) had an effect on forage production. To some extent, year to year variation in productivity can be accounted for by grazing season precipitation. With fertilization, forage yield increased

Table 5. Growing seasons precipitation and temperature data, Brandon, Manitoba, including a 92 year average

Month	1995	1996	1997	1998	Long-term Average
			Precipitation (mm)		
May	64.0	66.0	14.4	85.9	49.0
June	72.0	53.0	53.0	163.0	79.3
July	20.0	59.0	98.0	68.0	73.0
August	19.0	25.0	45.0	122.0	64.5
September	31.0	60.0	9.0	26.0	46.1
Total	206.0	263.0	219.4	464.9	311.9
			Temperature (°C)		
May	10.8	8.6	9.5	11.9	10.8
June	18.9	17.6	18.9	14.8	15.9
July	19.3	18.3	19.7	19.1	19.0
August	19.5	18.7	18.2	19.9	17.6
September	12.2	12.4	14.3	13.8	11.9
Average	16.1	15.1	16.1	15.9	15.0

Grazing seasons: 13/06/95 - 24/08/95; 15/06/96 - 09/09/96; 05/06/97 - 27/08/97; 28/05/98 - 17/09/98.

Table 6. Carrying capacity (CGD ha^{-1}) of fertilized (F) and unfertilized (U) alfalfa-meadow bromegrass (A) and meadow bromegrass (G)-only pastures over four grazing seasons

	Rotation	Rotation Length (d)	Treatment (n= 8)				SEM	Contrast p-values	
			AF	AU	GF	GU		A vs G	F vs U
CGD ha^{-1}, 4 yr ave.	1		134.9^{b}	115.7^{c}	151.4^{a}	91.5^{d}	2.52	0.68	0.01
	2		65.2^{a}	48.2^{b}	57.3^{a}	36.1^{c}	2.61	0.14	0.03
	Total		200.4^{a}	163.9^{b}	208.7^{a}	127.6^{c}	3.29	0.30	0.01
1995	1	56	115.9	106.6	128.4	91.1	6.94	0.83	0.03
	2	13	20.4	23.4	18.2	16.6	1.90	0.08	0.74
	Total	69	136.3	130.0	146.6	107.7	8.10	0.50	0.05
1996	1	72	156.5^{b}	127.0^{b}	202.4^{a}	125.0^{b}	11.13	0.12	0.01
	2	14	29.5	22.7	26.8	24.9	3.86	0.95	0.33
	Total	86	186.0^{a}	149.7^{b}	229.2^{a}	149.9^{b}	12.73	0.16	0.01
1997	1	39	73.9	75.0	91.9	60.3	6.76	0.82	0.09
	2	35	81.1	68.4	84.3	51.1	10.03	0.52	0.08
	3	9	17.0	14.7	13.8	9.9	1.32	0.04	0.08
	Total	83	172.0	158.1	190.0	122.3	15.62	0.60	0.06
1998	1	75	193.4^{a}	154.2^{a}	182.8^{a}	89.6^{b}	12.50	0.04	0.01
	2	37	129.7^{a}	$78.2b^{c}$	100.0^{ab}	51.9^{c}	9.09	0.04	0.01
	Total	112	323.1^{a}	232.4^{b}	282.8^{ab}	141.5^{c}	16.42	0.02	0.01
DM Yd, t ha^{-1}, 4 yr ave.	Total		4.9^{a}	4.1^{a}	4.9^{a}	2.6^{b}	0.24	0.01	0.01

$^{a-d}$ Means within rows not having a common superscript differ (P <0.05).

by 1.6 t DM ha^{-1} ($P < 0.01$) and alfalfa-based pastures produced 0.8 t DM ha^{-1} more forage than the grass pastures ($P < 0.01$). Nuttall et al. (1980) found that when alfalfa-bromegrass pastures were fertilized with 90 kg N ha^{-1} and 20 kg P ha^{-1}, there was an average increase of 74% in herbage yield. In the current study, productivity of AF did not differ ($P > 0.05$) from AU pastures over a four year period. The unfertilized grass treatment produced only 53% of the fertilized pastures and pastures containing alfalfa, which reinforces the benefit of including a legume or fertilizing to improve the overall productivity of the pasture. These observations are similar to those of Smith et al. (1992) who observed that when alfalfa was sown with tall fescue it produced the same level of forage production as a fertilized tall fescue mono-culture.

3.4.3 Carrying Capacity

Forage production alone does not indicate how useful a pasture is to a cow-calf operation. Carrying capacity measured as cow grazing days per hectare (CGD ha^{-1}) takes into account pasture utilization, since there is trampling and refusal of less palatable forage. The four year average carrying capacity indicated that the GF (208.7 CGD ha^{-1}) and AF (200.4 CGD ha^{-1}) pasture treatments were the most productive ($P < 0.05$) and GU (127.6 CGD ha^{-1}) was the least productive. The most productive year was 1998 ($P < 0.01$), when rainfall was above the long-term average (Table 5). The effect of pasture treatment on carrying capacity was consistent for R1 and R2. The widest range in pasture carrying capacity was observed for AF (136.3 to 323.1 CGD ha^{-1}) which suggests that utilization can only be optimized if flexible harvest options are used, for example a combination of haying and grazing. By comparison, GF had a carrying capacity range of 146.6 to 282.8 CGD ha^{-1}.

3.4.4 Botanical Composition

Alfalfa percentage declined in all alfalfa-grass mixed pastures over the four years from 75.4 and 84.1% in 1995 to 32.5 and 40.3% in 1998 for AF and AU pastures, respectively. The decline was more rapid ($P < 0.05$) for the AF pastures; AU pasture taking 4 grazing seasons to get to levels observed for AF pastures in the second grazing season (Figure 1). The AU pastures contained 17.6% more alfalfa than the AF pastures ($P < 0.05$) in 1996. Similar results were found in R1 of 1997 ($P < 0.05$) and 1998 ($P < 0.05$) with AU producing on average 14.2% more alfalfa than the AF pastures. The treatment response in R1 may be a reflection of the spring fertilizer application which can encourage bromegrass growth and more aggressive competition.

Generally, the alfalfa content was greater in the unfertilized pastures than the fertilized pastures. When fertilizing legume-grass pastures, increasing the nitrogen supply results in decreasing legume populations, because of greater grass competition (Dougherty and Rhykerd 1985; Sheard 1974). Alfalfa persistence has been observed to decrease when grasses are included in the pasture mix (Smith et al. 1992). However, with the selection and development of improved grazing tolerant and more vigorous alfalfa cultivars, the persistence of alfalfa under different environments may be improved.

3.4.5 Forage Quality

Forage quality is affected by plant maturity, seasonal variations in temperature, light intensity, day length and grazing management (Coors et al. 1986). Pasture treatment had an effect on forage CP, NDF and ADF concentrations ($P < 0.001$; Tables 7, 8 and 9). Alfalfa-grass pastures had 3.1% units more CP than the grass-based pastures (Table 7; $P < 0.01$).

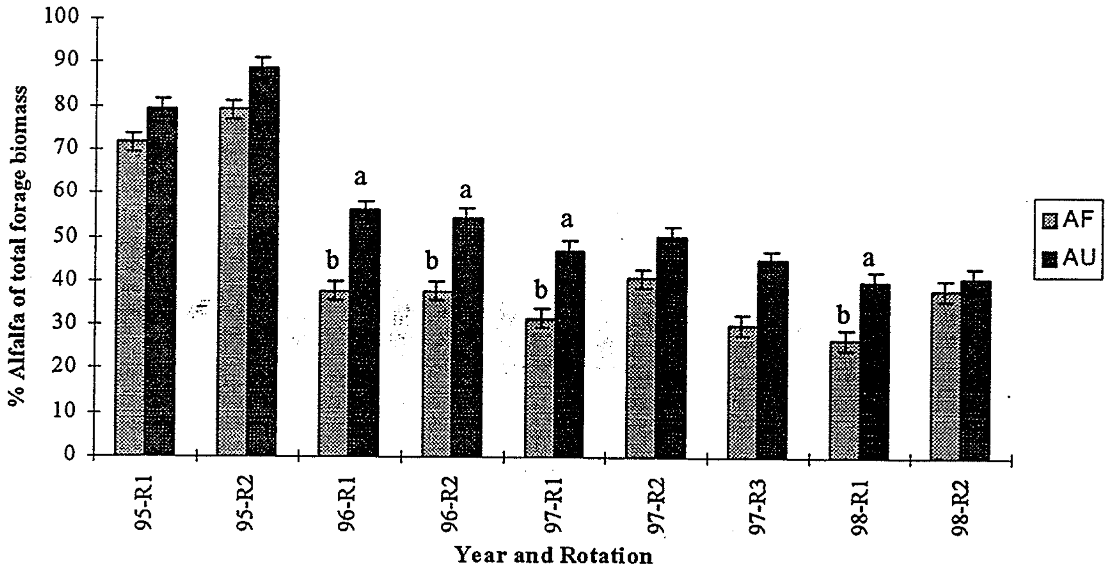


Figure 1. Botanical composition of fertilized (AF) and unfertilized (AU) alfalfa-meadow bromegrass pastures over a 4 year period.

Table 7. Forage protein content, % DM basis, for alfalfa-meadow bromegrass (A) and meadow bromegrass (G) pastures in fertilized (AF, AG) and unfertilized (AU, GU) conditions over three pasture seasons

	Rotation	n	Treatment AF	AU	GF	GU	SEM	Contrast p-values A vs. G	F vs.U
3 Yr Ave.	1	120	14.1[a]	13.3[b]	12.4[c]	8.3[d]	0.26	0.01	0.01
	2	48	14.3[a]	14.1[a]	13.0[b]	9.7[c]	0.28	0.01	0.01
1995	1	40	15.8[a]	13.8[b]	10.6[c]	8.3[d]	0.28	0.01	0.01
	2	16	12.0	11.7	10.6	10.1	0.62	0.07	0.58
1996	1	40	11.4[a]	11.5[a]	10.6[a]	7.2[b]	0.38	0.01	0.01
	2	16	14.1[a]	13.2[b]	12.9[b]	7.7[c]	0.22	0.01	0.01
1997	1	40	15.1[a]	14.5[a]	16.1[a]	9.3[b]	0.84	0.07	0.01
	2	40	14.4	14.6	13.3	10.5	0.88	0.04	0.22
	3	16	17.5	15.7	16.0	11.8	1.11	0.08	0.06

[a-d] Means within rows not having a common superscript differ ($P < 0.05$).

Fertilization increased the CP content of grass-based pastures an average of 3.7% units ($P < 0.01$). When the alfalfa-grass pastures were fertilized, the CP content increased 0.8% units in R1, but were not different in R2.

Forage CP concentrations were greater ($P < 0.05$) in the first growth of AF pastures compared to AU pastures for all years, except in 1996. The GU pastures always had the lowest forage CP ($P < 0.01$), the lowest level (7.2% CP) observed for initial growth (R1) of 1996.

In 1995 and 1997, no treatment effects were apparent for CP content of forage regrowth (R2), probably because most of the available nutrients were taken up by the plant in R1. In dry conditions, gaseous losses of N may occur (Russelle 1992) resulting in decreased forage quality and yield. When precipitation is inadequate, NO_3-N can accumulate in the soil and becomes susceptible to leaching below the root zone in the event that substantial rainfall occurs (McCaughey and Simons 1998). Since 1995 and 1997 were dry years, there was little benefit to fertilizing during these years.

One of the main concerns of this study was the low levels of CP for GU in 1996, due to N-deficiency. On the basis of the three years of data, GU would not be able to support a high level of production under hot and dry conditions. A 635 kg beef cow's requirement for CP at 5 months after calving with milk production of 4.9 kg d^{-1} is at least 8.3% CP (National Research Council 1996). When the above cow-calf pair is first put on pasture (2 months after calving, producing 9 kg milk d^{-1}) it requires approximately 10.3% CP (National Research Council 1996), therefore, producers should consider supplementing unfertilized grass pastures. This problem could be alleviated by the use of fertilization and/or the inclusion of a legume in the pasture mix. Nitrogen fertilization increased the CP or nitrogen concentration in smooth bromegrass, meadow bromegrass (McCaughey and Simons 1998) crested wheatgrass (Nyren et al. 1983; McCaughey and Simons 1998), western wheatgrass (White 1985b), native pastures, Russian wild ryegrass (Nyren et al. 1983) and in alfalfa-bromegrass mixed pastures (Nuttall et al. 1980).

Neutral detergent fibre (NDF) analysis measures the amount of cellulose, hemi-cellulose, lignin and insoluble ash in a plant tissue sample and provides an estimate of the potential voluntary intake of the animal (Fahey and Berger 1988). The three-year average for forage NDF concentration (Table 8) was similar for both R1 and R2. Treatments were ranked in descending order from the highest level of NDF to the lowest to be GU>GF>AF>AU ($P < 0.01$). The level of NDF increased as the grazing period progressed or as the forage matured, increasing on average 2.6% from R1 to R2. This contrasts with the results of Adams et al. (1993) who observed that NDF concentrations were 8.3% higher in September than May in esophageal fistula samples. This is important because esophageal samples represent what the grazing animal was actually ingesting and thus may provide a better estimate of diet quality than clipped samples.

The lowest NDF levels were recorded in 1997, and the highest NDF values were seen in 1996 (Table 8). This observation may be reflective of the amount of precipitation received in the months of July and August. In 1997, the pastures received 39 and 20 mm more rainfall than the same months in 1996. As well, the 1996 grazing season started and finished later

Table 8. Forage neutral detergent fibre, % DM basis, for alfalfa-meadow bromegrass (A) and meadow bromegrass (G) pastures in fertilized (AF, GF) and unfertilized (AU, GU) conditions over three pasture seasons

			Treatment					Contrast p-values	
	Rotation	n	AF	AU	GF	GU	SEM	A vs G	F vs U
3 Yr Ave.	1	120	53.0^{c}	51.2^{d}	61.7^{b}	63.3^{a}	0.40	0.01	0.83
	2	48	56.4^{c}	53.6^{d}	62.9^{b}	66.5^{a}	0.70	0.01	0.55
1995	1	40	50.5^{b}	49.4^{b}	63.7^{a}	63.8^{a}	0.38	0.01	0.22
	2	16	59.2^{b}	56.2^{c}	65.8^{a}	65.2^{a}	0.62	0.01	0.04
1996	1	40	60.2^{b}	57.5^{b}	65.1^{a}	65.7^{a}	0.91	0.01	0.31
	2	16	60.1^{b}	58.5^{b}	66.5^{a}	73.0^{a}	0.90	0.01	0.05
1997	1	40	48.1^{c}	46.6^{c}	56.2^{b}	60.4^{a}	0.47	0.01	0.05
	2	40	51.3^{c}	49.3^{c}	58.3^{b}	61.9^{a}	0.94	0.01	0.46
	3	16	60.8	62.2	64.9	67.0	1.45	0.04	0.28

$^{a-d}$ Means within rows not having a common superscript differ ($P < 0.05$).

than the 1997 grazing season and therefore, the 1996 forage was more physiologically mature. The AF treatment had the largest range in forage NDF concentration, with a 6.8 percentage units difference from the highest to the lowest year averages and AU had the most stable NDF levels with a 5.3% range. Alfalfa-grass pastures had on average 9.2% less NDF ($P < 0.01$) than the grass-only pastures. Including alfalfa in the pasture mix, consistently reduced the NDF content of the forage, which is important to maximize intake.

Fertilization of the alfalfa-grass pastures resulted in NDF concentrations either increasing or staying the same. This may have been due to changes in botanical composition, as the level of alfalfa in the alfalfa-grass stands decreased more with fertilization over the 3 years. In contrast to the alfalfa-grass pastures, when the grass-only pastures were fertilized, the level of NDF stayed the same or decreased. Fertilization improved the quality of grass pastures and maintained the grass pastures in a less mature, vegetative state with lower NDF concentrations than the unfertilized grass pastures.

Plant tissue concentrations of ADF provides an estimate of relative digestibility of the forage ingested by the animal (Fahey and Berger 1988). The ranking of ADF concentration for the experimental pastures, from highest to lowest was: GU > GF > AF = AU) ($P < 0.01$) in R1, and changed only slightly in R2 (GU > GF = AF = AU). Similar to NDF; ADF concentrations were higher in regrowth than in initial growth (Table 9). Fertilization did not affect the ADF concentration in the alfalfa-grass pastures and resulted in a reduced level of ADF for most rotations in the grass-only pastures. Incorporation of a legume improved the quality of grass-only pastures more so than fertilization.

Table 9. Forage acid detergent fibre, % DM basis, for alfalfa-meadow bromegrass (A) and meadow bromegrass (G) pastures in fertilized (AF, GF) and unfertilized (AU, GU) conditions over three pasture seasons

			Treatment					Contrast p-values	
	Rotation	n	AF	AU	GF	GU	SEM	A vs G	F vs U
3 Yr Ave.	1	120	34.9^{c}	34.8^{c}	36.8^{b}	39.0^{a}	0.31	0.01	0.01
	2	48	39.7^{b}	39.2^{b}	39.8^{b}	41.2^{a}	0.30	0.01	0.20
1995	1	40	36.9^{b}	37.1^{b}	40.7^{a}	41.0^{a}	0.30	0.01	0.43
	2	16	45.2	43.5	42.8	42.9	0.52	0.04	0.19
1996	1	40	39.3	38.3	39.0	39.6	0.58	0.41	0.80
	2	16	41.4^{b}	43.0^{b}	42.6^{b}	47.1^{a}	0.74	0.02	0.01
1997	1	40	28.4^{b}	29.0^{b}	30.7^{b}	35.9^{a}	0.80	0.01	0.02
	2	40	33.5^{c}	32.8^{c}	35.5^{b}	36.6^{a}	0.25	0.01	0.45
	3	16	36.3^{bc}	38.9^{ab}	34.6^{c}	40.0^{a}	0.72	0.74	0.01

$^{a-c}$ Means within rows not having a common superscript differ ($P < 0.05$).

The lack of rainfall in 1995, caused alfalfa plants to drop leaves and the meadow bromegrass plants to turn brown (dormancy), this resulted in high ADF levels in 1995 (Table 9). The greatest range in ADF levels was seen in the AF pasture samples, with a range of 8.3%. The most stable ADF concentrations were observed in the GU samples, with a difference of 5.9%. The GU samples, however, also had the highest level of ADF. Unfertilized alfalfa-grass pastures tended to be of better quality and were less variable over the course of the 3-year study.

3.4.6 Cost Benefit Assessment of Fertilization

For producers to use fertilizer on their pastures, the cost has to be outweighed by the potential improvements in pasture or animal productivity. The cost of fertilizing the GF pastures was on average \$30.38 ha^{-1} more than fertilizing the AF pastures.

The number of CGD ha^{-1} were increased when some type of fertility management program was used. The greatest improvement was observed when the grass-based pastures were fertilized (GF), this yielded an average of 81.8 ± 43.1 additional CGD ha^{-1} (Table 10) at a cost of \$1.22 per extra CGD. The AF pastures produced 74.0 ± 72.3 additional CGD ha^{-1} compared to the GU pastures, at a cost of \$1.04 per extra CGD. When precipitation was not limiting (1998), fertilization was approaching cost effectiveness, the 141.3 and 90.9 additional CGD ha^{-1} were produced at a cost of \$0.49 and \$0.37 per extra cow day by the GF and AG pastures compared to the GU pastures, respectively. Government- owned pastures charge a total cost of \$0.48 cow-calf $pair^{-1}$ d^{-1} (Saskatchewan Agriculture and Food 2000), thus fertilizing grass-based pastures to increase carrying capacity can be economical in years

Table 10. Additional cow grazing days (CGD ha^{-1}) and fertilizer cost per additional CGD ($ CGD^{-1}), comparing AF, AU and GF to GU over four grazing seasons

	GF-GU	AU-GU	AF-GU
	Additional CGD ha^{-1}		
1995	38.9	22.3	28.6
1996	79.3	-0.2	36.1
1997	67.7	35.8	49.7
1998	141.3	90.9	181.6
Average	81.8	37.2	74.0
Standard Deviation	43.1	38.8	72.3
	Fertilizer cost ($) of additional CGD		
1995	2.11	-	1.97
1996	1.10	-	1.24
1997	1.16	-	0.57
1998	0.49	-	0.37
Average	1.22	-	1.04
Standard Deviation	0.67	-	0.73

Fertilizer prices based on average market values (3 year market survey of Manitoba fertilizer suppliers) for each nutrient; $0.56 kg^{-1} N, $0.69 kg^{-1} P, $0.31 kg^{-1} K and $0.54 kg^{-1} S; plus the cost of custom broadcasting granular fertilizer ($10.38 ha^{-1}) (Manitoba Agriculture and Food 2000).

of adequate precipitation.

Yearly climatic variations influence the productivity, quality and persistence of forages. Incorporation of a legume into a grass pastures was the most stable in terms of quality and productivity over the four-year experiment. Fertilization improved the DM yield of grass pastures by 39%, when grown on fine sandy loam soils, and forage nutrient profiles met the lactating beef cow recommended nutrient requirements.

3.5 ACKNOWLEDGMENTS

The authors wish to express their appreciation for the technical assistance provided by Clayton Robins, Jim McGee, Rusty Mussbacher, Cindy Rose, Barb Kristjansson, Dave Corrigan and Dr. Av Singh.

4.0 Manuscript 2: Management strategies to improve cow-calf productivity on meadow bromegrass pastures

J.C. Kopp[1], K.M. Wittenberg[1] and W.P. McCaughey[2]

[1]Department of Animal Science, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2. [2]Agriculture and Agri-Food Canada, Brandon, Manitoba, Canada R7A 5Y3

4.1 ABSTRACT

A four-year grazing experiment was conducted to determine the effects of fertilization, incorporation of a legume and use of the Rumensin® controlled release capsules (CRC) on productivity of cow-calf pairs grazing meadow bromegrass (*Bromus biebersteinii* Roem & Schult.). There were four pasture treatments (T), alfalfa-grass fertilized (AF), alfalfa-grass unfertilized (AU), grass-only fertilized (GF) and grass-only unfertilized (GU). Each 3.7 ha pasture was split into five equally sized paddocks and rotationally stocked with first-calf cows in 1995 and 1998, and with mature cows in 1996 and 1997 using 'put and take' stocking. Half of the cows on each pasture received a Rumensin® CRC one week prior to the start of the pasture season. Consumed forage quality declined as the grazing season progressed. Monensin had an effect on DMI, cows that were treated with monensin consumed less (2.2 %BW) compared to the control cows (2.4 % BW) ($P < 0.05$). Cow DMI was not influenced by fertilization or incorporation of a legume. Cow average daily gain (ADG, g d^{-1}) was affected by a pasture treatment by monensin interaction ($P < 0.05$); monensin use resulting in a higher cow ADG on GU and AU pastures ($P < 0.05$) and having no effect when cows grazed GF or AF pastures. Pasture treatment did not affect milk yield or milk composition. Despite differences in diet quality, calf ADG for AU, AF and GF were similar. Calf ADG were lower for GU pastures ($P < 0.05$), probably as a result of the high fibre content of pasture forage. Total calf gain, kg ha^{-1}, when tester and 'put and take' cow-calf pairs are considered, increased with incorporation of a legume, however, the increase due to fertilization was greater.

Abbreviations: **AF**, alfalfa-grass fertilized; **AU**, alfalfa-grass unfertilized; **GO**, grass-only fertilized; **GU**, grass-only unfertilized; **T,** pasture treatment; **Y,** year; **M**, monensin; S, sex of calf; **SUN**, serum urea nitrogen; **R1**, rotation one; **R2**, rotation two

Key Words: Beef Cows, Calves, Milk Yield, Pasture Gains, Alfalfa, Meadow Bromegrass

4.2 INTRODUCTION

Alfalfa (*Medicago sativa* L.) provides high forage yields and exceptional forage quality that translates into high rates of live-weight gain (Douglas 1986). Meadow bromegrass has good forage quality, is well adapted to grazing and is an excellent grass species to sow with alfalfa (Pearen and Baron 1996; Holt and Jefferson 1999). Very little research has been conducted on the benefits of including legumes such as alfalfa in pasture mixtures for cow-calf production. To improve the productivity of grass pastures one can fertilize at soil-test recommended rates (Manitoba Agriculture 1978) or plant a mixture of grass and legume species such as alfalfa and meadow bromegrass. There is little available data relative to beef cow weight gain and milk production response to improved pasture management for alfalfa-meadow bromegrass mixed stands or pure meadow bromegrass under fertilized or unfertilized conditions.

Based on data with dairy cattle, monensin has the potential to increase milk production by 0.41 to 0.75 L d^{-1} (Beckett et al. 1998; Hayes et al. 1996). Monensin also can have an effect on milk composition. In a study by Ramanzin et al. (1997), monensin treated dairy cows had lower percentages of milk fat and protein compared to the untreated cows, but the daily production of fat and protein per cow was increased. There is a lack of data relative to the effects of monensin on suckled beef cows and their calves.

The objective of this study was to determine the effect of fertilization, incorporation of a legume, combination of fertilization and incorporation of a legume and administration of Rumensin® controlled release capsule (CRC) (active ingredient crystalline monensin sodium; manufactured and provided by PROVEL®, Division Eli Lilly

Canada Inc.) on cow and calf weight gain, and on voluntary intake, milk production, milk composition and serum urea nitrogen (SUN) levels of lactating beef cows.

4.3 MATERIALS AND METHODS

4.3.1 Description

Data was collected to determine the effect of four pasture treatments on the productivity of beef cows, during a four year grazing trial conducted east of Brandon, Manitoba, Canada (49° 52' N; 99° 59' W; 363 m above sea level). Eight experimental 3.7 ha pastures were randomly assigned to one of four treatments, alfalfa (*Medicago sativa* L.)-meadow bromegrass (*Bromus biebersteinii* Roem & Schult.), fertilized (AF), alfalfa-meadow bromegrass, unfertilized (AU), meadow bromegrass, fertilized (GF) and meadow bromegrass, unfertilized (GU). Each pasture treatment combination was replicated twice. Each pasture was equally divided into five paddocks by an electric fence and all cow-calf pairs were rotationally grazed.

On each pasture, four 'tester' cow-calf pairs were used to collect animal performance data and additional 'put and take' cow-calf pairs were used to maintain equal herbage availability. The productivity of each paddock was estimated 1 to 3 times per week and stocking rates were adjusted accordingly to achieve a uniform level of forage residue at the time the animals exited the paddocks. The cattle were moved when approximately 1000 kg forage DM ha^{-1} remained. This ensured the same length of grazing season for all treatments and that all animals were rotated at the same time.

Breed and age of the cow herd was different in each of the four years (Table 11).

Table 11. Cow breed, age, initial weights, milking dates, initial and final calf age and weights for the four year pasture study

	1995	1996	1997	1998
Cow Breed	Simmental x Angus	Composite Breed[z]	Composite Breed[z]	Composite Breed[z]
Cow Age	First Calf	Mature	Mature	First Calf
Initial Cow Weight (kg ± SD)	463 ± 30.6	566 ± 54.5	521 ± 56.2	464 ± 46.7
Pre-trial Milking	Jun 8	Jun 12	May 22	na
Rotation 1 Milking	Jul 13	Jul 22	Jun 23	na
Rotation 2 Milking	Aug 11	Sep 4	Jul 24	na
Calf Age On Test (days ± SD)	121 ± 12	75 ± 6	67 ± 7	57 ± 13
Calf Age Off Test (days ± SD)	193 ± 12	161 ± 6	150 ± 7	169 ± 13
Initial Calf Weight (kg ± SD)	138 ± 13.8	114 ± 9.2	96 ± 10.9	86 ± 14.5
Final Calf Weight (kg ± SD)	218 ± 16.7	198 ± 14.9	188 ± 16.7	186 ± 22.2

[z]The composite breed consists of 7/16 British (Angus, Hereford, Shorthorn), 1/4 Charolais, 1/4 Simmental, 1/16 Limousin)

Of the 4 'tester' animals in each pasture, 2 cows had steer calves and 2 cows had heifer calves, with the exception of 1998 when there were three heifer calves and one steer calf per pasture. Half of the 'tester' animals in each pasture received a monensin controlled release capsule in 1995, 1996 and 1997; monensin CRC was not used in 1998. All cow-calf pairs had ad lib access to water, salt and 2:1 (Ca:P) granular mineral on the meadow bromegrass pastures and 1:1 granular mineral on the alfalfa-meadow bromegrass pastures. The Brandon Research Centre Animal Care committee reviewed the experimental protocol to ensure that the cattle used in this study were cared for in agreement with the principles outlined by the Canadian Council on Animal Care.

4.3.2 Data Collection

Shrunk body weights of all the 'tester' cow-calf pairs were taken on two consecutive days (12 hour fast), at the beginning and end of the grazing season. Cow-calf average daily gains (ADG g d^{-1}) and calf gain per hectare (kg ha^{-1}; calf ADG (kg d^{-1}) x average CGD ha^{-1}) were determined.

Two data collection periods per year were conducted in 1995, 1996 and 1997, firstly when cattle entered (I) and exited (O) paddock 3 in rotation 1 (R1) and again when cattle entered and exited paddock 1 or 2 in rotation 2 (R2). To monitor the quality of grazed forage (1995 to 1997), four esophageal fistulated steers were maintained on pastures similar to the treatment pastures. During each data collection period, the esophageal fistulated steers were fitted with canvas collection bags and one steer was used to collect samples from each pasture treatment. The steers were fasted overnight and allowed to graze for 20 to 40 minutes on each pasture, the consumed forage collected at the end of the grazing bout. Extrusa samples were squeezed through muslin cloth, the saliva samples were collected and subsequently analysed to correct for organic matter losses (Cohen 1979). Squeezed plant material was dried in a forced-air oven at 50°C for at least 48 h and ground using a Wiley mill fitted with a 1-mm screen. The dried samples were analysed for Kjeldahl nitrogen (Association of Official Analytical Chemists (AOAC) 1990, method no. 984.13), acid detergent fibre (ADF; AOAC, 1990; method no. 973.18), and neutral detergent fibre (NDF; Van Soest et al. 1991) using the Tecator Fibertec System M 1020 Hot Extractor (Herndon, Virginia, U.S.A). *In vitro* organic matter digestibility (IVOMD) was determined by using a modification (Troelson and Hanel 1966) of the method of Tilley and Terry (1963) using bovine instead of ovine inoculum. Voluntary intake of the tester cows was determined using chromium sesquioxide (Cr_2O_3) controlled-release capsules (CRC, Captechrome, Nufarm Ltd., New Zealand) to estimate fecal output (Barlow et al. 1988).

The 'tester' cows were milked prior to being put out to pasture to determine a pre-test milk yield and composition. This information was used as a covariate for the analysis of milk data collected during the grazing season. Calves were separated from cows immediately prior to the first milking at 0630 h. To aid milk let down, 3 ml of oxytocin was injected intramuscularly (on the advice of a veterinarian) as the cows were milked using a portable milking machine. The milking machine was removed from the cow when milk flow from each quarter ceased. Calves remained separated from their dams until after a second milking occurred about 12 hours later. Milk weight was recorded and daily milk yield was calculated (milk yield measured (kg) x 1440 minutes d^{-1}/ number of minutes between milkings) and corrected to 4% milk fat (4% milk fat = [(0.4 x kg milk) + (15 x kg milk fat)], National Research Council 1989). Milk was sampled for analysis of protein, fat, and solids non-fat (SNF) by an accredited lab (#125) ISO Guide 25 (Milk-O-Scan 303AB, Foss Electric, Hillerød, Denmark). Milk somatic cell counts (SCC) were performed on a Fossomatic 300 Cell Counter (Foss Electric, Hillerød, Denmark).

Blood samples were taken from the cow's tail vein during the 0630 h milking of each collection period. Blood samples were centrifuged, and serum was decanted and frozen until analysed for serum urea nitrogen. Serum urea nitrogen values were determined using a colorimetric diacetyl monoxine procedure (Urea Nitrogen, Procedure No. 535, Sigma Diagnostics, St. Louis, MO).

4.3.3 Statistical Methods

The quality of the consumed forage (CP, NDF and ADF) for the initial three years was analysed as a split plot design. Main plots in this design were paddocks and these were physically arranged as a randomized complete block with blocks as strips of land sub-dived into paddocks. There were four pasture treatments and two paddocks per treatment in each block, thus 8 paddocks per block. Sub-plots in this design were measurements taken in different rotations (R) and upon entering (I) and exiting (O) the paddocks. Cow dry matter intake and SUN levels were analysed in the same manner as the consumed forage data, but with the addition of sex of calf (S) and monensin (M) in the sub-plot. Cow ADG and calf productivity (ADG and gain ha^{-1}) were analysed in the same manner as cow DMI and SUN data, but in the sub-plot the timing of data collection was at the beginning and end of the experiment. Data were collected from this experimental material over a three year period, so year effects and certain interactions of year with factors described above were included in the model. Block, year and interaction of other factors with block and year were considered random effects, all other effects were considered fixed.

The effect of monensin was included in the analysis for 1995 to 1997, however, in 1997 cows assigned to the monensin treatments were not balanced for sex of calf (12 cows with male calves were treated with monensin and only 4 cows with female calves were treated with monensin).

Milk production and composition data was analysed in the same manner as the cow weight and SUN data, however, the pre-trial milk yield and composition values were used as covariates.

In 1998, the cows were not treated with monensin, thus the data was analysed as a split-plot design with the effect of pasture treatment in the main plot and the effect of sex of calf in the sub-plot.

The general linear model procedure of SAS (1990) was used for all analyses. Duncan's multiple range test was used to detect differences among treatment means when $P < 0.05$ (Steele and Torrie 1980).

4.4 RESULTS AND DISCUSSION

4.4.1 Consumed Forage Quality

The 'put and take' stocking system resulted in a similar forage availability across all pasture treatments. Residual forage DM averaged 811.6, 820.0 864.4 and 730.5 ±

111.9 kg DM ha^{-1} for AF, AU, GF and GU, respectively. Therefore, animal production differences were due to forage quality, which was influenced by the pasture treatments and selectivity of the animals.

The forage consumed from the AF, AU and GF pastures were 3.0 ± 0.28 percentage units higher in CP than the GU pastures ($P < 0.001$; Table 12). Fertilizing the alfalfa-based pastures did not further improve consumed forage CP levels and CP levels in the GF and AU pastures were similar. There was a rotation by 'in/out' of the paddock interaction ($P < 0.001$). Cattle entering paddocks containing forage regrowth (R2) consumed forage with the highest average CP levels (13.5%, DM basis) than cattle entering paddocks containing initial growth (R1, 9.5%, DM basis) By the time the cattle exited the paddock, the level of CP was the same in both rotations, averaging 7.4%, DM basis.

The CP requirement for a 516 kg beef cow over a six month lactation period, when producing on average 5.8 kg d^{-1} of milk, is at least 8.1% CP (National Research Council 1996). When the above cow-calf pair is first put on pasture (2 months after calving, producing 8 kg milk d^{-1}) the cow requires approximately 9.0% CP (National Research Council 1996). During the three years that consumed forage data was collected, 41 out of the 96 samples collected were below the 8% CP content. Of these 41 samples, 15 were collected from the GU pastures and averaged 5.0% CP, DM basis. Crude protein levels below 8% for an extended period of time could have a negative effect on beef cow milk production.

Serum urea N (SUN) and milk urea N levels of dairy cows are being used as

Table 12. Three year average (1995-1997) quality and *in vitro* organic matter digestibility (IVOMD) of forage consumed by esophageal fistulated animals for the alfalfa-meadow bromegrass (A) and meadow bromegrass (G) pastures in fertilized (AF, GF) and unfertilized (AU, GU) conditions

	Treatment (T) (n=24)					Rotation (R) (n=48)			In/Out of Paddock (I/O) (n=48)					
	AF	AU	GF	GU	SEM	R1	R2	SEM	In	Out	SEM	TxR	TxI/O	RxI/O
CP	11.1^{a}	10.1^{ab}	9.4^{b}	7.2^{c}	0.28	8.4^{b}	10.5^{a}	0.31	11.5^{a}	7.4^{b}	0.31	NS	NS	***
NDF	59.6^{b}	59.3^{b}	67.8^{a}	66.5^{a}	0.81	64.8^{a}	61.8^{b}	0.78	58.1^{b}	68.5^{a}	0.78	NS	***	**
ADF	39.8^{b}	41.8^{ab}	41.2^{ab}	43.0^{a}	0.60	42.8^{a}	40.1^{b}	0.42	37.5^{b}	45.4^{a}	0.70	NS	*	*
IVOMD	61.4	61.1	59.1	58.1	0.99^{y}	63.6^{a}	56.3^{b}	0.81^{y}	62.5^{a}	57.4^{b}	0.81^{y}	NS	NS	*

^{a,b,c}Means within rows not having a common superscript differ ($P < 0.05$), Duncan's mean separation test was used.

^{y}Average of standard errors

NS= Not significant, *P<0.05, **P<0.01, ***P<0.001

indicators of the efficiency of protein and energy utilization (Roseler et al. 1993). Therefore, the levels of SUN were examined in the grazing beef cows to determine their nitrogen status under the different pasture treatments.

Serum urea N levels for cows grazing AF, AU, GF and GU pastures were 6.3, 6.2, 4.8 and 2.5 mmol l^{-1}, respectively. Boyd (1984) suggested 2.8 mmol l^{-1} to be the lower end of the normal SUN range for cattle. Approximately 67% of serum samples for cows grazing the GU pastures were below 2.8 mmol l^{-1}. Incidence of low SUN was 2.1, 0, and 16.7% for AF, AU and GF pastures, respectively. It has been suggested that beef cows fed low quality forages, can increase total tract organic matter and NDF digestion and increase body weight gain with supplemental protein feeding (Sletmoen-Olsen, et al., 2000a,b). They observed that Hereford-Angus cross cows consuming low quality prairie grass hay (5.8% CP) with 1.3 kg DM d^{-1} of a low, medium or high level of undegradable intake protein had plasma urea nitrogen (PUN) concentrations proportional to N intake and concluded PUN could be used as an indicator of protein intake (Sletmoen-Olson et al. 2000b). Furthermore, they demonstrated that dietary protein levels and PUN concentration were related to body weight change. The lactating cows that were not offered supplemental protein had PUN levels averaging 3 mmol l^{-1} and had the greatest weight loss over the lactation period.

There was a positive linear relationship between cow ADG and SUN level (cow ADG = 0.21SUN - 0.58, $R^2 = 0.36$, $P < 0.01$) for the cows that grazed the unfertilized grass pastures over three years. The SUN level explained only 18% of the variation in cow ADG when all of the pasture treatments were combined (cow ADG = 0.06SUN -

0.31, $P < 0.001$). There were periods with high plant CP levels, but the lactating cows could not maintain a linear increase in gain with the concurrent increase in SUN. Further research should be carried out to determine the threshold values of SUN required to sustain viable beef cow productivity. Once defined, these values may be a very useful tool to monitor the protein status of beef cows while grazing low quality forages.

The consumed forage NDF content at the time cattle entered or exited a paddock differed for pasture treatments and rotations ($P < 0.001$, Table 12). Consumed forage NDF for legume-based pastures was significantly lower when cattle were put on pasture and became similar to grass pastures when cattle left the legume-based pastures (Figure 2). This shows that cattle had more opportunity to select against NDF on the legume pastures. High forage levels of NDF in the grass pastures could limit the DM intake by the grazing animals (Fahey and Berger 1988). Consumed forage NDF was 10.1 ± 1.1 percentage units higher for cattle entering paddocks in R1 as compared to R2 (Figure 2). Consumed forage NDF increased to $68.5 \pm 1.6\%$, DM basis in both rotations at the time cattle exited the paddocks.

The negative correlation between forage NDF and DM intake is well established (National Research Council 1996). No relationship could be established between NDF concentration of consumed forage samples and cow DMI (% BW). Although consumed forage had a wide range for NDF content (31.6 - 79.2%, DM basis) and measured forage NDF levels frequently exceeded levels known to decrease intake, cow DMI in this pasture study showed no relationship to consumed forage NDF levels. It is possible that other factors, such as pasture forage moisture content are more important determinants of

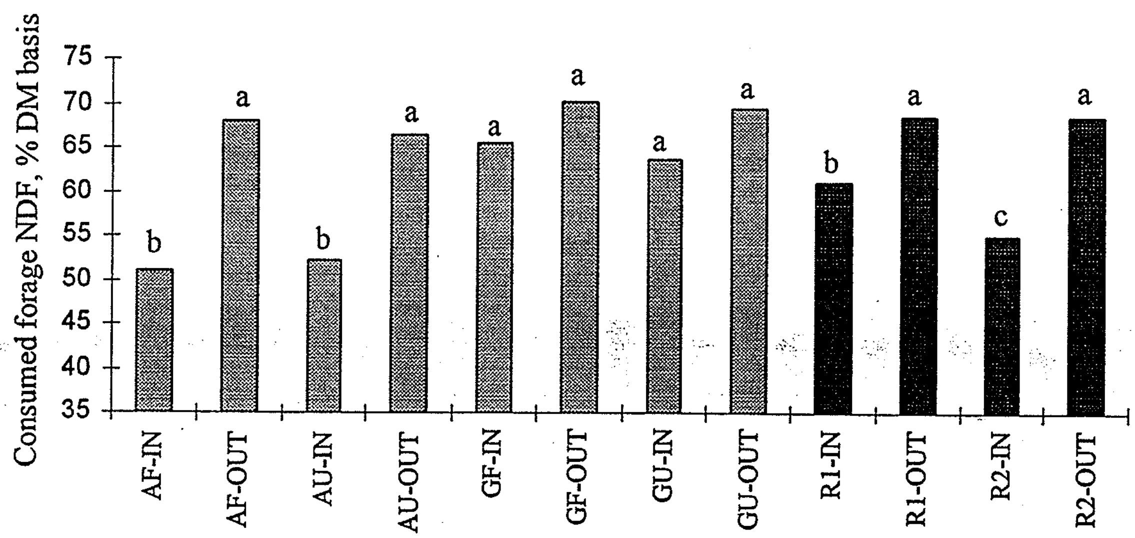


Figure 2. The effect of pasture treatment (T) at entry (I) and exit (O) from paddocks and of rotation (R) and I and O of paddock on the consumed forage NDF content (% DM basis) (TxI/O SE = 1.55; RxI/O SE = 1.10)

pasture forage intake. The consumed forage ADF content at the time cattle entered or exited a paddock differed for pasture treatments and rotations ($P < 0.05$, Table 12). Fertilization and incorporation of a legume resulted in lower consumed forage ADF level at the time cattle entered paddocks. Consumed forage ADF levels were equal across pasture treatments when cattle exited paddocks. The consumed forage ADF RxI/O interaction follows the same pattern as the above NDF RxI/O interaction.

Consumed forage quality, as measured by CP, NDF and ADF improved in R2 compared to R1 ($P < 0.05$) which could have a positive influence on the cow and calf productivity during a time of higher nutritional needs set by the growing calf. As calves grow they become less dependent on the energy and protein supply provided by their dams and more reliant on pasture forage to meet their requirements (National Research Council 1996). In the same manner, Marshall et al. (1998a) found that forage quality of legume-grass mixed pastures improved late in the grazing season when rotationally stocked and regrowth was grazed.

Contrary to the forage fibre trends, IVOMD of consumed forage was highest for animals entering paddocks in R1 (67.6%) as compared to 57.4% for animals entering paddocks in R2. The IVOMD decreased 10% from the time cattle entered to the time they exited paddocks in R1, with little decline observed when grazing regrowth in R2. In vitro organic matter digestibility was not strongly related to consumed forage ADF content, specifically digestibilities in R1 were higher than in R2, even though the ADF values were lower in the regrowth.

The quality of the consumed forage in each pasture treatment was similar to the quality of the clipped forage samples (Figure 3). Fertilization and legume incorporation strategies improved the clipped and consumed forage CP content. The NDF concentration of the clipped samples was lowered with fertilization, however, the greatest improvement was observed with the addition of a legume. The advantage of fertilization on forage NDF level was not apparent in consumed forage samples. A similar pattern was observed for ADF of clipped forage samples. The ADF levels of the consumed forage samples followed a different pattern than the clipped samples, where only legume incorporation plus fertilization resulted in significantly lower consumed forage ADF concentration relative to GU pastures. In general, fertilization and legume incorporation strategies clearly improved the clipped forage quality but the benefit of fertilization was only apparent for CP when evaluating forage actually consumed by the animal.

4.4.2 Dry Matter Intake

Fertilization and incorporation of a legume did not have an effect on DMI relative to grass unfertilized pastures ($P > 0.05$; Table 13). Monensin administration as CRC, however, did decrease DMI, % BW ($P < 0.05$). Cows that were treated with monensin consumed 0.2 percentage units less of their body weight in forage DM compared to the control cows. A number of studies involving the feeding of harvested forages to cows have shown monensin can reduce DMI by as much as 10.2% during gestation and early lactation (Turner et al. 1980; Walker et al. 1980; Clanton et al. 1981).

4.4.3 Cow Productivity

The cows used in this study were representative of beef cows commonly used in Manitoba (Table 11). From 1996 to 1998, a composite beef breed developed at the

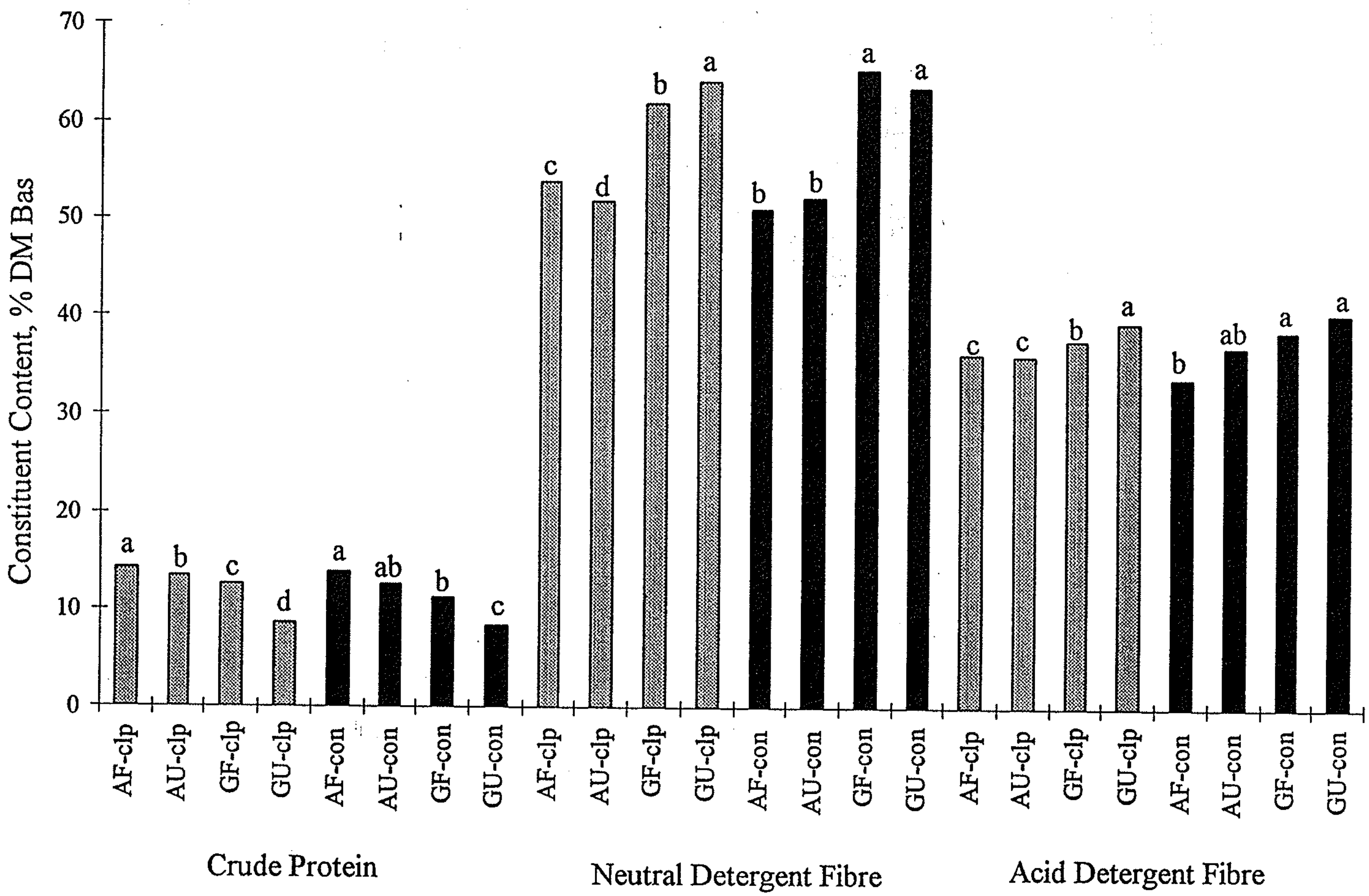


Figure 3. Forage quality of clipped (Clp, ▩) and consumed (Con, ■) forage for the alfalfa-meadow bromegrass (A) and meadow bromegrass (G) pastures in fertilized (AF, GF) and unfertilized (AU, GU) conditions (CP-clp SE = 0.22, CP-con SE = 0.51, NDF-clp SE = 0.28, NDF-con SE = 1.38, ADF-clp SE = 0.28, ADF-con SE = 0.99). Bars with different letters within each quality parameter and collection method reflect treatment differences, $P < 0.05$.

Table 13. Effect of pasture treatment (T), monensin controlled release capsule (M) and sex of calf (S) on cow productivity during the grazing season

	Treatment (n=24)					Monensin (n=48)			Sex of Calf (n=48)					
	AF	AU	GF	GU	SEM	Yes	No	SEM	M	F	SEM	TxM	TxS	MxS
1995-1997														
DMI,% BW	2.3	2.4	2.3	2.5	0.11[z]	2.3[b]	2.5[a]	0.10[z]	2.5	2.3	0.09[z]	NS	NS	NS
DMI, kg d^{-1}	12.8	13.0	13.5	13.8	0.73[z]	12.7	13.8	0.62[z]	13.6	12.9	0.62[z]	NS	NS	NS
ADG, g d^{-1}	-4	-20	103	-73	57.5	2.0	1.0	34.6	19	-17	34.6	*	NS	NS
Milk yield, kg[y]	5.8	5.8	5.9	5.8	0.30[z]	6.0	5.6	0.29[z]	5.7	5.9	0.29[z]	NS	NS	NS
Fat, %	3.1	3.0	3.3	3.1	0.11[z]	3.1	3.1	0.09[z]	3.2	3.1	0.09[z]	NS	NS	NS
Protein,%	3.7	3.8	3.8	3.8	0.08[z]	3.7	3.8	0.06[z]	3.8	3.7	0.06[z]	NS	NS	NS
SNF, %	9.2	9.3	9.2	9.0	0.07[z]	9.2	9.2	0.05[z]	9.2	9.1	0.05[z]	NS	NS	NS
SCC log	5.5	5.4	5.4	5.4	0.14[z]	5.4	5.4	0.08[z]	5.4	5.4	0.08[z]	NS	NS	NS
1998														
ADG (g)[x]	343	338	216	276	56.3	NA	NA	NA	341	246	42.8[z]	NA	NS	NA

[a,b,c]Means within rows not having a common superscript differ ($P < 0.05$), NS = not significantly different
[x]Cow 1998 ADG: Treatment n=8, Sex: females n=24, males n=8
[y]4 % fat corrected milk yield
[z]Average of standard errors NA= Not applicable, the factor was not part of the analysis.

Agriculture Agri-Food Canada Research Centre in Brandon, Manitoba was used in the grazing experiment. The cows were average to superior in terms of productivity versus a Hereford-Angus control for weight of calf weaned per mating opportunity (Fredeen et al. 1988).

Cow ADG was influenced by the interaction of pasture type and monensin administration ($P < 0.05$; Figure 4). Monensin improved cow gain by 115 and 132 g d^{-1} for AU and GU pastures and reduced ADG on AF pastures ($P < 0.05$). It is unclear why monensin decreased cow ADG on the AF pastures; however it should be noted that the average weight changes recorded were small. Monensin improved the feed efficiency of the cows grazing the unfertilized pastures, but had no benefit when pastures were fertilized. In a review by Sprott et al. (1988), cows that were fed low quality forage diets had improved feed efficiency when supplemented with monensin. The fertilization and legume incorporation strategies did not have an effect on cow milk yield or composition ($P > 0.05$). There were no pasture treatment effects on 1998 cow productivity measurements ($P > 0.05$).

4.4.4 Calf Productivity

Calves on the alfalfa-grass pastures gained 59.5 g d^{-1} more than the calves on the GU pastures ($P < 0.05$). Fertilization of grass pastures did not result in improved ADG. Sex of calf also had an effect on ADG ($P < 0.01$), male calves gained on average 62 g d^{-1} more than female calves. Monensin did not have any affect on calf productivity ($P > 0.05$).

Pasture treatment affected calf gain ha^{-1} from 1995-1997 ($P < 0.001$, Table 14)

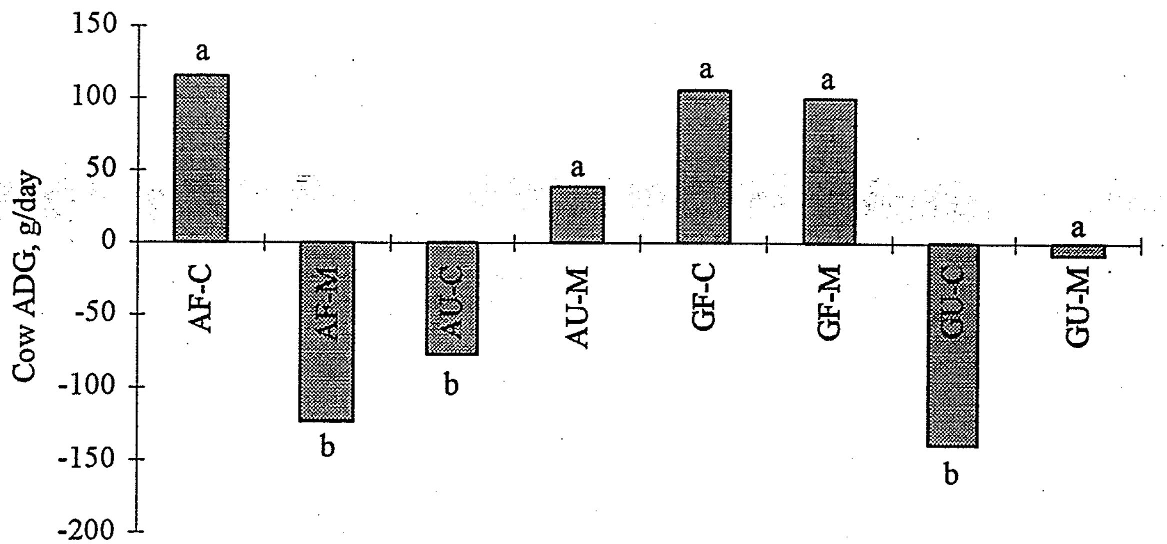


Figure 4. The effect of pasture treatment and monensin on cow ADG (SE = 65.8). Bars with different letters are different, $P < 0.05$.

Table 14. Effect of pasture treatment (T), monensin controlled release capsule (M) and sex of calf (S) on calf productivity during the grazing season

	Treatment (n=24)					Monensin (n=48)			Sex of Calf (n=48)			P-values		
	AF	AU	GF	GU	SEM	Yes	No	SEM	M	F	SEM	TxM	TxS	MxS
1995-1997														
ADG, g d^{-1}	1100^{a}	1087^{a}	1099^{ab}	1034^{b}	16.6^{y}	1086	1074	17.0	1111^{a}	1049^{b}	17.0	NS	NS	NS
Gain, kg ha^{-1}	179.2^{b}	158.0^{c}	204.8^{a}	129.1^{d}	5.78^{y}	168.0	167.6	2.89	172.7^{a}	162.9^{b}	2.89	NS	NS	NS
1998														
ADG^{z}, g d^{-1}	863	902	859	901	52.2	NA	NA	NA	887	876	28.7^{y}	NA	*	NA
Gain^{z}, kg ha^{-1}	279.0^{a}	210.1^{c}	242.7^{b}	127.0^{d}	21.30	NA	NA	NA	211.5	217.9	7.1^{y}	NA	*	NA

^{a,b,c}Means within rows not having a common superscript differ ($P < 0.05$), Duncan's mean separation test was used.

^{z}Calf 1998 ADG and gain per hectare: Treatment n=8, Sex: females n=24, males n=8

^{y}Average of standard errors

NA= Not Applicable, the factor was not part of the analysis.

NS= Not Significant, *P<0.05, **P<0.01, ***P<0.001

with the treatment rank from highest to lowest being, GF>AF>AU>GU. The GF pastures produced 44 kg calf weight gain ha^{-1} more than GU pastures. These results are reflective of the high forage production on the GF pastures (Manuscript 1).

4.4.5 Cost Benefit Assessment of Fertilization

When grazing alfalfa the main concern is the risk of frothy bloat but with proper management techniques during the four-year experiment, none of the 180 hd grazing alfalfa-grass pastures had to be treated for bloat.

The GF pastures showed the greatest improvement in calf gain ha^{-1}, an additional 87.2 ± 34.9 kg ha^{-1} more calf gain compared to GU pastures (Table 15). The AF pastures had an additional 77.2 ± 54.4 kg ha^{-1} compared to GU pastures. There was no difference in establishment costs between the grass and alfalfa-grass pastures (McCaughey personal communication). Given this, the cost for the additional gain on the AU pasture is zero. The cost of the additional gain on the GF and AF pastures is \$1.08 and \$0.79 kg^{-1}, respectively. The question of whether it is cost effective to fertilize grass-based pastures or to use a combination of fertilization and incorporation of a legume, revolves around the value of the calves. If the weaned calves are valued at \$0.79 kg^{-1} or more then AF is profitable, and if the calves are valued at more than \$1.08 kg^{-1} then GF is profitable. The bottom line is that the biggest increase in productivity comes from fertilizing the grass-based pastures (GF). The smallest increase in productivity comes from incorporating a legume into grass-based pastures (AU). However, the most profitable fertility management practice is the incorporation of a legume.

Table 15. Additional calf gain (kg ha^{-1}) and cost per calf gain (\$ kg^{-1} ha^{-1}), comparing AF, AU and GF to GU over four grazing seasons

	GF-GU	AU-GU	AF-GU
	Additional calf gain, kg ha^{-1}		
1995	43.1	39.3	44.8
1996	82.7	15.3	44.1
1997	95.5	37.7	61.9
1998	127.4	80.3	157.9
Average	87.2	43.2	77.2
Standard Deviation	34.9	27.1	54.4
	Fertilizer cost (\$) per kg gain		
1995	1.91	-	1.26
1996	1.05	-	1.02
1997	0.82	-	0.46
1998	0.55	-	0.42
Average	1.08	-	0.79
Standard Deviation	0.59	-	0.42

Fertilizer prices based on average market values (3 year market survey of Manitoba fertilizer suppliers) for each nutrient; \$0.56 kg^{-1} N, \$0.69 kg^{-1} P, \$0.31 kg^{-1} K and \$0.54 kg^{-1} S; plus the cost of custom broadcasting granular fertilizer (\$10.38 ha^{-1}) (Manitoba Agriculture and Food 2000).

4.5 CONCLUSION

Despite differences in diet quality, cow productivity for AU, AF and GF pastures were similar. Lactating beef cows assigned to unfertilized grass or alfalfa-grass pastures lost body weight, this trend was prevented with monensin administration.

Incorporation of a legume on grass pastures was the only management strategy that increased calf ADG relative to unfertilized grass pastures. However, the dramatic improvement in forage biomass associated with fertilization of grass pastures resulted in the greatest increase in total calf weight gain per hectare. From an agronomic point of view, fertilizing meadow bromegrass pastures would be the most productive strategy, in terms of calf gain ha^{-1}. However, incorporating a legume in meadow bromegrass pastures improves calf productivity without incurring the cost of fertilization.

4.6 ACKNOWLEDGMENTS

The authors wish to thank and acknowledge the financial assistance provided by Provel/Elanco and the invaluable help of the technicians who collected the field data, Clayton Robins, Jim McGee, Rusty Mussbacher, Cindy Rose, Barb Kristjansson, Dave Corrigan and Dr. Av Singh. The laboratory assistance of Janice Haines was also invaluable.

5.0 Manuscript 3: Forage and milk intake of suckling beef calves grazing alfalfa-meadow bromegrass and meadow brome grass-only pastures

J.C. Kopp[1], K.M. Wittenberg[1] and W.P. McCaughey[2]

[1]Department of Animal Science, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2. [2]Agriculture and Agri-Food Canada, Brandon, Manitoba, Canada R7A 5Y3

5.1 ABSTRACT

Suckling calf forage intake was determined as the difference between net energy required for maintenance (Ne_m) and gain (NE_g), and energy provided by milk received from the dam. Calf NE_m requirement was determined on the basis of metabolic body size. Net shrunk body weight gain during the pasture season was used to establish calf NE_g requirements, the composition of the gain estimated by regression. Milk NE_m and NE_g provided by the dam were determined on the basis of the milk yield and the respective energy values of milk components (fat, protein and lactose) with the appropriate calf utilization efficiencies applied. Pasture treatment had an effect on calf total dry matter intake (TDMI; $P < 0.01$) when grazing initial pasture growth, although milk DM consumed was not different between treatments. Calves pastured on the meadow bromegrass (*Bromus biebersteinii* Roem & Shult.) unfertilized pastures had the largest forage DMI (5.3 ± 0.3 kg d^{-1}) followed by calves assigned to the meadow bromegrass, fertilized pastures (4.1 ± 0.3 kg d^{-1}). The alfalfa (*Medicago sativa* L.)-meadow bromegrass fertilized and alfalfa-meadow bromegrass unfertilized pastures had the same level of intake (3.5 ± 0.3 kg d^{-1}). These differences in forage DMI were not apparent in the second half of the grazing season when animals were grazing pasture regrowth. Depending on cow milk supply and pasture quality, calf forage dry matter intake (FDMI) can range from 0-8.7 kg DM d^{-1}.

Abbreviations: **NE_m**, net energy of maintenance; **NE_g**, net energy of gain; **MDMI**, milk dry matter intake; **FDMI**, forage dry matter intake; **TDMI**, total dry matter intake, **AF**, alfalfa-meadow bromegrass fertilized; **AU,** alfalfa-meadow bromegrass unfertilized; **GF**, meadow bromegrass fertilized; **GU,** meadow bromegrass unfertilized, **R1**, rotation one, **R2**, rotation two

Key Words: Milk Intake, Suckling Calves, Grazing, Forage Intake, Energy Balance

5.2 INTRODUCTION

There is a limited amount of information available on suckling calf intake behavior when improved pastures are rotationally stocked. The most current intake studies were conducted on native rangeland (Grings et al. 1996; Ansotegui et al. 1991; Bailey and Lawson 1981). The amount of forage consumed by calves is difficult to measure, however, intake of forage energy can be estimated by constructing energy balance equations. It has generally been agreed that dam milk yield is strongly correlated to calf pre-weaning gain and weaning weight (Chenette and Frahm, 1981; Boggs et al., 1980) and the milk DM intake by the calf. As milk production decreases during the grazing season, calves rely more on energy obtained from grazing. Butson and Berg (1984) suggested that as the calf increases its forage intake, there is a reduced dependance on milk intake. Cows with higher milk production would potentially have calves that do not rely on forage for their energy needs. It could also be suggested that forage quality and availability affect pasture forage energy density and that these differences in energy density may influence forage intake by the suckling calf. If an alfalfa-grass pasture is of better quality and higher energy density, it could be hypothesized that the calves would not have to consume as much of this pasture compared to grass-only pastures. Evaluation of the energy status of the grazing calves may also give some insight into which pasture treatments would benefit from the use of creep feeding. The objective of this study was to determine forage dry matter intake (FDMI, kg d^{-1} ; % BW), milk DMI (MDMI, kg d^{-1} ; % BW) and total DMI (TDMI = FDMI + MDMI ; kg d^{-1} ; % BW) of suckling calves pastured on fertilized and unfertilized alfalfa-meadow bromegrass and meadow bromegrass-only pastures.

5.3 MATERIALS AND METHODS

5.3.1 Description

Data was collected to determine the effects of four pasture treatments on the productivity of beef cows during a four year grazing trial conducted near Brandon, Manitoba, Canada (49° 52' N; 99° 59' W; 363 m above sea level). Eight 3.7 ha pastures on flat terrain, were randomly assigned to one of four treatments, alfalfa (*Medicago sativa* L.)-meadow bromegrass (*Bromus biebersteinii* Roem & Schult.), fertilized (AF), alfalfa-meadow bromegrass, unfertilized (AU), meadow bromegrass, fertilized (GF) and meadow bromegrass, unfertilized (GU) (Manuscript 1). Each pasture was equally divided into five 0.74 ha paddocks by an electric fence and all cow-calf pairs were rotationally grazed. On each pasture, four 'tester' cow-calf pairs were used to collect animal performance data and additional 'put and take' cow-calf pairs were used to maintain equal herbage availability. This ensured the same length of grazing season for all treatments and all animals were rotated between paddocks at the same time.

Angus-Simmental crossbred first-calf cows were grazed during 1995. A composite beef breed developed at the Brandon Research Centre and consisting of 7/16 British, 1/4 Charolais, 1/4 Simmental and 1/16 Limousin genetics (Fredeen et al., 1988), were used in 1996 and 1997 (for a more in-depth description of the animals refer to Manuscript 2). Of the 4 'tester' animals in each pasture, 2 cows had steer calves and 2 cows had heifer calves. Half of the 'tester' animals in each pasture received a monensin controlled release capsule. All cow-calf pairs had ad lib access to water, salt and 2:1 (Ca:P) granular mineral on the meadow bromegrass pastures and 1:1 granular mineral on the alfalfa mixed pastures.

5.3.2 Data Collection

Calves were weighed at the beginning and end of the grazing season (12 hr shrunk weights) to calculate the total weight gain (kg) over the grazing season. Total calf weight gain was used to calculate the amount of combustible energy produced.

Two milk collection periods per year were conducted for which a portable milking machine was used to measure milk yield and milk samples were collected (Manuscript 2). The milk samples were analysed for protein, fat, and solids non-fat (SNF) by an accredited lab (#125) ISO Guide 25 (Milk-O-Scan 303AB, Foss Electric, Hillerød, Denmark). Calves were weighed at the time of milk collection.

The Brandon Research Centre Animal Care Committee reviewed the experimental protocol to ensure that the cattle used in this study were cared for in agreement with the principles outlined by the Canadian Council on Animal Care.

5.3.3 Energy of Maintenance

Energy required for calf maintenance was estimated using NRC (1996).

$$\text{Calf } NE_m = 0.322 \text{ MJ kg}^{-0.75}$$

Compared to penned animals, cattle grazing under good pasture conditions require 20% more NE_m to cover the energy cost of grazing activity (CSIRO, 1990 in NRC, 1996, 2001). Cattle grazing pastures that are hilly or cover large areas, require 50% more NE_m than penned animals (CSIRO, 1990 in NRC, 1996). Values stated in NRC (1996, 2001) may be an over-estimation. The Standing Committee on Agriculture (1990) stated that under good grazing conditions, the energy expended from grazing would only be 10-20 % of NE_m. Experimental pastures were of flat terrain and 0.74 ha in size. To avoid underestimation calf NE_m requirements were increased by 20%, in the current study.

5.3.4 Energy of Calf Tissue Gain

Specific whole body combustion energy was determined by Parks (1982), by using cattle body composition data (Kleiber 1975) to establish a straight line function of the degree of maturity (*m*, % of mature weight, proportion of 1100 kg) to specific combustion energy (*c*, MJ kg^{-1}) of steers where:

$$c = (1.25 + 6.15m) \times 4.184$$

5.3.5 Energy of Milk

The milk energy values were calculated from equations obtained from NRC (2001). The following equations were the steps taken to calculate milk net energy of maintenance (NE_m) and gain (NE_g), on a dry matter basis.

Gross Energy (GE, MJ kg^{-1}) = 4.184 (0.057 CP, % DM basis + 0.092 fat, % DM basis + 0.0395 lactose, % DM basis),

where lactose (% DM basis) was calculated as 100 - CP% - fat% - ash%.

Net Energy of Maintenance (NE_m, MJ kg^{-1}) = 0.801 GE

Net Energy of Gain (NE_g, MJ kg^{-1}) = (0.38q + 0.337) 0.801 GE

where q is the metabolizability of the diet (ME/GE).

5.3.6 Energy of Forage

The forage energy values were based on the botanical composition of each pasture (Manuscript 2). The equations used to estimate forage energy were adapted by Norwest Labs

(1994) from Van Soest et al (1979) and National Research Council (1978). For pastures containing 70% or more grass, net energy of maintenance and net energy of gain are calculated as:

NE_m, MJ kg^{-1} = 4.184 x (2.018 - 0.038 x ADF + 0.7)

NE_g, MJ kg^{-1} = 4.184 x (2.018 - 0.038 x ADF)

Pastures containing mixed forages, between 31 and 69% grass used the following equations to determine net energy of maintenance and gain:

NE_m (MJ kg^{-1}) = 4.184 x (1.531 - 0.0252 x ADF + 0.7)

NE_g (MJ kg^{-1}) = 4.184 x (1.531 - 0.0252 x ADF)

In pastures containing 70% or more legumes, net energy of maintenance and gain were calculated as:

NE_m (MJ kg^{-1}) = 4.184 x (1.332 - 0.019 x ADF + 0.7)

NE_g (MJ kg^{-1}) = 4.184 x (1.332 - 0.019 x ADF)

5.3.7 Calculations for Forage DM Intake

The total amount of energy that the calf requires is represented as the sum of NE_m and NE_g. If the calf requirements exceed the amount of milk energy consumed for NE_m, forage energy must be consumed to meet the maintenance requirements plus the requirements for gain (NE_g). Forage DMI was estimated by calculating the difference between calf NE_m and NE_g required and NE_m and NE_g provided by the milk consumed.

To calculate the weight of forage the calf consumed, the following equation was used:

Calf forage DMI, kg d^{-1} = (forage NE_m required by the calf (MJ) / forage NE_m MJ kg^{-1}) + (forage NE_g required by the calf (MJ) / forage NE_g MJ kg^{-1})

5.3.8 Statistical Methods

Calf FDMI (kg d^{-1}, % BW), MDMI (kg d^{-1}, % BW), TDMI (kg d^{-1}, % BW), forage energy (NE_m and NE_g, MJ d^{-1}) and milk energy (NE_m and NE_g, MJ d^{-1}) consumed for the initial three years was analysed as split-plot design. Main plots in this design were paddocks and these were physically arranged as a randomized complete block with blocks as strips of land sub-divided into paddocks. There were four pasture treatments and two paddocks per treatment in each block, thus eight paddocks per block. Sub-plots in this design were measurements taken in the different rotations (R), the effect of sex of calf (S) and monensin (M) treatment. Replication within treatment was used to test the main effects, using the general linear model procedure of SAS (1990). Data were collected from this experimental material over a three year period, so year affects and certain interaction of year with factors described above were included in the model. Block, year and interaction of other factors with block and year were considered random effects, all other effects were considered fixed.

The effect of monensin administration on the cows was included in the analysis for 1995 to 1997, however, in 1997 cows assigned to the monensin treatments were not balanced for sex of calf (12 cows with male calves were treated with monensin and only 4 cows with female calves were treated with monensin).

5.4 RESULTS AND DISCUSSION

5.4.1 Milk Energy and DMI

There were uniform groups of calves within each year, but the age and body weights varied from year to year (Table 16). Monensin ($P < 0.05$) had an effect on R1 milk NE_m (MJ

Table 16. Initial age, initial weight, average daily gain, age at milking 1 and milking 2 and estimated energy requirements for maintenance and growth for suckling calves pastured from 1995 to 1997, means ± standard deviations

	1995	1996	1997
Initial Age On Test, d	122 ± 12	74 ± 6	67 ± 8
Initial Weight, kg	138 ± 13.8	114 ± 9.2	96 ± 10.9
Average Daily Gain, kg d^{-1}	1.1 ± 0.11	1.1 ± 0.12	1.1 ± 0.12
Age Milking 1, d[x]	152 ± 12	111 ± 6	85 ± 8
Age Milking 2, d[y]	181 ± 12	155 ± 6	116 ± 8
Calf NE_m R1, MJ d^{-1}	17.4 ± 1.10	16.1 ± 0.87	13.9 ± 1.01
Calf NE_m R2, MJ d^{-1}	19.7 ± 1.16	19.6 ± 1.10	16.6 ± 1.13
Calf NE_g R1, MJ d^{-1}	9.6 ± 1.07	9.3 ± 1.22	8.7 ± 1.09
Calf NE_g R2, MJ d^{-1}	10.2 ± 1.14	10.2 ± 1.36	9.4 ± 1.22

[x]Dates of milking 1: July 13, 1995; July 22, 1996; June 23,1997.
[y]Dates of milking 2: August 11, 1995; September 4, 1996; July 24, 1997.

d^{-1}) intake. Monensin treated cows provided 9% more milk NE_m for calves than control cows (Table 17). For the latter part of the grazing season, R2, there was a pasture treatment by sex interaction (TxS) on milk NE_m (MJ d^{-1}) consumed ($P < 0.05$, Figure 5) as male calves on AU pastures consumed 4 MJ d^{-1} more than female calves, with no difference between male and female calves on the other pasture treatments.

Milk and forage energy values in past studies were given as digestible energy (Ansotegui et al. 1991; Bowden 1981), therefore, direct comparisons with previous studies and the current study was not possible. The use of energy balance equations to estimate TDMI was not used in any of the studies reviewed. However, Ansotegui et al. (1990) showed that milk contributed on average 53.5 % of the total DE intake for calves grazing native range between July and September in Montana. Milk contributed an average of 50.8 % of the total energy requirements for the calves in the current study.

The amount of MDMI measured in the current study is comparable to the milk organic matter intake measured by Grings et al. (1996) where the suckling calves consumed on average 0.9 kg OM d^{-1}. There was very little variation in MDMI between R1 and R2 in the current study, whereas Grings et al. (1996) found that the June and September average milk organic matter intakes were 1.0 and 0.7 kg OM d^{-1}, respectively. Milk DMI, % BW, was 0.6 and 0.4% in R1 and R2, respectively in the current study which was within the range of values found by Grings et al. (1996) who observed milk organic matter intakes of 1.0 and 0.3% calf BW in June and September, respectively.

5.4.2 Forage Energy and DMI

The amount of forage energy consumed for maintenance and growth is presented in

Table 17. Effect of pasture treatment (T), monensin controlled release capsule (M) and sex of calf (S) on milk dry matter intake (DMI) and the contribution of milk to meet net energy of maintenance (NE_m) and gain (NE_g) during three grazing seasons (1995-1997)

	Treatment (n=24)					Monensin (n=48)			Sex of Calf (n=48)					
Milk	AF	AU	GF	GU	SEM[x]	Yes	No	SEM	M	F	SEM	MxS	TxS	TxM
R1 NE_m, MJ d^{-1}	13.7	13.6	12.8	12.9	0.63	12.6[b]	13.9[a]	0.45	13.5	13.1	0.45	NS	NS	NS
R2 NE_m, MJ d^{-1}	13.4	13.0	13.5	12.3	0.60	13.3	12.8	0.55	13.2	12.9	0.55	NS	*	NS
R1 NE_g, MJ d^{-1}	2.5	2.5	2.8	2.3	0.39	3.0	2.1	0.54	2.5	2.6	0.54	NS	NS	NS
R2 NE_g, MJ d^{-1}	1.5	1.7	1.0	1.7	0.68	1.9	1.0	0.47	1.0	1.9	0.47	NS	NS	NS
R1 DMI, kg d^{-1}	0.9	0.9	0.9	0.8	0.05	0.9	0.9	0.05	0.9	0.9	0.05	NS	NS	NS
R2 DMI, kg d^{-1}	0.8	0.8	0.8	0.8	0.05	0.8	0.8	0.05	0.8	0.8	0.05	NS	0.07	NS
R1 DMI, %BW	0.6	0.6	0.6	0.6	0.03	0.6	0.6	0.03	0.6	0.6	0.03	NS	NS	NS
R2 DMI, %BW	0.4	0.5	0.4	0.4	0.03	0.5	0.4	0.03	0.4	0.5	0.03	NS	NS	NS

[a,b,c]Means within rows not having a common superscript differ ($P < 0.05$), Duncan's mean separation test was used.
[x]Average of standard errors.
NS= Not Significant, *$P < 0.05$. **$P < 0.01$. ***$P < 0.001$.

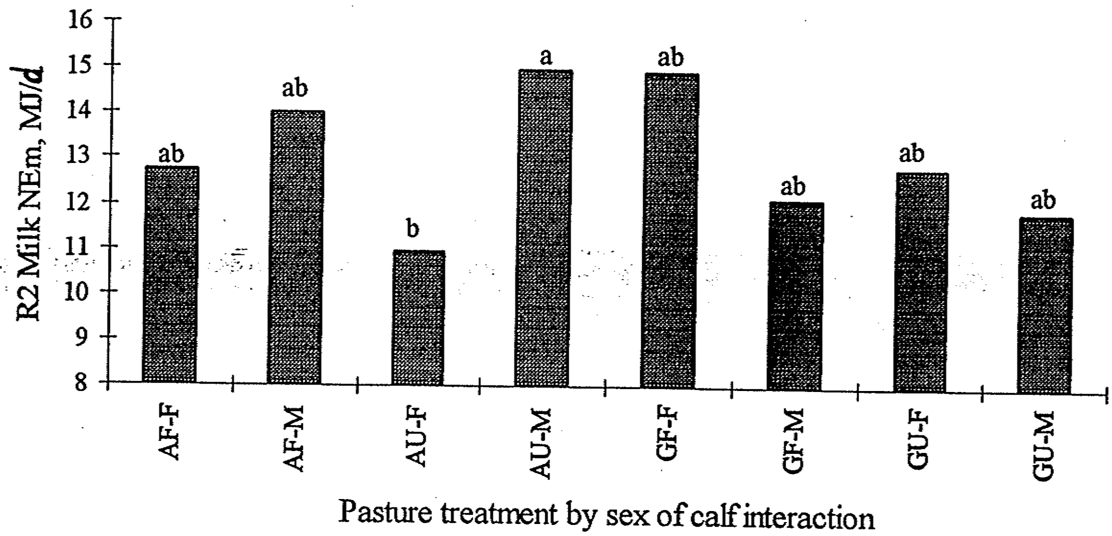


Figure 5. The effect of pasture treatment (T) by sex of calf (S) interaction on rotation two (R2) milk net energy of maintenance (NE_m, MJ d^{-1}) (n=12; SE = 1.05, $P < 0.01$)

Table 18. There was a treatment by sex (TxS) interaction for forage NE_m contribution ($P < 0.01$) in R2, with female calves on AU pastures receding 47% more MJ NE_m from forage than the male calves on that pasture treatment; all other TxS combinations had similar levels of NE_m contributed by the forage (Figure 6). This TxS interaction is the mirror image of the interaction seen in Figure 5. Since the amount of forage energy that is consumed is based on the amount of milk energy supplied these interactions are related. The mean milk fat % values for cows with female calves was 2.92 % when grazing AU pastures during R2, vs. 3.86 % for cows with male calves. As well the cows with male calves produced 1.3 kg more milk compared to the cows with females calves in the same pasture treatment during R2.

Fertilization of grass pastures and incorporation of alfalfa both resulted in lower ($P < 0.05$) forage DMI by suckling calves when grazing the initial growth, the ranking being GU>GF>AF=AU (Table 18). Calves grazing the GU pastures consumed 28% more forage DM when compared to calves on the other pasture treatments. Calf FDMI in this study was higher than intake values observed by Grings et al. (1996) but closer to the intake values recorded by Boggs et al. (1980) which averaged 3.5 kg d^{-1} during the later stages of the grazing season and by Bailey and Lawson (1981) who reported an average FDMI of 5.5 kg d^{-1} for calves weighing 175 kg (3.1 % BW). Boggs et al. (1980), who determined calf FDMI by administering chromic oxide as an external marker, found that FDMI as a % BW increased from 0.4 to 3.5 for Hereford calves grazing native range from April through September. The grazing seasons in the current study was much shorter in duration (Table 6, Manuscript 1).

Milk DMI ranged from 0.2 - 1.2 % BW and forage DMI ranged from 0 - 4.5 % BW

Table 18. Effect of pasture treatment (T), monensin controlled release capsule (M) and sex of calf (S) on the contribution of forage to meet net energy of maintenance and gain requirements and forage dry matter intake (DMI) during three grazing seasons (1995-1997)

	Treatment (n=24)					Monensin (n=48)			Sex of Calf (n=48)					
Forage	AF	AU	GF	GU	SEM[x]	Yes	No	SEM	M	F	SEM	MxS	TxS	TxM
R1 NE_m, kg d^{-1}	2.0	2.3	2.6	3.0	0.52	3.0	2.0	0.44	2.6	2.4	0.44	NS	NS	NS
R2 NE_m, kg d^{-1}	5.3	5.6	4.8	6.4	0.46	5.2	5.9	0.53	5.6	5.5	0.53	NS	**	NS
R1 NE_g, kg d^{-1}	6.5	6.4	6.1	7.0	0.32	6.3	6.7	0.34	6.4	6.6	0.34	NS	NS	NS
R2 NE_g, kg d^{-1}	8.3	8.0	7.7	7.3	0.49	7.8	7.9	0.28	8.1	7.5	0.28	NS	NS	NS
R1 DMI, kg d^{-1}	3.5^{c}	3.6^{c}	4.1^{b}	5.3^{a}	0.31	4.0	4.2	0.23	4.1	4.2	0.23	NS	NS	NS
R2 DMI, kg d^{-1}	4.6	4.7	4.9	5.1	0.40	4.7	5.0	0.22	5.1	4.6	0.22	NS	NS	NS
R1 DMI, %BW	2.2^{c}	2.3^{c}	2.6^{b}	3.3^{a}	0.20	2.5	2.7	0.17	2.5	2.7	0.17	NS	NS	0.10
R2 DMI, %BW	2.4^{b}	2.4^{b}	2.6^{a}	2.6^{a}	0.24	2.4	2.6	0.12	2.6	2.4	0.12	NS	NS	NS

[a,b,c]Means within rows not having a common superscript differ ($P < 0.05$), Duncan's mean separation test was used.

[x]Average of standard errors.

NS= Not Significant, *$P < 0.05$. **$P < 0.01$. ***$P < 0.001$.

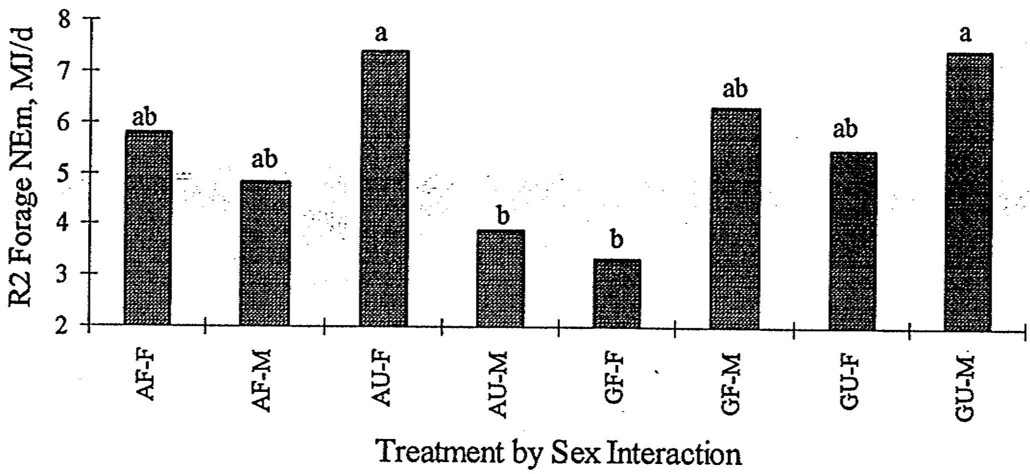


Figure 6. The effect of pasture treatment (T) by sex of calf (S) interaction on rotation two (R2) forage net energy of maintenance (NE_m) intake (MJ d^{-1}) (n=12; SE = 1.01, $P < 0.01$)

during the course of this study. Milk intake was a major factor influencing forage DMI (% BW, Figure 7) in this pasture study. For every 0.5 % unit decrease in MDMI (% BW), FDMI increased by 1.8 % units. This relationship was similar across pasture treatments. When comparison were made on the basis of kg d^{-1}, relationships were not as strong because calf age and size varied considerably from year to year.

5.4.3 Total DMI

Total DMI (TDMI, kg d^{-1}) is the sum of forage DMI (FDMI, kg d^{-1}) and milk DMI (MDMI kg d^{-1}). Suckling calves assigned to GU pastures had a 28% greater ($P < 0.05$) TDMI than calves assigned to AF and AU during R1. Total DMI by calves assigned to GF was intermediate. Although forage quality and availability was lower for GU pastures as compared to the other pasture treatments (Manuscript 1), the forage was suitable for calves to increase FDMI to meet their growth potential. The grass-legume pastures (AF and AU) had a higher energy density, therefore, the calves did not require as much forage DM as compared to the grass-only pastures (GF and GU). Total DMI, as a % BW, was affected by pasture treatment in the same manner as TDMI, kg d^{-1}, in that GU>GF>AU=AF ($P < 0.05$, Table 19).

The amount of milk produced by the cow will directly affect the amount of forage the calf with need to consume to meet the maintenance and tissue gain requirements. Ansotegui et al. (1991) found that the average total forage energy contribution from July to September (1984 to 1985) was 46.5% of the total DE intake by the calves on a foothill grassland near Bozeman, Montana. In the current study, forage energy intake contributed on average 49.2% of the total energy intake. Furthermore, the amount of energy per kg of forage (energy

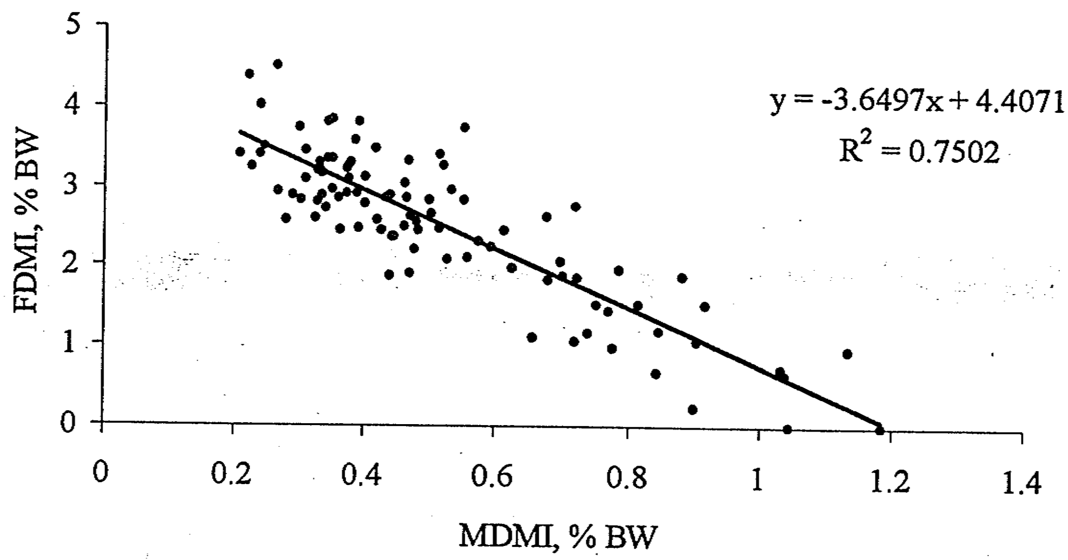


Figure 7. The relationship between calf forage dry matter intake (FDMI) and milk dry matter intake (MDMI) as a percentage of calf body weight (% BW)

Table 19. Effect pasture treatment (T), monensin controlled release capsule (M), and sex of calf (S) on calf total dry matter intake (forage plus milk DMI) during three grazing seasons (1995-1997)

	Treatment (n=24)					Monensin (n=48)			Sex of Calf (n=48)					
Total	AF	AU	GF	GU	SEM	Yes	No	SEM	M	F	SEM	MxS	TxS	TxM
R1 DMI, kg d^{-1}	4.3^{c}	4.5^{c}	5.0^{b}	6.1^{a}	0.28	4.9	5.1	0.20	5.0	5.0	0.20	NS	NS	NS
R2 DMI, kg d^{-1}	5.5	5.5	5.7	5.9	0.36	5.5	5.8	0.18	5.8	5.4	0.18	NS	NS	NS
R1 DMI, %BW	2.7^{c}	2.9^{c}	3.2^{b}	3.8^{a}	0.17	3.1	3.2	0.14	3.1	3.3	0.14	NS	NS	NS
R2 DMI, %BW	2.8	2.8	3.0	3.0	0.22	2.8	3.0	0.10	3.0	2.8	0.10	NS	NS	NS

^{a,b,c}Means within rows not having a common superscript differ ($P < 0.05$), Duncan's mean separation test was used.
^{x}Average of standard errors.

density of the forage, MJ kg d^{-1}) will affect the amount of forage the calf will need to consume to meet the energy deficiency incurred by decreasing milk production in the later stages of the grazing season.

Ansotegui et al. (1991) also pointed out that although the calves DE source differed from year to year, one year the calves consumed more of their total DE from grazed forage and the next year they received more of their DE from milk than from grazed forage, calf ADG and the amount of DE consumed was similar. This suggests that forage intake by suckling beef calves may not be solely regulated by rumen fill. Although forage quality and availability may be limited, as with the GU pastures in the current study, calves have the ability to select a diet that fulfills their requirements.

In a number of calf DMI studies (Grings et al. 1996; Ansotegui et al. 1991; Baker et al. 1976; Le Du et al. 1976) forage intake was determined by using total fecal collection of a representative sample of calves coupled with external markers such as sodium dichromate-mordanted fibre, or chromic oxide administered in gelatin capsules (Boggs et al. 1980) or as controlled release capsules (Grings et al. 1996). There are inherent limitations to all external marker techniques used to estimate forage intake, since no external marker fits all the criteria of an 'ideal marker' as defined by Merchen (1993). One may question the validity of using techniques developed to estimate the intake of high-fibre-low-digestibility diets to estimate forage intake while consuming milk, which is very digestible. How does the highly digestible milk affect the digestive kinetics of the external marker? Baker et al. (1976) and Le Du et al (1976) assumed that feeding milk and perennial ryegrass (*Lolium perenne*) together had no effect on the individually measured digestibilities of each dietary component. Other researchers, however, took steps to add a correction factor to their calculations of forage intake by suckling calves (Grings et al. 1996; Ansotequi et al. 1991). The above procedures involve a great deal of time and labour resources. Using energy balance equations to determine FDMI and MDMI appears to provide a good representation of what is occurring on pasture with much less effort.

Milk DMI is negatively correlated to the amount of forage DM the calf will ingest; as milk DMI increases, forage DMI decreases. It is evident that the grazing calf is more adaptable than originally presumed. It seems as though calves have a predetermined level of gain (kg d^{-1}) and consume only as much energy as required to meet that gain. All pasture treatments used in this study appear to have allowed calves to meet their growth potential. The highest milk yields were recorded during 1997, at this time calf forage DMI was at its lowest level. Similar ADG were recorded for all the years. The year-to-year variation in milk production and forage quality in this study had little effect on the calf's ability to select a diet to meet its nutritional requirements.

5.5 ACKNOWLEDGMENTS

The authors wish to thank and acknowledge the financial assistance provided by Provel/Elanco and the invaluable help of the technicians who collected the field data, Clayton Robins, Jim McGhee, Rusty Mussbacher, Cindy Rose, Barb Kristjanson, Dave Corrigan and Dr. Av Singh. The laboratory assistance of Janice Haines was also invaluable.

6.0 GENERAL DISCUSSION

Good pasture management which involves monitoring the overall maturity of the sward and achieving a short rotation length to ensure improved forage quality but still allowing sufficient rest period for the plants (Boyd et al. 2001), can be accomplished by rotational stocking. Furthermore, fertilizing grass-based pastures and incorporating a legume can have an impact on the success of cultivated grazing systems.

Pasture management is important but it is also important to properly manage the grazing animal. The administration of ionophores is one animal management strategy that can be used. Ionophores, such as monensin can help improve the productivity of cattle grazing low quality forages (Lemenager et al, 1978; Walker et al. 1980). Since most cow-calf operations are based on unfertilized grass pastures ionophores may be beneficial.

The research outlined in this thesis clearly indicates the value of alfalfa in a cultivated pasture. Identified plant or animal performance limitations during the four year trial did not occur on pastures that contained alfalfa.

6.1 FORAGE PRODUCTIVITY

The forage yield of the unfertilized alfalfa-grass pastures were similar to the fertilized pastures without incurring the high cost of fertilization. Fertilization of the grass-only pastures grown on fine sandy-loam soils, improved the DM yield by 39% and provided adequate nutrients for the grazing cow-calf pairs.

Carrying capacity measurements are more useful in evaluating pasture productivity than direct forage DM yields because CGD ha^{-1} takes into account how well a pasture is utilized since there is trampling and refusal of less palatable forage. The highest carrying capacities were seen in the fertilized pastures and the lowest carrying capacity was in the GU pastures. With the high cost of inorganic fertilizers, this study demonstrated that it is not economical to fertilize cultivated pastures, especially when precipitation is limiting. The fertilized pastures produced 38% more CGD ha^{-1} than the unfertilized grass pastures. Average fertilizer cost for each additional CGD ha^{-1} was $1.13 for the fertilized pastures. The unfertilized alfalfa-grass pastures produced 22% more CGD ha^{-1} than the unfertilized grass pastures, with no fertilization costs. Alternative sources of fertilizer can be used such as farmyard manure (Holt and Zentner 1985) and these sources are generally less expensive than inorganic fertilizers. Incorporation of a legume like alfalfa can also improve the quality and productivity of a pasture (Fairey 1991; Elliott 1969; Elliott et al. 1961). The bottom line is that the biggest increase in pasture productivity comes from fertilizing grass-based pastures. The smallest increase in productivity was from incorporating a legume in grass-based pastures. However, the most profitable fertility management practise is incorporation of a legume.

6.2 FORAGE QUALITY

Alfalfa-grass pastures had 3.1% units more CP than the grass-based pastures, based on analysis of clipped forage samples. Fertilization increased CP content of grass-based pastures an average of 3.7% units. When a combination of fertilizer and legume incorporation were used, the CP content increased 5.2% units compared to the unfertilized grass pastures. Low levels of CP in unfertilized grass pastures was a concern, since levels were below animal requirements. This problem was alleviated with fertilization and/or inclusion of a legume in the pasture.

The consumed forage CP concentrations were generally higher for the alfalfa-based pastures and the fertilized grass pastures than for the unfertilized grass pastures. The lowest levels of CP, % DM, consumed was in the unfertilized grass pastures. Fertilization of alfalfa-grass pastures did not improve consumed forage CP levels and the CP content of the GF and AU pastures were similar.

Fertilization of the grass-based pastures improved the nutrient density of the clipped samples, which reflected forage that was at a less mature, vegetative state with lower NDF and ADF concentrations than in unfertilized grass pastures. Including alfalfa in the pasture mix, reduced the NDF and ADF content of the clipped forage. Fertilization did not affect the ADF concentration in the alfalfa-grass pastures and resulted in a reduced level of ADF for most rotations in the grass-only pastures. Incorporation of a legume reduced the level of ADF in grass-only pastures more so than fertilization. The unfertilized alfalfa-grass pastures tended to have a less variable fibre content than the other pasture treatments.

Cattle had a greater opportunity to selected against NDF on the legume pastures compared to the grass-only pastures. High levels of NDF in the grass pastures could limit the DM intake by grazing animals as NDF is negatively correlated to intake potential of a forage (Fahey and Berger 1988). Of the four pasture treatments, unfertilized alfalfa-grass pastures had the most stable levels of NDF and AF had the largest NDF range (6.8% difference from the highest to lowest year NDF averages) therefore, animal intake estimates would be more consistent with unfertilized alfalfa-grass pastures throughout a variety of weather and environmental conditions.

The quality of the consumed forage in each pasture treatment was similar to the quality of the clipped forage samples. Fertilization and legume incorporation strategies improved the clipped and consumed forage CP content. The NDF concentration of the clipped samples was lowered with fertilization, however, the greatest improvement was observed with the addition of a legume. The advantage of fertilization was not apparent in consumed forage samples. Effect of pasture treatment on the ADF levels of consumed forage samples followed a different pattern than for the clipped samples. Only legume incorporation plus fertilization resulted in a significantly lower forage ADF content relative to GU pastures. In general, fertilization and legume incorporation strategies clearly improved the clipped forage quality but the benefit of fertilization was only apparent for CP when evaluating forage actually consumed by the grazing animal.

6.3 COW PRODUCTIVITY

The 'put and take' stocking system resulted in similar forage availability across pasture treatments, thus any differences in animal performance were due to forage quality or administration of a monensin controlled release capsule. Forage quality was influenced by fertilization, incorporation of a legume or by a combination of fertilization and legume incorporation to grass-based pastures.

Fertilization and legume incorporation strategies did not have an effect on cow DMI (% BW), milk yield or composition ($P > 0.05$). Although monensin decreased cow DMI, cow ADG was not compromised for the monensin treated cows grazing the unfertilized pastures. Monensin had no benefit when pastures were fertilized. Many studies have reported a positive effect on cow feed efficiency with monensin (Baile et al. 1982; Walker et al. 1980;

Lemenager et al. 1978). Cows treated with monensin had a more variable milk yield and milk fat content across years than the control cows. In dairy cow studies, monensin also had variable effects on milk fat content. Some studies show little or no effect (Hayes et al. 1996) while others show a reduction in milk fat (Van Der Werf et al. 1998; Abe et al. 1994).

There was a positive linear relationship between the ADG and SUN level of cows that grazed the unfertilized grass pastures (Appendix 19; $y = 0.21x - 0.58$, $P < 0.01$). Serum urea nitrogen levels explained 36% of the variation in cow ADG over three years. When all of the pasture treatments were evaluated together, the level of SUN explained only 18% of the variation in cow ADG (Appendix 20; $y = 0.06x - 0.31$). There were periods with high plant CP levels but the lactating cows could not maintain a linear increase in gain. The relationship was significant ($P < 0.001$) but had a large coefficient of variation (cv = 11388). Although there was a limited amount of SUN data collected during this research, it was evident that evaluating the levels of SUN throughout the grazing season monitors the protein status of the cow and could be especially useful when cows are grazing low quality pastures. However, further research should be conducted to confirm the maximum and minimum values of SUN that can sustain viable beef cow productivity.

6.4 CALF PRODUCTIVITY

Calves on alfalfa-grass pastures gained 59.5 g d^{-1} more than calves on the GU pastures ($P < 0.05$). Fertilization did not result in improved calf ADG. Sex of calf had an effect on ADG ($P < 0.01$), male calves gained on average 62 g d^{-1} more than female calves. Fertilizing the grass-based pastures (GF) produced 44 kg calf weight gain ha^{-1} more than the GU pastures, reflecting the higher carrying capacity of the GF pastures.

The calves pastured on the GU treatment had the highest level of FDMI. This was mainly due to the lower energy density of the consumed grass, since cow average milk production and composition was not affected by pasture treatment. The amount of milk produced by the cow directly affected the amount of forage the calf consumed. As the grazing season progressed milk production declined and the calf consumed more forage (Grings et al. 1996; Boggs et al. 1980). Even thought the calf's main energy source may vary (milk energy vs. forage energy) the calf has the ability to select a diet that maintains similar gains (Ansotegui et al. 1991) across years and treatments.

A good indication of calf DMI on pasture can be determined by using energy balance equations without the intensive work required for direct measurements. However, in the future the equations used in this study should be validated by direct measurements of all the parameters estimated (consumed forage energy, milk energy, energy of gain, energy of calf grazing, calf intake using external marker methods).

6.5 CONCLUSION

The yearly variations of environmental temperature and precipitation had an effect on all parameters measured including the quality of clipped and consumed forage samples, cow-calf DMI, cow-calf ADG and milk yield. Of the management strategies tested, the one that was most consistent and thus merits a recommendation for use by producers was the incorporation of a legume into grass-based pastures (AU). However, fertilizing grass-based pastures also showed consistent forage production (even during drought conditions) and with substantial calf gains per hectare.

Calf productivity was improved by fertilization and by including alfalfa in the pastures.

Whether it is cost effective to fertilize grass-based pastures or use a combination of fertilization and incorporation of a legume, revolves around the cost of fertilizer versus the value of calves. The bottom line is that the biggest increase in productivity comes from fertilizing the grass-based pastures (GF). The smallest increase in productivity comes from incorporating a legume into grass-based pastures (AU). However, the most profitable fertility management practise is the incorporation of a legume. The most 'ideal' forage is alfalfa, and meadow bromegrass has emerged as a good complement to alfalfa.

7.0 LITERATURE CITED

Abe, N., Lean, I. J., Rabiee, A., Porter, J. and Graham, C. 1994. Effects of sodium monensin on reproductive performance of dairy cattle. II. Effects on metabolites in plasma, resumption of ovarian cyclicity and oestrus in lactating cows. Aust. Vet. J. 71:277-281.

Adams, D.C., Staigmiller, R.B., Knapp, B.W. and Lamb, J.B. 1993. Native or seeded rangeland for cows with high or low milk production. J. Range Manage. 46:474-478.

Allen, C.L. and Entz, M.H. 1994. Zero-tillage establishment of alfalfa and meadow bromegrass as influenced by previous annual grain crop. Can. J. Plant Sci. 74:521-529.

Ansotegui, R.P., Havstad, K.M., Wallace, J.D. and Hallford, D.M. 1991. Effects of milk intake on forage intake and performance of suckling range calves. J. Anim. Sci. 69:899-904.

Association of Official Analytical Chemists. 1990. Official methods of analysis. 15th ed. AOAC. Washington, DC.

Baile, C.A., McLauglin,C.L. Chulupa, W.V., Snyder, D.L., Pendlum, LC. and Potter, E.L. 1982. Effects of monensin fed to replacement dairy heifers during the growing and gestation period upon growth reproduction, and subsequent lactation. J. Dairy Sci. 65:1941-1944.

Bailey, C.B. and Lawson, J.E. 1981. Estimated water and forage intakes in nursing range calves. Can. J. Anim. Sci. 61:415-421.

Balph, D.F., Balph, M.H. and Malechek, J.C. 1989. Cues cattle use to avoid stepping on crested wheatgrass tussocks. J. Range Manage. 42:376-377.

Barlow, R., Ellis, K.J., Williamson, P.J., Costigan, P. and Stephenson, P.D. 1988. Dry matter intake of Hereford and first-cross cows measured by controlled release of chromic oxide on three pasture systems. J. Agric. Sci. 110:217-231.

Barnes, D.K., Goplen, B.P. and Baylor, J.E. 1988. Highlights in the U.S.A. and Canada. In: A.A. Hanson, D.K. Barnes and R.R. Hill eds., Alfalfa and Alfalfa Improvement. Agronomy 29:1-4.

Baron, V.S. and Entz, M.H. 2000. Role of annual forage in ruminant feeding systems. Forage-Ruminant Workshop Proceedings of the Symposium, Winnipeg, Manitoba, July 20-21, 2000. Eastern Forage Ruminant Network, Western Region Forage/Beef Network. Pp. 160.

Beckett, S., Lean, I., Dyson, R., Tranter, W. and Wade, L. 1998. Effects of monensin on the reproduction, health, and milk production of dairy cows. J. Dairy Sci. 81:1563-1573.

Berdahl, J.D., Karn, J.F. and Hendrickson, J.R. 2001. Dry matter yields of cool-season grass monocultures and grass-alfalfa binary mixtures. Agon. J. 93:463-467.

Berg, B.P., Majak, W., McAllister, T.A., Hall, J.W., McCartney, D., Coulman, B.E., Goplen, B.P., Acharya, S.N., Tait, R.M. and Cheng, K.-J. 2000. Bloat in cattle grazing alfalfa cultivars selected for a low initial rate of digestion: a review. Can. J. Plant Sci. 80:493-502.

Bergen, W.G. and Bates, D.B. 1984. Ionophores: their effect on production efficiency and mode of action. J. Anim. Sci. 58:1465-1483.

Bittman, S., Waddington, J. and McCartney, D.H. 1991. Performance of alfalfa strains grown in mixture with smooth bromegrass as affected by management. Can. J. Plant Sci. 71:1029-1037.

Boggs, D.L., Smith, E.F., Schalles, R.R., Brent, B.E., Corah, L.R. and Pruitt, R.J. 1980. Effects of milk and forage intake on calf performance. J. Anim. Sci. 51:550-553.

Bolton, J.L. 1962. Alfalfa: botany, cultivation, and utilization. Interscience Publishers, New York, NY.

Bowden, D.M. 1981. Feed utilization for calf production in the first lactation by 2-year old F_1 crossbred beef cows. J. Anim. Sci. 51:304-315.

Boyd, N.S., Astatkie, T., Fredeen, A.H. and Martin, R.C. 2001. Rotationally stocked beef cattle responses to daily and weekly residence. J. Range Manage. 54:39-43.

Boyd, J.W. 1984. The interpretation of serum biochemistry test results in domestic animals. Veterinary Clinical Pathology, Veterinary Practice Publishing Co. Vol. XII, No. II.

Brown, P.W. and Tanner, C.B. 1983. Alfalfa stem and leaf growth during water stress. Agron. J. 75:799-804.

Bula, R.J. and Massengale, M.A. 1972. Environmental Physiology. In: C.H. Hanson ed. Alfalfa Science and Technology. American Society of Agronomy, Inc. Publisher, Madison WI. Pp. 167-184.

Butson, S. and Berg, R.T. 1984. Factors influencing lactation performance of range beef and dairy-beef cows. Can. J. Anim. Sci. 64:267-277.

Buxton, D.R., and Casler, M.D. 1993. Environmental and genetic effects on cell wall composition and digestibility. In H.G. Jung, D.R. Buxton, R.D. Hatfield, and J. Ralph (ed.) Forage cell wall structure and digestibility. ASA-CSSA-SSSA. Madison, WI. Pp.685-714.

Campbell, C.A., Zenter, R.P., Janzen, H.H. and Bowren, K.E. 1990. Crop rotation studies on the Canadian prairies. Agric Can. Publ. 1841/E. Supply and Services Canada, Ottawa, Ontario.

Campbell, C.A., Leyshon, A.J., Ukrainetz, H. and Zentner, R.P. 1986. Time of application and source of nitrogen fertilizer on yield, quality, nitrogen recovery, and net returns for dryland forage grasses. Can. J. Plant Sci. 66:915-931.

Carlson, I.T. and Newall, L.C. 1985. Smooth bromegrass. In: M.E. Heath et al. eds. Forages: The science of grassland agriculture. 4th ed. Iowa State Univ. Press, Ames, Iowa. Pp. 198-206.

Carter, P.R. and Sheaffer, C.C. 1983. Alfalfa response to soil water deficits: I. Growth, forage quality, yield, water use and water-use efficiency. Crop Sci. 23:669-675.

Casler, M.D., West, D.C. and Undersander, D.J. 1999. Establishment of temperate pasture species into alfalfa by frost-seeding. Agron. J. 91:916-921.

Casler, M.D. and Walgenbach, R.P. 1990. Ground cover potential of forage grass cultivars mixed with alfalfa at divergent locations. Crop Sci. 30:825-831.

Chen, W., McCaughey, W.P., Grant, C.A. and Bailey, L.D. 2001. Pasture-type and fertilization effects on soil chemical properties and nutrient redistribution. Can. J. Soil Sci. 81:395-404.

Chenette, C.G. and Frahm, R.R. 1981. Yield and composition of milk from various two-breed cross cows. J. Anim. Sci. 52:483-492.

Cherney, D.J.R., Cherney, J.H. and Pell, A.N. 1994. Inorganic nitrogen supply effects on alfalfa forage quality. J. Dairy Sci. 77:230-236.

Christian, K.R. 1987. Matching pasture production and animal requirements. In: J.L.Wheeler, C.J. Pearson and G.E. Robards eds. Temperate pastures: their production, use and management. Scientific and Industrial Research Organization Technical Publication, Austrailia. Pp. 463-476.

Clanton, D.C., England, M.E. and Parrott III, J.C. 1981. Effect of monensin on efficiency of production in beef cows. J. Anim. Sci. 53:873-880.

Cochran, V.L., Elliott, L.F. and Papendick, R.I. 1977. The production of phytotoxins from surface crop residues (spread over bare soil, phytotoxicity problems with no-till planting of winter wheat). J. Soil Sci. Soc. Am. 5:903-908.

Cohen, R.D.H. 1979. Factors influencing the estimation of the nutritive value of the diet selected by cattle fistulated at the esophagus. J. Agric. Sci. Camb. 93:607-611.

Coleman, S.W. 1992. Plant-animal interface. J. Prod. Agric. 5:7-13.

Cooper, J.P. 1973. Genetic variation in herbage constituents In: G.W. Butler and R.W. Bailey eds. Chemistry and biochemistry of herbage. London and New York Academic Press. Pp. 379-417.

Cooper, C.S. 1967. Relative growth of alfalfa and birdsfoot trefoil seedlings under low light intensity. Crop Sci. 7:176-178.

Coors, J.G., Lowe, C.C. and Murphy, R.P. 1986. Selection for improved nutritional quality of alfalfa forage. Crop Sci. 26:843-848.

Corbett, J.L. 1987. Energy and protein utilization by grazing animals. In: J.L. Wheeler, C.J. Pearson and G.E. Robards eds. Temperate pastures: their production, use and management. Commonwealth Scientific and Industrial Research Organization, Australia. Pp. 341-355.

Coulman, B., Goplen, B., Majak, W., McAllister, T., Cheng, K.-J., Berg, B., Hall, J., McCartney, D. and Acharya, S. 2000. A review of the development of a bloat-reduced alfalfa cultivar. Can. J. Plant Sci. 80:487-491.

Curll, M.L. and Jones, R.M. 1989. The plant-animal interface and legume persistence- An Australian perspective In: G.C. Martens, A.G. Matches, R.F. Barnes, R.W. Brougham, R.J. Clements and G.W. Sheath eds. Persistence of Forage Legumes. Madison, WI. American Society of Agronomy; Crop Science Society of America; Soil Science Society of America. Pp. 339-369.

Curran, B.S., Kephart, K.D. and Twidwell, E.K. 1993. Oat companion crop management in alfalfa establishment. Agron. J. 85:998-1003.

Donald, C.M. 1963. Competition among crop and pasture plants. Adv. Agron. 15:1-18.

Dougherty, C.T. and Rhyderd, C.L. 1985. The role of nitrogen in forage-animal production. In: M.E. Heath, et al. eds. Forages. The science of grassland agriculture. Iowa State Univ. Press, Ames. Pp.318-325.

Douglas, J.A. 1986. The production and utilization of lucerne in New Zealand. Grass Forage Sci. 41:81-128.

Dubbs, A.L. 1971. Competition between grass and legume species on dryland. Agron. J. 63:359-362.

Ehrlich, W.A., Poywer, E.A. and Pratt, L.E. 1957. Report of reconnaissance soil survey of Carberry map sheet area. Soils Report No. 7 Manitoba Dept. of Agric. and Immigration, Winnipeg, Manitoba.

Elizadle, J.C., Merchen, N.R. and Faulkner, D.B. 1999. Fractionation of fiber and crude protein in fresh forages during spring growth. J. Anim. Sci. 77:476-484.

Elliott, C.R. 1969. Dryland pasture in north-western Canada. In: K.F. Nielsen, ed. Canadian Forage Crops Symposium Proc., Edmonton, AB. Pp. 297-308.

Elliott, C.R., Anderson, C.H. and Owen, R. 1961. Studies with fertilized pastures on heavy textured soil in northern Alberta. Can. J. Plant Sci. 41:261-267.

Ensminger, M.E. and Perry, R.C. 1997. Beef cattle management. Chapter 10. In: M.E. Ensminger and R.C. Perry. Beef Cattle Science. Seventh Edition. Interstate Publishers, Inc. Danville, Illinois. Pp. 373-402.

Environment Canada 2001. Prairie econzones. www.ec.gc.ca/soer-ree/English/vignettes/Terrestrial/pr/land.cfm, website accessed August 20, 2001, 9:51 pm.

Ethridge, D.E., Nance, J.D. and Dahl, B.E. 1987. Integration of cattle production and marketing strategies with improved pastures and native range. J. Range Manage. 40:199-202.

Fahey, G.C. Jr. and Berger, L.L. 1988. Carbohydrate nutrition of ruminants. In: D.C. Church ed. The ruminant animal: Digestive physiology and nutrition. Prentice-Hall, Engelwood Cliffs, N.J. Pp. 269-297.

Fairey, N.A. 1991. Effects of nitrogen fertilizer, cutting frequency and companion legume on herbage production and quality of four grasses. Can. J. Plant Sci. 71:717-725.

Falkner, L.D. and Casler, M.D. 1998. Preference for smooth bromegrass clones is affected by divergent selection for nutritive value. Crop Sci. 38:690-695.

Farnham, D.E. and George, J.R. 1993. Dinitrogen fixation and nitrogen transfer among red clover cultivars. Can. J. Plant Sci. 73:1047-1054.

Forage and Grazing Terminology Committee. 1992. Terminology for grazing lands and grazing animals. J. Prod. Agric. 5:191-202.

Frame, J. 1975. A comparison of herbage production under cutting and grazing. In: J.

Hodgson and D.K. Jackson eds., Pasture utilization by the grazing animal. Hurley, UK: Occasional Symposium No. 8. British Grassland Society. pp. 39-49.

Fredeen, H.T., Weiss, G.M., Rahnefeld, G.W., Lawson, J.E. and Newman, J.A. 1988. Genotype x environment interactions for beef cow performance during lactation. Can. J. Anim. Sci. 68:619-636.

Goplen, B.P., Baenziger, H., Bailey, L.D., Gross, A.T.H., Hanna, M.R., Michaud, R., Richards, K.W. and Waddington, J. 1983. Growing and managing alfalfa in Canada. Agriculture Canada Publication 1705/E.

Grings, E.E., Short, R.E., MacNeil, M.D., Haferkamp, M.R. and Adams, D.C. 1996. Efficiency of production in cattle of two growth potentials on northern great plains rangelands during spring-summer grazing. J. Anim. Sci. 74: 2317-2326.

Halim, R.A., Buxton, D.R., Hattendorf, M.J. and Carlson, R.E. 1989. Water-stress effects on alfalfa forage quality after adjustment for maturity differences. Agron. J. 81:189-194.

Hall, R.D. and Wiesner, L.E. 1990. Relationship between seed vigor tests and field performance of 'Regar' meadow bromegrass. Crop Sci.30:967-970.

Hansen, L.H. and Krueger, C.R. 1973. Effect of establishment method, variety, and seeding rate on the production and quality of alfalfa under dryland and irrigation. Agron. J. 65:755-759.

Hart, R.H., Bissio, J., Samuel, M.J. and Waggoner, J.W. Jr. 1993. Grazing systems, pasture size and cattle grazing behavior, distribution and gains. J. Range Manage. 46:81-87.

Hart, R.H., Samuel, M.J., Test, P.S. and Smith, M.A. 1988a. Cattle, vegetation and economic responses to grazing systems and grazing pressure. J. Range Manage. 41:282-286.

Hart, R.H., Waggoner, J.W. Jr., Dunn, T.G., Kaltenbach, C.C. and Adams, L.D. 1988b. Optimal stocking rate for cow-calf enterprises on native range and complementary improved pastures. J. Range Manage. 41:435-441.

Hart, R.H. and Dean, J.G. 1986. Forage establishment: Weather effects on stubble vs. fallow and fall vs. spring seeding. J. Range Manage. 39:228-230.

Hayes, D.P., Pfeiffer, D.W. and Williamson, N.B. 1996. Effect of intraruminal monensin capsules on reproductive performance and milk production of dairy cows. J. Dairy Sci. 79:1000-1008.

Haynes, R.J. and Williams, P.H. 1993. Nutrient cycling and soil fertility in the grazed pasture ecosystem. Adv. Agron. 49:119-197.

Haynes, R.J. 1980. Competitive aspects of the grass-legume association. Adv. Agron. 33:227-262.

Heichel, G.H. and Henjum, K.I. 1991. Dinitrogen fixation, nitrogen transfer and productivity of forage legume-grass communities. Crop Sci.31:202-208.

Hodgson, J., Clark, D.A. and Mitchell, R.J. 1994. Foraging behaviour in grazing animals and its impact on plant communities. In: G.C. Fahey, L.E. Moser, D.R. Mertens and M. Collins eds. Forage quality, evaluation, and utilization. American Society of Agronomy; Crop Science Society of America; Soil Science Society of America. Madison, WI. Pp. 796-824.

Hodgson, J. 1990. Grazing management science into practice. John Wiley & Sons, Inc., New York, NY.

Hodgson, J. 1981. Testing and improvement of pasture species. In F.H.W. Morley ed., Grazing Animals. Elsevier Scientific Publishing Company. New York, NY. pp. 309-317.

Holt, N.W. and Jefferson, P.G. 1999. Productivity and sustainability of four grazed grass-alfalfa mixtures. Can. J. Anim. Sci. 79:83-89.

Holt, N.W. and Zentner, R.P. 1985. Effects of applying inorganic fertilizer and farmyard manure on forage production and economic returns in east-central Saskatchewan. Can. J. Plant Sci. 65:597-607.

Hoveland, C.S., Durham, R.G. and Bouton, J.H. 1995. Management effects on productivity of alfagraze alfalfa-tall fescue mixtures. J. Prod. Agric. 8:244-248.

Hoveland, C.S. 1992. Grazing systems for humid regions. J. Prod. Agric. 5:23-27.

International Feedstuffs Institute. 1997. Feed Composition Bank. National Agricultural Library, United States Department of Agriculture, Beltsville, MD. In: M.E. Ensminger, and R.C. Perry, Beef Cattle Science. Seventh Ed. Interstate Publisher, Inc. Danville, Illinois.

Irving, B.D., Rutledge, P.L., Bailey, A.W., Naeth, M.A. and Chanasyk, D.S. 1995. Grass utilization and grazing distribution within intensively managed fields in central Alberta. J. Range Manage. 48:358-361.

Jefferson, P.G. and Kielly, G.A. 1998. Reevaluation of row spacing/plant density of seeded pasture grasses for the semiarid prairie. Can. J. Plant Sci. 78:257-264.

Jefferson, P.G. and Zentner, R.P. 1994. Effect of an oat companion crop on irrigated alfalfa yield and economic returns in southwestern Saskatchewan. Can. J. Plant Sci. 74:465-470.

Joosse, D., McCaughey, W.P., Stewart, F. and Goodwin, V. A guide to management intensive grazing: Managing grazing for better results. Manitoba Agriculture Publication.

Kilcher, M.R. 1982. Beef production from grass-alfalfa pastures grown in different stand patterns in a semiarid region of the Canadian prairies. Can. J. Plant Sci. 62:117-124.

Kilcher, M.R., Heinrichs, D.H. and Lodge, R.W. 1976. Row spacings of Russian wildrye for fall pastures in southern Saskatchewan. J. Range Manage. 29:237-240.

Kilcher, M.R. and Heinrichs, D.H. 1966a. Persistence of alfalfas in mixture with grasses in a semiarid region. Can. J. Plant Sci. 46:163-167.

Kilcher, M.R. and Heinrichs, D.H. 1966b. Performance of some grass-alfalfa mixtures in southwestern Saskatchewan during drought years. Can. J. Plant Sci. 46:177-184.

Kilcher, M.R., Smoliak, S., Hubbard, W.A., Johnston, A., Gross, A.T.H. and McCurdy, E.V. 1965. Effects of inorganic nitrogen and phosphorus fertilizers on selected sites of native grassland in western Canada. Can. J. Plant Sci. 45:229-237.

Kleiber, M. 1975. The Fire of Life: An Introduction to Animal Energetics. Revised Edition. New York: Robert E. Krieger Publishing Co., Inc. Pp.41-59.

Knowles, R.P., Baron, V.S. and McCartney, D.H. 1993. Meadow bromegrass. Agric. Canada Publ. 1889/E. Communications Branch, Agric. Canada, Ottawa, ON.

Knowles, R.P. 1990. Registration of 'Paddock' meadow bromegrass. Crop Sci. 30:741.

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

Knowles, R.P. and Sonmor, L.G. 1985. Grasses for irrigated pasture in central Saskatchewan. Can J. Plant Sci. 65:455-458.

Kopp, J.C., McCaughey, W.P. and Wittenberg, K.M. Submitted for publication in the Can. J. Anim. Sci., May 2002. The use of fertilizer inputs versus legume incorporation for meadow bromegrass pastures.

Lana, R.P. and Russell, J.B. 1997. Effect of forage quality and monensin on the ruminal fermentation of fistulated cows fed continuously at a constant intake. J. Anim. Sci. 75:224-229.

Lanini, W.T., Orloff, S.B., Vargas, R.N., Orr, J.P., Marble, V.L. and Grattan, S.R. 1991. Oat companion crop seeding rate effect on alfalfa establishment, yield and weed control. Agron. J. 83:330-333.

Lawrence, T and Dyck, F.B.A. 1990. A comparison of two furrow opener-depth control assemblies for seeding forage grasses. J. Range Manage. 43:82-83.

Lawrence, T. 1977. An evaluation of thirty grass populations as forage crops for south-western Saskatchewan. Can. J. Plant Sci. 58:107-115.

Lawrence, T. and Heinrichs, D.H. 1968. Long-term effects of row spacing and fertilizer on the productivity of Russian wild ryegrass. Can. J. Plant Sci. 48:75-84.

Ledgard, S.F. and Steele, K.W. 1992. Biological nitrogen fixation in mixed legume/grass pastures. Dev. Plant Soil Sci. 49:137-153.

Lee, C. and Smith, D. 1972. Influence of nitrogen fertilizer on stands, yields of herbage and protein and nitrogenous fractions of field-grown alfalfa. Agron. J. 64:527-530.

Lemenager, R.P., Owens, F.N., Lusby, K.S. and Totusek, R. 1978. Monensin, forage intake and lactation of range beef cows. J. Anim. Sci. 47:247-254.

Leyshon, A.J., Cutforth, H., Waddington, J. and Rymes, P.C. 1990. Effect of row spacing on biomass production and aboveground harvestability of Russian wildrye. Can. J. Plant Sci. 70:555-558.

Leyshon, A.J., Kilcher, M.R. and McElgunn, J.D. 1981. Seeding rates and row spacings for three forage crops grown alone or in alternate grass-alfalfa rows in southwestern Saskatchewan. Can. J. Plant Sci. 61:711-717.

Loewen-Rudgers, L.A., McGill, K, Fehr, P., Racz, G.J., Ridley, A.O. and Soper, R.C. 1977. Soil fertility and fertilizer practices. In: Manitoba Soils and Their Management. Reprinted by Manitoba Department of Agriculture from: Principles and Practices of Commercial Farming. Faculty of Agriculture, University of Manitoba, Winnipeg, Manitoba. Pp. 61-89.

Lowe, L.B., Ball, G.J., Carruthers, V.R., Dobos, R.C., Lynch, G.A., Moate, P.J., Poole, P.R. and Valentine, S.C. 1991. Monensin controlled-release intraruminal capsule for the control of bloat in pastured cows. Aust. Vet. J. 68:17-20 .

Majak, W., Hall, J.W. and McCaughey, W.P. 1995. Reducing the risk of legume bloat. J. Anim. Sci. 73:1493-1497.

Malhi, S.S., Heier, K., Zhang, M. and Nyborg, M. 1998. Meadow bromegrass response to coated and conventional urea fertilizers. Can. J. Plant Sci. 78:589-595.

Malik, N. 1991. Meadow bromegrass and crested wheatgrass forage yield response to herbicides applied during establishment. J. Prod. Agric. 4:508-515.

Manitoba Agriculture and Food. 2000. Manitoba Agriculture and Food home page. Available at: http://www.gov.mb.ca/agricultrue/soil/water/soilfert/fbd02s09.html. Accessed Aug. 17, 2000.

Mapfumo, E., Chanasyk, D.S., Baron, V.S. and Naeth, M.A. 2000. Grazing impacts on selected soil parameters under short-term forage sequences. J. Range Manage. 53:466-470.

Marshall, S.A., Campbell, C.P. and Buchanan-Smith, J.G. 1998a. Seasonal changes in quality and botanical composition of a rotationally grazed grass-legume pasture in southern Ontario. Can. J. Anim. Sci. 78:205-210.

Marshall, S.A., Campbell, C.P. and Buchanan-Smith, J.G. 1998b. Herbage biomass and intake of beef cows with calves grazing a grass legume pasture in southern Ontario. Can. J. Anim. Sci. 78:211-218.

Matches, A.G. 1992. Plant response to grazing: a review. J. Prod. Agric. 5:1-6.

Matches, A.G., Thompson, G.B., Martz, F.A. 1975. Post-establishment harvesting and management systems for forages. Missouri Agricultural Experiment Station Journal Series No. 7371.

McCartney, D.H., Waddington, J. and Lefkovitch, L.P. 1999. Animal and plant response on renovated pastures in western Canada. J. Range Mange. 52:19-26.

McCartney, D.H. 1998. Annual for grazing. Proceedings from the Manitoba Grazing School Profit from Pasture. December 8-9, 1998, Winnipeg, Manitoba. Published by Manitoba Agriculture.

McCaughey, W.P. and Simons, R.G. 1998. Harvest management and N-fertilization effects on protein yield, protein content and nitrogen use efficiency of smooth bromegrass, crested wheatgrass and meadow bromegrass. Can. J. Plant Sci. 78:281-287.

McCaughey, W.P. and Simons, R.G. 1996. Harvest management and N-fertilization effects on yield and regrowth of smooth bromegrass, crested wheatgrass, and meadow bromegrass in the eastern prairies. Can. J. Plant Sci. 76:773-782.

McMahon, L.R., McAllister, T.A., Berg, B.P., Majak, W., Acharya, S.N., Popp, J.D.,

Coulman, B.E., Wang, Y and Cheng, K.-J. 2000. A review of the effects of forage condensed tannins on ruminant fermentation and bloat in grazing cattle. Can. J. Plant Sci. 80:469-485.

Merchen, N.R. 1993. Digestion, absorption and excretion in ruminants. Chapter 9 In: D.C. Church ed. The Ruminant Animal: Digestive Physiology and Nutrition. Waveland Press Inc., Prospect Heights, Illinois. Pp. 172-201.

Moyer, J.R., Cole, D.E., Maurice, D.C. and Darwent, A.L. 1995. Companion crop, herbicide and weed effects on establishment and yields of alfalfa-bromegrass mixture. Can. J. Plant Sci. 75:121-127.

Murphy, B. 1987. Greener pastures on your side of the fence. Arriba Publishing. Colchester, VT. 215 pp.

National Research Council, 2001. Nutrient requirements of dairy cattle. Chapter 10. Nutrient requirements of the young calf. Seventh Revised Edition. National Academy Press.Washington, D.C. Pp. 225-226.

National Research Council, 1996. Nutrient requirements of beef cattle. Seventh Revised Edition. National Academy Press. Washington, D.C.

National Research Council. 1989. Nutrient requirements of dairy cattle. Sixth Revised Edition. National Academy Press. Washington, D.C.

National Research Council, 1984. Nutrient requirements of beef cattle. Sixth Edition. National Academy Press. Washington, D.C.

National Research Council. 1978. Nutrient requirements of dairy cattle. Fifth Revised Edition. National Academy Press Washington, D.C. Pp. 76.

Nichols, J.T. 1989. Range, plus complementary forages for beef cattle production. In: Proc. Amer. Forage and Grassland Congr. Univ. Guelph, Ontario, Canada. Pp. 196-203.

Nichols, J.T and Johnson, J.R. 1969. Range productivity as influenced by biennial sweet clover in western South Dakota. J. Range Manage. 22:342-347.

Nielsen, R.L., Stuthman, D.D. and Barnes, D.K. 1981. Interference between oats and alfalfa in mixed seedings. Agron. J. 73:635-638.

Norwest Labs. 1994. Agricultural Feed Reference Chart. Main Office and Lab, 9938-67 Ave. Edmonton, AB, T6E 0P5 (1-800-661-7645).

Nuttall, W.F., Cooke, D.A., Waddington, J. and Robertson, J.A. 1980. Effect of nitrogen and phosphorus fertilizers on a bromegrass and alfalfa mixture grown under two systems of pasture management. I. Yield, percentage legume in sward, and soil tests. Agron. J. 72:289:298.

Nyren, P.E., Whitman, W.C., Nelson, J.L. and Conlon, T.J. 1983. Evaluation of a fertilized 3-pasture system grazed by yearling steers. J. Range Manage. 36:354-362.

Owens, L.B., Edwards, W.M. and Van Keuren, R.W. 1994. Groundwater nitrate levels under fertilized grass and grass-legume pastures. J. Environ. Qual. 23:752-758.

Parks, J.R. 1982. A Theory of Feeding and Growth of Animals. Advanced Series in Agricultural Sciences; II. Springer-Verlag Berlin Heidelberg, Germany. Pp.243-312.

Pearen, J.R. and Baron, V.S. 1996. Productivity, and composition of smooth and meadow bromegrass mixtures with alfalfa under frequent cutting management. Can. J. Plant Sci. 76:763-771.

Pearen, J.R., Baron, V.S. and Cowan, I.W. 1995. Productivity and composition of bromegrass alfalfa mixtures for hay in the Aspen Parklands of western Canada. Can. J. Plant Sci. 75:429-436.

Peterson, P.R. and Gerrish, J.R. 1995. Grazing management affects manure distribution by beef cattle. Proc. Amer. For. Grassl. Counc. 4:170-174.

Peterson, R.G., Woodhouse, W.W.-Jr. and Lucas, H.L. 1956. The distribution of excreta by freely grazing cattle and its effect on pasture fertility: Effect of returned excreta on the residual concentration of some fertilizer elements. Agron. J. 48:444-449.

Popp, J.D., McCaughey, W.P., Cohen, R.D.H., McAllister, T.A. and Majak, W. 2000. Enhancing pasture productivity with alfalfa: a review. Can. J. Plant Sci. 80:513-519.

Popp, J.D., McCaughey, W.P. and Cohen, R.D.H. 1997a. Effect of grazing system, stocking rate and season of use on diet quality and herbage availability of alfalfa-grass pastures. Can. J. Anim. Sci. 77:111-118.

Popp, J.D., McCaughey, W.P. and Cohen, R.D.H. 1997b. Effect of grazing system, stocking rate and season of use on herbage intake and grazing behaviour of stocker cattle grazing alfalfa-grass pasture. Can. J. Anim. Sci. 77:677-682.

Popp, J.D., McCaughey, W.P. and Cohen, R.D.H. 1997c. Grazing system and stocking rate effects on the productivity, botanical composition and soil surface characteristics of alfalfa-grass pastures. Can. J. Anim. Sci. 77:669-676.

Poppi, D.P., Minson, D.J. and Ternouth, J.H. 1981. Studies of cattle and sheep eating leaf fractions of grasses III. The retention of time in the rumen of large feed particles. Aust. J. Agric. Res. 32:123-137.

Ramanzin, M. L., Bailoni, L., Schiavon, S. and Bittante, G. 1997. Effect of monensin on milk production and efficiency of dairy cows fed two diets differing in forage to concentrate ratios. J. Dairy Sci. 80:1136-1142.

Rehm, G.W., Sheaffer, C.C., Martin, N.P. and Becker, R.L. 1998. Methods for establishing legumes on sandy soils. J. Prod. Agri. 11:108-112.

Reid, R.L. and Jung, G.A. 1982. Problems of animal production from temperate pastures. In: Nutritional Limits to Animal Production from Pastures - Proceedings of an International Symposium held at St. Lucia, Queensland, Australia. August 24-28th, 1981. Pp. 21-43.

Reuss, J.O. and Innis, G.S. 1977. A grassland nitrogen flow simulation model. Ecology 58:379-388.

Rice, W.A. and Hoyt, P.B. 1980. Crop rotations: the role of legumes. In: Section E, NRG Publication 80-2 Agriculture Canada Research Station, Beaverlodge, Alberta. Pp. 1-8.

Roseler, D.K., Ferguson, J.D., Sniffen, C.J. and Herrema, J. 1993. Dietary protein degradability effects on plasma and milk urea nitrogen and milk nonprotein nitrogen in Holstein cows. J. Dairy Sci. 76:525-534.

Russelle, M.P. 1992. Nitrogen cycling in pasture and range. J. Prod. Agric.5:13-23.

SAS Institute Inc. 1990. SAS/STAT User's Guide. Version 6. Fourth Edition. Volume 2. SAS Institute Inc. Cary, NC.

Saskatchewan Agriculture and Food. 2000. Saskatchewan pastures program. Available at: http://www.agr.gov.sk.ca/DOCS/CR.../pasturefees.asp. Accessed Aug. 21, 2000.

Saskatchewan Agriculture. 1987. Guide to farm practice in Saskatchewan. Saskatchewan Agriculture, Regina Sk. 240 pp.

Savory, A. and Parsons, S.D. 1980. The Savory grazing method. Rangelands 2:234-237.

Schellenberg, M.P., Waddington, J. and King, J.R. 1994a. Sod-seeding alfalfa in spring into established crested wheatgrass in southwest Saskatchewan. Can. J. Plant Sci. 74:293-301.

Schellenberg, M.P., Waddington, J. and King, J.R. 1994b. Direct seeding of alfalfa into established Russian wildrye pasture in southwest Saskatchewan. Can. J. Plant Sci. 74:539-542.

Scholefield, D. and Hall, D.M. 1985. A method to measure the susceptibility of pasture soils to poaching by cattle. Soil Use Manage. 1:134-138.

Sheaffer, C.C., Mathison, R.D., Martin, N.P., Rabas, D.L., Ford, H.J. and Swanson, D.R. 1993. Forage legumes. Minnesota Agric. Exp. Stn. Bull. 597.

Sheaffer, C.C., Wyse, D.L., Marten, G.C. and Westra, P.H. 1990. The potential of quackgrass for forage production. J. Prod. Agri. 3:256-259.

Sheard, R.W. 1974. Nitrogen enhancement of surface applied fertilizer P uptake by forage species. Can. J. Soil. Sci. 54:89-95z.

Simmons, S.R., Sheaffer, C.C., Rasmusson, D.C., Stuthman, D.D. and Nickel, S.E. 1995. Alfalfa establishment with barley and oat companion crops differing in stature. Agron. J. 87:268-272.

Singh, A. 2000. Alfalfa Response to Grazing: Cultivar Evaluation and Visual Modelling. Ph.D. Thesis University of Manitoba, Winnipeg, Manitoba.

Sletmoen-Olson, K.E., Caton, J.S., Olson, K.C. and Reynolds, L.P. 2000a. Undegraded intake protein supplementation: I. Effects on forage utilization and performance of periparturient beef cows fed low-quality hay. J. Anim. Sci. 2000. 78:449-455.

Sletmoen-Olson, K.E., Caton, J.S., Olson, K.C., Redmer, D.A., Kirsch, J.D. and Reynolds, L.P. 2000b. Undegraded intake protein supplementation. II. Effects of plasma hormone and metabolite concentrations in periparturient beef cows fed low-quality hay during gestation and lactation. J. Anim. Sci. 78:456-463.

Smith, S.R.-Jr., Bouton J.H., Singh, A. and McCaughey, W.P. 2000. Development and evaluation of grazing-tolerant alfalfa cultivars: A review. Can. J. Plant Sci. 80:503-512.

Smith, R.R. and Kretschmer, A.E. 1989. Breeding and genetics of legume persistence In: G.C. Martens, A.G. Matches, R.F. Barnes, R.W. Brougham, R.J. Clements and G.W. Sheath eds. Persistence of Forage Legumes. Madison, WI. American Society of Agronomy; Crop Science Society of America; Soil Science Society of America. Pp. 541-552.

Smith, S.R.-Jr., Bouton J.H. and Hoveland, C.S. 1992. Persistence of alfalfa under continuous grazing in pure stands and in mixtures with tall fescue. Crop Sci. 32:1259-1264.

Smith, S.R.-Jr., Bouton, J.H. and Hoveland, C.S. 1989. Alfalfa persistence and regrowth potential under continuous grazing. Agron. J. 81:960-965.

Smoliak, S. 1992. Hay and pasture crops. In: Alberta Forage Manual. Print media Branch Alberta Agriculture, Edmonton, Alberta. Agdex 120/20-4. Pp. 7-37.

Sprott, L.R., Goehring, T.B., Beverly, J.R. and Corah, L.R. 1988. Effect of ionophores on cow herd production: a review. J. Anim. Sci. 66:1340-1346.

Staley, T.E., Stout, W.L. and Jung, G.A. 1991. Nitrogen use by tall fescue and swtichgrass established on acidic soils of varying water holding capacity. Agron. J. 83:732-738.

Standing Committee on Agriculture. Ruminants Subcommittee. 1990. Feeding standards for Australian livestock. CSIRO Publications, East Melbourne, Australia

Steele, R.G.D. and Torrie, J.H. 1980. Principles and Procedures of Statistics A Biometrical Approach. Second Edition. McGraw-Hill, Inc.

Stinner, B.R. and House, G.J. 1989. The search for sustainable agroecosystems. J. Soil Water Conserv. 44:111-116.

Stout, W.L. 1995. Evaluating the "added nitrogen interaction" effect in forage grasses. Commun. Soil Sci. Plant Anal. 26:2829-2841.

Stout, W.L. 1992. Water-use efficiency of grasses as affected by soil, nitrogen and temperature. Soil Sci. Soc. Amer. J. 56:897-902.

Stout, W.L. 1988. Effects of soil and nitrogen on water use efficiency of tall fescue and switchgrass under humid conditions. Soil Sci. Soc. Amer. J. 52:429-434.

Stout, W.L., Jung, G.A., Shaffer, J.A. and Estepp, R. 1986. Soil water conditions and yield of tall fescue, switchgrass and caucasian bluestem in the Appalachian Northeast. J. Soil Water Conserv. 41:184-186.

Ta, T.C. and Faris, M.A. 1987a. Effects of alfalfa proportions and clipping frequencies on timothy-alfalfa mixtures. II. Nitrogen Fixation and transfer. Agron. J. 79:820-824.

Ta, T.C. and Faris, M.A. 1987b. Species variation in the fixation and transfer of nitrogen from legumes to associated grasses. Plant Soil 98:265-274.

Thomson, D.J. 1979. Effect of the proportion of legumes in the sward on animal output. Occasional Symposium No. 10. British Grassland Society, University of York. Pp. 101-109.

Tingle, J.N. and van Adrichem, M.C. 1974. Meadow foxtail lengthens the spring pasture season. Canada Agriculture 19:26.

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

Tomm, G.O., Walley, F.L., van Kessel, C. and Slinkard, A.E. 1995. Nitrogen cycling in an alfalfa and bromegrass sward via litterfall and harvest losses. Agron. J. 87:1078-1085.

Tomm, G.O., van Kessel, C. and Slinkard, A.E. 1994. Bi-directional transfer of nitrogen between alfalfa and bromegrass: short and long-term evidence. Plant Soil 164:77-86.

Townsend, C.E. 1982. Diseases, insects and other pests of rangeland alfalfa. In: R.J. Lorenz, R.E. Ries, C.S. Cooper, C.E. Townsend and M.D. Rumbaugh eds., Alfalfa for Dryland Grazing U.S. Gov. Print Office, Washington, D.C.: USDA, Agric. Inf. Bull.444.

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

Turner, H.A., Young, D.C., Raleigh, R.J. and Zobell, D. 1980. Effect of various levels of monensin on efficiency and production of beef cows. J. Anim. Sci. 50:385-390.

Ukrainetz, H. and Campbell, C.A. 1988. N and P fertilization of bromegrass in the Dark Brown soil zone of Saskatchewan. Can. J. Plant Sci. 68:457-470.

Ulyatt, M.J. 1981. The feeding value of temperate pastures. In: F.H.W. Morley ed., Grazing Animals. Elsevier Scientific Publishing Company. New York, NY. pp.125-141.

Undersander, D.J., West, D.C. and Casler, M.D. 2001. Frost seeding into aging alfalfa stands: sward dynamics and pasture productivity. Agron. J. 93:609-619.

Van Der Werf, J.H.J., Jonker, L.J. and Oldenbroek, J.K. 1998. Effect of monensin on milk production by Holstein and Jersey cows. J. Dairy Sci. 81:427-433.

Van Esbroeck, G.A., Baron, V.S. and King, J.R. 1995. Regrowth of bromegrass species, a bromegrass interspecific hybrid, and meadow foxtail in a short-season environment. Agron. J. 87:244-251.

Van Keuren, R.W. and Matches, A.G. 1988. Pasture production and utilization. In: A.A. Hanson, D.K. Barnes, and R.R. Hill eds., Alfalfa and Alfalfa Improvement. Agronomy 29:515-562.

Van Soest, P.J., Robertson, J.B. and Lewis, B.A. 1991. Methods for dietary fiber, neutral detergent fiber and non-starch polysaccharides in relation to animal nutrition. J. Dairy Sci.

74:3583-3597.

Van Soest, P.J., Fadel, J. and Sniffen, C.J. 1979. Discount factors for energy and protein in ruminant feeds: formulation of diets. Proc. Cornell Nutr. Conf. Feed Manuf. Pp. 63-75.

Vough, L.R., Decker, A.M. and Taylor, T.H. 1995. Forage establishment and renovation. In: R.F. Barnes, D.A. Miller and C.J. Nelson eds. Forages. 5th ed. Volume III. The Science of Grassland Agriculture. Iowa State University Press, Ames, IA. pp. 29-43.

Waddington, J. and Bittman, S. 1983. Bromegrass and alfalfa establishment with a wheat companion crop in northeastern Saskatchewan. Can. J. Plant Sci. 63:659-668.

Walker, J.W. 1995. Viewpoint: grazing management and research now and in the next millennium. J. Range Manage. 48:350-357.

Walker, P.M., Weichenthal, B.A. and Cmarik, G.F. 1980. Efficacy of monensin for beef cows. J. Anim. Sci. 51:532-538.

Walley, F.L., Tomm, G.O., Matus, A., Slinkard, A.E. and van Kessel, C. 1996. Allocation and cycling of nitrogen in an alfalfa-bromegrass sward. Agron. J. 88:834-843.

Walton, P.D., Martinez, R. and Bailey, A.W. 1981. A comparison of continuous and rotational grazing. 34:19-21.

Wery, J., Turc, O. and Salsac, L. 1986. Relationship between growth, nitrogen fixation and assimilation in a legume (*Medicago sativa* L.). Plant Soil 96:17-29.

White, L.M. 1985. Long-term residual effects of nitrogen fertilization on western wheatgrass. J. Range Manage. 38:461-466.

White, L.M. and Wight, J.R. 1984. Forage yield and quality of dryland grasses and legumes. J. Range Manage. 37:233-236.

White, L.M. 1983. Seasonal changes in yield, digestibility and crude protein of vegetative and floral tillers of two grasses. J. Range Manage. 36:402-405.

Wiedemann, H.T. and Cross, B.T. 1981. Rangeland seeder development using semicircular seed-box and auger agitator seed metering concept. J. Range Manage. 34:340-342.

Wilkins, R.J. and Garwood, E.A. 1986. Effects of treading, poaching and fouling on grassland production and utilization. In: J. Frame ed. Grazing. Occasional Symposium No. 19. British Grassland Society.

Wilson, P.N., Ray, D.E. and Ruyle, G.B. 1987. Integration of cattle production and marketing strategies with improved pastures and native range. J. Range Manage. 40:199-202.

Wolf, D.D., Hagood, E.S.-Jr. and Lentner, M. 1985. No-till alfalfa establishment as influenced by previous cover crop. Can. J. Plant Sci. 65:609-613.

Wolton, K.M. 1979. Dung and urine as agents of sward change: a review. In: A.H. Charles and R.J. Haggar eds. Changes in Sward Composition and Productivity. Occasional Symposium No. 10, British Grassland Society. Hurley, UK. Pp. 131-135.

8.0 APPENDIX

Appendix 1. Precipitation data (mm) from Brandon, Manitoba 1995 to 1998, including a 92 year average

Month	1995	1996	1997	1998	Long-term Average
January	32.4	10.9	18.2	33.0	21.8
February	27.2	11.1	10.6	57.1	18.0
March	64.5	22.9	26.8	15.2	24.5
April	30.6	30.5	35.3	15.0	30.0
May	64.0	66.0	14.4	85.9	49.0
June	72.0	53.0	53.0	163.0	79.3
July	20.0	59.0	98.0	68.0	73.0
August	19.0	25.0	45.0	122.0	64.5
September	31.0	60.0	9.0	26.0	46.1
October	47.0	40.8	46.4	73.0	25.1
November	47.8	13.6	21.0	24.2	20.9
December	26.7	22.5	11.4	31.4	20.3
Annual Total	482.2	415.3	389.1	713.8	472.5

Grazing seasons: 13/06/95-24/08/95; 15/06/96-09/09/96; 05/06/97-27/08/97; 28/05/98-17/09/98.

Appendix 2. Temperature data (°C) from Brandon, Manitoba 1995 to 1998, including a 92 year average

Month	1995	1996	1997	1998	Long-term Average
January	-16.3	-23.8	-20.5	-17.3	-18.7
February	-14.4	-14.7	-11.4	-4.9	-16.0
March	-7.1	-11.4	-9.4	-8.8	-8.2
April	-0.4	-0.2	1.4	7.3	3.3
May	10.8	8.6	9.5	11.9	10.8
June	18.9	17.6	18.9	14.8	15.9
July	19.3	18.3	19.7	19.1	19.0
August	19.5	18.7	18.2	19.9	17.6
September	12.2	12.4	14.3	13.8	11.9
October	4.7	4.4	4.9	5.4	5.1
November	-10.2	-6.3	-5.0	-4.8	-5.5
December	-16.3	-14.8	-5.8	-14.5	-14.3
Annual Means	1.7	0.7	2.9	3.5	1.7

Grazing seasons: 13/06/95-24/08/95; 15/06/96-09/09/96; 05/06/97-27/08/97; 28/05/98-17/09/98.

Appendix 3. The statistical models used to analyse the forage data. Manuscript 1.

Data Set	Individual / Combined	Parameter	Model	Description
CGD	Individual	R1, R2, Total	$Y_i = \mu + T_i + e_i$	Y_i = cow grazing days; T_i = *i*th treatment; e_i = experimental error
CGD	Combined (4 yrs)	R1, R2, Total	$Y_{ijk} = \mu + T_i + A_j + (TA)_{ij} + R_k(T_i) + e_{ijk}$	Y_i = cow grazing days; T_i = *i*th treatment; A_i = *j*th year of experiment; $(TA)_{ij}$ = treatment by year interaction; $R_k(T_i)$ =*k*th replication within *i*th treatment (used as error term to test h); e_i = experimental error
Forage Yield	Combined (4 yrs)	per ha yield	$Y_{ijk} = \mu + T_i + A_j + (TA)_{ij} + R_k(T_i) + e_{ijk}$	Y_{ijk} = forage yield; T_i = *i*th treatment; A_i = *j*th year of experiment; $(TA)_{ij}$ = treatment by year interaction; $R_k(T_i)$ =*k*th replication within *i*th treatment (used as error term to test h); e_{ijk} = experimental error
% Alfalfa	Individual	Alfalfa	$Y_{ijk} = \mu + T_i + R_j(T_i) + P_k + (TP)_{ik} + e_{ijk}$	Y_{ijk} = % Alfalfa; T_i = *i*th treatment; $R_j(T_i)$ = *j*th replication with in *i*th treatment (error term to test T_i); P_k = *k*th paddock or time of sampling; $(TP)_{ik}$ = *i*th treatment by *k*th time of sampling interaction; e_{ijk} = experimental error
% Alfalfa	Combined (4 yrs)	Alfalfa	$Y_{ijkl} = \mu + T_i + A_j + (TA)_{ij} + R_k(T_i) + R_k[(TA)_{ij}] + P_l + (TP)_{il} + e_{ijk}$	Y_{ijk} = % Alfalfa; T_i = *i*th treatment; A_i = *j*th year of experiment; $(TA)_{ij}$ = treatment by year interaction; $R_k(T_i)$ =*k*th replication within *i*th treatment; $R_k[(TA)_{ij}]$ = *k*th replication within *i*th treatment by *j*th year interaction (used as error term to test T_i, A_j, $(TA)_{ij}$ and $R_k(T_i)$); P_l =*k*th time of sampling; $(TP)_{il}$ = *i*th treatment by *l*th time of sampling interaction; e_{ijk} = experimental error
Forage Quality	Individual	CP, NDF, ADF	$Y_{ijk} = \mu + T_i + R_j(T_i) + P_k + (TP)_{ik} + e_{ijk}$	Y_{ijk} = forage CP, NDF & ADF; T_i = *i*th treatment; $R_j(T_i)$ = *j*th replication with in *i*th treatment (error term to test T_i); P_k = *k*th paddock or time of sampling; $(TP)_{ik}$ = *i*th treatment by *k*th time of sampling interaction; e_{ijk} = experimental error
Forage Quality	Combined (3 yrs)	CP, NDF, ADF	$Y_{ijkl} = \mu + T_i + A_j + (TA)_{ij} + R_k(T_i) + R_k[(TA)_{ij}] + P_l + (TP)_{il} + (TAP)_{ijl} + e_{ijk}$	Y_{ijk} = % Alfalfa; T_i = *i*th treatment; A_i = *j*th year of experiment; $(TA)_{ij}$ = treatment by year interaction; $R_k(T_i)$ =*k*th replication within *i*th treatment; $R_k[(TA)_{ij}]$ = *k*th replication within *i*th treatment by *j*th year interaction (used as error term to test T_i, A_j, $(TA)_{ij}$ and $R_k(T_i)$); P_l =*k*th time of sampling; $(TP)_{il}$ = *i*th treatment by *l*th time of sampling interaction; $(TAP)_{ijl}$ = treatment by year by time interaction; e_{ijk} = experimental error

Appendix 4. Herbage biomass (kg DM ha^{-1}) 'In', clipped upon entering a paddock (1995-1998)

			GU		GF		AU		AF	
Year	Padd	R	P 9	P16	P 11	P15	P10	P14	P12	P13
95	1	1	2369	3656	4927	4144	3628	4241	3659	3682
95	2	1	2018	2506	4196	3396	3535	3955	3941	4008
95	3	1	2616	2568	4390	4711	3134	3943	5414	4246
95	4	1	2089	5090	4204	4410	4173	3948	5689	4849
95	5	1	2634	3929	4382	5815	3220	6347	4417	4706
95	1	2	1153	1109	1132	1280	1466	1850	1542	1636
95	2	2	610	1078	915	868	1100	1051	1540	1477
96	1	1	3311	3371	5716	5479	3825	4013	4719	4640
96	2	1	3700	4195	6640	6625	6835	3475	5300	6560
96	3	1	2230	3101	5168	4350	3978	3652	4980	3595
96	4	1	1569	5890	6714	6111	3052	4062	5303	5355
96	5	1	2907	3467	6504	6455	3470	6911	4400	4834
96	1	2	1649	2180	1519	1475	1212	1967	1525	1885
96	2	2	998	1411	1392	2258	1384	1716	1473	1956
97	1	1	1205	1493	2250	1858	1893	2223	1783	2162
97	2	1	1132	1085	1968	2157	2004	1404	1487	2011
97	3	1	962	1114	1506	1186	1673	1399	1399	1402
97	4	1	1395	3820	2500	2605	2540	1865	2370	2360
97	5	1	1755	2440	2500	4025	1920	3675	2655	2340
97	1	2	837	1119	2020	2231	1544	1925	1732	2161
97	2	2	951	1252	2392	3135	2232	2387	2667	2625
97	3	2	885	1590	1809	2127	1637	2308	2443	2335
97	4	2	1106	2009	1528	2018	1329	1654	1665	1788
97	5	2	991	1114	790	1941	1009	2975	749	935
97	1	3	450	625	780	390	655	1045	880	675
97	2	3	375	450	700	493	438	438	445	493
98	1	1	1320	1348	2448	2344	2068	2444	2512	3508
98	2	1	996	1776	3312	3620	3146	2544	3391	3970

98	3	1	1024	1744	3464	3804	2405	2188	3768	4012
98	4	1	1216	5728	4332	4350	3044	2984	4280	4688
98	5	1	1932	3805	8928	5552	5266	5829	7488	5924
98	1	2	1664	2100	4612	4140	3560	3736	4696	5460
98	2	2	1132	1156	2964	3684	2708	3084	4372	4012
98	3	2	872	1536	1644	1628	2084	2400	3952	3016
98	4	2	796	1920	2000	2088	1944	1780	2408	2196

Appendix 5. Herbage biomass (kg DM ha^{-1}) 'Out', clipped upon exiting a paddock (1995-1998)

			GU		GF		AU		AF	
Year	Padd	R	P 9	P16	P 11	P15	P10	P14	P12	P13
95	1	1	325	518	1408	835	1225	1341	740	1012
95	2	1	931	505	1158	897	958	700	1170	821
95	3	1	734	853	1059	1121	1678	1555	1335	1606
95	4	1	531	2385	1053	1134	1822	1611	1466	1941
95	5	1	1882	2398	255	3462	1596	2727	2933	2256
95	1	2	613	448	561	649	497	310	520	477
95	2	2	314	766	592	578	728	669	1030	1113
96	1	1	1740	1635	2490	1940	730	1765	1120	1050
96	2	1	1044	1605	2612	2112	1193	1345	1524	1196
96	3	1	1379	1447	1361	1360	1402	1328	1126	2086
96	4	1	878	1141	1153	1008	1095	866	1127	1148
96	5	1	1836	1580	814	957	809	2448	866	1267
96	1	2	927	983	1140	1179	696	1326	754	871
96	2	2	566	815	951	612	801	675	668	657
97	1	1	595	635	724	638	515	669	703	666
97	2	1	547	508	770	417	656	227	624	331
97	3	1	580	635	550	235	290	485	285	540
97	4	1	645	11175	810	1065	1030	1125	950	1155
97	5	1	484	651	529	1065	412	1653	748	481
97	1	2	399	668	1087	1033	772	1218	1226	1154
97	2	2	374	757	1174	759	808	583	605	659
97	3	2	208	498	170	321	279	148	179	171
97	4	2	285	871	573	633	380	687	639	498
97	5	2	195	750	215	1135	300	885	195	260
97	1	3	380	520	335	260	235	590	430	265
97	2	3	330	328	350	245	340	290	275	293
98	1	1	525	1167	699	735	965	1175	750	720
98	2	1	476	536	512	644	488	508	796	968

98	3	1	472	764	100	688	1044	628	912	856
98	4	1	524	1652	1633	2150	912	1260	2045	1518
98	5	1	1216	1856	1076	1684	804	1744	1564	1244
98	1	2	480	452	617	872	784	1392	960	1140
98	2	2	444	592	944	952	1080	1264	1472	1792
98	3	2	452	880	664	1016	824	1244	816	1208
98	4	2	548	1044	936	1192	664	660	764	684

'Out' herbage biomass was not different across pasture treatments ($P>0.05$)

Appendix 6. Analysis of variance of cow grazing days and total forage production during four grazing seasons (1995 to 1998). Manuscript 1.

	P values						
Cow Grazing Days	Y	T	TxY	MSE e=rep(trt)	r^2	C.V.	Mean
Sum of Cow Grazing Days Rotation 1	0.0076	0.0303	0.4023	824.34	0.9900	5.77	123.38
Sum of Cow Grazing Days Rotation 2	0.0020	0.0721	0.2669	472.87	0.9827	14.30	51.70
Total Cow Grazing Days for the Grazing Season	0.0115	0.0285	0.3352	1999.14	0.9909	5.21	178.61
Pasture Yield Per Hectare (t DM ha^{-1})	0.0116	0.0070	0.4749	0.47	0.9460	12.73	4.11

Appendix 7. Analysis of variance of yearly cow grazing days. Manuscript 1.

Year	Rotation	P values Treatment	MSE	r^2	C.V.	Mean
1995	1	0.0741	96.37	0.7937	8.88	110.51
	2	0.2114	7.20	0.6401	13.64	19.66
	Total	0.1018	131.06	0.7563	8.79	130.17
1996	1	0.0228	247.92	0.8876	10.31	152.74
	2	0.6739	29.86	0.2925	21.06	25.95
	Total	0.0311	324.24	0.8682	10.08	178.68
1997	1	0.1206	91.39	0.7336	12.70	75.27
	2	0.2232	201.12	0.6293	19.91	71.22
	3	0.0766	3.47	0.7901	13.43	13.87
	Total	0.1354	487.94	0.7167	13.75	160.61
1998	1	0.0139	312.54	0.9126	11.41	155.00
	2	0.0153	165.10	0.9083	14.28	89.96
	Total	0.0056	539.26	0.9446	9.48	244.67

Appendix 8. Analysis of variance for percentage of alfalfa in the alfalfa-meadow bromegrass mixed pastures (AF, AU). Manuscript 1.

		P values		P values					
Y	R	T	MSE e=rep(T)	Time	TxTime	r^2	C.V.	MSE	Mean
1995	1	0.1047	38.62	0.0015	0.4086	0.9134	4.84	13.37	75.56
	2	0.1110	23.74	0.1354	0.1240	0.9778	2.06	3.00	83.95
1996	1	0.0227	40.20	0.2308	0.8080	0.8851	12.38	33.79	46.94
	2	0.0226	13.21	0.4089	0.8303	0.6727	30.56	198.33	46.09
1997	1	0.0159	19.28	0.1099	0.6868	0.8687	14.11	30.71	39.29
	2	0.1253	69.70	0.8823	0.6770	0.4758	27.65	157.77	45.44
1998	1	0.0490	45.01	0.0538	0.9040	0.8457	17.37	33.65	33.39
	2	0.5042	51.85	0.7905	0.3710	0.5020	24.54	93.66	39.43

Appendix 9. Analysis of variance for forage quality factors (DM basis) three year average (1995 to1997). Manuscript 1.

		P values				P values						
	R	Y	T	TxY	MSE e = rep(TxY)	Y x T x Time	Time	T x Time	r2	CV	MSE	Mean
CP	1	0.0001	0.0001	0.0022	2.11	0.0316	0.0001	0.2762	0.93	13.25	2.53	12.02
NDF	1	0.0001	0.0001	0.0015	4.77	0.0001	0.0001	0.0002	0.97	3.80	4.74	57.28
ADF	1	0.0001	0.0001	0.0020	2.85	0.0258	0.0001	0.1058	0.95	5.38	3.83	36.33
CP	2	0.0001	0.0001	0.0073	0.95	0.5825	0.0001	0.0126	0.99	5.42	0.48	12.76
NDF	2	0.0001	0.0001	0.1225	5.73	0.0111	0.0001	0.0029	0.99	2.75	2.70	59.82
ADF	2	0.0001	0.0074	0.0008	1.04	0.0001	0.0001	0.0001	0.99	2.49	0.99	39.96

Time refers to the paddock in which the sample was collected

Appendix 10. Analysis of variance for forage quality factors (DM basis). Manuscript 1.

			P values		P values					
Y	R		T	MSE e=rep(trt)	Time	TxTime	r^2	CV	MSE	Mean
1995	1	NDF	0.0001	1.47	0.0001	0.0001	0.9872	2.58	2.14	56.85
	1	ADF	0.0010	0.89	0.0001	0.0074	0.9328	4.10	2.55	38.93
	1	CP	0.0002	0.78	0.0001	0.4779	0.9373	12.78	2.40	12.11
	2	NDF	0.0010	1.55	0.0001	0.0018	0.9989	0.80	0.24	61.61
	2	ADF	0.0795	1.08	0.0001	0.0030	0.9957	1.34	0.34	43.58
	2	CP	0.2313	1.54	0.0003	0.3314	0.9789	5.93	0.43	11.11
1996	1	NDF	0.0080	8.20	0.0001	0.0829	0.9410	3.52	4.79	62.14
	1	ADF	0.5185	3.34	0.0001	0.2783	0.9418	4.74	3.43	39.07
	1	CP	0.0034	1.42	0.0001	0.3777	0.9167	16.53	2.82	10.17
	2	NDF	0.0011	3.23	0.0067	0.1364	0.9672	3.99	6.62	64.50
	2	ADF	0.0210	2.20	0.0001	0.0012	0.9963	1.09	0.22	43.51
	2	CP	0.0001	0.19	0.0001	0.0066	0.9958	3.38	0.16	11.97
1997	1	NDF	0.0001	2.25	0.0008	0.8220	0.9321	5.11	7.28	52.84
	1	ADF	0.0082	6.36	0.0002	0.9320	0.8802	7.57	5.50	31.00
	1	CP	0.0156	7.02	0.0391	0.7513	0.9027	11.21	2.38	13.77
	2	NDF	0.0019	8.80	0.0001	0.1611	0.9559	3.62	3.99	55.21
	2	ADF	0.0012	0.60	0.0001	0.0024	0.9218	3.83	1.76	34.60
	2	CP	0.0859	7.76	0.0001	0.0714	0.9362	9.41	1.54	13.18
	3	NDF	0.1194	8.38	0.0068	0.5234	0.9260	3.86	6.04	63.72
	3	ADF	0.0191	2.09	0.9794	0.5129	0.7554	7.77	8.46	37.44
	3	CP	0.0870	4.95	0.1022	0.3129	0.9129	10.82	2.71	15.22

Appendix 11. The statistical models used to analyse cow production data. Manuscript 2.

Data Set	Parameter	Model	Description
Consumed forage quality, %	CP, NDF, ADF and IVOMD	$Y_{ijklm} = \mu + A_i + T_j + P_k + (AT)_{ij} + (AP)_{ik} + (TP)_{jk} + (ATP)_{ijk} + R_l(ATP)_{ijk} + O_m + (PO)_{km} + (TO)_{jm} + (AO)_{im} + (TPO)_{jkm}$	Y_{ijklm} = consumed forage quality (CP, NDF, ADF and IVOMD); μ = population mean; A_i = *i*th year; T_j =*j*th pasture treatment; P_k = *k*th rotation; $(AT)_{ij}$ = year by treatment interaction; $(AP)_{ik}$ = year by rotation interaction; $(TP)_{jk}$ = treatment by rotation interaction; $(ATP)_{ijk}$ = year by treatment by rotation interaction; $R_l(ATP)_{ijk}$ = *l*th replication within year by treatment by rotation interaction (error term to test h); O_m = mth in or out of paddock i.e. sampling period; $(PO)_{km}$ = rotation by in/out of the paddock interaction; $(TO)_{jm}$ = treatment by in/out of paddock interaction; $(AO)_{im}$ =year by in/out of the paddock interaction; $(TPO)_{jkm}$ = treatment by rotation by in/out of the paddock interaction.
Cow Dry Matter Intake, % BW; Cow and Calf ADG, g d^{-1} and Calf Gain, kg ha^{-1}; Serum Urea Nitrogen, mmol l^{-1}	Mean DMI, ADG, Gain per hectare, Mean SUN	$Y_{ijklm} = \mu + A_i + R_j(A_i) + T_k + (TA)_{ik} + T_kR_j(A_i) + M_l + S_m + (MS)_{lm} + (TM)_{kl} + (TS)_{km} + (TMS)_{klm} + (AM)_{il} + (AS)_{im} + (AMS)_{ilm}$	Y_{ijklm} = mean DMI, cow and calf ADG, calf gain per hectare or mean SUN; μ = population mean; A_i = *i*th year; $R_j(A_i)$ = *j*th replication within *i*th year, used as the error term to test year; T_k = *k*th pasture treatment; $(TA)_{ik}$ = pasture treatment by year interaction; $T_kR_j(A_i)$ = *k*th pasture treatment by *j*th replication within *i*th year, used as the error term to test pasture treatment and pasture treatment by year interaction; M_l = *l*th monensin treatment; S_m = *m*th sex of calf; $(MS)_{lm}$ = monensin by sex of calf interaction; $(TM)_{kl}$ = pasture treatment by monensin interaction; $(TS)_{km}$ = pasture treatment by sex of calf interaction; $(TMS)_{klm}$ = pasture treatment by monensin by sex of calf interaction; $(AM)_{il}$ = year by monensin interaction; $(AS)_{im}$ = year by sex of calf interaction; $(AMS)_{ilm}$ = year by monensin by sex of calf interaction.
1998 Cow and Calf ADG, g d^{-1} and Calf Gain, kg ha^{-1}	ADG, Gain per hectare	$Y_{ijk} = \mu + T_i + R_j(T_i) + S_k + (TS)_{ik}$	Y_{ijk} = 1998 cow and calf ADG, calf gain per hectare; μ = population mean; T_i = *i*th pasture treatment; $R_j(T_i)$ = *j*th replication with in *i*th pasture treatment, used as the error term to test pasture treatment; S_k = *k*th sex of calf; $(TS)_{ik}$ = pasture treatment by sex of calf interaction.

Data Set	Parameter	Model	Description
Milk Yield, kg d^{-1}; Milk Composition, %; Somatic Cell Count	Mean yield, Fat, Protein, SNF, SCC log	$Y_{ijklm} = \mu + A_i + R_j(A_i) + T_k + (TA)_{ik} + T_kR_j(A_i) + M_l + S_m + (MS)_{lm} + (TM)_{kl} + (TS)_{km} + (TMS)_{klm} + (AM)_{il} + (AS)_{im} + (AMS)_{ilm} + B$	Y_{ijklm} = mean DMI, cow and calf ADG, calf gain per hectare or mean SUN; μ = population mean; A_i = *i*th year; $R_j(A_i)$ = *j*th replication within *i*th year, used as the error term to test year; T_k = *k*th pasture treatment; $(TA)_{ik}$ = pasture treatment by year interaction; $T_kR_j(A_i)$ = *k*th pasture treatment by *j*th replication within *i*th year, used as the error term to test pasture treatment and pasture treatment by year interaction; M_l = *l*th monensin treatment; S_m = *m*th sex of calf; $(MS)_{lm}$ = monensin by sex of calf interaction; $(TM)_{kl}$ = pasture treatment by monensin interaction; $(TS)_{km}$ = pasture treatment by sex of calf interaction; $(TMS)_{klm}$ = pasture treatment by monensin by sex of calf interaction; $(AM)_{il}$ = year by monensin interaction; $(AS)_{im}$ = year by sex of calf interaction; $(AMS)_{ilm}$ = year by monensin by sex of calf interaction; B = covariate (pre-test milk yield, milk fat, milk protein, milk solids non-fat and somatic cell count)

Appendix 12. Analysis of variance for calf ADG, total gain and gain per hectare. Manuscript 2.

Yr		P values Trt	MSE e=rep(trt)	P values Mon	Sex	T*M	T*S	M*S	r^2	CV	MSE	Mean
95	ADG, g d^{-1}	0.0608	4.77	0.0672	0.0635	0.5407	0.0291	0.5579	0.81	6.89	6.45	1166.3
	Gain, kg ha^{-1}	0.1097	416.89	0.0786	0.1013	0.6671	0.0402	0.5095	0.93	6.91	48.01	100.3
96	ADG, g d^{-1}	0.2151	5.97	0.9065	0.2826	0.5818	0.9769	0.2139	0.49	11.24	11.74	963.8
	Gain, kg ha^{-1}	0.0251	543.17	0.7261	0.2503	0.4870	0.9728	0.1549	0.90	11.34	194.26	122.9
97[a]	ADG, g d^{-1}	0.0370	3.83	0.8030	0.0770	0.9305	0.8582	0.2973	0.49	10.39	13.10	1101.4
	Gain, kg ha^{-1}	0.0333	220.68	0.8654	0.1719	0.8148	0.7350	0.4699	0.87	11.95	78.44	74.1
98	ADG, g d^{-1}	0.8937	16.36	na	0.8085	na	0.0290	na	0.48	11.70	10.56	878.8
	Gain, kg ha^{-1}	0.0282	834.12	na	0.5448	na	0.0304	na	0.91	11.79	200.37	120.1

[a]Unbalanced data for sex of calf and monensin due to randomization errors, therefore, mean values and standard. deviations are presented since lsmeans are not available.

Appendix 13. Energy concentration of consumed forage. Manuscript 3.

	Year				Treatment					Contrast p-values	
Energy	95	96	97	SEM	AF	AU	GF	GU	SEM	A vs G	F vs U
NE_m R1	5.1[a]	4.5[b]	4.6[b]	0.11	5.1[a]	4.9[ab]	4.7[b]	4.3[c]	0.13	0.0027	0.0148
NE_m R2	5.4[a]	5.1[b]	4.4[c]	0.10	5.2	5.0	4.9	4.8	0.12	0.0062	0.0899
NE_g R1	2.2[a]	1.6[b]	1.8[b]	0.10	2.2[a]	2.0[ab]	1.8[b]	1.5[c]	0.11	0.0020	0.0134
NE_g R2	2.5[a]	2.2[b]	1.5[c]	0.10	2.3	2.1	2.0	1.8	0.12	0.0060	0.0875

[a-c]Values within a row with different letters differ (P<0.05)

Appendix 14. Effect of year (Y), pasture treatment (T), monensin controlled release capsule (M) and sex of calf (S) on calf milk dry matter intake and the contribution of milk to meet net energy of maintenance and gain, analysis of variance results

Milk	Y	T	T x Y	M	S	M x S	T x S	T x M	Y x M	Y x S	C.V.	r^2	Mean
R1 NE_m, MJ d^{-1}	**	NS	NS	*	NS	NS	NS	NS	NS	NS	19.55	0.5	13.49
R2 NE_m, MJ d^{-1}	*	NS	NS	NS	NS	NS	*	NS	NS	NS	25.09	0.57	13.05
R1 NE_g, MJ d^{-1}	*	NS	0.06	NS	NS	NS	NS	NS	0.07	NS	133.44	0.6	2.41
R2 NE_g, MJ d^{-1}	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	163.79	0.64	1.70
R1 DMI, kg	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	31.11	0.56	0.87
R2 DMI, kg	*	NS	NS	NS	NS	NS	0.07	NS	NS	NS	33.97	0.66	0.82
R1 DMI, %BW	**	NS	NS	NS	NS	NS	NS	NS	*	NS	31.53	0.7	0.58
R2 DMI, %BW	**	NS	NS	*	NS	NS	NS	NS	*	0.07	33.78	0.77	0.44

NS= Not Significant, *P < 0.05, **P < 0.01, ***P < 0 .001.

Appendix 15. Effect of year (Y), pasture treatment (T), monensin controlled release capsule (M) and sex of calf (S) on the contribution of forage to meet net energy of maintenance and gain requirements and calf forage dry matter intake, analysis of variance results

Forage	Y	T	T x Y	M	S	M x S	T x S	T x M	Y x M	Y x S	C.V.	r^2	Mean
R1 NE_m, kg d^{-1}	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	110.3	0.66	2.34
R2 NE_m, kg d^{-1}	*	NS	NS	NS	NS	NS	**	NS	NS	NS	56.0	0.73	5.59
R1 NE_g, kg d^{-1}	**	NS	0.08	NS	NS	NS	NS	NS	0.10	0.09	30.33	0.78	6.68
R2 NE_g, kg d^{-1}	***	NS	NS	NS	0.1	NS	NS	NS	NS	NS	21.1	0.86	7.88
R1 DMI, kg d^{-1}	***	**	0.07	NS	NS	NS	NS	NS	*	0.1	32.74	0.78	4.21
R2 DMI, kg d^{-1}	*	NS	NS	NS	NS	NS	NS	NS	0.10	0.09	26.47	0.75	4.81
R1 DMI, %BW	***	*	NS	NS	NS	NS	NS	0.1	*	NS	36.97	0.67	2.63
R2 DMI, %BW	*	*	NS	NS	NS	NS	NS	NS	0.07	0.09	30.03	0.63	2.44

NS= Not Significant, *P < 0.05. **P < 0.01. ***P < 0.001.

Appendix 16. Effect of year (Y), pasture treatment (T), monensin controlled release capsule (M) and sex of calf (S) on calf total dry matter intake (forage plus milk DMI), analysis of variance results

Total	Y	T	T x Y	M	S	M x S	T x S	T x M	Y x M	Y x S	C.V.	r^2	Mean
R1 DMI, kg	***	**	0.06	NS	NS	NS	NS	NS	NS	NS	23.07	0.8	5.08
R2 DMI, kg	*	NS	NS	NS	0.1	NS	NS	NS	NS	0.08	18.83	0.76	5.63
R1 DMI, %BW	***	**	NS	NS	NS	NS	NS	NS	*	NS	25.49	0.67	3.22
R2 DMI, %BW	0.07	NS	NS	NS	NS	NS	NS	NS	0.1	NS	20.68	0.6	2.88

NS= Not Significant, *P < 0.05, **P < 0.01, ***P < 0.001.

Appendix 17. Clipped forage quality data for three grazing seasons (1995-1997)

Pasture	Treatment	Paddock	Rotation	Replication	1995 CP	1995 NDF	1995 ADF	1996 CP	1996 NDF	1996 ADF	1997 CP	1997 NDF	1997 ADF
9	GU	1	1	1	10.84	62.66	37.90	10.37	60.20	32.55	10.27	57.39	33.28
9	GU	2	1	1	12.99	64.43	41.09	5.85	64.43	39.31	7.66	61.74	37.21
9	GU	3	1	1	6.83	63.13	41.23	5.88	67.70	36.73	7.63	58.79	36.10
9	GU	4	1	1	5.39	62.72	41.94	5.58	65.52	42.09	6.50	63.47	38.18
9	GU	5	1	1	5.77	67.01	44.67	5.21	68.87	45.88	7.61	64.88	41.77
9	GU	1	2	1	10.95	61.04	41.05	8.06	76.46	45.66	11.20	64.39	38.77
9	GU	2	2	1	7.55	69.70	45.52	6.67	72.24	47.23	9.17	63.53	29.46
9	GU	3	2	1							8.52	61.00	37.09
9	GU	4	2	1							7.03	65.74	40.69
9	GU	5	2	1							8.43	63.03	38.19
9	GU	1	3	1							13.58	60.18	37.39
9	GU	2	3	1							10.63	72.85	43.44
16	GU	1	1	2	10.59	64.62	39.41	11.15	64.06	35.42	12.53	54.46	31.15
16	GU	2	1	2	7.89	65.01	41.56	7.89	66.81	38.89	10.30	57.52	33.98
16	GU	3	1	2	6.91	60.36	38.64	5.46	69.55	40.81	9.89	59.61	32.81
16	GU	4	1	2	8.58	64.42	42.60	6.90	67.44	43.09	11.53	61.03	34.89

16	GU	5	1	2	6.95	63.30	41.26	7.27	62.40	41.61	9.45	65.14	40.03
16	GU	1	2	2	12.29	60.76	40.26	8.78	69.71	46.68	14.01	58.78	35.31
16	GU	2	2	2	9.69	69.45	44.63	7.23	73.39	48.65	10.22	58.86	30.79
16	GU	3	2	2							9.91	62.78	38.83
16	GU	4	2	2							10.69	63.35	40.46
16	GU	5	2	2							15.45	57.78	36.17
16	GU	1	3	2							10.47	66.08	40.34
16	GU	2	3	2							12.68	69.00	39.00
10	AU	1	1	1	16.87	45.40	34.24	17.28	49.34	28.58	15.40	47.29	28.23
10	AU	2	1	1	16.68	42.92	33.46	11.29	54.92	38.05	14.15	47.53	31.40
10	AU	3	1	1	14.36	45.55	34.35	9.32	62.67	34.91	14.20	39.59	27.11
10	AU	4	1	1	11.77	51.43	39.84	9.28	62.68	45.78	12.20	46.86	30.56
10	AU	5	1	1	9.16	59.88	44.49	8.32	66.40	47.63	12.38	51.05	30.71
10	AU	1	2	1	12.72	48.69	38.83	14.33	52.56	42.47	18.67	48.07	31.90
10	AU	2	2	1	8.99	65.35	49.66	12.06	62.24	45.44	14.42	49.26	31.30
10	AU	3	2	1							14.12	44.97	29.66
10	AU	4	2	1							10.26	56.81	37.30
10	AU	5	2	1							12.32	51.80	35.24

10	AU	1	3	1							15.29	60.27	37.00
10	AU	2	3	1							14.41	69.40	42.84
14	AU	1	1	2	16.38	47.32	34.26	17.97	47.71	30.44	16.33	45.54	28.30
14	AU	2	1	2	16.32	45.59	34.00	7.37	52.43	33.47	16.56	41.73	26.23
14	AU	3	1	2	13.68	46.89	35.83	10.91	58.99	38.03	13.76	47.68	23.33
14	AU	4	1	2	12.56	47.99	35.62	10.45	60.63	43.45	15.44	46.35	27.14
14	AU	5	1	2	10.15	60.78	44.83	12.83	59.52	43.07	14.61	52.55	36.94
14	AU	1	2	2	15.34	47.35	36.50	13.90	56.88	39.77	19.11	41.10	29.83
14	AU	2	2	2	9.88	63.28	48.90	12.36	62.30	44.42	17.68	45.51	30.79
14	AU	3	2	2							15.15	48.71	32.07
14	AU	4	2	2							11.54	53.72	34.10
14	AU	5	2	2							12.84	52.60	36.07
14	AU	1	3	2							14.85	55.47	38.66
14	AU	2	3	2							18.04	63.69	36.90
11	GF	1	1	1	13.03	63.41	39.06	16.43	59.14	32.16	18.15	54.07	29.33
11	GF	2	1	1	11.14	67.01	42.62	7.87	63.39	38.44	15.41	55.30	30.17
11	GF	3	1	1	10.08	63.04	40.17	9.01	68.39	41.55	15.02	56.00	30.11
11	GF	4	1	1	13.26	63.63	42.07	8.74	69.03	44.43	17.42	57.00	31.63

11	GF	5	1	1	7.28	64.56	41.45	9.89	67.92	43.07	16.16	56.71	31.35
11	GF	1	2	1	12.82	60.66	39.80	15.08	61.41	39.88	18.03	55.18	33.03
11	GF	2	2	1	8.20	71.47	46.18	10.19	71.91	47.06	14.34	55.95	34.82
11	GF	3	2	1							10.84	59.03	37.29
11	GF	4	2	1							10.83	61.43	37.24
11	GF	5	2	1							11.50	59.05	35.44
11	GF	1	3	1							13.12	63.99	32.93
11	GF	2	3	1							14.71	67.47	34.67
15	GF	1	1	2	13.83	61.48	38.68	16.64	59.34	32.58	16.88	51.15	26.99
15	GF	2	1	2	12.04	65.17	39.33	8.53	62.91	35.00	17.08	54.67	29.80
15	GF	3	1	2	8.06	62.14	40.72	9.45	69.39	39.40	19.09	54.79	27.06
15	GF	4	1	2	8.79	62.39	39.84	10.96	67.78	41.86	15.83	56.94	31.08
15	GF	5	1	2	8.17	64.51	43.35	8.36	63.82	41.84	10.08	65.37	39.39
15	GF	1	2	2	12.98	59.74	39.41	15.99	62.06	37.84	16.72	56.37	34.56
15	GF	2	2	2	8.25	71.33	45.60	10.33	70.56	45.46	12.63	57.51	33.83
15	GF	3	2	2							11.42	57.68	35.57
15	GF	4	2	2							12.14	59.59	36.49
15	GF	5	2	2							14.33	61.51	36.50

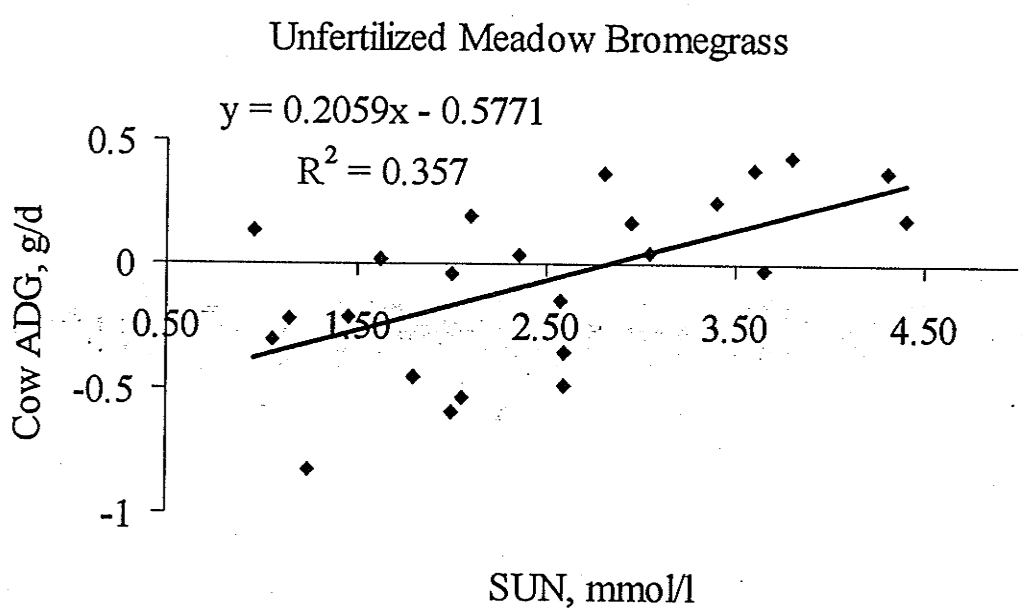
15	GF	1	3	2							17.27	62.02	36.88
15	GF	2	3	2							18.69	66.00	33.84
12	AF	1	1	1	19.51	42.55	29.64	18.55	50.62	31.80	15.02	47.25	29.12
12	AF	2	1	1	17.80	46.90	33.69	3.62	59.82	36.70	14.49	47.03	27.76
12	AF	3	1	1	16.00	48.56	36.79	12.75	59.09	37.45	15.75	45.92	25.21
12	AF	4	1	1	13.70	50.98	39.33	11.65	63.58	44.66	15.40	47.46	29.83
12	AF	5	1	1	10.13	62.35	46.41	9.67	66.16	45.91	14.01	52.67	32.59
12	AF	1	2	1	14.16	53.68	40.33	16.11	56.53	36.55	19.19	49.26	31.44
12	AF	2	2	1	9.73	66.51	51.15	12.39	64.00	45.50	15.96	49.45	32.32
12	AF	3	2	1							14.11	49.53	32.87
12	AF	4	2	1							10.82	56.87	36.87
12	AF	5	2	1							13.35	50.89	32.52
12	AF	1	3	1							14.67	59.09	37.56
12	AF	2	3	1							19.56	63.83	34.11
13	AF	1	1	2	18.99	46.53	32.44	17.66	51.27	32.21	16.10	45.87	26.59
13	AF	2	1	2	17.36	46.92	34.56	8.95	59.25	36.90	14.27	48.98	29.01
13	AF	3	1	2	16.24	47.64	34.79	9.35	65.98	39.17	17.09	49.66	24.94
13	AF	4	1	2	17.65	51.13	38.37	11.09	63.03	43.26	14.70	44.83	28.69

13	AF	5	1	2	10.78	61.70	42.71	10.98	63.49	44.54	14.42	51.57	30.03
13	AF	1	2	2	13.44	52.80	40.19	16.46	53.82	39.96	18.23	48.56	31.38
13	AF	2	2	2	10.83	63.97	49.29	12.39	65.91	46.55	13.52	51.73	34.89
13	AF	3	2	2							14.48	48.65	31.93
13	AF	4	2	2							9.65	57.15	38.71
13	AF	5	2	2							14.23	51.02	32.23
13	AF	1	3	2							15.56	57.35	38.59
13	AF	2	3	2							20.01	62.81	34.87

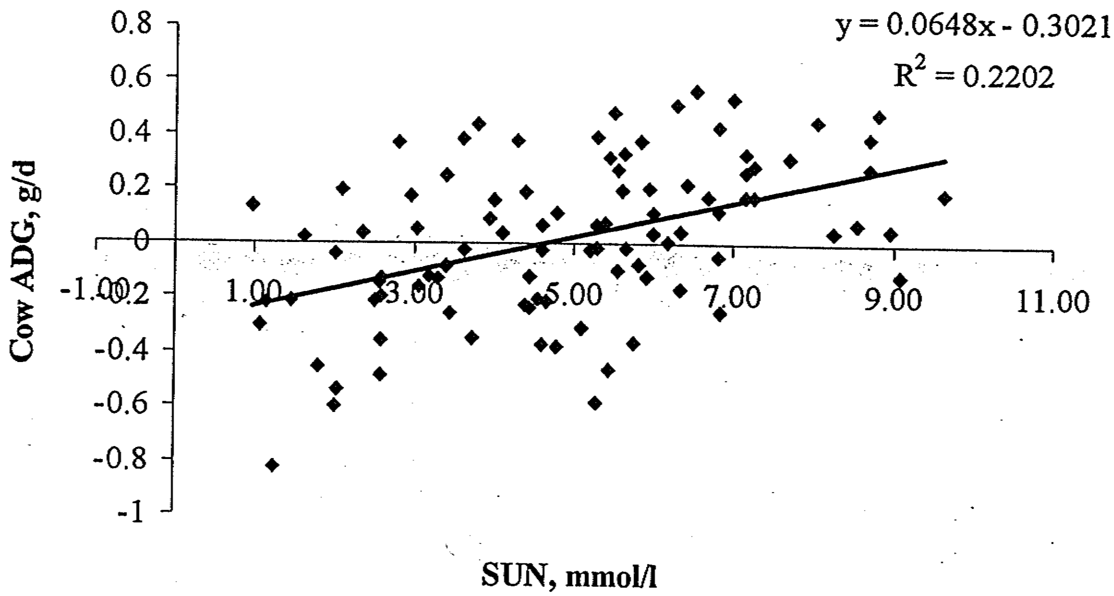
Appendix 18. Consumed forage quality data for three grazing seasons (1995-1997), collected from esophageally fistulated steers

Pasture	Trt	Rotation	Replication	In/Out of Paddock	1995 ADF	1995 NDF	1995 CP	1996 ADF	1996 NDF	1996 CP	1997 ADF	1997 NDF	1997 CP
9	GU	1	1	I	38.99	61.39	7.29	41.13	62.72	3.75	53.42	77.30	6.99
9	GU	1	1	O	43.82	67.85	4.44	47.11	69.17	3.02	47.81	79.15	4.89
9	GU	2	1	I	38.21	58.56	8.02	36.28	54.87	9.43	43.62	71.34	10.94
9	GU	2	1	O	37.92	55.04	9.54	48.24	68.48	5.30	50.89	79.18	5.34
16	GU	1	2	I	41.34	64.76	6.47	43.01	67.45	3.86	41.01	76.20	8.15
16	GU	1	2	O	40.59	66.90	5.62	44.86	70.26	3.39	50.03	67.80	10.75
16	GU	2	2	I	35.33	58.11	10.12	27.69	36.38	16.34	44.78	73.36	10.41
16	GU	2	2	O	38.75	67.19	9.05	47.82	71.23	3.72	48.79	71.63	6.85
10	AU	1	1	I	31.46	40.34	12.67	39.78	57.05	6.77	57.42	68.82	9.28
10	AU	1	1	O	40.73	53.37	9.31	48.88	66.45	4.66	45.97	74.11	12.19
10	AU	2	1	I	32.70	46.31	11.86	28.31	37.52	14.37	35.98	53.47	19.54
10	AU	2	1	O	45.08	56.96	7.29	49.96	68.89	4.85	51.38	77.46	7.97
14	AU	1	2	I	28.89	31.55	16.23	41.08	60.52	5.73	40.00	62.85	12.43
14	AU	1	2	O	43.93	54.53	7.76	45.38	66.04	6.77	46.08	79.80	6.92
14	AU	2	2	I	32.74	45.87	12.90	36.97	57.41	11.14	40.06	65.46	18.46
14	AU	2	2	O	43.02	60.46	7.85	49.05	67.85	6.12	48.87	70.98	8.89

11	GF	1	1	I	40.44	66.83	8.55	40.95	65.81	5.08	35.07	71.44	15.39
11	GF	1	1	O	44.17	71.48	5.21	45.62	70.36	4.01	39.62	67.33	12.86
11	GF	2	1	I	37.56	61.72	12.05	36.35	59.64	11.54	41.75	70.24	13.63
11	GF	2	1	O	37.94	61.93	10.17	45.93	69.23	5.82	46.34	75.39	8.04
15	GF	1	2	I	40.22	66.40	7.01	40.61	64.30	5.74	36.04	70.03	16.06
15	GF	1	2	O	45.14	71.19	5.65	46.19	71.42	4.94	45.87	77.81	11.97
15	GF	2	2	I	40.04	63.28	8.51	32.70	54.31	14.25	40.82	70.33	15.74
15	GF	2	2	O	38.02	63.00	8.17	4521	69.18	5.93	45.28	73.80	8.86
12	AF	1	1	I	30.72	40.97	14.48	42.46	63.50	5.75	32.55	59.18	14.97
12	AF	1	1	O	42.76	62.73	9.39	49.68	68.37	5.67	41.48	64.47	12.62
12	AF	2	1	I	29.63	40.23	15.34	29.74	40.03	14.61	36.79	62.00	18.72
12	AF	2	1	O	38.41	67.19	11.48	46.14	66.76	7.82	46.35	70.64	7.53
13	AF	1	2	I	31.23	40.71	15.28	45.22	66.17	6.10	30.24	59.95	14.73
13	AF	1	2	O	47.03	61.81	7.76	45.57	68.92	4.41	44.64	73.17	11.01
13	AF	2	2	I	36.65	50.02	11.86	27.60	38.47	13.50	33.24	51.92	20.89
13	AF	2	2	O	39.99	62.52	9.61	49.56	71.26	5.75	58.71	78.91	6.29



Appendix 19. The relationship between cow average daily gain (ADG) and serum urea nitrogen (SUN) levels of cows that grazed unfertilized meadow bromegrass pastures over three years (1995-1997)



Appendix 20. The relationship between cow average daily gain (ADG) and serum urea nitrogen (SUN) levels over three years (1995-1997).