Productivity and Environmental Sustainability of Grasslands Receiving Liquid Hog Manure

A Thesis Submitted to

The Faculty of Graduate Studies

The University of Manitoba

By

Colleen Heather Wilson

In partial fulfillment of requirements for the degree of

Master of Science

Department of Animal Science

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

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MASTER OF SCIENCE

ABSTRACT

A two-year (2004 to 2005) experiment was conducted to determine the effect of liquid hog manure as a fertilizer on grasslands composed primarily of Kentucky bluegrass (*Poa pratensis*) and quackgrass (*Agropyron repens*), its effect on forage yield and quality, as well as pasture and animal performance. Environmental sustainability in terms of nutrient removal and enteric methane (CH_4) emissions were also examined. Forage production data was collected from replicated grass hayfields and pastures receiving no liquid hog manure or liquid hog manure as a single application (Full) of 155 kg ha^{1} of available nitrogen (N) in the spring or as a split application (Split) of 74 kg ha^{-1}of available N in both the spring and the autumn. Multiple 0.25m^2 quadrats of standing forage were clipped in hayfields immediately prior to haying to determine DM yield and forage nutrient composition. Quadrat samples were collected in pastures every 28 days to determine DM yield, and hand-plucked forage samples were collected to determine nutrient composition of forage consumed by cattle. As well, pasture productivity, animal production, and enteric CH_4 emissions data were collected. Enteric CH_4 emissions were quantified using the sulphur hexafluoride (SF_6) tracer gas technique. Animal weight, blood samples and 24-h CH_4 expiration were measured once in each of three 28-day periods. Nutrient balance of hayfields and pastures was determined by comparing nutrient removal in the form of animal gain or baled hay to nutrients applied in the form of liquid hog manure.

Hog manure application on hayfields increased forage yield and nutrient profiles relative to hayfields receiving no fertility. Average standing forage biomass generated in Control, Split and Full hayfields were 3.7, 8.8 and 8.4 ± 0.31 t ha^{-1}, respectively (P=0.0001). Mean

standing forage CP was lowest in unmanured standing forage (7.1 ± 0.24 % CP, P=0.0004), while Split and Full hayfields had CP concentrations of 9.4 and 10.5 %, respectively. Neutral detergent fibre was higher in Split hayfields (61.9 ± 1.05 %, P=0.0545) than in Control or Full hayfields (57.1 and 58.9 %) due to its advanced state of maturity at cutting. Gross energy was highest in manured hayfields (18.3, 18.6 and 18.5 ± 0.06 kJ g^{-1} DM, in Control, Split and Full hayfields, respectively, P=0.0443). Application of hog manure increased nutrient profile of pasture forages relative to those receiving no fertility. Mean forage CP was more than doubled with manure application (P=0.0492). Steers grazing unmanured pastures had lower serum urea N (2.56 ± 0.61 mmol L^{-1}, P=0.0225) values compared to steers grazing manured pastures (Split = 6.06, Full = 6.09 mmol L^{-1}). Animal DMI and enteric CH_4 emissions (% GEI) were unaltered by the changes in forage quality as a result of manure application. The addition of hog manure increased pasture carrying capacity over the grazing season by more than three-fold compared to unmanured pastures, which averaged 101 grazing days ha^{-1} yr^{-1}. Animal productivity increased from 104 kg gain ha^{-1} for unfertilized to 325 and 344 kg gain ha^{-1} for Split and Full pasture treatments, respectively (P=0.0019). Nitrogen and phosphorus (P) removal efficiencies based on nutrients applied were up to 7- and 4-fold greater in the hayed system compared to the pastoral system, in which only 4.7 % of applied N and 6.1 % of the applied P were recovered. The low nutrient utilization efficiencies in each system indicate a need to monitor the rate or frequency of liquid hog manure application to reduce nutrient build-up in the grassland system.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

ADF	=	acid detergent fibre
~~ADG~~	~~=~~	~~average daily gain~~
BW	=	body weight
CC	=	carrying capacity
CH_4	=	methane
CO_2	=	carbon dioxide
CP	=	crude protein
CRC	=	controlled release capsule
DM	=	dry matter
DMI	=	dry matter intake
DMY	=	dry matter yield
g	=	gram
GD	=	grazing days
GE	=	gross energy
GEI	=	gross energy intake
GHG	=	greenhouse gas
GWP	=	global warming potential
ha	=	hectare
hd	=	head
K	=	potassium
kg	=	kilogram
kJ	=	kilo joule
LWG	=	liveweight gain
Mg	=	magnesium
N	=	nitrogen
N_2O	=	nitrous oxide
NDF	=	neutral detergent fibre
P	=	phosphorus
SF_6	=	sulphur hexafluoride
SUN	=	serum urea nitrogen
t	=	metric tonne
y	=	year

1.0. INTRODUCTION

The Manitoba beef cattle industry is highly dependent upon grasslands to provide low cost forages in the form of hay and pasture for animal feed. As nitrogen (N) is the main limiting nutrient in forage production (Dougherty and Rhykerd 1985), the addition of nutrients to grasslands in the form of commercial fertilizer or manure can increase forage production and thus influence animal productivity.

Manitoba's substantial hog industry provides an opportunity for cattle producers to utilize liquid hog manure on grasslands to improve pasture fertility without incurring the costs associated with inorganic fertilizer. Increased levels of available soil N (Mooleki et al. 2002) and increased forage yield and quality (Blonski et al. 2004) have been observed with the use of liquid hog manure on grasslands.

Utilization of liquid hog manure on pasture may serve to improve forage quality such that methane production, a byproduct of microbial fermentation in the rumen, is reduced. Reductions in enteric emissions are significant to the cattle sector, as in 2005, enteric fermentation accounted for 3.3% of Canadian GHG emissions and 43.9% of Canadian agricultural emissions (Environment Canada 2007). Low forage quality has been found to increase methane produced as a percentage of gross energy consumed (Ominski et al. 2006), representing a loss of energy that is not available for meat or milk production.

There is a risk of nutrient loading in the soil when the uptake of nutrients by forage species is less than the level of nutrients applied. As manure is often applied to land to supply the N requirements of the pasture or crop, phosphorus may build up in the soil. Excess soil nutrients can result in losses to the environment through leaching or erosion and can contribute to the pollution of surface waters (Koelsch 2005; Pierzynski and Gehl 2005). Few studies have been conducted in a field environment evaluating grassland efficiency at utilizing applied nutrients in the form of liquid hog manure.

The study was conducted to evaluate the effect of liquid hog manure as a fertilizer on grassland productivity, yield, quality and performance in terms of carrying capacity and liveweight gain, and environmental sustainability as measured by enteric methane emissions and nutrient removal. Treatments included: 1) time and frequency of application in either spring or spring and autumn and its impact on productivity and enteric methane emissions, and 2) forage utilization (mechanical harvesting versus grazing) and its impact on nutrient removal from the grassland system.

2.0. LITERATURE REVIEW

~~Recent expansion of the hog industry in Western Canada has created~~ an opportunity to increase the quality and productivity of forages for the beef and dairy industries by applying hog manure to pasture and hayfields. As nitrogen (N) is the main limiting nutrient in grass production (Dougherty and Rhykerd 1985), hog manure can provide a readily available and inexpensive source of plant nutrients, thereby increasing forage quality and productivity (Blonski et al. 2004), which in turn improves animal productivity (Kopp et al. 2003).

While coupling the hog and cattle industries to optimize forage production may result in the efficient use of available nutrients, the sustainability of this practice requires additional scientific validation prior to its promotion as an environmentally sustainable practice.

2.1. GRASSLANDS

2.1.1. Grasslands and grassland production

Grasslands can be defined as land covered by grass-dominated vegetation and occur where moisture is sufficient for grass growth, but where environmental conditions inhibit tree growth (Allaby 1998). The majority of grasslands provide a source of feed for ruminants, either as pasture or hay, but also provide habitat for a diverse array of wildlife (Trottier 2002).

In the southern portion of the Canadian prairies it is estimated that beef cattle ranches utilize 70% native and naturalized grasslands (Trottier 2002). Naturalized grasslands occur when the original plant species seeded has shifted over time to reflect a balance of seeded and native plant species. Seeded pastures comprise the balance of the grazed land. Conversely, ranches in the northern regions of the prairie utilize 48% native and naturalized grasslands (Trottier 2002) with the remaining 52% of land grazed as seeded pasture. In 2001, 75% of the 10.8 million hectares of pasture land in Canada associated with grazing beef and dairy cattle was native pasture (Statistics Canada 2005).

2.1.2. Grasslands of the Canadian Prairies

Climate, topography, exposure to fire and soil type all play a role in influencing the appearance and extent of grassland types that exist on the Canadian Prairies (Joern and Keeler 1995). There are three main types of grasslands in the Canadian prairies, characterized by geographic location as well as their dominant plant species. There is rarely a distinct physical boundary that exists between grassland types or between grassland and parkland. Rather, one observes areas of transition at the interface of the regions (Trottier 2002).

The main types of grasslands in the Canadian prairies are Tallgrass, Mixed and Fescue Prairies. Tallgrass Prairie originally accounted for 6000 square kilometres located in the vicinity of the Red River Valley of Manitoba, but has been almost entirely eliminated by human influence (Trottier 2002). Tallgrass prairie is present in high rain-fall areas and is bordered by forest on its eastern border (Joern and Keeler 1995). Mixed Prairie now accounts for more than half of the native grasslands in the Canadian prairies, while Fescue Prairie, which was once 255,000 square kilometers of the Canadian prairies, is today primarily an area of cereal production (Trottier 2002).

The proportion of native pasture is considerably higher in the Prairie Provinces than in Eastern Canada, where seeding pastures is a more common practice (Statistics Canada 2005). In 2001, the prairie provinces' unseeded pastures accounted for an average of 76.5% of grazed land, compared with only 65.1, 43.5, and 47.7% in Ontario, Quebec and the Atlantic provinces, respectively (Statistics Canada 2005). Statistics Canada (2005) also indicates that as farm size increases, the proportion of native pasture also tends to increase in order to achieve sufficient production of the lower productivity forage which is typical of native pastures.

2.1.3. Botanical composition

Tallgrass Prairie is characterized by native grasses that grow to over a metre in height at maturity (Trottier 2002). Dominant grass species are big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), Indian grass (*Sorghastrum nutans*) and switchgrass (*Panicum virgatum*) (Pieper 2005).

Mixed Prairie contains a mixture of tall, short and medium-height grasses with the proportions dependent on grazing pressure and levels of moisture (Trottier 2002). Grasses common to Mixed Prairie include needle-and-thread grass (*Stipa comata*), blue grama (*Bouteloua gracilis*) and western wheatgrass (*Pascopyrum smithii*) (Pieper 2005).

Fescue Prairie is dominated by rough fescue (*Festuca scabrella*), western porcupine grass (*Stipa curtiseta*) and wild oatgrass (*Danthonia intermedia*), and produces an average of twice the forage biomass as Mixed Prairie, in large part due to its moister environment (Trottier 2002).

Botanical composition and total plant biomass are restricted by low water and nutrient availability during the growing season, (Willms and Jefferson 1993), particularly ~~in the western prairies, as water availability tends to be greater in the eastern prairies~~ (Bragg 1995). As a result of the limited moisture available in the western prairies, parts of Alberta are dominated by shortgrass prairie and bunchgrass species, such as blue grama (*Bouteloua gracilis*), buffalo grass (*Buchloe dactyloides*), bluebunch wheatgrass (*Agropyron spicatum*) and sagebrush (*Artemisia vulgaris*) (Joern and Keeler 1995).

Overgrazing of grassland pastures may also influence botanical composition as it results in a shift toward plant species that are more resistant to grazing, but that are often less productive and possess shallower roots (Dormaar and Willms 1990). Kentucky bluegrass (*Poa pratensis*), a species of grass introduced to North America from Europe, has become so well established in rangelands that it is often considered native (Looman 1983). Kentucky bluegrass will overtake regions grazed to excess, and without the control of prairie fires, it will shift towards becoming the dominant grassland species along with another introduced species, such as Smooth bromegrass (*Bromus inermis*), as well as Western snowberry (*Symphoricarpos occidentalis*) and Aspen poplar (*Populus tremuloides*) in moister areas (Trottier 2002).

2.1.4. Grassland productivity

2.1.4.1. Grassland yield and quality

Grasslands have evolved to have sustained low productivity throughout the growing season (Dormaar and Willms 1990). Several factors contribute to the yield and quality of forage, including forage species, level of maturity and seasonal variations in environmental factors such as temperature, light intensity and day length (Coors et al. 1986). The influence of environment on a grassland system was found to account for 38.4% of total dry matter yield (DMY) variation (McCaughey and Simons 1996). In his report on range plants of the Canadian prairies, Looman (1983) indicates that native grasses tend to have crude protein (CP) concentrations of approximately 16% during May, with values generally dropping off quite abruptly as the forage matures. Little bluestem, Indian grass, needle and thread, western wheatgrass, rough fescue and wild oatgrass generally have CP contents of 5% by late summer. The low CP content available in many of the native grasses could inhibit animal performance (National Research Council 1996). Kentucky bluegrass is beneficial in pasture environments, as it has CP levels as high as 30% in the spring and maintains its high quality when exposed to frequent grazing (Looman 1983). Looman (1983) reports that quackgrass (*Agropyron repens*), an introduced species that quickly established itself in areas of higher moisture, is also highly beneficial in a pasture system due to its early emergence and rapid spring growth, as well as its nutrient content. Unimproved grass-based pastures typical of those in Manitoba were observed to yield between 0.7 to 1.9 t standing available DM ha^{-1}, with NDF and CP ranging from 61 to 69% and 5 to 19%, respectively, over the grazing season (Ominski et al. 2006).

Animal grazing also influences yield and quality of the grassland system. Attempts to maximize utilization of grasslands via continuous grazing have resulted in either over- or undergrazing leading to a reduction in productivity. Grazing directly influences the redistribution of nutrients and consumed forage seeds within a pasture through animal excreta (Mouissie et al. 2005), but can also affect the cycling of water and nutrients in a grassland system by influencing botanical composition, defoliation of plants and reducing plant litter. Overgrazing results in a shift towards less productive, drought ~~tolerant forage species (Willms and Jefferson 1993).~~

2.1.4.2. Grassland fertility

Ninety-five percent of prairie in Canada is arable land (Trottier 2002), but fertility of the grassland prairie in Western Canada is naturally low (McCartney et al. 1999). The response to introduced nutrients in the form of commercial fertilizer includes increased forage DMY, carrying capacity and liveweight gain (Kopp et al. 2003). Also, the influence of grazing can result in a redistribution of nutrients available to plant roots in unfertilized pasture systems. Grazing of native prairie grasslands results in the relocation of nutrients to the upper soil strata (Dormaar and Willms 1990). The placement of these nutrients encourages the shift toward plants with shallow roots that are better able to take advantage of the available nutrients within the shallow root zone. This shift occurs at the expense of plants that have deeper root growth that can survive periods of drought due to their ability to acquire water from greater soil depths.

2.2. GRASSLAND RESPONSE TO FERTILITY

2.2.1. Effect of fertilization on botanical composition of pasture

The trend with the use of N fertilization is to encourage growth of the most productive and competitive species, often the tall, upright grasses (Dougherty and Rhykerd 1985) such as smooth bromegrass (*Bromus inermis*). In a study examining the effects of inorganic fertilizer on continuously grazed pastures containing mixtures of smooth bromegrass, Kentucky bluegrass, creeping red fescue (*Festuca rubra*) and alfalfa (*Medicago sativa*), N applied at rates of 45 and 90 kg ha^{-1} was found to increase the ratio of fine grasses at the cost of legumes and forbs (Bittman et al. 1997). These same researchers demonstrated that the addition of phosphorus (P) at 20 kg ha^{-1} with N application increased the proportion of coarse grass species such as smooth bromegrass by more than 10%, while the fine grass species such as Kentucky bluegrass and creeping red fescue declined in excess of 10%.

2.2.2. Effect of fertilization on pasture quality

The application of inorganic N fertilizer can improve pasture quality by encouraging regrowth and high N concentrations in resulting biomass, thereby increasing forage CP concentrations over the course of the grazing season (Dougherty and Rhykerd 1985). The application of 448 kg ha^{-1} N in the form of urea to orchard grass hayfields resulted in an increase of crude protein (CP) concentrations from 11.6% to 20.0%, while reducing the soluble carbohydrates from 10.0% to 4.5% (Reid et al. 1966). Inorganic N fertilizer applied at a rate of 110 kg ha^{-1} to meadow bromegrass pastures, improved CP concentrations by an average of 3.7% units, with observed average CP concentrations up to 13.0% (Kopp et al. 2003).

Neutral and acid detergent fibre (NDF and ADF) can be used to estimate voluntary intake and relative forage digestibility, respectively (Fahey, Jr. and Berger 1988). Kopp et al (2003) observed a decline in NDF and ADF content by 2.6 and 1.8 % units, respectively, in the fertilized meadow bromegrass pastures, indicating an increase in the quality of forage with pasture fertilization.

When soil moisture was not limiting, Cohen et al (2004) observed a linear increase in organic matter digestibility of extrusa samples obtained from heifers grazing crested wheatgrass pastures fertilized with up to 200 kg N ha^{-1}. Ash content of the extrusa samples was unaffected by the fertility treatments.

With the addition of 85 kg N ha^{-1} on perennial ryegrass (*Lolium perenne)* pastures, the estimated metabolizable energy was improved from 10.46 to 10.96 MJ kg DM^{-1} while water-soluble carbohydrates exhibited an inverse relationship with the use of fertilizer and were reduced from 33.40 to 25.09 g kg DM^{-1} (Kenny et al. 2001).

2.2.3. Effect of fertilization on pasture productivity and carrying capacity

The addition of N to pasture systems often results in substantial yield increases, as N is usually the limiting nutrient (Dougherty and Rhykerd 1985). Nitrogen-fertilization at rates up to 160 kg N ha^{-1} has been shown to account for 15.4% of the variation of DMY in two-cut hay and three- and four-cut simulated pasture systems in established meadow bromegrass (*Bromus biebertsteinii*), crested wheatgrass (*Agropyron cristatum*) and smooth bromegrass plots grown on loam soils, when environment, species and harvest management were also considered in total variation (McCaughey and Simons 1996). In a review by Dougherty and Rhykerd (1985), the authors concluded that the addition of N to forage systems resulted in an increase in leaf area indices and stimulated meristematic activity, both factors which can be attributed to the increase in growth rates and yield attributed to N fertilization. The use of fertilizer on grasslands can result in a reduction in yield variability that often occurs between years (McCartney et al. 1999).

This reduction in yield variability can reduce the need for supplemental feed required in low productivity years.

In meadow bromegrass pastures fertilized to provide 110 kg available N ha^{-1}, the four-year average grass yield was twice that of unfertilized pastures (3.95 t vs. 1.94 t DM ha^{-1}, respectively) (Kopp et al. 2003). Also observed in this study was a 64% improvement of carrying capacity (CC), which lead to an increase in the average cow grazing days per hectare (CGD ha^{-1}) to 209 in fertilized pastures, a significant improvement allowing for more extensive utilization of the pasture when compared to unfertilized meadow bromegrass pastures. While fertilization may lead to an improvement in carrying capacity and liveweight gain (LWG) per hectare, individual animal performance may not necessarily be influenced. In an eight-year study examining crested wheatgrass pastures fertilized at rates of 0, 50, 100 and 200 kg N ha^{-1}, animal grazing days (GD) per hectare increased significantly with each increased increment of applied fertilizer, but average daily gain (ADG) was not influenced (Cohen et al. 2004). The opportunity for increased animal production is therefore related to the pastures' improved DMY and its ability to sustain higher stocking rates, as opposed to the increased productivity of individual animals.

2.2.4. Effect of pasture fertilization on serum urea nitrogen (SUN) concentrations of grazing steers

Analysis of blood metabolites can be used as an indicator to determine if nutrient requirements are being met, and can also be an indicator of health. The normal or reference range for serum biochemical values is established by using 95% of values from a representative group of disease-free animals (Boyd 1984). An abnormal result would have a value outside of the reference range. Urea is a product of protein catabolism formed in the liver and excreted mainly via the kidneys (Coles 1980). Systemic urea and pasture CP concentrations have been shown to have a linear relationship (Kenny et al. 2001). Urea content is measured in either blood plasma or serum. Normal SUN values for steers range from 2.8 to 8.8 mmol L^{-1} (Boyd 1984), where levels above or below this range could be indicative of a protein excess or deficiency in the diet.

The use of fertilizers on pastures and cropland has been shown to influence the nutrient concentrations of forages. Nitrogen fertilizers can increase the CP content of forages, which in turn influence the urea concentrations in the blood of grazing cattle. Kenny et al (2001) found that the addition of 85 kg N ha^{-1} resulted in perennial ryegrass pastures with CP concentrations of 23.2%; unfertilized forages contained 12.8% CP. The beef heifers consuming the fertilized forages had SUN concentrations of 6.64 mmol L^{-1} as a result of consuming forage with high CP concentrations, whereas the animals on the lower CP forages had substantially lower SUN concentrations, measured at 2.81 mmol L^{-1}.

2.2.5. Efficiency of nutrient removal in fertilized grassland systems

The removal of nutrients from grassland systems occurs in the form of plant harvest from hayfields (King 1981; Stout and Jung 1992), through the accretion of nutrients in animal body weight gain on pasture and their subsequent removal from the grassland system (Dougherty and Rhykerd 1985), and also from environmental losses through leaching, erosion and volatilization (Pierzynski and Gehl 2005).

Application of inorganic N fertilizer at rates of 50, 100 and 200 kg ha^{-1} to fescuegrass (*Festuca arundinacea*) grown on loam soils resulted in recovery rates of applied fertilizer N which ranged from 42 to 53% (King 1981). Further, a study utilizing ^{15}N-tracer fertilizer at a rate of 250 kg N ha^{-1} on orchard grass demonstrated that 37-50% of applied N in the form of herbage was recovered, while 14-18% remained in forage litter, stubble and roots and 24% was located within the top 50 cm of soil (Kimura and Kurashima 1991). The remaining 10 to 22% of the applied N was unaccounted for in forage, residue, roots or soil and may have been lost through leaching or volatilization.

Nutrient utilization is dependent upon the time of fertilizer application and is most beneficial if applied when plants are able to employ them most effectively for growth. Equal, split applications of ^{15}N depleted ammonium nitrate at total annual rates of 84 and 168 kg ha^{-1} to orchard grass field plots resulted in a three-year average recovery of the applied N fertilizer of 42% in spring growth, but only 15% in autumn growth (Stout and Jung 1992).

The removal efficiencies of applied fertilizers are greater in hayed systems than in pastoral ones. The recovery of nutrients by grazing animals is minimal (Dougherty and Rhykerd 1985) due to the low level of nutrient incorporation into cattle by way of body weight gain. Nitrogen and P content of a 300 kg carcass has been estimated at 3.03% (Haecker, 1920) as cited by Berg and Butterfield (1976) and 0.84% (Hogan and Nierman 1927; Moulton et al. 1922), respectively. Total nutrient utilization on fertilized pastures can be improved compared to unfertilized pastures with a higher stocking density and subsequently a greater liveweight gain per hectare (Cohen et al. 2004), but even then total nutrient accretion is low. Much of the nutrients consumed by cattle are recycled to the pasture through urine and feces. A study examining N utilization in a grassland system found that while N from urine patches is available to plants, over half of the urinary N deposited could not be accounted for in either herbage or soil (Kimura and Kurashima 1991) and may have been lost to the environment. In the same study, the N originating from feces was found to have low availability and would enter the soil in organic forms not immediately available for plant use. After three years, N uptake by surrounding forage accounted for only 19% of N that was originally present in the feces.

When utilization of nutrients is low, a carry-over effect may occur, whereby nutrients can influence forage yield and quality in subsequent years. Studies have indicated that fertilizer not immediately utilized by the plants can improve pasture productivity for years after the cessation of fertilizer applications due to high residual N in the form of NO_3-N in the soil (Cohen et al. 2004).

2.2.6. Use of hog manure as a fertilizer

2.2.6.1. Growth of the hog industry in Western Canada

There has been substantial growth of the hog industry in recent years. The quarterly inventories of hogs in Western Canada peaked at 6.5 million in July 2005 (Statistics Canada 2007). Since then the industry growth has slowed across the nation. A reduction in inventory to 6.4 million hogs in January 2007 was attributed to lower slaughter prices, higher feed costs and an increase in animal exports (Statistics Canada 2007). As a province, Manitoba has an annual pig production of approximately nine million head with a value of approximately one billion dollars that has increased steadily from 1993, when annual pig production was two million animals and contributed $300 million to the provincial economy (MAFRI 2007).

2.2.6.2. Hog manure characteristics in Western Canada

In 1998 and 1999 Fitzgerald and Racz (2001a) performed a survey on hog manure samples from various Elite Swine hog barns in Manitoba. A total of 145 samples were collected from 38 different operations. The samples were collected from feeder, sow, nursery and farrow to finish barns and analyzed for nutrient composition (Table 1).

Total N content of manure is comprised of both inorganic and organic forms of N. Values of total N vary from 5.77 to 13.14% DM and were related to protein levels in the diet. As protein content of the diet varies with the stage of animal development, total N content of manure was therefore dependent on operation type. Available N is the sum of inorganic N plus 25% of the organic N. Available N was inconsistent between samples, necessitating analysis throughout manure application in order to establish an application rate that provided an accurate estimate of available N (Fitzgerald and Racz 2001b).

Average P concentration was 2.63% DM and was found to correlate with the solid fraction of manure. The N to P ratio was 4:1 or less in 45% of the samples collected, indicating a high probability of P-loading in the soil. Generally, a ratio of 5-7:1 is required for crops (Fitzgerald and Racz 2001b). Below this ratio a build-up of P in the soil can occur. In order to prevent soil accumulation of P, it is recommended that stored manure be well mixed to increase the ratio of N:P, or to consider using the solid fraction of manure as a phosphorus fertilizer (Fitzgerald and Racz 2001a).

Table 1. Summary of the mean nutrient composition of liquid hog manure collected from different types of hog barns from a survey conducted in Manitoba

Barn Type	n	Average % Solids	Total N % DM	Inorganic N % DM	Organic N % DM	Available N % DM	Total P % DM	N:P	Total K % DM	Total Na % DM	Total S %DM	Total Ca %DM	Total Mg %DM
Feeder Barns	92	3.7	9.14	6.97	2.11	7.49	2.68	3.41	4.14	1.24	0.73	3.03	1.67
Sow Barns	37	3.0	5.77	4.10	1.70	4.53	2.17	2.66	3.37	1.30	0.48	2.90	1.32
Nursery Barns	11	3.1	8.77	6.29	2.77	6.90	3.77	2.32	5.23	1.45	0.86	3.79	2.03
Farrow to Finish	5	2.1	13.14	11.48	1.67	11.90	5.05	2.60	6.62	2.38	0.77	1.81	0.63
Total	145	3.5	8.26	6.23	2.00	6.71	2.63	3.14	4.00	1.26	0.67	2.96	1.56

Data adapted from Fitzgerald and Racz, 2001

Sodium content of manures was consistent between sampling years and depths and averaged 1.26% DM content. Sulfur content of the manure was consistent between operations and averaged 0.67% DM. Potassium content of hog manure was lowest from sow barns and was highest in farrow to finish barns, with levels ranging between 3.37 – 6.62 % DM. Both Ca and Mg content of the manure was lowest in farrow to finish operations and highest in nursery barns. Some tested manures, especially from nursery barns, had trace elements and heavy metals that were considered high (Fitzgerald and Racz 2001a).

Modification of diet can alter the type and amount of manure P and thus influence its potential for environmental impact. Options to reduce the loading of P in the environment include: the addition of enzymes to the diet to increase the digestibility of the P; feeding more digestible forms of P to reduce the need for inorganic P supplementation; and reducing the amount of P in the feed while still meeting the animals' needs (Pierzynski and Gehl 2005).

There is great variability in nutrients from different sources of hog manure, between both types of hog operations and within barns of the same type of operation, making it difficult to characterize. The lack of predictability among hog manures necessitates the analysis of manure upon spreading in order to ensure suitable application rates (Racz and Fitzgerald 2001).

2.2.6.3. Use of hog manure as a fertility source

In order for the hog industry to be successful, there must be a well-devised strategy for manure disposal. In a report examining the environmental sustainability of the hog industry in Manitoba, it is estimated that the hog industry produces enough manure to fertilize 6% of Manitoba's total agricultural land base on the basis of N requirements (Manitoba Conservation 2006). Basing manure application on P content, the same amount of manure would fertilize approximately 730,000 hectares or 15% of Manitoba's annual cropland (Manitoba Pork Council 2007). While N is usually the most limiting nutrient to grassland systems, P and K are also occasionally limiting (Vallentine 1989). Utilization of hog manure on agricultural lands can be a viable option to supply the fertilizer needs of agricultural land while reducing the need for inorganic fertilizer application.

2.2.6.4. Grassland response to hog manure application

2.2.6.4.1. Effects on soil characteristics

Hog manure can provide a source of nutrients such as N, P, K, S and Mg for plant growth (Fitzgerald and Racz 2001b). Autumn application of liquid hog manure at approximate rates of 100, 200 and 400 kg total N ha^{-1} to sandy loam soils resulted in substantially elevated levels of available soil N in the spring, 60% of which was available to plants in the form of ammonium (Mooleki et al. 2002). Levels of soil nitrate, a source of N taken up by plant roots, were found to increase with the addition of manure (Van Wieringen et al. 2005). Further benefits include improved soil structure, water-holding capacity, drainage and aeration (Miller et al. 2002). A 14-year study examining application of liquid hog manure on maize plots in silt loam soils at rates up to 120 m^3 ha^{-1} y^{-1} was found to increase soil C content by 48.7% when compared to the soil C present in the unmanured, unfertilized plots (Hountin et al. 1997).

Although application of hog manure can improve the quality and fertility of the soil, provisions must be made to prevent nutrient loading (Fitzgerald and Racz 2001a). A comparison of hog manure based on N application rates and inorganic fertilizer recommendations demonstrates the ability of hog manure to contribute nutrients to a grassland system (Table 2). One advantage of utilizing inorganic fertilizer is the ability to accurately apply nutrients at a desired rate. With the application of hog manure at a rate of 123 kg available N ha^{-1}, P and K are provided in excess of the recommended rates while S is inadequately supplied. At this rate, unutilized P is retained at a rate of 33 kg ha^{-1} and builds in the soil. Magnesium is not included in the MAFRI grassland fertilizer recommendation, but is supplied in excess of 10 kg ha^{-1} via hog manure application. While Ca and Mg fertilization is not included in the recommendations for inorganic fertilizer rates on grasslands, the hay is estimated to harvest 72 and 18 kg ha^{-1}, respectively, from nutrients present in the soil. Similarly, more K is removed from the soil than was applied (Table 2). Large quantities of K are present in many soils, where average K content is about 1.9% (Tisdale et al. 1993c).

When elements found in hog manure are elevated, including copper (Cu), zinc (Zn), boron (B) and sodium (Na), then additional monitoring of soil quality will be required to ensure levels do not exceed recommendations (Fitzgerald and Racz 2001b) which could limit plant performance. Alberta and Ontario have guidelines limiting the additions of various elements via hog manure application based on soil type. With hog manure application rates at 70 kg available N ha^{-1} on Class 3 land, total Cu, Zn and B content of manure could accumulate to the maximum recommended limits in as few as 25 manure applications when crop removal is not considered (Racz and Fitzgerald 2001).

Generally soil properties can influence the accumulation of nutrients in soil. Soils with heavier textures and higher pH are less sensitive to accumulation of nutrients due to their ability to bind nutrients in the soil.

Table 2. A comparison of inorganic fertilizer and liquid hog manure application to meet the nutrient requirements of grasslands

		N	P	K	S	Ca	Mg
Grass hay[z] nutrient harvest	kg ha^{-1}	115	15	121	15	72	18
Inorganic fertilizer recommendations[y]	kg ha^{-1}	123	15	56	17	NA	NA
Hog manure[x] fertilizer	kg ha^{-1}	123	48	73	12	54	28

[z]Nutrient removal with 7.4 t ha^{-1} grass hay (MAFRI)
[y]MAFRI, 2006
[x]Nutrients applied from hog manure when available nitrogen supplied at a rate of 123 kg ha^{-1}, 52340 L ha^{-1}, based on mean hog manure composition in Fitzgerald and Racz (2001)

2.2.6.4.2. Benefits to pasture systems

Utilizing manure as a pasture fertility source can be an economically viable option to reduce the costs associated with the purchase of inorganic fertilizers and can have a greater influence on productivity compared to inorganic fertilizers (Mooleki et al. 2002; Van Wieringen et al. 2005). Observations have indicated that application of hog manure results in greater nutrient uptake by plants and a greater overall yield when compared to application of inorganic fertilizer (Lupwayi et al. 2005). Increased uptake has been attributed to the rate at which the N becomes available; the N from inorganic fertilizer is available to the plant upon application, whereas the addition of manure as a source of plant nutrients supplies both sources of plant-available N as well organic matter that releases N over a series of years as it mineralizes (Pang and Letey 2000), providing a continual source of N in the soil.

Blonski et al (2004) utilized liquid hog manure on meadow bromegrass and crested wheatgrass pastures at rates from 10 to 160 kg ha^{-1} NH_4-N. Yield response improved from 1.6 to 3.6 t ha^{-1} and CP concentrations increased from 6.9 to 9.1% with the highest application rate. McCaughey and Simons (1996) demonstrated that the addition of commercial fertilizer at rates up to 160 kg N ha^{-1} y^{-1} to crested wheatgrass, meadow bromegrass or smooth bromegrass grassland systems increased regrowth by 7 to 33.5% in simulated pasture systems receiving three to four cuts when compared to two-cut hay management systems. Further, they also demonstrated a linear relationship between N and regrowth when sufficient moisture was available. An evaluation of liquid dairy manure applied to a perennial ryegrass-orchard grass field for two years resulted in increases in DMY and CP concentrations of the forage, but also extended forage production later into the autumn (Van Wieringen et al. 2005). Increasing the length of the grazing season by extending the pasture's production into the autumn provides an opportunity to maintain animals on pasture longer, reducing the need to provide animals with harvested feed.

The addition of nutrients in the form of hog manure can influence the botanical composition of grasslands. After applying liquid hog manure at rates of 50, 100 or 200 m^3 ha^{-1} y^{-1} to perennial ryegrass swards, a shift toward redtop (*Agrostis stolonifera*) and *Poa* species was observed, especially when swards were exposed to the higher rate of slurry application (Christie 1987). This response is similar to those obtained using inorganic fertilizer, where the additional nutrients result in a botanical shift toward more productive and competitive species (Dougherty and Rhykerd 1985).

The use of hog manure as a source of fertility on pasture supplies nutrients required for plant growth while utilizing a nutrient-rich by-product of the hog industry. Plants respond to the available nutrients in terms of improved yield and quality, while soil responds with increased reserves of organic matter and improved soil structure, water-holding capacity, drainage and aeration. The utilization of hog manure also reduces the costs associated with purchasing inorganic fertilizers that would be necessary for similar improvements in forage yield and quality. While there are many benefits to utilizing hog manure on pasture, there needs to be careful consideration for the limitations and the potential risks associated with the practice.

2.2.6.4.3. Challenges with pasture systems

Livestock are unable to completely convert nutrients from feed to meat or milk, which results in N and P excretion as manure. In a review examining feeding management strategies as a means of reducing the nutrients excreted by swine, hogs in 27 nutrition studies were found to retain 40 to 55% of N, 20 to 50% of P, 5 to 20% of potassium (K) and 15 to 38% of magnesium (Mg) from the diet (Kornegay and Harper 1997). While some soils have the potential to store N, most manure-N is utilized by plants or lost to the environment through volatilization and leaching within a few years (O'Connor et al. 2005). In a review, Pierzynski and Gehl (2005) pointed out that when manure is applied, the risk of nitrate leaching to groundwater increases.

Phosphorus has the potential to build up in soil and is considered an environmental risk with the potential to enter and detrimentally affect waterways and water bodies (Koelsch 2005) by leaching or erosion. A ten-year study on intensive hog manure application showed that after four years, P had accumulated to a concentration of 376 mg Mehlich-3 P kg^{-1} soil in the top 15 cm of soil, with 168 mg kg^{-1} contained at a soil depth of 30 to 45 cm, indicating P was leaching down the soil profile (Novak et al. 2000). The quantity of soil P does not necessarily represent its availability to plants, due to its ability to adsorb to mineral surfaces (Tisdale et al. 1993a). In a review examining sustainable land application of manure, O'Connor et al (2005) remarked that it is often the properties of the soil and its biogeochemical reactions that will dictate the fate of an applied waste product. In general, P is more strongly adsorbed in fine-textured soils than in sandier soils due to the presence of clay minerals to which P compounds bind. High build-ups of P can result in reductions in forage yield due to its interaction with minerals in the soil (Marschner 1995) or due to high cellular P affecting leaf-water associations (Bhatti and Loneragan 1970). The result is the appearance of symptoms associated with deficiencies of micronutrients such as zinc and iron; symptoms include a reduction in growth, early leaf senescence and chlorotic or necrotic patches on leaves (Shane et al. 2004). In order to avoid P loading in the soil, the P applied must be equal or less than removed.

Leaching losses of K and Mg from manure are influenced by soil type. Tisdale et al. (1993) had indicated that leaching losses of K are low due to adsorption to soil colloids, except in sandy-textured soils or those where flooding occurs. Magnesium is available in the soil primarily as exchangeable and solution Mg; it can be leached from soils depending on soil Mg content, weathering rate, rate of plant uptake and intensity of leaching, but losses are reduced when K is applied in equal quantities to Mg (Tisdale et al. 1993a). Based on the application of 123 kg available N ha^{-1} in the form of liquid hog manure and the ability of nutrients to be harvested as grass hay (Table 2), Mg would be provided in excess, whereas K could potentially be completely utilized for plant requirements.

In addition to nutrients beneficial to plant growth, hog manure can also contain less desirable components that influence plant mineral content. Some manures have high levels of heavy metals and trace minerals that can be toxic to both plants and animals. After sixteen years of applying pig slurry at a rate of 200 m^3 ha^{-1} y^{-1} to perennial ryegrass grown on clay loam soils, EDTA-extractable copper and zinc in the top 5 cm of soil were 85.2 and 50.8 mg kg^{-1} with concentrations present in herbage at 10 and 44 mg kg^{-1}, respectively (Christie and Beattie 1989). Copper levels as low as 10-20 mg kg^{-1} have been shown to be toxic to sheep (McDonald et al. 1995). Anecdotal evidence has suggested that beef herds affected by tetany-like symptoms may be affected by the mineral content of local feed sources (Walker 2003). The "tetany ratio" is described as the ratio of K/(Ca+Mg) (in milliequivalents kg^{-1} DM) which results in a value > 2.2 (Kemp and 't Hart 1957). Kemp and 't Hart found that when the ratio of K/(Ca+Mg) in the forage was greater than 2.2, the incidence of tetany, a dysfunction of the nervous system, increased. Diets with excess potassium or inadequate calcium and magnesium intake can result in a greater likelihood of animals experiencing tetany and would require greater care when feeding to prevent the risk of a dietary mineral imbalance.

Greenhouse gases (GHG) can be produced as a consequence of hog manure application. Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are some of the GHGs that are produced by natural processes associated with manure application on land (Pierzynski and Gehl 2005). The method and timing of manure application can affect which gases are produced and the extent to which they are produced. Manure application during cool, dry weather just prior to peak plant growth, allows plants to maximize utilization of applied nutrients, and reduce nutrient loss to the environment through air and water. Having mineral N available at the time and in the quantity required by the crop will result in the highest available crop yields with the lowest environmental losses (Pang and Letey 2000).

There are potential human health implications as a result of applying hog manure to cropping and pasture systems. In a review assessing the fate of pathogenic microorganisms during land application of wastes, Gerba and Smith Jr. (2005) summarize that animal manure contains pathogenic bacteria including *Salmonella* spp., *Escherichia coli, Yersinia enterocolitica, Campylobacter* spp., and *Cryptosporidium parvum* that have the potential to transmit zoonotic organisms to humans via several means: direct contact, consumption of contaminated food or water, indirectly via vectors, or possibly through the inhalation of pathogenic bioaerosols. Pathogens from animal manures are thought to have been the contributing factor in multiple disease outbreaks in North America (Smith, Jr. et al. 2004). Outbreaks can occur where manure is used to fertilize food crops that are consumed raw or when pathogen-infected waters run off or percolate to ground water from sites where manure is present, thereby infecting drinking water supplies (Gerba and Smith, Jr. 2005). O'Connor et al (2005) report that while there are restrictions on the number of pathogens allowed in land-applied human biosolids, the pathogen content of applied animal manures are not well regulated.

Some factors influencing the utilization of hog manure on pasture and cropland have little to do with science basis, but instead are based on opinion. Land application guidelines are usually put in place to protect human health and the environment, but also consider an array of other factors including public and political pressure (O'Connor et al. 2005). The Government of Manitoba has been criticized for imposing restrictions on the hog industry despite a lack of direct scientific evidence that would indicate that the quality of Lake Winnipeg was being detrimentally affected by hog production and manure management practices (Manitoba Pork Council 2007). In 2003 the Lake Winnipeg Stewardship Board was established to examine water quality of Lake Winnipeg. Elevated levels of phosphorus have resulted in water quality issues, including excessive algae growth that affects fish habitat, water recreation, quality of drinking water and causes difficulties with commercial fishing nets. Other actions initiated to protect Lake Winnipeg water quality included introducing sewage and septic field regulations, development of shoreline protection projects to reduce erosion, expansion of soil testing to reduce excess nutrient application, and expansion of riparian zones (Manitoba Conservation 2007). In 2006 the Government of Manitoba announced a moratorium on expansion of the hog sector to allow for the Clean Environment Commission to conduct a review determining the impact of hog farms on the environment.

2.2.6.4.4. Long term impacts of hog manure application

In a review on sustainable land application, O'Connor et al (2005) observe that information available on the long term impact of using hog manure on pasture land is limited. The majority of the research available is as a result of controlled laboratory studies where conditions are carefully manipulated. These studies do not account for climatic factors and results are often in conflict with those obtained from field studies. Multi-disciplinary field studies should be conducted over a number of years at multiple locations to account for the differences in climate, soil type and geographical differences (O'Connor et al. 2005) much like the work already completed for inorganic fertilizers.

2.3. GREENHOUSE GAS EMISSIONS AND GLOBAL WARMING

Global warming is associated with the increase in atmospheric temperature as a result of elevated concentrations of GHGs. Greenhouse gases in the atmosphere act to trap some of the heat that is re-radiated from the surface of the earth, allowing the earth to maintain above-freezing temperatures. Increased concentrations of GHGs are being attributed to an enhancement of the greenhouse effect, with global temperatures projected to increase by 0.5 to 2.5°C by 2030 (Intergovernmental Panel on Climate Change 2001). The three most important GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Methane is one of the most significant GHGs given its prevalence in the atmosphere and its global warming potential (GWP). Methane is second only to carbon dioxide. Global warming potentials of each GHG can be used to compare the radiative efficiency in comparison to CO_2, as well as the rate of decay of the gas molecule. The GWP of CH_4 is 23 (Ramaswamy et al. 2001), indicating that CH_4 has a heat-absorbing ability 23 times greater relative to CO_2. Atmospheric CH_4 has a lifetime of approximately twelve years (Intergovernmental Panel on Climate Change 1995) before chemical reactions can convert it to carbon dioxide. It has been estimated that CH_4's radiative effects account for 20% of global warming effects (Intergovernmental Panel on Climate Change 2001). Methane is produced by both natural and anthropogenic sources.

2.3.1. Livestock methane production

Methane is a by-product of microbial digestion and represents inefficiency in the fermentation process. The majority (89%) of CH_4 produced by ruminants is produced in the rumen as a result of enteric fermentation, with the remainder of production occurring in the hindgut (Murray et al. 1976). Under a more efficient fermentation process, the energy lost as CH_4 would instead be directed to production of volatile fatty acids, acetate, propionate and butyrate, to be utilized by the animal for maintenance or meat and milk production.

The variation in estimated CH_4 losses between ruminant livestock classes and their geographic location is associated with the quality of consumed feed, as well as animal genetics (Table 3). Changes in CH_4 production estimates from 1983 (Crutzen et al. 1986) to 1990 (Gibbs and Johnson 1994) to 2005 (Ominski et al. 2007) would be indicative of improved methods of estimation associated with increased research and knowledge of animal management.

2.3.1.1. Global production estimates

Agriculture accounts for approximately 20% of anthropogenic GHGs world-wide (Intergovernmental Panel on Climate Change 2001). Global CH_4 concentrations in the atmosphere have increased 155% in the last 250 years as a result of anthropogenic activities (World Meteorological Organization 2006). Globally, enteric fermentation accounts for 20-25% of the anthropogenic CH_4, a production value of

Table 3. Estimated methane losses (%GEI and kg hd^{-1} yr^{-1}) from ruminants of different classes[a]

Class	Region	Crutzen et al. (1986)		Gibbs and Johnson (1994)		Ominski et al. (2007)			
		%	kg hd^{-1} yr^{-1}	%	kg hd^{-1} yr^{-1}	%[b]	kg hd^{-1} yr^{-1}[b]	%[c]	kg hd^{-1} yr^{-1}[c]
Dairy cow	North America	5.5	84	6.0	118	6.0	126	8.9	187
Dairy cow	Europe	5.5	95	6.0	100	NA	NA	NA	NA
Dairy cow	India	9.0	35	6.0	46	NA	NA	NA	NA
Range cow	North America	7.5	54	6.0	69	6.0	90	9.5	126
Feedlot	North America	6.5	65	3.5	14	4.0	60[d]	2.5	53[d]
Buffalo	India	9.0	50	7.5	53	NA	NA	NA	NA
Camels	Global	9.0	58	7.0	46	NA	NA	NA	NA

[a]Data from Crutzen et al. (1986), Gibbs and Johnson (1994), and Ominski et al (2007).
[b]Data obtained using methane conversion rate recommended by IPCC Tier-2 (2000)
[c]Data obtained using Canadian research studies
[d]Average value for heifers and steers
NA - no information available

approximately 80 Tg y^{-1} (Lassey 2007). A reduction of 8% is recommended in order to stabilize atmospheric CH_4 (Intergovernmental Panel on Climate Change 1996).

2.3.1.2. Canadian production estimates

In Canada's 2005 Greenhouse Gas Inventory Report (Environment Canada 2007), agricultural emissions accounted for 7.6% of Canada's GHG emissions. Greenhouse gases related to livestock production are a result of enteric fermentation and manure management. In 2005, these two sources accounted for 59% of Canadian agriculture's GHG emissions. From 1990 to 2005 there was a 36% increase in livestock emissions, attributed primarily to an increase in cattle population; enteric fermentation accounted for 3.3% of Canadian GHG emissions and 43.9% of agricultural emissions in 2005 (Environment Canada 2007).

2.3.1.3. Canadian estimates for steers on pasture

The estimate of CH_4 production varies considerably among models and research studies conducted. Tier-1 methodology (Intergovernmental Panel on Climate Change 1997), which estimates CH_4 emissions by applying an emission factor for specific animal categories, provides an estimate of 47 kg CH_4 hd^{-1} y^{-1} for steers over one year of age. Tier-2 methodology factors in animal management, weight, age and gender and predicts a 16.2% higher estimate than that of Tier-1, with 56 kg CH_4 hd^{-1} y^{-1}. The emission estimates provided by Canadian research studies indicate emissions are 12.2% lower than those predicted by Tier-2 methodology, at 50 kg CH_4 hd^{-1} y^{-1} (Ominski et al. 2007).

Methane emissions for grazing cattle vary according to factors such as pasture type and management. Steers grazing alfalfa-grass pastures in both continuous and rotational pasture systems averaged CH_4 losses of 4.5 ± 1.4% gross energy intake (GEI); highest CH_4 losses (L d^{-1}) were observed in continuously stocked pastures with low animal stocking densities (McCaughey et al. 1997). A comparison of alfalfa-grass pastures with grass-only pastures indicates that beef cows grazing grass-only pastures produced more CH_4 (9.5 vs. 7.1 ± 0.4 %) as a percentage of GE consumed (McCaughey et al. 1999). The use of unimproved, low-input pastures tends to result in greater energy lost as CH_4 because fermentation efficiency is reduced with the low quality forages. Steers consuming unimproved grass pastures in a continuous graze system lost between 6.9 to 11.3 ± 0.9% GEI as CH_4, the wide range dictated by the availability and quality of forage in the pastures (Ominski et al. 2006). In general, CH_4, %GEI lost, is lowest when grazing cattle have greater access to forage of higher quality. The IPCC Tier-2 (2000) CH_4 conversion rates suggest CH_4 losses of 6% GEI for grazing steers over the age of one year, while Canadian research studies suggest higher losses, at 8.7% GEI (Ominski et al. 2007).

2.4. METHANE PRODUCTION FROM MICROBIAL FERMENTATION

2.4.1. Methanogens

Methane is produced by a group of microorganisms in the *Archaebacteria* family known as methanogens. Methanogens are characterized by their anaerobic nature and ability to produce CH_4. Methanogens inhabit environments with redox potentials less than -300 mV (Stewart and Bryant 1989) and can be found in landfills, intestinal tracts, marshes, hot springs, peat bogs and salt lakes (Mackie et al. 1992). Rumen methanogens usually originate from the *Methanobacteriaceae* family and are commonly associated with the *Methanobrevibacter* genus (Skillman et al. 2006). Utilizing molecular techniques, Wright et al (2004) found that rumen fluid of sheep fed pellets comprised of 68% lucerne hay and 28% concentrates, had 90% of all recognized *Methanobrevibacter* strains SM9, M6 or NT7.

2.4.2. Substrates and energetics of methanogenesis

Methanogens are involved in the process of converting organic matter to CH_4 in the rumen. Proteins, starches and cell walls of plants are broken down into their constituent parts by other bacteria, protozoa and fungi residing in the rumen. These resultant products are in turn fermented to produce volatile fatty acids, hydrogen and carbon dioxide. Using mainly hydrogen and formate as substrates, CH_4 is produced by the methanogens in the rumen (Whitman et al. 1992). Other substrates used in methanogenesis include acetate, methanol, mono-methylamine, di-methylamine and tri-methylamine (Wolin and Miller 1987).

Production of CH_4 by methanogens provides a source of energy and nutrients for further growth of methanogens. The rumen microorganisms subsequently provide an important source of water-soluble nutrients and amino acids for their host as they move through the gastro-intestinal system and are digested (Miller 1991). The production of CH_4 represents both a carbon and an energetic loss to the animal. Converting fermentation pathways to produce acetate instead of CH_4 as an end-product would result in a usable end-product instead of a loss of energy and nutrients, as is the case when CH_4

is the end product (Miller 1991). Methanogens' higher affinity for hydrogen over competing microbial populations (Greening and Leedle 1989) prevents population shifts that would promote the production of usable end-products in lieu of CH_4.

2.4.3. Biochemistry of methanogenesis

Micro-organisms produce volatile fatty acids acetate, propionate and butyrate in addition to CH_4 and CO_2 (Miller 1991). The volatile fatty acids are absorbed through the rumen wall and utilized as a source of energy and carbon (Miller 1991). A series of six co-enzymes are included in the seven-step cycle of methanogenesis (Figure 1) employed by rumen methanogens to reduce CO_2 to CH_4 (DiMarco et al. 1990). In a review on microbial aspects of CH_4 production, McAllister et al (1996) summarizes the cycle of methanogenic reduction of CO_2 to CH_4. Initially, CO_2 fixation with methanofuran (MFR) forms formyl-MFR. The formyl group is subsequently transferred to H_4MPT to form methenyl- H_4MPT, which is reduced first to methylenyl-H_4MPT, then methyl-H_4MPT. Next methyl-H_4MPT transfers its methyl group to coenzyme M, which is then reduced to CH_4 by methyl-coenzyme reductase. Methane and CO_2 are eructated or absorbed into the circulatory system and exhaled by the lungs (Murray et al. 1976).

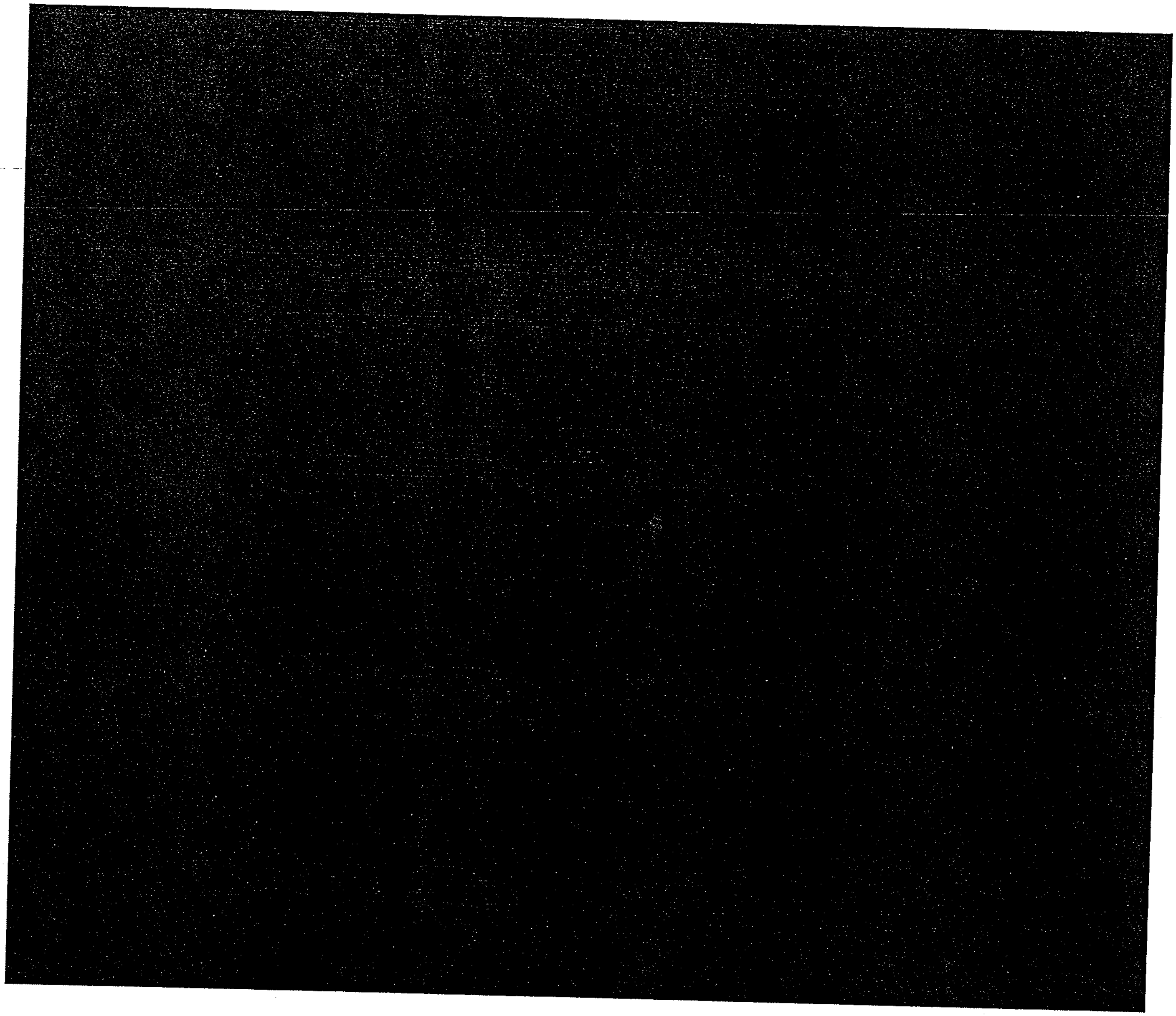


Figure 1. Methanogenic reduction of carbon dioxide to methane (McAllister et al, 1996), adapted from (Rouviere and Wolfe, 1988).

2.5. DIETARY FACTORS THAT AFFECT RUMINANT METHANE PRODUCTION

2.5.1. Quality of feed

Diets high in fibre result in greater fermentable substrate in the rumen. By encouraging interspecies hydrogen transfer, which reduces the build-up of reduced nucleotides (NADH), methanogens enhance energetic efficiency and digestion of fibre by other microorganisms in the rumen. In cattle fed hay with varying levels of digestible organic matter (DOM) content, CH_4 production (L kg^{-1} DOM) was highest in animals fed the lowest quality diet (38.5 % vs 50.7 and 61.5% in vitro organic matter digestibility) (Boadi and Wittenberg 2002).

Methane lost as a %GEI has been reported as low as 2-3% in cattle consuming a high-grain feedlot diets (Boadi et al. 2004) to as high as 11% in cattle grazing low quality grass pastures in Canadian studies (Ominski et al. 2006). In ruminants fed increasing levels of grain, an increase in CH_4 production expressed as a proportion of gross energy intake (%GEI) was witnessed *in vitro*; the same dietary shift resulted in the opposite response *in vivo* (Baker 1999). The author's suggested explanation was the competitive relationship between methanogens and other microbial populations for hydrogen in the rumen which resulted in lower methanogenic fermentation. A general observation is that propionate and CH_4 production in the rumen have an inverse relationship. Diets high in starch or soluble carbohydrates result in higher rates of propionate production and a lower acetate:propionate ratio; the shift increases the rate of ruminal fermentation, supporting propionate production over CH_4 production (Demeyer and Van Nevel 1975).

This type of diet can also result in rumen pH falling below what is typical in forage-fed ruminants and may inhibit CH_4-producing micro-organisms (Eadie et al. 1970).

2.5.2. Level of feed intake and feeding frequency

The proportion of CH_4 emitted, %GEI, tends to decrease as the level of feed intake increases (McAllister et al. 1996). An increase in intake results in a faster rate of passage, reducing the level of fermentation and CH_4 production as a result of reduced microbial access to consumed feed (Mathison et al. 1998). Conversely, restricted feeding has resulted in an increased %GEI lost as CH_4 (Whitelaw et al. 1984). However, Boadi and Wittenberg (2002), observed no differences between enteric CH_4 as a consequence of ad libitum or restricted feeding strategies emissions in cattle fed legume and grass hay. If CH_4 emitted, %GEI, decreases as intake increases, then maximizing intake serves to promote a reduction in days to market and reduces the related CH_4 produced during the lifetime of the animal (Beauchemin and McGinn 2006).

2.5.3. Transit time of rumen digesta

Forage properties that slow the digestion rate or increase the retention time within the rumen tend to increase the amount of CH_4 production per unit of intake (McAllister et al. 1996). In a study where rumen retention time was reduced with the use of weights in the rumen, but without an increase in feed intake, CH_4 production ($L\ d^{-1}$) was reduced by 29% (Okine et al. 1989). This reduction was attributed to a 63% increase in passage rate of fibre measured with chromium mordanted feed, and a rumen fluid dilution rate increase of 43% determined using crystalline Co-EDTA. Passage rate was found to account for 28% of CH_4 production variation, while 25% was attributed to ruminal fluid dilution rates.

2.5.4. Types of forage species

The production of CH_4 tends to increase as the proportion of forage in the diet increases (Blaxter and Wainman 1964). As well, more CH_4 is produced when animals are fed grass-forage diets than when fed a legume-based diet (Varga et al. 1985). Cows grazing alfalfa-grass pastures lost 7.1% GEI as CH_4, whereas cows grazing grass-only pastures lost 9.5% GEI (McCaughey et al. 1999). Legumes have lower levels of fibre and therefore faster rates of digestion and passage, leading to a shift in fermentation towards propionate (Demeyer and Van Nevel 1975).

2.6. FACTORS AFFECTING DMI OF GRAZING STEERS

Predicting and understanding forage intake in grazing animals is paramount to the successful management of grazing systems. Intake of feed is regulated by many different signals that influence the animal response in order to maximize benefits to the animal (Ellis et al. 2000). Grazing behaviour can be considered a process in which the grazing animal approaches a particular patch and appraises its suitability prior to either ingesting or proceeding to another patch (Griffiths et al. 2003). These same authors suggest that the cues used by animals to evaluate a monoculture forage patch, given order of importance, are: depth of regrowth, plant maturity and plant height.

2.6.1. Botanical composition

Botanical composition, as well as physical and chemical characteristics of pasture plants influence animal intake. In a tall-forb pasture, preference among sheep for more succulent and less coarse forage species, such as sweetanise (*Osmorhiza occidentalis*), pale agoseris (*Agoseris glauca*) and thickleaf groundsel (*Senecio crassulus*), has been observed in studies examining the senses involved in forage selection (Krueger et al. 1974). In the same study the botanical selection indicated a preference for sour and sweet plants and distaste for most bitter plants. A cattle preference for legumes over grass species has been observed. Cattle grazing pasture combinations of cocksfoot (*Dactylic glomerata*), crested wheatgrass (*Agropyron cristatum*), sainfoin (*Onobrychis viciifolia*), white clover (*Trifolium repens*) and bird's foot trefoil (*Lotus corniculatus*) spent 48.7% of their time grazing legumes, 40.6% grazing grass-legume combinations, and only 10.7% of the time grazing grass mixtures (Kirilov et al. 2006).

2.6.2. Plant maturity

Intake of diets that have lower digestibility and energy density, such as all-forage pasture diets, is dictated by available space within the gastro-intestinal system (Waldo 1986). Waldo (1986) indicates that the concentration of cell wall components in forage diets is the best indicator of intake, where undigested forage residues residing in the rumen results in a physical limitation of further intake. This relationship between intake and forage digestibility is applicable to cattle of all ages (Ferrer Cazcarra et al. 1995). Digestibility of forage decreases as ADF content increases (Holloway et al. 1979). Further, as forage matures, ADF content increases (Cohen et al. 2004). Esophageal-fistulated steers grazing orchard grass-red clover pastures were found to selectively graze forages that provided higher levels of crude protein and digestible DM and lower concentrations of ADF (CP=22.1 vs. 18.8%; digestible DM = 66.3 vs. 64.2%; ADF = 36.0 vs. 37.2%) than was available in the hand-clipped forage samples representative of the pastures (Coleman and Barth 1973). Pasture quality and maturity have been proven to affect animal gains, as well as intake. Cattle grazing 35% legume (red clover – [*Trifolium pretense*] and lespedeza [*Lespedeza stipulacea*]) and 65% tall fescue pastures that were kept in a vegetative state had intakes 1.3 kg d^{-1} higher and consumed forage that was 2.5% more digestible than those grazing 100% tall fescue pastures that had been allowed to mature (Holloway et al. 1979).

There is further evidence that the rate of intake can be influenced by the maturity of a sward. In a simulated sward, steers were found to selectively graze leaves and select against plant parts that require greater tensile resistance, a process negatively influencing bite mass, time per bite and rate of intake (Benvenutti et al. 2006).

In addition to selection for higher quality, grazing animals also tend to select forage based upon the relationship between the particular plant and the animals' sensory cues. A preference for more succulent forage was observed in grazing sheep when all senses but the sense of touch had been inhibited (Krueger et al. 1974).

2.6.3. Animal behaviour

Animal senses play a role in forage selection. As described above, a study was performed examining forage grazing behaviour and preferences of sheep after chemically impairing one or more senses of taste, smell, taste and sight (Krueger et al. 1974). Taste was found to have the strongest influence on forage selection, although there were frequently complex interactions with other senses that appear to supplement taste.

A review by Dougherty and Rhykerd (1985) has indicated that fertilized pastures may be more palatable than unfertilized to grazing animals due to an increase in forage succulence, increased leaf:stem ratios, lower cell wall content and greater forage availability typical with N fertilization. Conversely, Reid et al. (1966) found that the palatability of forage can also be negatively affected by rates of fertilization and type of fertilizer. The authors noted that when provided with first-cut orchard grass (*Dactylis glomerata*) hay and regrowth from fields utilizing N in the form of urea at application rates of 0 to 448 kg ha^{-1}, sheep responded by preferentially selecting unfertilized first cut hay and reducing selection of other forage options with each incremental increase in rate of fertilization; intake of the first-cut hay from fields treated with the highest levels of N was half the rate of the unfertilized hay. Intake decreased when forage was fertilized in excess of 112 kg ha^{-1}. When the authors offered sheep chopped orchard grass that had been grown using different fertilizers, the order of preference was for forage fertilized with sodium nitrate > ammonium nitrate > ammonium sulfate > urea = diammonium phosphate. Type of fertilizer has been shown to influence forage productivity and chemical composition, which in turn can influence palatability (Devine and Holmes 1963).

The presence of manure on pasture can influence grazing behaviour. With cattle grazing perennial ryegrass pastures, an aversion to forages that had been contaminated by their own dung patches was observed (Bao et al. 1998). Utilizing manure as a fertilizer on pasture can also reduce the palatability of the forage. Cattle that were offered perennial ryegrass swards that were untreated or that had surface-applied dairy slurry at a rate of 36 m^3 ha^{-1} spent an average of only 11.3% of their time eating from the manured sward, with the balance spent grazing from the unmanured control sward (Laws et al. 1996). The authors observed the aversion to swards treated with manure throughout the 21-day experiment.

The productivity of a grazing animal is related to the quality and quantity of forage it has access to. Interestingly, an abundance of easily accessible feed can depress time spent grazing, likely as a consequence of requiring less time to consume the same amount. With forage availability ranging from 1.9 to 4.9 t ha^{-1}, cattle have been found to graze less when available forage DM was greatest, while not influencing level of intake (8.86 to 10.18 kg OM d^{-1}) (Popp et al. 1997a). Conversely, Stockdale et al (1985) has reported that the relationship between DM intake and herbage allowance are positively associated, with an increase in intake of 0.15 to 0.35 kg DM d^{-1} with each additional kg of forage offered on pasture, with intake ranging from 8.7 to 10.8 kg DM d^{-1} when herbage allowance ranged from 22.7 to 32.9 kg DM d^{-1}. Patch selection by mature dairy cows offered a combination of perennial ryegrass patches of different sward or stubble heights was least influenced by sward height, while forage maturity was the most influential factor in patch selection (Griffiths et al. 2003). Sward height can influence the rate of animal intake, with greatest impact observed when sward height is low. When sward heights were as low as 7.3 cm but grazing surface area was generous, animals responded by increasing the amount of time spent grazing, but were unable to make up the for the reduced rate of intake (Ferrer Cazcarra et al. 1995; Holloway et al. 1979). A physical constraint that results in a reduction of intake, such as low sward height, may also result in a loss of animal motivation to achieve the desired level of intake (Ginane and Petit 2005). Another physical consideration that can influence plant selection is location of the plant, such as its proximity to an obstacle such as a prickly thistle, can provide a sufficient deterrent to an animal that it will forage for plants less difficult to acquire (Arnold 1972).

The social interactions of ruminants can contribute to factors associated with animal intake. Stocking density has been proven to influence grazing behaviour. Cattle graze less but have increased intake rates when stocking densities are lower (Popp et al. 1997a).

2.7. CHALLENGES ESTIMATING INTAKE ON PASTURE

The level and composition of consumed feed influences animal performance. Intake can easily be determined if total fecal output, as well as the digestibility of the diet, is known. Estimating the feed intake of grazing animals on pasture can present some challenges, as total fecal collection of each treatment animal in a field environment is not practical or logistically possible and would likely disturb normal grazing behaviour. In order to estimate animal intake on pasture it is common to utilize an external marker – a substance administered orally that will pass through the digestive system. Feces collected from dosed animals can be analyzed for the marker and intake can be calculated. Examples of external markers include transition metals such as chromium and cobalt, rare earth elements, bacterial spores, labeled elements and even-chain n-alkanes (Marais 2000).

2.7.1. The n-alkane marker technique to estimate DMI and digestibility

N-alkanes are long-chain hydrocarbons that can be found mainly in the cuticular wax of plants. These hydrocarbons contain between 27 to 37 carbon atoms. Odd-numbered hydrocarbons account for more than 90% of n-alkanes, with C_{29}, C_{31} and C_{33} dominant in most pasture forages (Dove and Mayes 2005). Because of the prevalence of odd-numbered n-alkanes, orally-dosed, synthetic, even-numbered n-alkanes can be used to estimate DM intake on pasture. By analyzing the fecal alkane content and calculating ratios of dosed and plant-sourced alkanes, individual intake can be determined.

Challenges with the n-alkane technique include observed variation of n-alkane concentrations throughout plant parts and between plant species with considerable variation as a consequence of maturity (Dove and Mayes 2005). The observation of elevated alkane concentrations with increasing plant maturity is related to the development of reproductive tissues which contain substantially higher levels of most individual alkanes (Dove et al. 1996). In a greenhouse study examining the differences in alkane concentrations due to plant species, plant part and maturity in six temperate pasture plant species, Dove et al. (1996) found perennial ryegrass reproductive tissues had C_{31} concentrations of 592.2 mg kg^{-1} organic matter, while the leaf, sheath, base and stem contained 168, 82.9, 27.5 and 34.9 mg kg^{-1}, respectively. However, only 5% of the variation between individual n-alkane concentrations was attributed to plant maturity, whereas species accounted for 85%. Analysis of n-alkane profiles of several native and tame forage species in Canada established that there is much variation between plant species, while only small differences were identified between cultivars grown in different locations (Boadi et al. 2002a). Due to the variation between forage species, it is critical that a precise representation of the test diet is collected. As alkane analysis of the test diet is required to estimate intake, great care must be taken to ensure that the diet is an accurate representation of what the animals are consuming or the intake estimate may be inaccurate (Dove and Mayes 2005).

The oral administration of n-alkane-containing materials for the estimation of intake in grazing ruminants creates challenges. The utilization of a carrier matrix such as cellulose powder or one of many forms of paper products impregnated with known amounts of n-alkanes (Giráldez et al. 2004) requires dosing up to twice per day involving more intensive animal contact than is common in a grazing environment, and is labour intensive. N-alkanes can also be sprayed onto forages that will be subsequently consumed by ruminants as a means of providing orally dosed exogenous n-alkanes to ruminants (Duncan et al. 1999). Although the invasiveness of contact with animals is reduced in this method, it requires intensive labour to spray forages and can be limited by area. The utilization of control release capsules (CRCs) allows for the intake estimation without invasive and restrictive animal handling. Contrary to findings with sheep and goats (Dove and Mayes 2005), the use of CRCs has presented challenges in cattle. Charmley et al. (2003) examined the accuracy of intake estimation with the use of n-alkane CRCs with daily fecal sampling under ad libitum and 70% ad libitum feeding strategies with timothy-red clover silage. These authors observed erratic levels of dosed alkanes with release rates 20% higher than expected, resulting in inconsistent ratios of plant-alkanes and dosed alkanes. These inconsistent ratios of endogenous and exogenous alkanes lead to feed intake being underestimated by 2.74 to 3.40 kg when actual intake was measured at 7.42 kg d^{-1}. While it is recommended that exact release rates of alkane CRCs be determined under the specified experimental field conditions (by monitoring its release in a fistulated animal or by collecting fecal samples to determine when the CRC is exhausted), it has also been suggested that the use of the CRC manufacturer's release rate is satisfactory in comparing intake between treatments in sheep and goats (Dove and Mayes 2005), but recovery of alkanes in cattle is lower and more variable than in sheep (Dove and Mayes 1996). The use of the alkane ratio C_{31}:C_{32} under estimated the intake of meadow bromegrass hay by 15.8%, and of bromegrass and alfalfa hay by 19.2% when compared to estimates of DMI based on total fecal collection in Holstein steers (Moshtaghi Nia and Wittenberg 2002).

2.7.2. Analysis and recovery of n-alkanes

The methodology for analysis of plant and fecal alkanes is identical, and as such, may be analyzed concurrently, reducing error (Mayes and Dove 2000). An internal standard, C_{34} alkane (tetratriacontane), which does not occur naturally in plant or fecal material is used (Mayes et al. 1986). The alkanes in the dried and ground material are saponified with potassium hydroxide and extracted with heptane (Marais 2000). The extract is purified through a column of silica gel. The extract is then analyzed for the type and quantity of each alkane using a capillary gas chromatograph (Dove and Mayes, 2001).

Fecal recovery of dosed and natural alkanes is incomplete and this has been mainly attributed to absorption in the small intestine of the ruminant digestive system (Mayes et al. 1988). As well, fecal alkane recoveries have been found to decrease as the digestibility of the feed increases, leading to an underestimation of intake (Ferreira et al. 2004). Studies in sheep have resulted in observed increases in recovery of alkanes of greater chain length (Mayes et al. 1986). Results have been inconsistent with cattle. In beef steers fed timothy-red clover silage, chain length and recovery did not always correspond; using the measured exogenous release rate of alkanes, fecal recovery of C_{29}, C_{31} and C_{33} were 92.7, 85.6 and 100%, respectively (Charmley et al. 2003). Recovery was higher (C_{29}, C_{31} and C_{33} were 97.8, 97.4 and 90.5%, respectively), in Holstein cows grazing orchard grass pastures (Froebe 2002). While fecal recovery of alkanes is incomplete, this can be overcome if the synthetic, even-chain alkane is paired with an adjacent plant-sourced, odd-chain alkane that has a comparable fecal recovery (Mayes et al. 1986). There is no available evidence that other plant compounds interfere with intake estimates based on alkanes (Dove and Mayes 2005).

2.7.3. Estimating DMI using n-alkane markers

Numerous studies have validated the alkane procedure in sheep in an indoor environment, demonstrating that the resultant intake estimates were reliable in this species (Dove et al. 2002; Vulich et al. 1991). The following calculation can be used to calculate DM intake:

$$\text{DM intake} = F_i/F_j \times D_j / (H_i - F_i/F_j \times H_j)$$

where H_i and F_i are odd-chain alkanes in herbage and feces, H_j and F_j are even-chain dosed alkanes in herbage and feces, and D_j is the release rate of the dosed even-chain alkane.

Despite the challenges associated with the use of n-alkanes as an external marker, it is currently the only practical technique for determining intake on pasture. As such, n-alkanes have been utilized in studies in Canada to determine level of the level of DMI by cattle (Charmley et al. 2003; Chaves et al. 2006).

2.8. Summary

Grasslands in Western Canada have low soil fertility resulting in low DM yield, and protein content which is marginal. As a consequence, animal productivity is compromised. Therefore, fertilization of native and naturalized grasslands in Western Canada can improve the productivity of hay and pasture systems by improving the protein and utilizable energy content of forage stands, while increasing the productivity in terms of forage yield and carrying capacity.

The abundance of hog production facilities across the prairies has provided cattle operations with the unique opportunity to incorporate hog manure as a plant fertility source for forage production. Liquid hog manure application on grasslands has resulted in increased soil fertility as a consequence of both the addition of nutrients immediately available for use and the addition of organic matter, which releases nutrients over time.

The addition of N to the soil via hog manure application allows for more forage regrowth and less dormancy during the grazing season. Improved forage availability and quality provide greater opportunity for animals to select lower fibre plant biomass with N levels that are adequate to meet the ruminal microbial needs for efficient fermentation. The relationship between the use of liquid hog manure fertilizer on grassland pasture and its effects on blood urea of grazing animals is not well understood. By improving fermentation efficiency through dietary manipulation, CH_4 production as a percent of gross energy intake has been reduced to as low as 4.5% on pasture. The energy retained can generate additional animal production.

The application of nutrients in the form of liquid hog manure to grasslands provides both an opportunity for the utilization of plant nutrients, but also presents a risk of nutrient loading in forage systems due to low nutrient removal efficiencies. Examining the relationships between liquid hog manure application and animal and plant response in a production environment will provide an opportunity to assess the environmental sustainability of this production system.

3.0. RESEARCH HYPOTHESES AND OBJECTIVES

3.1. Hypothesis

Yield and quality of grasslands can be improved using liquid hog manure as a fertility source. Liquid hog manure is a readily available source of nutrients for grasslands in Manitoba because it contains all nutrients required for forage growth. Soil fertility and nutrient utilization will be most improved in grasslands receiving two half-rate applications compared to a single application due to reduced volatilization of ammoniacal-N as a result of the cool autumn conditions, potential for late summer/early autumn growth if the regrowth potential of the species, as well as adequate soil moisture and temperature are available, and the increased availability of residual nutrients at the start of the growing season the succeeding spring after late summer/early autumn application. Liquid hog manure will reduce enteric CH_4 emissions (% GEI) from cattle with adequate pasture DM in response to the improvement in forage CP and reduced NDF, which results in improved rumen fermentation efficiency and in turn reduces CH_4 production. Hay is a more efficient mechanism for removal of grassland nutrients than pasture due to the export of nutrients in the form of hay; grazing animals cycle the nutrients from the plants to the soil and remove minimal nutrients in the form of gain. The use of liquid hog manure will increase pasture carrying capacity and liveweight gain per hectare due to the improved yield, quality and regrowth of pastures as a result of improved fertility.

3.2. Objectives

The overall objective is to assess production and environmental impacts related to the use of liquid hog manure as a fertility source for grasslands in Manitoba. Specific objectives include: 1) to compare grassland productivity and environmental impacts (including methane production and nutrient removal efficiencies) of liquid hog manure application and frequency with grasslands not receiving manure application; 2) to determine the relative production and environmental benefits and costs of a single full versus split liquid hog manure applications over a two year period in terms of forage yield and productivity and nutrient removal efficiencies; 3) to determine the relative production and environmental benefits and costs of haying versus grazing grasslands over a two year period in terms of nutrient utilization and nutrient removal efficiencies.

4.0 MANUSCRIPT I

Productivity and environmental sustainability of grasslands receiving liquid hog manure

4.1. ABSTRACT

Expansion in the hog sector in Western Canada has created opportunities for the beef and dairy cattle industries to improve forage productivity through the application of hog manure as a source of plant nutrients. However, the advantages and disadvantages of this practice in terms of productivity and environmental sustainability require exploration. In response to this need, forage yield and quality data were collected from replicated grass hayfields receiving no liquid hog manure or liquid hog manure as a single application of 155 kg ha^{-1} (Full) of available N in the spring or as a split application (Split) of 74 kg ha^{-1} of available N in both the spring and the autumn. Multiple 0.25m^2 quadrats of forage were clipped just prior to cutting hay to determine standing hay DM yield and quality. Resulting bales were weighed, core sampled and analyzed for quality. Hayfield nutrient balance was determined by comparing the removal of nutrients in the form of hay to the nutrients applied in the form of liquid hog manure. Hog manure application on hayfields increased forage yield and nutrient profiles relative to hayfields receiving no fertilizer. Two-year average forage biomass generated in Control, Split and Full hayfields were 3.7, 8.8 and 8.4 ± 0.31 t ha^{-1}, respectively. Mean standing forage CP was lowest for unmanured land (7.1 ± 0.24 % CP, P=0.0004), while Split and Full standing forage had CP concentrations of 9.4 and 10.5%, respectively. Neutral detergent fibre was higher in forage from Split fields (61.9 ± 1.05%, P=0.0545) than from Control or Full (57.1 and 58.9%, respectively) as a consequence of increased maturity at cutting. Gross energy was highest in forage from manured hayfields (18.6 and 18.5 kJ g^{-1} DM in Split and Full, respectively, P=0.0443) compared to that in the unmanured treatment (18.3 kJ g^{-1} DM).

Nitrogen and phosphorus (P) exported from the land base as baled hay was five- and six-fold greater, respectively, for manured plots compared to Control plots (P=0.0013 and P=0.0034, respectively). This accounted for up to 32.6 % of applied N and 24.8 % of the applied P. Calculations do not include residual N in the forage and soil, nor that which was lost to the air and water. Potassium (K) was the most efficiently harvested nutrient, with up to 68.9% of applied K removed, while removal efficiency of applied magnesium was the lowest at 13.9%.

Abbreviations: CP, crude protein; **N**, nitrogen; **P**, phosphorus; **K**, potassium, **Mg**, magnesium

Keywords: liquid hog manure, grasslands, hay, quality, crude protein, nitrogen, phosphorus

4.2 INTRODUCTION

Native grass species tend to have low crude protein (CP) concentrations and are low yielding (Looman 1983). The application of nitrogen (N) fertilizer can improve grassland quality by encouraging regrowth and higher N in resulting biomass, thereby increasing forage CP concentrations (Dougherty and Rhykerd 1985).

There has been substantial growth of the hog industry in recent years. Manitoba has an annual pig production of approximately nine million head (MAFRI 2007). As a by-product of production, hog manure can provide a source of nutrients such as N, P, K, S and Mg for plant growth (Fitzgerald and Racz 2001b). It is estimated that the hog industry produces enough manure to fertilize 6% of Manitoba's total agricultural land base on the basis of N requirements (Manitoba Conservation 2006) or 15% on the basis of P requirements (Manitoba Pork Council 2007).

Blonski et al (2004) utilized liquid hog manure on meadow bromegrass (*Bromus biebertsteinii*) and crested wheatgrass (*Agropyron cristatum*) pastures at a rate of 160 kg ha^{-1} NH_4-N and found forage yield improved from 1.6 to 3.6 t ha^{-1} and CP concentrations increased from 6.9 to 9.1%. As well as improved forage yield and quality, the addition of nutrients has been shown to improve forage regrowth. McCaughey and Simons (1996) demonstrated that commercial fertilizer applied at rates up to 160 kg N ha^{-1} y^{-1} to crested wheatgrass, meadow bromegrass or smooth bromegrass (*Bromus inermis*) grassland systems resulted in increased regrowth by 7 to 33.5% in simulated pasture systems receiving three to four cuts over a two-cut hay management systems.

When hog manure is spread to meet the N needs of plants, other nutrients present in excess of plant requirements can begin to build-up in the soil. The objective of this study was to determine not only the effect of liquid hog manure application on grassland hay yield and quality, but also to assess the environmental sustainability of manure application on hayfields in terms of nutrient removal in the form of hay.

4.3 MATERIALS AND METHODS

4.3.1. Site description

Research was conducted on a 40 hectare site (SE 20-05-08E), located eight miles south of La Broquerie, Manitoba, Canada on Class 3M land, which is comprised of loamy sands with low moisture holding capacity (Canada Land Inventory 1965). The site was comprised primarily of mixed grass forages and was divided into six hay fields. Two hayfields were assigned to each of three fertility treatments (Table 1): no hog manure application (Control), 74 kg ha^{-1} available N via applied liquid hog manure in both autumn and spring (Split), and 155 kg ha^{-1} available N via applied liquid hog manure in the spring (Full).

4.3.2. Site management

4.3.2.1. Manure application

Liquid hog manure was tested in the field for ammoniacal-N with a NOVA meter and organic-N with a hydrometer to target an application rate of 123 kg available N ha^{-1}, with the actual annual application rates reaching 148 kg available N ha^{-1} in the Split treatments and 155 kg available N ha^{-1} in the Full treatments (Table 1). Samples of manure taken at the beginning, middle and end of each application day were also analyzed in a laboratory. Liquid hog manure from a local feeder barn was surface-applied using drag lines (autumn

Table 1. Summary of manure nutrient application rate on forage land[z] over two years.

	Control		Split		Full	
	Spring	Fall	Spring	Fall	Spring	Fall
n	NA	NA	12	7[x]	12	NA
% DM	NA	NA	8.3	2.8	8.3	NA
Application Rate						
Volume (' 000 L ha^{-1})	NA	NA	24	30	49	NA
Available N[y] (kg ha^{-1})	NA	NA	77	71	155	NA
Total N (kg ha^{-1})	NA	NA	143	112	285	NA
P (kg ha^{-1})	NA	NA	33	12	67	NA
K (kg ha^{-1})	NA	NA	52	62	103	NA
Mg (kg ha^{-1})	NA	NA	33	17	66	NA
S (kg ha^{-1})	NA	NA	9	5	18	NA

[z]Class 3M land - loamy sands with low moisture holding capacity (MARC, 1998).

[y]Application to meet N requirement was estimated in the field from measurements of ammoniacal nitrogen (using a NOVA meter) and organic nitrogen (calculated from specific gravity determination using a hydrometer). Application rates were then determined using the Tri-Provincial Manure Application and Use Guidelines assuming 25% volatilization for surface application of manure and 25% N available from organic N in the year of application (http://www.gov.mb.ca/agriculture/livestock/beef/pdf/baa08s01a.pdf, 2006).

[x]n is lower in the Fall treatment due to a reduction in total volume of manure applied and thus fewere days of application.

NA, no manure applied

2003) and a tanker (remaining applications), targeting specific levels of available N in each treatment after accounting for volatilization. Application rates of the hog manure were established based on Manitoba Agriculture, Food and Rural Initiatives recommendations for Class 3M land in the Tri-Provincial Manure Application and Use Guidelines (The Prairie Provinces Committee on Livestock Development and Manure Management 2006). The guidelines are based on the assumption that surface application under cool conditions will result in volatilization of 25% of ammoniacal-N and that 25% of N is available from organic N applied the first year of the study. Ammoniacal-N in the liquid hog manure was measured using a NOVA meter and organic N was estimated by measuring specific gravity with a hydrometer. Liquid hog manure was sampled at the beginning, middle and end of each application day and analyzed in a laboratory.

4.3.2.2. Hayfield management

Hayfields were 1.2 hectares in size. Hay harvesting criteria for first cut hay was based on reaching the early head stage, while second cut hay was dependent upon available standing forage reaching 2.5 t DM ha^{-1}. However, inclement weather influenced the time of haying and the resulting hay quality. Hayfields were cut on June 29 and October 4 in Year 1 and on July 20 in Year 2. Standing forage biomass of each hayfield was determined immediately prior to harvest by clipping nine $0.25 m^2$ quadrats down to 3.75 cm above the soil surface, in a W-pattern. Hayfields were raked to facilitate drying. Once dry, the hay was baled, sampled and removed from the hayfield. One-third of the bales from each hayfield were weighed on a platform scale. These bales were then each individually sampled with a forage probe (5 cores per bale, Penn State Core Sampler).

Collected forage samples were analyzed for proximate analysis and mineral composition. Residual standing forage was determined at the end of the growing season by collecting nine quadrat clippings in a W-pattern throughout each hayfield.

4.3.3. Forage samples and analysis

4.3.3.1. Chemical analyses

Forage samples were dried for 48 hours at 60^0C in a forced-air oven to determine DM content. After drying, samples were ground through a 1 mm screen (Cyclotec tecator 1093 Sample Mill, Foss Analytical, Denmark).

Forage samples were analyzed for CP using a Leco NS 2000 (LECO Corporation, St. Joseph, MI) and ash, method no. 942.05 (Association of Official Analytical Chemists 1990). Gross energy was determined using a Par 6300 Automatic Isoperibol Calorimeter (Moline, IL). Acid detergent fibre (ADF) and neutral detergent fibre (NDF) were determined using an ANKOM 200 fiber analyzer (Fairport, NY) as described by Komarek (1993). Phosphorus (P), potassium (K) and magnesium (Mg) concentrations were determined by flame atomic absorption spectroscopy (Method No. 968.08; AOAC 1990) using a Vista MPX CCD Simultaneous ICP-OES (Varian, Mississauga, ON).

4.3.3.2. Calculations

The standing forage biomass in the hayfields was calculated from quadrat samples using the following calculation:

Standing forage biomass (kg DM ha^{-1}) = (Forage DM collected from quadrat [kg]/Quadrat area [m^2]) x 10,000m^2 ha^{-1}

Net removal of nutrients from the hayfields was calculated using nutrient content of hay bales using the following calculation:

Net nutrient removal (kg DM ha^{-1}) = (Number of bales x average bale weight x % DM) x (% Nutrient content)

The nutrient removal efficiency was determined by dividing total nutrients removed from the land base by the nutrients applied, as described in the following equation:

Nutrient removal efficiency (% of applied) = (Net nutrient removal kg DM ha^{-1}) / (Nutrients applied kg DM ha^{-1})

When determining N removal efficiency, N applied was calculated as the total N applied, minus 25% of ammoniacal-N.

4.3.3.3. Statistical analysis

Standing forage in hayfields and proximate analysis were analyzed by analysis of variance using a General Linear Model (SAS Institute Inc. 1990) with model: $Y_{ikl} = \mu + t_i + r_j + y_k + yt_{ki} + \varepsilon_{ijk}$ where t_i = treatment effect, r_j = rep effect, y_k = year effect, yt_{ki} = year x treatment interaction, ε_{ijk} = experimental error term.

Year and rep were considered random factors in the models. Mean separation was performed using Bonferonni at a significance level of 5%.

4.4 RESULTS AND DISCUSSION

4.4.1. Fertilization

Actual available N applied was 148 kg ha^{-1} and 155 kg ha^{-1} for the Split and Full treatments, respectively (Table 1). Final available N application rates were 20 and 26% above the targeted application rate for Split and Full treatments, respectively. Except for K, the Split application manure treatment received greater quantities of nutrients in the spring than in the autumn. Application rate of manure P appeared to have the greatest seasonal variability, as it was 49% higher in the Full applications than in the Split. These differences may be attributed to variability in chemical composition of the manure as indicated in Table 2. The greatest variability in manure composition was observed for DM content, nitrate (NO_3) and P. As a consequence, P applied to the land base has a CV of 43 (Table 2). The NO_3 and NH_4 present in the manure provide an immediate source of plant-available nutrients. Dougherty and Rhykerd (1985) summarize that NO_3 is the main N-compound in the rooting zone of grassland soils and is a major source of N; it does not tend to bind to soil colloids, but moves freely in soil water and is highly available to the plant. Further, NH_4 ions are easily absorbed by roots, but are less available due to their ability to bind in soil.

4.4.2. Forage productivity

The average forage biomass generated for Control, Split and Full hayfields was 3.7, 8.8 and 8.4 ± 0.31 t DM ha^{-1}, respectively (Table 3). Manure application (P = 0.0001) had a significant effect on forage production, increasing total forage biomass

Table 2. Variability in chemical composition of liquid hog manure from a single source over two years of land application (n=13).

Nutrient	Mean	Min	Max	CV
Manure Composition				
% DM	7.0	1.8	12.8	56.5
Total N (%)	0.5	0.3	0.7	22.6
NO_3 (mg N L^{-1})	1.3	0.1	3.0	59.0
NH_3 (mg N L^{-1})	3328.4	2630.0	3820.0	11.0
P (mg L^{-1})	1116.8	140.0	1720.0	49.6
K (mg L^{-1})	2102.6	1890.0	2270.0	5.4
Mg (mg L^{-1})	1143.4	420.0	1710.0	39.2
S (mg L^{-1})	319.5	100.0	480.0	40.1

Table 3. Standing biomass[z] of forage, hay harvested[y] (control n=4; split and full n=6) and nutrient profile of standing forage biomass immediately prior to first hay cut (n=4) over two years.

Parameter (DM basis)	Control	Split	Full	SE	P-value
Total forage biomass generated, t ha^{-1}	3.7b	8.8a	8.4a	0.31	0.0001
Hay harvested, t ha^{-1} y^{-1}	1.3b	4.6a	4.6a	0.31	0.0009
Nutrient profile of standing forage biomass at first cut					
Crude protein (%)	7.1b	9.4a	10.5a	0.24	0.0004
Neutral detergent fibre (%)	57.1	61.9	58.9	1.05	0.0545
Acid detergent fibre (%)	32.4	35.2	33.9	0.77	0.1141
Ash (%)	6.2	5.8	6.3	0.25	0.3658
Gross energy (kJ g^{-1})[w]	18.3	18.6	18.5	0.06	0.0443

[z]Biomass refers to the cumulative biomass of forage standing prior to harvest as hay and residual forage at the end of the growing season.

[y]Hay harvested refers to the amount of forage baled and removed.

[w]Mean separation test did not show differences between means.

a,b Values within a row are different ($P < 0.05$).

yield by 2.4-fold greater compared to the unmanured Control treatment. Soils are often deficient in N and respond with increased yield when N, the most limiting nutrient, is applied (Tisdale et al. 1993a).

Harvested hay averaged 1.3, 4.6 and 4.6 ± 0.31 t DM ha^{-1}, respectively (Table 3). Manure application (P = 0.0009) influenced the harvest yield of the hay plots, with up to a 3.5-fold increase in forage removal with treatments receiving manure. In the first year of study (2004) a second hay cut was harvested from the Split and Full treatments but not from the Control treatment as the latter treatment had insufficient regrowth to warrant a second cut. In the second year of the study, all treatments were harvested only once. Precipitation that year was limited from mid-summer to early autumn and as a result regrowth was limited until late in the autumn. As such, sward height was inadequate to merit a second cut, which contributed to the low hay harvest efficiency. The low efficiencies of hay harvested compared to forage biomass available (32 to 55%) was a consequence of inclement weather, as well as labour and equipment shortages. The small 1.2 ha plots were harvested with field-scale sized equipment, resulting in high amounts of residual forage left where equipment had difficulty maneuvering. As well, rain and poor drying conditions lead to respiration and leaching, as well as leaf loss associated with raking and baling. In addition, lower leaf and stem material were left in the field. Residual forage was also present in the field at the end of the growing season.

4.4.3. Forage quality

In this study, nutrient profiles of the standing forage prior to the first harvest of each year were compared between treatments. Crude protein concentrations were up to

3.4% units higher in standing forage that had received manure than in those that had not (Table 3; P = 0.0004). The observed increase in CP concentrations with the addition of N agrees with findings using inorganic N fertilizer (Dougherty and Rhykerd 1985). In order to ensure efficient N use and good rumen fermentation of forage in cattle, dietary CP must be adequately supplied. Standing available forage from unmanured hayfields ranged from 4.3 to 10.8% CP content with 53% of samples below 7.3% CP. By comparison, CP content of hayfields fertilized with manure ranged from 4.2 to 24.1%. Crude protein in the unmanured treatment hay (Table 3) is below that required (7.3%) to achieve 0.35 kg d^{-1} gain in a 325 kg steer, assuming energy in the diet is not limiting (National Research Council 1996). Hay produced from fields receiving manure (9.4 to 10.5% CP) could provide gains in excess of 1 kg d^{-1} for animals in the same category; the maximum CP content for animals in this category is 18.3%, allowing for weight gains of 2.0 kg d^{-1} (National Research Council 1996). Excessive CP in the diet, beyond the needs of the growing cattle, is undesirable as it is energetically expensive for the animals to process and excrete the excess nutrient (National Research Council 1996). As well, a large proportion of the N excreted in urine is lost to the environment through leaching or volatilization (Kimura and Kurashima 1991). Only 3% of manured hayfield samples collected were in excess of 18.3% CP, and these were isolated to the Full treatment plots.

Neutral detergent fibre is composed of cellulose, hemicellulose, lignin and insoluble ash and can influence voluntary intake (Fahey, Jr. and Berger 1988). The concentration of cell wall components in forage diets is the best indicator of intake, where undigested forage residues residing in the rumen results in a physical limitation to further intake (Waldo 1986). Neutral detergent fibre was highest in the Split application treatment, but similar between Control and Full applications (Table 3; P=0.0545). Time of manure application and date of harvest could have influenced the maturity of the hay from the Split treatment compared to that of the Full and Control treatments. In the autumn of 2003, the Split treatment received an initial half-rate application of liquid hog manure, which could have allowed for late season forage growth and the advancement of maturity. In 2004, the spring application of manure was delayed for several weeks due to a late snowstorm. Grassland forages were already growing before liquid hog manure was applied. The Split treatments had access to residual nutrients from the autumn application and grew quickly in the spring at the onset of warm temperatures. The Full treatments responded more slowly until additional nutrients were added through manure application. Although all hayfields were harvested on the same date, both visual observation and the analysis of forage indicate that forage in the Split hayfields (63.7 % NDF) had been allowed to mature to a greater extent than the forage in Control or Full treatments, which contained 55.0 and 56.4 % NDF, respectively. In 2005, after a timely hog manure application, forage from Control, Split and Full treatments had comparable NDF contents of 59.3, 61.0 and 61.4 %, respectively. However, the delayed harvest resulted in all treatments being harvested at a more mature state, as indicated by higher average NDF values than were observed the previous year.

Acid detergent fibre can be used to estimate relative forage digestibility (Fahey, Jr. and Berger 1988). Forage acid detergent fibre content was not different for hayfields representing the three fertility treatments (Table 3; P = 0.1141), with values 32.4, 35.2 and 33.9% DM basis for Control, Split and Full treatments, respectively.

Gross energy of standing forage biomass appears to increase in hayfields receiving hog manure (Table 3; $P = 0.0443$), but mean separation using Bonferroni did not detect differences between the means. The observed increase in herbage energy agrees with research indicating that the addition of inorganic N fertilizer to grass pasture leads to an increase in the estimated metabolizable energy (Kenny et al. 2001).

Differences in forage ash content was not detected between hayfield treatments (Table 3; $P > 0.05$), but differences were apparent for N and P. Nitrogen, % DM basis, was higher in Full treatments than Control (1.79 vs. 1.23 ± 0.07; $P=0.0075$), but not statistically different from Split treatments (1.47). Phosphorus content was highest in forage receiving manure (0.24 and 0.29 ± 0.013%; $P=0.0032$) in Split and Full treatments, respectively, compared to Control hayfields (0.17). There were no differences detected ($P > 0.05$) in K (1.1-1.4 ± 0.07 % DM basis) or Mg (0.15-0.17 ± 0.011 % DM basis) content of baled hay.

The addition of hog manure to grass-based hayfields clearly improved the quantity and quality of the forage as measured by increased CP and energy content. Further, the Full application offered the additional benefit of lower NDF values than were present in the first cut standing forage which received a split application of manure.

4.4.5. Nutrient export

The removal of nutrients from grass based hay systems occurs in the form of plant harvest from hayfields (King 1981; Stout and Jung 1992). Manure can be applied to land to supply the N requirements of grasslands. As a result of N-based application, P and other nutrients present in manure are often provided in excess of grassland requirements and can build-up in the soil (Racz and Fitzgerald 2001). The rate of removal can be affected by plant requirements and nutrient interactions in the soil. Unutilized nutrients that remain in the soil represent an environmental risk in which nutrients may be lost through leaching or erosion and have the potential to detrimentally affect waterways (Koelsch 2005) by providing limiting nutrients for algae production, or by directly affecting drinking water quality.

In the current study, the application of liquid hog manure to hayfields resulted in increased removal of N, P, K, and Mg ($P < 0.05$; Table 4) in the form of hay compared to unmanured hayfields. Nitrogen, a constituent in plant cell amino acids, proteins and nucleic acids (Taiz and Zeiger 2006) which comprised 0.9 to 2.6% of plant tissue DM in bale core samples, is almost always the nutrient which limits yield and therefore is frequently supplemented (Tisdale et al. 1993a). The recommended rate of N application to grasslands producing 7.4 t grass hay ha^{-1} is 123 kg available N ha^{-1}, with an estimated removal of 115 kg N ha^{-1} associated with harvest (MAFRI 2006).

In the current study, the average annual removal of N in the form of hay for Control, Split and Full treatment fields was 15.2, 68.6 and 77.9 kg ha^{-1}, respectively ($P = 0.0013$). Harvest efficiency of N, measured as nutrients removed as a percentage applied, was comparable between the Split and Full treatment groups, with an approximate removal rate of 32% ($P = 0.9437$).

The recovery of applied N is reliant on the method, rate and time of application, as well as the availability of soil N, source of N, plant species, environmental factors and

Table 4. The effect of applying no (Control) or 155 kg ha^{-1} available nitrogen in the form of liquid hog manure in one (Full) or two (Split) applications annually on the annual removal of nutrients in the form of hay (n=4).

	Control	Split	Full	SE	P-value
Nutrients removed in the form of hay, kg ha^{-1} y^{-1}					
Nitrogen	15.2b	68.6a	77.9a	5.89	0.0013
Phosphorus	2.2b	11.2a	13.0a	1.24	0.0034
Potassium	13.4b	58.2a	67.0a	5.56	0.0022
Magnesium	2.1b	7.0b	8.1b	0.81	0.0070
Nutrients removed in the form of hay, % of total applied					
Nitrogen^{z}	NA	32.6	32.3		
Phosphorus	NA	24.8	18.9		
Potassium	NA	52.2	68.9		
Magnesium	NA	13.9	12.2		

^{z} The % nitrogen removed is the N removed as hay divided by applied N after subtracting 25% of ammoniacal N for volatilization, multiplied by 100.

a,b Values within a row are different ($P < 0.05$)

NA - no manure applied

the period of time between N application and the removal of the forages. With forages, 50 to 80% N recovery can be anticipated at harvest (Dougherty and Rhykerd 1985). A twelve-year study by McCartney et al. (1998) found that the average uptake of N by forage was equivalent to the amount of inorganic N fertilizer that had been applied when N was applied at rates of 0, 45 and 90 kg ha^{-1} in combination with P at 0 and 20 kg ha^{-1} on eight different grass and mixed grass-legume pastures on loam soils.

Nutrient removal efficiencies may also be influenced by soil fertility. The land utilized for the present trial had no known history of fertilization prior to commencing the trial. The N added to the soil in the form of liquid hog manure may have become immobilized in the soil and temporarily unavailable to forage plants (Looman 1983), explaining the lower rates of N harvest efficiency. A Japanese study determining the fate of applied labeled N in soil and herbage found herbage recovered 37 to 50% of applied N, with approximately half of the N incorporated into grass originating from soil N reserves (Kimura and Kurashima 1991).

McCartney et al. (1998) also noted that considerable differences in nutrient uptake between years can be attributed to annual variation in precipitation and temperature. The difference observed between the greater nutrient uptake and the observed 32% N removal efficiencies in the present study could be a function of having only two observation years with less than optimum harvest management. Further observations under different climatic conditions may result in a greater removal of N. Precipitation may very well influence more than just nutrient uptake. Cut hay exposed to precipitation may have lost nutrients due to leaching before it was baled and removed from the hayfield, contributing to the low nutrient removal efficiencies. A more optimum harvest management, in terms of harvest efficiencies and timely baling and removal, would have improved the rate of nutrient removal and removal efficiencies. Assuming an idealized harvest of 80% of total forage biomass generated in a season (Cundiff 1996), N removal efficiency could have been improved to 49% (Appendix 1).

Phosphorus, which comprised 0.15 to 0.32% of plant tissue DM in bale core samples, is a component of DNA, RNA, nucleotides, respiration and photosynthesis intermediates and also phospholipids present in the plant membranes (Taiz and Zeiger 2006). As manure is often applied to land to supply the N requirements of the crop or pasture, the levels of P applied are often greater than can be utilized and as a result build up in the soil. However, the quantity of soil P does not necessarily represent its availability to plants. Phosphorus that is applied can remain unavailable in the soil due to its ability to adsorb to mineral surfaces (Tisdale et al. 1993b). It is often the properties of soil and its biogeochemical reactions that dictate the fate of a nutrient (O'Connor et al. 2005). In general, P is more strongly adsorbed in fine-textured soils than in sandier soils due to the presence of clay minerals to which P compounds bind. In some soil environments, the accumulation of P in soil demonstrates an environmental risk due to its potential to leach or erode into waterways and water bodies with detrimental results (Koelsch 2005). A ten-year study examining intensive hog manure application on loamy sand soils showed that after four years of annual application at rates up to 625 kg P ha^{-1}, P had accumulated in topsoil and leaching was evident (Novak et al. 2000). In order to avoid phosphorus loading in the soil, the P removed must be equal or greater than the P applied.

Phosphorus removal in the form of hay in the current study was up to six-fold greater in fields that had received manure treatments compared to those which had not ($P = 0.0034$). Unmanured hay removed only 2.2 ± 1.24 kg P ha^{-1}. In manured fields, the efficiency of P removal ranged between 24.8 % for the Split treatment and 18.9% for the Full. A more optimum harvest of 80% of total forage biomass generated in a season would have resulted in P removal efficiencies of up to 37% (Appendix 1).

Following N, K is the nutrient absorbed by plants in the greatest quantity. It comprised 0.9 to 2.0% of plant tissue DM in bale core samples and is required for the regulation of osmotic potential in cells as well as respiration and photosynthesis (Taiz and Zeiger 2006).

Potassium in the soil is only 1 to 10% available due to its ability to adsorb to soil minerals; the available fraction is removed from the root zone by plant uptake or is lost due to leaching (Tisdale et al. 1993c). Estimates of K removal for grass hay are 121 kg ha^{-1}, while the addition of inorganic K fertilizer is recommended at rates of 56 kg ha^{-1} based on an estimated yield of 7.4 t grass hay ha^{-1} (MAFRI 2006). In the present study, potassium was supplied via hog manure (based on available N content to hayfields) at a rate of 103 to114 kg ha^{-1} (Table 1), approximately twice as high as recommended. The most efficient removal of applied nutrients from the hay fields was observed with K. Removal of K was lowest in the unmanured Control hayfield, where only 13.4 ± 5.56 kg ha^{-1} was harvested ($P = 0.0022$). In contrast, Split and Full treatment fields yielded 58.2 and 67.0 kg K ha^{-1}. When expressed as a percent of that applied, 68.9% of applied K was removed in full treatments, while 52.2% of that applied was removed in Split treatments. Assuming a more optimum harvest of 80% of total forage biomass generated in a season, all K added to the hayfields in the form of liquid hog manure could have been accounted for in the form of hay (Appendix 1). The removal of K in excess of applied indicates that K adsorbed to the soil became available to the plant over the growing season. As well, the variability in manure application could have resulted in a higher K application in Full hayfields than was accounted for in the averaged application rate.

The high K content in the hay may indicate a potential problem. Hypomagnesemic or grass tetany is a metabolic disorder usually associated with an electrolyte imbalance. While little research has been conducted on tetany in beef cattle, there has been anecdotal evidence that beef herds affected by tetany-like symptoms may be affected by the mineral content of local feed sources (Walker 2003). The "tetany ratio" is described as the ratio of K/(Ca+Mg) (in milliequivalents kg^{-1} DM) which results in a value > 2.2 (Kemp and 't Hart 1957). Kemp and 't Hart (1957) found that when the ratio of K/(Ca+Mg) in the forage was greater than 2.2, the incidence of tetany increased. It follows that diets with excess potassium or inadequate calcium and magnesium intake can result in a greater likelihood of animals experiencing tetany. Given the elevated K levels in the manured forage, forage from the manured fields should be tested and dietary ratio of K/(Ca+Mg) monitored to ensure that the dietary tetany ratio remains below 2.2.

Magnesium comprised 0.13 to 0.21% of plant tissue DM in bale core samples. It contributes to the structure of chlorophyll and is necessary for respiration, photosynthesis and the synthesis of DNA and RNA (Taiz and Zeiger 2006). Magnesium is slowly available from the weathering of parent material. It is absorbed by plants or soil organisms, adsorbed to soil, precipitated or leached from the root zone – particularly in coarse-textured soils (Tisdale et al. 1993d). Application of Mg to grasslands in Manitoba is not necessary (MAFRI 2006), as its presence in soil is generally sufficient.

An almost 4-fold increase in Mg was removed from manured fields, compared to that (2.1 ± 0.81 kg ha^{-1}) removed from the Control fields (P = 0.0070). The efficiency of removal was lowest in Mg compared to all other nutrients, averaging a removal efficiency of 12.2 % in the Full treatment. Even with a calculated 80% hay harvest efficiency, Mg removal as a percent of applied was only 21% (Appendix 1). Low Mg forages can contribute towards grass tetany (hypomagnesemia) if Ca is also limited or K supplied in excess (Tisdale et al. 1993d).

4.5. Conclusion

The use of liquid hog manure on mixed-grass hayfields improved standing forage CP and GE content prior to first cut relative to fields receiving no manure, while forage ash and ADF content were not affected. Forage NDF increased when the stand received a split application of manure, likely due to its earlier and accelerated growth after the initial manure application in the autumn. The total forage biomass generated and harvested was increased by 2.4-fold and 3.5-fold, respectively, with manure application. Nutrients harvested in the form of hay were up to 6 times greater from the manured hayfields than unmanured, but the efficiency of nutrient removal as a percentage of applied was less than 35% for all measured nutrients except K.

5.0 MANUSCRIPT II

Productivity and environmental sustainability of Western Canadian (Manitoba) grasslands receiving liquid hog manure to enhance fertility

5.1. ABSTRACT

Forage and animal production, enteric methane (CH_4) emissions, serum urea nitrogen (N) and mineral harvest efficiencies were collected from replicated grass pastures receiving no liquid hog manure or liquid hog manure applied as a single application of 155 kg ha^{-1} (Full) of available N in the spring or a split application (Split) of 74 kg ha^{-1}of available N in both the spring and the autumn, or unmanured pastures. Enteric CH_4 emissions were quantified using the sulphur hexafluoride (SF_6) tracer gas technique. Multiple 0.25m^2 quadrats of forage were clipped every 28 days to determine pasture DM yield and hand-plucked forage samples were collected to determine nutrient composition of forage consumed by cattle. Animal weight, blood samples and 24-h CH_4 emissions were measured once in each of three 28-day periods. Nutrient balance of pastures was determined by comparing the removal of nutrients as animal gain with nutrients applied to pasture in the form of liquid hog manure.

Hog manure application on pastures increased forage yield and nutrient profiles relative to pastures receiving no fertility. Mean forage CP was more than doubled with manure application, resulting in higher serum urea nitrogen (Split = 6.06, Full = 6.09 ± 0.61 mmol L^{-1}, P=0.0225) values in steers grazing manured pastures compared to those grazing unmanured pastures (2.56 mmol L^{-1}). Animal DMI and enteric CH_4 emissions (% GEI) were unaltered by the changes in forage quality as a result of hog manure application. The addition of hog manure increased pasture carrying capacity over the grazing season more than three-fold compared to unmanured pastures which supported 101 grazing days ha^{-1} yr^{-1}. Animal productivity increased from 104 kg gain ha^{-1} for

unfertilized pastures to 325 and 344 kg gain ha^{-1} for Split and Full pasture treatments, respectively ($P=0.0019$).

Nitrogen and phosphorus (P) exported as body weight gain by steers was at least three times greater in manured plots compared to control plots ($P=0.0019$). However, this only accounted for up to 4.7 % of applied N and 6.1 % of the applied P. Calculations do not include residual N in the forage and soil, nor that which was lost to the air and water.

Abbreviations: **CH_4**, methane; **CP**, crude protein; **DM**, dry matter; **DMI**, dry matter intake; **GEI**, gross energy intake; **N**, nitrogen; **P**, phosphorus; **SF_6**, sulphur hexafluoride; **SUN**, serum urea nitrogen

Keywords: liquid hog manure, methane, cattle, pasture, crude protein, serum urea nitrogen

5.2 INTRODUCTION

In 2001, 79% of the 0.72 million hectares of Manitoban pasture land utilized by grazing beef and dairy cattle was native or naturalized (Statistics Canada 2005). Native grass species tend to be low yielding and have low crude protein concentrations (Looman 1983). The application of nitrogen (N) fertilizer can improve grassland quality by encouraging regrowth and high N in resulting biomass, thereby increasing forage crude protein concentrations (Dougherty and Rhykerd 1985). Also improved is pasture performance, as the introduction of nutrients in the form of commercial fertilizer has been shown to increase carrying capacity and liveweight gain per unit area (Kopp et al. 2003).

There has been substantial growth of the hog industry in recent years. Manitoba has an annual pig production of approximately nine million head (MAFRI 2007). As a by-product of production, hog manure can provide a source of nutrients such as N, P, K, S and Mg for plant growth (Fitzgerald and Racz 2001b). It is estimated that the hog industry produces enough manure to fertilize 6% of Manitoba's total agricultural land base on the basis of N requirements (Manitoba Conservation 2006) or 15% on the basis of P requirements (Manitoba Pork Council 2007). Blonski et al (2004) utilized liquid hog manure on meadow bromegrass (*Bromus biebertsteinii*) and crested wheatgrass (*Agropyron cristatum*) pastures at a rate of 160 kg ha^{-1} NH_4-N and found forage yield improved from 1.6 to 3.6 t ha^{-1} and crude protein concentrations increased from 6.9 to 9.1%. Researchers have shown that by improving forage quality, CH_4 production can be reduced (Demeyer and Van Nevel 1975). The potential to reduce enteric CH_4 emissions by producing higher quality forages with the application of hog manure to grasslands has yet to be explored.

When hog manure is applied to meet the N needs of plants, other nutrients present in excess of plant requirements can begin to build-up in the soil, especially in pastoral systems where nutrient removal in the form of animal gain is quite low. The objective of this study was to examine changes in forage yield and quality, as well as animal performance, associated with the application of liquid hog manure. Further objectives were to assess the environmental sustainability of hog manure application in terms of nutrient removal, animal gain, as well as its influence on enteric CH_4 emissions. Such information may be utilized by forage and cattle producers to ensure that productivity of naturalized pastures is improved in a sustainable fashion.

5.3 MATERIALS AND METHODS

5.3.1. Site description

The research site, located near La Broquerie, Manitoba (SE20-5-8E) on loam soils was divided into six pastures. Two pastures were assigned to each of the three fertility treatments. The three fertility treatments were: no hog manure application (Control), 74 kg ha^{-1} available N via applied liquid hog manure in both autumn and spring (Split), and 155 kg ha^{-1} available N via applied liquid hog manure in the spring (Full).

5.3.2. Site management

5.3.2.1. Manure application

Hog manure was surface applied by drag lines (autumn 2003) and tanker (remaining applications) from a nearby feeder barn with dry matter varying from 1.8 to 12.8 % and N content from 0.3 to 0.7 %. Phosphorus content was the most variable nutrient ranging from 140 to 1720 mg L^{-1}. Application rate was based on N content. A more complete nutrient profile of the liquid hog manure was provided in Manuscript I.

5.3.2.2. Pasture management

Each fertility treatment was replicated twice. Manured pastures were 4.0 hectares while unmanured (Control) pastures were 8.0 hectares in size to ensure adequate forage availability for the experimental animals assigned to each pasture. Pastures, which were divided by 3-wire high-tensile electric fence, were continuously grazed for the duration of the trial.

Standing available forage of each pasture was determined at the beginning and middle of each 28-day period by clipping nine $0.25m^2$ quadrats in a W-pattern to a height of 3.75 cm. Animals were introduced to pastures when available standing forage was visually estimated to be approximately 1000 kg DM ha^{-1}. Steers were grazed over the three 28-day periods. Put and take steers, as described in Kopp et al. (2003), were used in an attempt to maintain standing available forage between 1.0 to 1.5 t DM ha^{-1} and maintain plant growth at the vegetative stage in all pastures. These put and take steers were kept on an adjacent pasture, similar in botanical composition to the research pasture. To collect an accurate sample of forage material consumed by steers, animal grazing activity was observed from a distance and similar plant species were collected to the height grazed. Two such hand-plucked samples from each pasture representative of the animals' diet composition were collected each period concurrent with enteric CH_4 collections.

Botanical composition of the pastures (Table 2) was estimated by taking 10 duplicated transects along the diagonal of each pasture. Each transect had 10 points below which the nearest plant was recorded, thus a total of 200 plants were identified in each pasture. Measurements were taken in mid-July of each year.

5.3.2.3. Animal management

Ten British-cross yearling steers were assigned to each pasture on the basis of body weight (mean ± SE: Year 1 = 286.4 ± 17.3 kg; Year 2 = 282.7 ± 7.2 kg). Treatment groups in each pasture were balanced such that the total mass of each group at the onset of the grazing trial was equal.

Prior to pasture introduction, steers were treated with Spotton ® pour-on solution (Bayer Inc., Toronto, ON), vaccinated with Bovi-Shield 4 ® (Pfizer Animal Health, Exton, PA) and One Shot ® (Pfizer Animal Health, Exton, PA), and Valbazen ® oral suspension (Pfizer Animal Health, Kirkland, QC) administered. Steers received Revlar-G ® implants (Intervet Canada Ltd, Whitby, ON) immediately prior to pasture introduction. On pasture, steers were sprayed with Ectiban ® (Durvet Animal Health Inc, Bluesprings, MO) to protect against biting flies and mosquitoes as per the manufacturer's directions when flies were observed settling on animals.

Steers were weighed full and empty on two consecutive days prior to trial commencement and every 28 days thereafter. Canadian Council on Animal Care guidelines were followed in the care and management of the steers (CCAC, 1993).

Ad libitum fresh water and loose trace mineral (Appendix 3; Rancher's Choice 8:4:50 Interlake Beef Pasture Premix, Puratone Feeds, Niverville, MB) were available in each pasture. In 2004, trace mineral was mixed 1:1 with limestone.

All cattle were removed from pasture at the cessation of the third period, generally in mid-August.

5.3.3. Samples and analysis

5.3.3.1. Enteric methane emissions

Enteric CH_4 emissions were collected once per 28-day period from each treatment animal using the sulphur hexafluoride (SF_6) technique (Boadi et al. 2002b). Sulphur hexafluoride was released at a known release rate from stainless steel permeation tubes (12.5 x 40 mm) that were administered orally into the rumen via a speculum two weeks prior to the initial CH_4 gas collection to stabilize. The average tracer gas release rate for perm tubes was 335 ± 198 ng min^{-1} in 2004 and 707 ± 136 ng min^{-1} in 2005. Twenty-four hour gas collection was achieved using pre-evacuated (40 mm Hg) stainless steel canisters (130 mm diameter) to collect the exhalation from the mouth and nose of the animal. Two of these collection systems were placed in each of the pastures to collect background air samples. Canisters were pressure-checked to ensure a complete collection and the absence of blocks or leaks in the collection system before being pressurized with 110 kpa N_2 to prevent contamination of the samples prior to gas analysis. A second 24-hour collection was performed if sampling apparatus was compromised resulting in canister pressures greater than 650 mm Hg or lower than 220.

5.3.3.2. Methane and SF_6 analysis

Pressurized gas samples were injected into the sample loop of the gas chromatograph (Year 1: Star 3600, Varian, Mississauga, ON; Year 2: CP-3800, Varian, Mississauga, ON). Sulphur hexafluoride (SF_6) in the sample was quantified using an electron capture detector, while the amount of CH_4 was detected using a flame ionization detector (Boadi et al., 2002). The presence and concentration of gases were determined from the sample's peak area and retention time following the instrument calibration with prepared standards (20.73 ppt SF_6 – Scott-Marrin Inc., Riverside, CA; 100.1 ppm CH_4 – Supelco, Mississauga, ON). Enteric CH_4 emission was calculated using the following equation:

$$CH_4\ (L\ min^{-1}) = \text{Permeation tube } SF_6 \text{ release rate x } [CH_4]/\ [SF_6]$$

where $[CH_4]$ and $[SF_6]$ are concentrations of CH_4 and SF_6 that account for the removal of background concentrations of CH_4 and SF_6.

Background air samples collected with the CH_4 collection canisters occasionally had low levels of CH_4 or SF_6 present that could have been collected from the exhalation of a nearby animal, or produced by soil microorganisms or present in the atmosphere in the case of CH_4.

5.3.3.3. Estimation of dry matter intake

Dry matter intake (DMI) was determined using alkane controlled-release capsules (MCM Alkane, Aukland, New Zealand) as described by Charmley et al (2003). Alkane capsules were administered orally 11 to 14 days prior to fecal sampling to allow the capsule sufficient time to reach a steady release rate in the digestive system. Fecal grab samples were collected from each treatment animal and frozen at -20^{0}C prior to analysis for DM and alkane content. Intake was calculated using the following equation (Boadi et al. 2002b)

$$DMI\ (kg\ d^{-1}) = F_i/F_j \times D_j/(H_i - F_i/F_j \times H_j)$$

where the herbage and fecal concentrations of C_{31} respectively, are H_i and F_i, and herbage and fecal concentrations of C_{32} are H_j and F_j, and where D_j is the amount of dosed C_{32} released per day.

5.3.4. Chemical analyses

Forage and fecal samples were dried for 48 hours at 60^0C in a forced-air oven to determine DM content. After drying, samples were ground through a 1 mm screen (Cyclotec tecator 1093 Sample Mill, Foss Analytical, Denmark).

Forage samples were analyzed for crude protein using a Leco NS 2000 (LECO Corporation, St. Joseph, MI) and ash (Association of Official Analytical Chemists (AOAC) 1990, method no. 942.05). Gross energy was determined using a Par 6300 Automatic Isoperibol Calorimeter (Moline, IL). Acid detergent fibre (ADF) and neutral detergent fibre (NDF) were determined using an ANKOM 200 fiber analyzer (Fairport, NY) as described by Komarek (1993). Alkane concentrations in fecal and forage samples were determined by gas chromatograph (Year 1: Varian 3400, Mississauga, ON; Year 2: Varian 3900, Mississauga, ON) using a modification of the method by Dove (1992) described by Boadi et al (2002a).

Blood samples were collected from the tail vein of treatment steers once per 28-day period. Samples were placed on ice in a cooler and refrigerated prior to submission for analysis. Serum urea nitrogen (SUN) profiles were analyzed by Manitoba

Agriculture, Food and Rural Initiatives Veterinary Services Branch, (Winnipeg, Manitoba), using a colorimetric test with a Vitros 250 (Ortho Clinical Diagnostics Inc., Pub.No. MP2-9, Rochester, NY).

5.3.5. Other calculations

The total available forage in the pastures was calculated from quadrat samples using the following calculation:

Pasture standing available forage (kg DM ha^{-1}) = (Forage DM collected from quadrat [kg DM]/Quadrat area [m^2]) x 10,000m^2 ha^{-1}

Animal productivity was gauged by determining the total weight gain of each animal group (including put and take animals) divided by the size of pasture they were grazing:

Liveweight gain (kg ha^{-1}) = (Sum of each steer's end weight – start weight [kg])/pasture size (ha)

Pasture carrying capacity (CC) was determined using the daily stocking rate, the length of time the pasture was grazed and the area of the pasture with the following equation:

Grazing days ha^{-1} = (No. of head x days grazed)/pasture size (ha)

5.3.6. Statistical analysis

Average daily gain (ADG), DMI, CH_4 and SUN were analyzed using Proc Mixed procedures of SAS Institute, Inc. (1990), with animal as the experimental unit, using the following model: $Y_{ijkl} = \mu + t_i + p_j + pt_{ij} + r_k + y_l + yt_{li} + ytr_{lik} + a(ytr_{lik}) + py_{jl} + pty_{jil} + \varepsilon_{ijkl}$ where t_i = treatment effect, p_j = period effect, pt_{ij} = period x treatment interaction, r_k = replicate effect, y_l = year effect, yt_{li} = year x treatment effect, ytr_{lik} = year x treatment x replicate interaction, $a(ytr_{lik})$ = effect of year x treatment x replicate interaction on animal, py_{jl} = period x year interaction, pty_{jil} = period x treatment x year interaction, ε_{ijkl} = experimental error term.

After a 24-hour collection, CH_4 collection spheres with pressures below 220 mm Hg and above 650 mm Hg were excluded from statistical analysis to ensure measurements were complete and had not been hindered by a plugged line, nor reached atmospheric pressure prematurely. Likewise, measurements where the harness and collection system had been compromised by a leak or tear were removed.

Data from one replicate each in the Full treatment, third period, year 2, and Split treatment, second period, year 2, was removed from statistical analysis for CH_4 (%GEI). This was related to inadequate amounts of forage collected to complete chemical analysis for estimation of DMI.

Available pasture forage and proximate analysis were analyzed using Proc Mixed procedures of SAS with model: $Y_{ijkl} = \mu + t_i + p_j + pt_{ij} + r_k + y_l + tr_{ik} + ry_{kl} + yt_{li} + ytr_{lik} + py_{jl} + pty_{jil} + \varepsilon_{ijkl}$ where tr_{ik} = treatment x rep interaction and ry_{kl} = rep x year interaction.

Grazing days (GD) and liveweight gain (LWG) were analyzed by analysis of variance using the General Linear Model of SAS with model: $Y_{ikl} = \mu + t_i + r_k + y_l + yt_{li} + \varepsilon_{ikl}$.

Botanical composition was analyzed by analysis of variance using a General Linear Model (SAS Institute Inc. 1990) with model: $Y_{ikl} = \mu + t_i + r_j + y_k + \varepsilon_{ijk}$ where t_i = treatment effect, r_j = rep effect, y_k = year effect, ε_{ijk} = experimental error term.

Year and replicate were considered random factors in all models. Mean separation was performed using Bonferonni at a significance level of 5%.

5.4 RESULTS AND DISCUSSION

5.4.1. Botanical composition

The research site was originally seeded to alfalfa (*Medicago sativa*), timothy (*Phleum pretense*) and meadow bromegrass (*Bromus riparius*). Prior to the start of this trial in 2003, the land had been used for hay production. At the start of the research trial, however, the pastures had naturalized to primarily Kentucky bluegrass (*Poa pratensis*) and Quackgrass (*Agropyron repens*). Botanical composition of pastures was not determined in 2003, prior to manure application or introduction to grazing. In 2004, there were less than 10% of either legumes or other forbs in any pasture, with an immediate reduction to less than 1% in each manured pasture after the second year of application (Table 1). The greatest species diversity over the course of the study was observed in the unmanured pastures. Manured pastures were composed primarily of grasses. This observation agrees with research conducted by Dougherty and Rhykerd (1985) which demonstrated that the addition of N fertilizer tended to encourage growth of the more productive and competitive species, which are often the tall, upright grasses. When compared to botanical composition of grasslands receiving 90 kg N ha^{-1}, the addition of 20 kg P ha^{-1} and 90 kg N ha^{-1} has been found to result in an increase in the proportion of coarse grasses such as smooth bromegrass from 38.9 to 52.6% while reducing fine grasses such as Kentucky bluegrass and creeping red fescue from 50.9 to 37.8% (Bittman et al. 1997). The liquid hog manure applied to pastures contained both N

Table 1. Botanical composition in pastures after receiving no (Control) or 155 kg ha^{-1} available nitrogen in the form of liquid hog manure in one (Full) or two (Split) applications annually for two years (n=4).

	Poa pratensis (%)		*Agropyron repens* (%)		*Phleum pretense (%)*		Other grasses (%)		Legumes (%)		Forbs (%)	
	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
Treatment												
Control[z]	32.0	42.0	39.0	41.5	10.0	2.0	7.0	7.0	4.0	4.0	8.0b	4.5b
Split	14.0	27.0	57.5	63.5	17.5	0.0	7.0	9.0	3.5	0.5	0.0a	0.5a
Full	20.5	32.0	45.0	63.0	22.5	1.5	11.0	4.0	11.0	0.0	0.5a	0.0a
	P value	SE	P value	SE	P value	SE	P value	SE	P value	SE	P value	SE
Treatment	0.0682	4.10	0.0802	5.56	0.7767	5.87	0.9490	2.27	0.0870	1.00	0.0005	0.66

[z]Control treatment received no manure application, Split treatment received 74 kg ha^{-1} available nitrogen twice annually and Full treatment received 155 kg ha^{-1} available nitrogen annually through the application of liquid hog manure

a,b Values within a row are different (P < 0.05) and P (Manuscript I, Table 1), however, there was an increase in Kentucky bluegrass, one of the fine grasses, as well as coarse grasses in all pastures. This contrast to the research by Bittman et al. (1997) could be the result of grazing management.

An increase in Kentucky bluegrass in pastures was observed in all treatments after one year, but the greatest difference was observed in the Split pasture, where nearly a 2-fold increase was observed ($P = 0.0682$). Kentucky bluegrass is known to be an opportunistic grass species that will encroach on land that experiences overgrazing (Trottier 2002). Other species, such as timothy, have a lower ability to tolerate increased grazing pressure. In the present study, the presence of timothy was greatly reduced in all pasture treatments, which may be a result of the continuous grazing management system and the potential for animals to re-graze sections of the pasture while the plant was susceptible to grazing pressure. The reduction in timothy in all treatments ($P = 0.7767$) was met with a shift towards increasing proportions of bluegrass and quackgrass in the second year of manure application.

Quackgrass is quick to establish itself in areas of higher moisture; its early emergence and rapid spring growth (Looman 1983) allow for its dominance of many pastures, especially when provided with readily available nutrients as was supplied through the application of hog manure. The manured pastures experienced the most rapid increase in quackgrass at the expense of other grasses when compared to the unmanured Control pasture ($P=0.0802$). The Split and Full manured treatments responded comparably to the nutrients applied and exposure to grazing, and after a two-year period, both treatments were almost equivalent in botanical composition.

Botanical composition could also have been influenced by the act of grazing itself. An increase in prevalence of Kentucky bluegrass and a drastic reduction in timothy in all pastures indicate that grazing pressure may have resulted in a shift in botanical composition to species more tolerant of grazing. The application of manure resulted in a shift toward the grass component of pastures and a reduction in pasture diversity as demonstrated with the near elimination of the legume and forb species in the manured pastures. The 44% reduction in the forb population in the unmanured Control pasture community indicates that grazing pressure may contribute to its decline, while it's near absence from the manured pasture communities indicate that forb populations decline with the application of hog manure ($P = 0.0005$).

5.4.2. Pasture standing forage biomass

Standing forage biomass for Control, Split and Full pastures was 1.2, 3.0 and 1.9 ± 0.53 t DM ha^{-1}, respectively, over the course of two grazing seasons (Table 2). Neither treatment nor period was found to have a significant effect on available forage. This was anticipated, as "put and take" steers were used to maintain standing forage biomass at 1.0 to1.5 t DM ha^{-1} for all treatments. Standing forage biomass for the total grazing season for manured pastures, as well as for Periods 2 and 3 were above this goal (Table 2). Control pastures started below the target range at 0.8 t ha^{-1} but increased to 1.4 t ha^{-1} for periods two and three.

Early summer growth was more rapid and therefore most difficult to control for pastures receiving a Split manure application, as evidenced by higher Period 1 standing biomass (2.0 t ha^{-1}) compared to Full (1.3 t ha^{-1}) and Control (0.8 t ha^{-1}). Forage availability in excess of the targeted availability peaked in the second period, with 4.5 and 2.7 t DM ha^{-1} in Split and Full pastures, respectively. These pastures retained excess forage into the third period, where forage availability was measured at 2.5 and 1.8 t ha^{-1} in Split and Full pastures, respectively.

Target forage yields were met only in Control pastures, and in the first period in the Full pastures before rapid growth resulted in forage availability increasing by 2-fold at the start of the second period. The extreme forage excess witnessed in the second period in the manured pastures was a consequence of insufficient access to "put and take" cattle to adequately manage the pasture system. As a result, forage matured and its quality began to decline, as indicated by decreasing forage CP and increasing fibre content (Table 2). The inability to control the range of available forage and the consequential effects may have impacted animal gain (Table 3).

5.4.3. Pasture quality

Dietary CP must be in adequate supply to ensure good fermentation and efficient N utilization by the animal. The ideal forage CP requirement for a growing 325 kg steer expected to gain 1 to 2 kg d^{-1} is 10.2 to 18.4% when energy is not limiting (National Research Council 1996). The minimum CP value is 7.3% for 325 kg steers gaining 0.3 kg d^{-1} when consuming 8.4 kg DM d^{-1}; the maximum CP content is 18.3%, with expected gains of 2.0 kg d^{-1} and DMI of 7.8 kg d^{-1} (National Research Council 1996). Pasture fertility can play a major factor in forage CP levels for grazing animals. In this study, animals assigned to unfertilized pastures were consuming forage (as determined by analysis of hand plucked samples) with a CP content that ranged from 5.8 to 13.1%.

Although CP values of forage from unmanured pastures averaged 9.7 ± 1.36% (Table 2), 54% of the samples collected were below 7.3%. By comparison, animals grazing fertilized pastures consumed forage that ranged from 9.2 to 26.6% CP. Average CP concentration of the hand-plucked forage samples was doubled when liquid hog manure was applied (P = 0.0492; Table 2). Crude protein levels in the Control pastures in Period 1 (11.7 ± 2.13%) were adequate, but fell below the threshold level for Periods 2 (8.6%) and 3 (8.9%) as the pasture forages matured. A consequence of CP deficiencies is a reduction in animal performance in the form of reduced gain (National Research Council 1996). However, steers grazing unmanured Control pastures had gains that were comparable to Split and Full treatment animals (Table 3; P > 0.05). The CP estimates were based on hand-plucked samples representative of the forage consumed by the grazing herd. However, forage selection may vary between individual animals (Dove and Mayes 1991) where some animals may select for higher CP forages, as has been previously observed (Coleman and Barth 1973). As such, some animals received adequate CP and energy content resulting in comparable weight gains between treatments. Grazing esophageal-fistulated cattle and analyzing the consumed forages allows for a more accurate method of determining forage quality than is observed with hand-plucked forage samples (Coleman and Barth 1973).

Table 2. Standing forage biomass[z] and nutrient profile[y] of grazed forage over three 28-day periods for pastures receiving no (Control) or 155 kg ha^{-1} available nitrogen in the form of liquid hog manure in one (Full) or two (Split) applications annually over a two year period (n=12).

Parameter	Treatments				Period				P-values		
	Control	Split	Full	SE	1	2	3	SE	Treatment	Period	T x P
Standing forage biomass (t DM ha^{-1})	1.2	3.0	1.9	0.53	1.4	2.9	1.9	0.38	0.2571	0.1135	0.3777
Crude protein (%)	9.7b	17.2a	19.8a	1.36	17.1	14.4	15.2	1.47	0.0492	0.4844	0.7449
Neutral detergent fibre (%)	60.3	59.3	55.1	1.60	57.7	59.2	57.7	1.93[†]	0.1282	0.7996	0.1046
Acid detergent fibre (%)	33.4	32.5	29.0	1.22	30.0	33.0	32.0	1.12[†]	0.1179	0.1239	0.0995
Gross energy (kJ g^{-1})	18.7	19.0	19.2	0.10	19.3	18.8	18.8	0.10[†]	0.1305	0.1061	0.5903

[z]Calculated from 9 quadrat clippings per pasture.

[y]Nutrient profile of hand-plucked forage samples representative of grazed forage.

[†]SE of period means ranged from 1.10 - 1.13 (ADF), 1.91-1.94 (NDF) and 0.09-0.10 (GE) due to unbalanced data.

a,b Values within a row are different ($P < 0.05$)

High levels of forage NDF have been shown to limit DMI (Fahey, Jr. and Berger 1988). Forage NDF content ranged from 55.1% in the Full treatment to 60.3% in the Control but did not differ significantly between treatments (Table 2; P=0.1282). Accordingly, the resulting DMI levels of the grazing steers did not differ between either treatment or pasture period (P > 0.05) and consistently remained above 2% BW (Table 3).

Acid detergent fibre was not consistent across periods for each of the three treatments (P<0.10). While forage from Control pastures had an increase in ADF content from 31.6% to 35.9% from the first period to the third period, both manured pastures had peak ADF levels in the second period. The peak in forage ADF content from 29.9% to 36.1% in the Split treatment was observed following a flush of plant growth, when animal numbers were insufficient to maintain the forage in the pasture in a vegetative state. The result was the maturation of forage, as indicated by levels of ADF. As the grazing season progressed the rate of growth was exceeded by the rate of biomass consumption and ADF levels in the Split pastures fell to 31.5%. Control pastures initially had the highest ADF content, which steadily increased to finish the grazing season with a 4.4 and 7.2% increase over Split or Full treatments, respectively. Control pastures were twice as large as the manured pastures to account for their lower fertility and pasture productivity. With the low stocking density and continuous grazing system that allowed for increased selective grazing, the pasture forages reached maturity earlier. Full treatment pastures were the best managed pastures overall and saw only a small fluctuation in ADF content over the three grazing periods, ranging from 28.4 to 30.05%.

Gross energy values of forage were 18.7, 19.0 and 19.2 ± 0.10 kJ g^{-1} in Control, Split and Full pastures, respectively (Table 2; P = 0.1305). Average gross energy did not differ across the grazing season, with values starting at 19.3 ± 0.09 kJ g^{-1} forage and remaining at 18.8 kJ g^{-1} for the second and third periods of the grazing season (P=0.1061)

5.4.4. Dry matter intake

Dry matter intake (kg d^{-1}) ranged from 6.5 to 7.3 ± 0.96 kg d^{-1} between treatments (P = 0.7898) and from 6.5 to 7.5 ± 1.10 kg d^{-1} over the grazing season (P=0.8085). In the first period, within the first month after hog manure application, steers in manured pastures were observed to be selectively grazing forage near the fence and between the manured strips in areas that had received minimal manure due to uneven application. While intake was not affected (P<0.05), a longer period between manure application and the start of grazing should be considered to reduce the forage selection in response to manure proximity. Intake, %BW, was not different between treatments and ranged from 2.0 ± 0.31% BW in Full treatment animals to 2.3 % in Split. Control animals achieved an average intake of 2.2% BW (Table 3; P = 0.6909). Intake, %BW, did not change during the grazing season, with intakes for first, second and third periods at 2.4, 2.0 and 2.1 ± 0.35%, respectively. The rates of intake within the present study is within an expected range; other studies within Manitoba have reported intakes on pasture ranging from 1.8% BW (Ominski et al. 2006) up to 3.8% BW (McCaughey et al. 1997). The present study observed a trend (P=0.0549) in which Control hand-plucked forages contained a higher level of DM (40.5 ± 1.75%) than either Split or Full forages (31.2 and 30.2%, respectively). As well, forage DM increased as the grazing season progressed (25.1,

Table 3. Animal gain, intake, enteric methane production and blood urea nitrogen values of steers grazing forage land receiving no (Control) or 155 kg ha^{-1} available nitrogen in the form of liquid hog manurein one (Full) or two (Split) applications annually over a two year period (n=120).

Parameter	Treatments				Period				P-values		
	Control	Split	Full	SE	1	2	3	SE	Treatment	Period	T x P
Dry matter intake (kg d^{-1})	7.2	6.5	7.3	0.96	7.1	6.5	7.5	1.10	0.7898	0.8085	0.6694
Dry matter intake (% BW)	2.2	2.3	2.0	0.31	2.4	2.0	2.1	0.35	0.6909	0.6505	0.7273
Average daily gain (kg d^{-1})	1.1	0.7	1.0	0.29	0.5	1.4	0.8	0.43	0.4707	0.4550	0.0460
Methane (L d^{-1})^z	177.8	147.4	162.5	31.66	155.6	171.6	160.6	31.40	0.1348	0.1704	0.2138
Methane (L kg BW^{-1} d^{-1})	0.54	0.46	0.50	0.104	0.53	0.52	0.45	0.104	0.1604	0.0697	0.1697
Methane (% GEI)	6.2	5.3	6.1	1.16	5.2	6.9	5.5	1.01	0.7329	0.2153	0.9610
Serum urea nitrogen (mmol L^{-1})	2.56b	6.06a	6.09a	0.610	4.31	4.93	5.47	0.580	0.0225	0.1336	0.0484

^{z}Cannisters not meeting criteria were removed from the data set.

a,b Values within a row are different ($P < 0.05$)

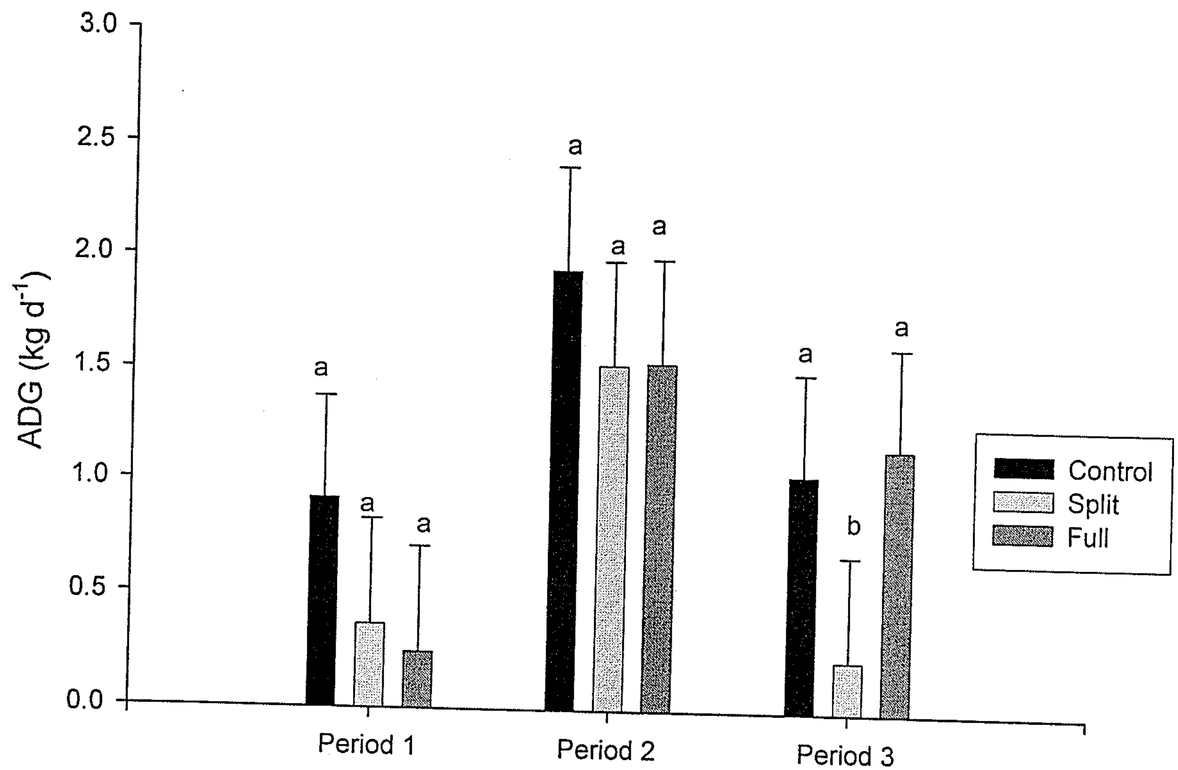
35.1, and 41.6 ± 2.26% for Periods 1, 2 and 3, respectively; P=0.0672). The high moisture forages available at pasture introduction, especially in the manured pastures, could have functioned to influence animal gain (Figure 1) in the first period.

5.4.5. Average daily gain

A treatment by period interaction was observed in average daily gain (ADG) (P=0.0460; Figure 1). First period weights were taken approximately 17 days after introduction of cattle to pasture. Average daily gain in the first period following introduction to the pasture was low for all steers. Depressed gains were likely a consequence of adjusting to consumption of pasture forages with low DM after over-wintering on harvested forages with high DM content. In addition, animals were adjusting to pasture environment from a confined feedlot environment. Available forage biomass in Control pastures averaged 1.1, 1.4 and 1.3 t DM ha^{-1} over the three periods, respectively, resulting in an average stocking density of 1.2 steers ha^{-1} in each period. Available forage biomass in Split pastures averaged 3.2, 3.3 and 2.3 t DM ha^{-1} over the three periods, respectively, with stocking rates of 2.5 to 6.9 steers ha^{-1} in the first two periods, and a range of 2.5 to 5.2 in the third period. Over the three periods, Full pastures had an average available forage biomass of 2.0, 2.3 and 1.7 t ha^{-1}, respectively, with stock densities ranging from 2.5 to 6.7 steers ha^{-1} in the first two periods and 2.5 to 3.7 t ha^{-1} in the third period. Gains increased comparably between treatments until the third period, when Split treatment steers experienced a marked reduction with gain declining to 0.23 ± 0.46 kg d^{-1}, compared with Control and Full treatment steers (1.04 and 1.16 kg d^{-1} respectively; P = 0.046). The reduction in performance of steers in the Split pastures

Figure 1. Average daily gain of steers grazing grass pastures receiving no (Control) or 155 kg ha^{-1} available nitrogen in the form of liquid hog manure in one (Full) or two (Split) applications annually (n=40).

a,b Values with period with different letters differ (P<0.05)


3.0
2.5
2.0
1.5
1.0
0.5
0.0
ADG (kg d-1)
a
a
a
a
a
a
a
b
a
Period 1
Period 2
Period 3
Control
Split
Full

reflects the quality of forage that had been available the preceding period. Forage availability in the Split pastures was more than twice that available in the Control pastures (Table 3), but with insufficient access to "put and take" animals to maintain forage in a vegetative state, forage was allowed to mature. As a consequence of grazing management, ADF levels peaked at 36.1% in Split pastures in Period 2. An increase in ADF content in forage is related to a decrease in its digestibility (Holloway et al. 1979). Although intake was not different between treatments and remained above 2% of BW (Table 3), the reduction in forage digestibility was reflected by a reduction of ADG in the succeeding period.

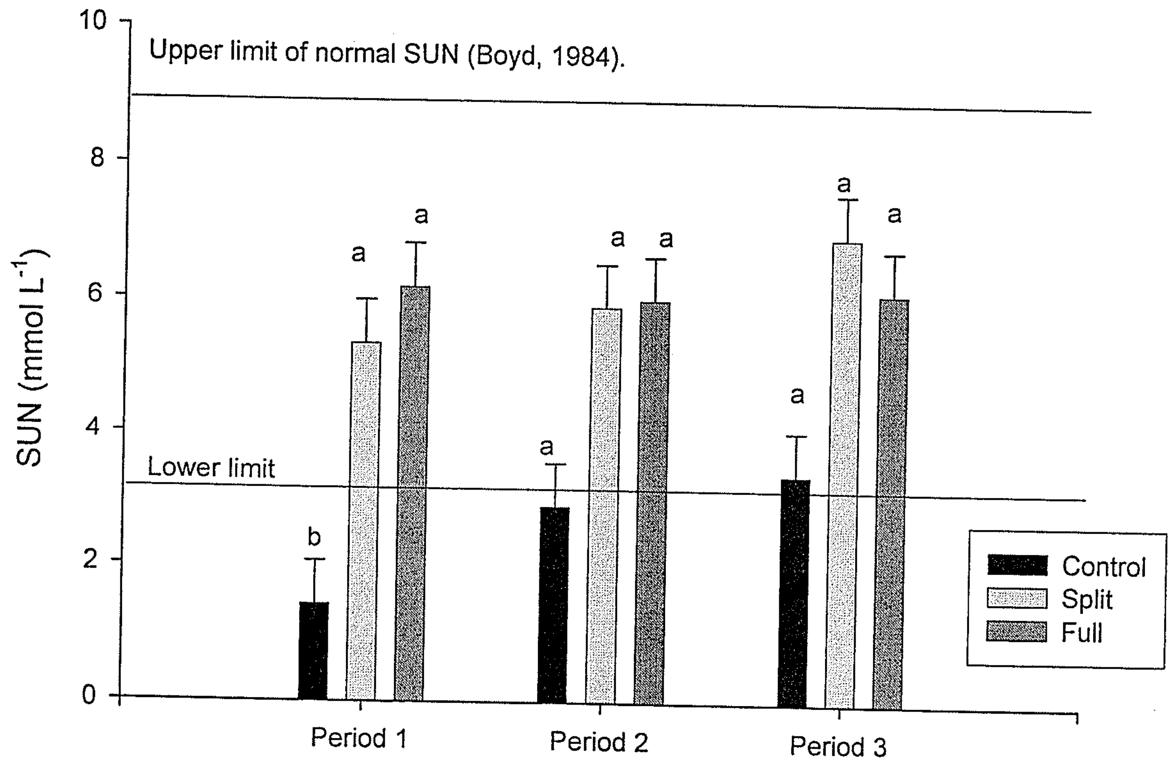
Fertilization of grasslands can improve forage yield and quality. High forage availability and quality improves individual animal gains by providing adequate amounts of forage with a high plane of nutrition to support animal growth. Previous research has indicated that the use of N fertilizer on grasslands can improve animal gain (McCartney et al. 1999). However, Dougherty and Rhykerd (1985) warn that the addition of N to pastures will not necessarily improve the performance of individual animals unless either the forage quality or the availability is increased. While available forage was always adequate and CP content increased with manure treatment, the elevated levels of fibre as a result of pasture management did serve to reduce ADG in the Split treatment steers. In another study, animals grazing at a lighter stocking density (1.1 steers ha^{-1}) were found to perform better than their peers (1.3 kg d^{-1} vs 1.1 kg d^{-1}) in heavily stocked pastures (2.2 steers ha^{-1}) in terms of gain despite uniform diets (Popp et al. 1997b). Stocking densities in the present trial were lowest in the unmanured pastures, in which the maximum number of steers never increased above 10 head despite the two-fold increase in area compared to manured pastures. Frequently, these unmanured pastures were reduced to eight steers by August due to limited available forage DM.

5.4.6. Serum urea nitrogen

Concentrations of SUN were lowest in steers grazing pastures that were not receiving liquid hog manure (Table 3). Forage in unmanured pastures was as much as 10 % units lower in CP content than that of manured pastures (Table 2). Previous work using different combinations of 70% roughage (Lucerne-meal or milled veld-hay) and 30% concentrate (maize-meal or cotton-seed-meal) in order to provide varying concentrations of dietary CP has indicated that consumption of diets high in protein results in elevated levels of blood urea (Richardson 1984). Urea, the primary end-product of protein catabolism, is formed in the liver and excreted via the kidneys (Coles 1980). Serum urea and CP concentrations have been shown to have a linear relationship in growing beef heifers with dietary CP concentrations ranging from 10 to 30% using unfertilized perennial ryegrass (*Lolium perenne)* pastures or those fertilized with 85 kg N ha^{-1} (Kenny et al. 2001). Normal SUN values for steers range from 2.8 to 8.8 mmol L^{-1} (Boyd 1984). Fifty-one of the 356 blood samples collected from treatment animals over the two grazing seasons were below this "normal" threshold. All but one sample was from steers grazing Control pastures. Seventy-six percent of the low observations occurred in the first period, after over-wintering on low quality forages, with the remainder observed in the second period. By the third period all animals had recovered to normal SUN concentrations. Levels of CP had declined in Control pastures as the grazing season progressed (from 11.7 to 8.9 ± 2.13 %) as reflected in hand-plucked

Figure 2. Serum urea nitrogen concentrations of steers grazing grass pastures receiving no (Control) or 155 kg ha^{-1} available nitrogen in the form of liquid hog manure in one (Full) or two (Split) applications annually (n=40).

a,b Values with period with different letters differ (P<0.05)


10
8
6
4
2
0
SUN (mmol L-1)
Upper limit of normal SUN (Boyd, 1984).
Lower limit
a
b
Control
Split
Full
Period 1
Period 2
Period 3

forage samples at the same time as levels of SUN increased (from 1.41 to 3.38 ± 0.650 mmol L^{-1}) such that they were in the range of normal measurements. A suggestion for the improved SUN values in spite of the reduction in forage CP is that individual animal variation in forage selection (Dove and Mayes 1991) resulted in an increase in CP consumption by a few individual animals that was not reflected in the hand-plucked samples representing the diet of the herd. As a consequence, the overall SUN, which includes values from the animals grazing the representative diet, as well as those individuals selecting for higher CP, could be higher than estimated by forage CP values. Previous research utilizing esophageal-fistulated steers grazing orchard grass-red clover pastures has also shown that pastured steers will selectively graze higher quality forages that contain higher levels (22.1 vs. 18.8%) of CP (Coleman and Barth 1973). Another suggestion for the improved SUN values despite the reduction in forage CP is that steers were preferentially selecting the higher quality regrowth in the pastures, or the legumes and forbs, which was not reflected in the hand-plucked samples.

With increased stocking densities in pastures, reduced access to relief from biting insects, or additional stresses that increase the activity of the animals while reducing their selective behaviour, one might anticipate a reduction in SUN as a consequence of decreased CP consumption.

5.4.7. Carrying capacity

Carrying capacity (CC) is an indication of pasture utilization and is measured as grazing days per hectare. The most productive pasture, as measured by average grazing days over the 2-year trial, was the Split treatment, which supplied an average of 376 ± 9.4

grazing days per hectare (Table 4; $P < 0.0001$). This treatment resulted in a 3.7 fold increase in productivity compared to the unmanured Control pastures and had 57 more grazing days per hectare than the Full pastures. This increase in CC of Split over Full may be in response to the treatment protocol for manure application. In 2004 the spring manure application was delayed for several weeks due to a late snowstorm. The Split application had received its initial half-rate application of liquid hog manure in the autumn of 2003 and responded to the available nutrients with a strong flush of plant growth the following spring. By the time steers were introduced to pasture in the spring of 2004, forage DM yields in the Split pastures had approximately 3-fold the available forage (2.2 ± 0.7 t ha^{-1}) than either Control or Full pastures (0.7 and 0.8 t ha^{-1}, respectively). Pasture growth improved in Full pastures with the nutrients available after application, but they were not able to attain the same standing forage biomass as was seen in the Split pasture in 2004 (1.6 and 3.8 t ha^{-1}, respectively). More put and take animals were allotted to Split treatments to attempt to bring forage availability back to the goal of 1.5 to 2.0 t ha^{-1}. As a result, Split pastures averaged an additional 110 GD ha^{-1} over Full pastures in 2004. Although 2005 saw similar levels of CC between the manured treatments, the initial increase in Split CC in 2004 was sufficient to report a difference between Split and Full treatment pastures. The measurements of residual forage in the Split and Full pastures (Table 4; 1.7 and 2.0 t ha^{-1}, respectively; $P=0.0254$) indicated that further utilization of these pastures in the form of more grazing animals or a longer grazing season would have been possible in order to maximize pasture efficiency. Provided sufficient heat and moisture were available to encourage plant growth after manure application in the autumn, Split pastures could be utilized for autumn grazing,

Table 4. Pasture carrying capacity and liveweight gain of grazing steers and residual forage measurements of pastures receiving no (Control) or 155 kg ha^{-1} available nitrogen in the form of liquid hog manure in one (Full) or two (Split) applications annually over a two year period (n=4).

Parameter	Control	Split	Full	SE	P-value
Grazing days (d ha^{-1})	101c	376a	319b	9.4	<0.0001
Liveweight gain (kg ha^{-1})	104b	325a	344a	25.2	0.0019
Residual forage (t ha^{-1})	1.4b	1.7ab	2.0a	0.1	0.0254

a,b Values within a row are different ($P < 0.05$)

further increasing pasture CC. Fertilizer application is most beneficial if applied when plants are able to employ them most effectively for growth. In a three-year study examining equal split applications of ^{15}N depleted ammonium nitrate at total annual rates of 84 and 168 kg ha^{-1} applied to orchard grass field plots, recovery of the applied N fertilizer was 42% in spring growth, and 15% in autumn growth (Stout and Jung 1992). However, nutrients not utilized by plants have been shown to have a carry-over effect, improving forage yield and quality in subsequent years. Cohen et al (2004) observed an improvement in pasture productivity for three years after the cessation of fertilizer applications due to high residual N in the form of NO_3-N in the soil. In the present study, the Split manure application received a half-rate of manure in the autumn, which may have allowed for some initial pasture forage growth prior to its winter dormancy. The availability of these nutrients in the spring could have also resulted in early spring growth, prior to the application of the remaining nutrients to the Split application and the Full spring application.

Kopp et al (2003) found that meadow bromegrass pastures fertilized using 110 kg available N ha^{-1} experienced a 64% improvement in CC when compared to unfertilized meadow bromegrass pastures over the four year period. The increased magnitude of response in CC observed in the manured pastures in the present study were attained under a higher rate of available N application than in the study previously described, and included additional nutrients and organic matter present in the hog manure that could have influenced pasture fertility and thus performance. When application rates were based on crop N requirements as per soil test, observations have indicated that an average annual application of 44 m^3 ha^{-1} hog manure resulted in greater nutrient uptake by plants, as measured by above-ground plant material nutrient content, and a greater overall yield when compared to an average annual application of 69 kg N ha^{-1} inorganic fertilizer (Lupwayi et al. 2005). Based on the higher rate of N applied, it could be anticipated that the present study would show a greater response in terms of pasture CC compared to that of Lupwayi et al (2005).

5.4.8. Liveweight gain per hectare

The liveweight gain of steers grazing unmanured Control pastures was lower (104 ± 25.2 kg ha^{-1}) than either Split (325 kg ha^{-1}) or Full (344 kg ha^{-1}) pastures ($P = 0.0019$; Table 4). The pastures receiving manure provided grazing animals with improved forage quality as well as an increase in forage availability (Table 2) and were able to support more grazing animals. The present findings agree with observations of greater liveweight gains ha^{-1} in fertilized pastures. Cohen et al (2004) found that the addition of up to 200 kg N ha^{-1} to crested wheatgrass pastures improved pasture DMY and increased liveweight gain by up to 100%, but did not affect cattle ADG.

5.4.9. Enteric methane production

Examination of this data set indicated that pasture treatment did not affect ($P > 0.05$; Table 3) total CH_4 production (L d^{-1}) nor CH_4 production as a percentage of gross energy intake (% GEI). Methane was produced at a rate of 177.8, 147.4 and 162.5 ± 31.66 L d^{-1} for Control, Split and Full treatments, respectively. When expressed as a percentage of energy lost, CH_4 losses were 6.2, 5.3 and 6.1 ± 1.16 % GEI. A study within the same region of Manitoba found that yearling steers consuming unimproved grass pastures in a continuous graze system lost between 156.4 to 237.3 L CH_4 d^{-1} with an energetic cost of 6.9 to 11.3 % GEI as CH_4 when pasture DM availability ranged from 0.7 to 1.9 t ha^{-1} (Ominski et al. 2006). The authors indicated that the range of values was a function of pasture availability and quality, where reductions in either resulted in higher levels of CH_4 production. The lower CH_4 emissions in the present study are likely a consequence of higher available forage biomass that provided cattle with a better opportunity to select for forage of higher quality, with less potential to be fermented. As well, intake was higher in the present study (2.0 to 2.4% BW) than in the previously mentioned research (which had a maximum intake of 1.8 % BW), contributing to an increased passage rate and a resultant reduction in CH_4 production.

When measured in terms of production per unit of body weight, enteric CH_4 emissions were 0.53 and 0.52 ± 0.104 L kg BW^{-1} d^{-1} for Periods 1 and 2, respectively, but declined to 0.45 L kg BW^{-1} d^{-1} in Period 3 (Table 3; P = 0.0697). The reduction in CH_4 production could have been as a result of animal growth and an increased rate of passage, or as a result of improved forage quality. Treatment steers entered pastures at an average weight of 285 kg, and exited at 361 kg. A larger rumen as a product of growth is coupled with a faster passage rate of consumed forage, which in turn is associated with a reduction in CH_4 production (McAllister et al. 1996). In a study by Okine et al. (1989), weights placed in the rumen with no change in feed intake resulted in a 29% reduction in CH_4 (L d^{-1}). The researchers attributed 25% of the reduction to the increase in rumen fluid dilution rates. Dry matter intake ranged from 2.0 to 2.4 % BW, but was not different (P>0.05) across the grazing season. Similarly, DM content of the hand-plucked samples was numerically but not statistically different ($P=0.0672$) with values of 25.1, 35.1 and 41.6 ± 2.26% in Periods 1, 2 and 3, respectively.

However, without a difference in DMI (%BW), the consumed feed is more diluted in the rumen (as a consequence of animal growth), allowing for a faster rate of passage and consequently reduced CH_4 emissions. The reduction in emissions in the current study may also be related to the observed reduction in structural carbohydrates in the analyzed hand-plucked forage samples in the third period (Table 2) compared to the previous period. Mature and lower quality forages tend to have increased amounts of structural carbohydrates that can be fermented by rumen microorganisms with CH_4 as an end-product (Schofield 2000). In addition to improved pasture quality in the third period, the steers' ability to select for specific forages and parts of plants may have improved over the grazing season. Steers on pasture have been found to selectively graze forages that are more digestible, with higher levels of CP and soluble carbohydrates and lower levels of ADF (Coleman and Barth 1973). The ability to select can be reduced when forage becomes less available, as is often the case as the grazing season progresses. In this study, average available standing forage across the grazing season was always above the minimum goal of 1.0 t DM ha^{-1} and limitations to selective grazing were nominal. Forage properties that slow the digestion rate or increase the retention time or reduce the rate of passage within the rumen tend to increase the amount of CH_4 production per unit of intake (McAllister et al. 1996; Okine et al. 1989). Further, Boadi and Wittenberg (2002) have demonstrated that CH_4 emissions were lowest (56.6 and 62.2 vs. 83.1 L CH_4 kg^{-1} digestible organic matter) when forage digestible organic content was highest (50.7 and 61.5 vs. 38.5%). In the present study, if the grazing steers were selectively grazing plant material that was less mature and more digestible, then there would be a reduced potential for fermentation to CH_4 by the rumen microbial population.

5.4.10. Nutrient export

The concentration of N and P in a 300 kg carcass is estimated to be 3.03% (Haecker, 1920) as cited by Berg and Butterfield (1976) and 0.84% (Hogan and Nierman 1927; Moulton et al. 1922), respectively. Using these values, nutrient export as animal gain was calculated from each of the treatments. Inorganic mineral intake was not included in calculations. Application of manure ($P = 0.0019$) had an effect on both N and P exported from the pastures (Table 5). The removal rate of N was 3.1, 9.9 and 10.4 $\pm$ 0.76 kg ha^{-1} y^{-1} for Control, Split and Full treatment pastures, respectively. Phosphorus was removed at a rate of 0.9, 2.7 and 2.9 $\pm$ 0.21 kg ha^{-1} y^{-1} for the same pastures. The removal rate for each nutrient was approximately three times higher for the manured pastures when compared to the unmanured Control pasture. This increase in nutrient export is partially due to the increased productivity of the manured pastures as their ability to support more animals (Table 4) resulted in an increase in liveweight gain harvested per hectare in manured pastures.

Nutrient removal efficiency, based on animal gain was similar for Split and Full treatments for both N and P (Table 5). Nutrients provided in excess of animal requirements are redeposited onto the land in the form of urine or feces. The export of nutrients by grazing animals is minimal (Dougherty and Rhykerd 1985) due to the low level of nutrient incorporation into BW gain (Haecker 1920; Hogan and Nierman 1927). In this study, less than 5% of applied N was removed from the pasture system through

Table 5. Nutrient exported as body weight gain, by steers grazing pastures receiving no (Control) or 155 kg ha^{-1} available nitrogen in the form of liquid hog manure in one (Full) or two (Split) applications annually over a two year period (n=4).

	Control	Split	Full	SE	P-value
Nutrient exported, kg ha^{-1} y^{-1}					
Nitrogen	3.1b	9.9a	10.4a	0.76	0.0019
Phosphorus	0.9b	2.7a	2.9a	0.21	0.0019
Nutrients removed in the form of gain, % of total applied					
Nitrogen	NA	4.7	4.5		
Phosphorus	NA	6.1	4.2		

[z] The % nitrogen removed is the N removed as gain divided by applied N after subtracting 25% of ammoniacal N for volatilization, multiplied by 100.

a,b Values within a row are different ($P < 0.05$)

NA - no manure applied

animal gain. The efficiency of removal of P was similar, with up to 6.1% removed. Total nutrient removal from fertilized pastures may increase due to the increased CC and overall LWG when compared to unfertilized pastures (Cohen et al. 2004). Under more intense grazing pressure, nutrient removal efficiencies would increase only minimally (Appendix 2). By maximizing pasture utilization such that residue was 0.5 t DM ha^{-1}, approximately 7% of applied N and P was removed from pastures.

Nutrient removal efficiency calculations on pasture did not consider the mineral supplementation provided to animals. The mineral supplement supplied in all pastures was produced to meet the mineral needs of cattle consuming the Control pasture forages, which contained the lowest mineral content. As a result, cattle grazing manured pastures would have a greater mineral intake, from both forages and supplement, than cattle grazing Control pastures. As unutilized mineral is excreted by cattle, excessive mineral would have been redeposited to the pastures. As a result of this additional source of mineral, nutrient removal efficiencies would have been even lower than reported above. Nitrogen originating from feces was found to have low availability and would enter the soil in forms not immediately available for plant use; after three years only 19% of the N from feces had been absorbed by forage, indicating slow and incomplete N cycling in the pastoral environment (Kimura and Kurashima 1991). With such low nutrient utilization in pastures, even with incomplete nutrient cycling, reducing the rate of nutrient application or the frequency of application may be necessary to prevent nutrient loading. Studies have indicated that fertilizer not immediately utilized by the plants can improve pasture productivity for years after the cessation of fertilizer applications due to high residual N in the form of NO_3-N in the soil (Cohen et al. 2004).

5.5. Conclusion

The differences in forage quality in response to pasture treatments did little to influence individual animal intake and CH_4 production presumably as a consequence of sufficient available forage biomass to allow for selective grazing. Levels of SUN were often low in Control treatment animals that entered pasture with low SUN values and took longer to recover as a consequence of grazing the often CP-deficient pastures. While incorporating liquid hog manure into a pasture system did not serve to improve individual animal gains, it did have clear benefits in terms of improving pasture utilization with an increase in GD ha^{-1} and LWG ha^{-1}. This, in turn, lead to an increase in nutrients exported from the manured pastures, but at low removal efficiencies when compared to nutrients applied. In order to reduce the potential for build-up of nutrients in the soil, application and land-use strategies must be carefully considered. Lowering application rates to supply the needs of the pastures annually could also function to reduce excess nutrients. Another option would be to apply manure less frequently to the land base to allow for utilization of the residual nutrients in succeeding years.

6.0. GENERAL DISCUSSION

6.1. Forage productivity and quality

In general, application of hog manure improved the quality of standing hay in terms of CP and GE content, but fibre and ash content did not improve over unmanured hayfields. Hayfield management likely contributed to the results of the forage quality. While inclement weather and labour shortages did delay hay harvest for all treatments, the management of hayfields did not allow for the individual physiological status of the hayfields. Cutting on the basis of physiological status or allowing for an earlier first cut for all treatments would have functioned to improve harvested hay quality. The production of silage in place of hay is an option that may assist in reducing the nutrients leached and material lost from the swaths due to reduced drying time.

While utilization of hand-plucked samples was an improvement over the collection of random pasture samples in terms of determining consumed forage quality, the method was not without fault. As proximate analysis of the test diet is required to estimate quality, great care must be taken to ensure that the collected sample is an accurate representation of what the animals are consuming (Dove and Mayes 2005). The limitations in collecting hand-plucked forages representative of the treatment steers' diets in this study included a large flight zone which prevented close observation, as well as the inability to collect forages that were available in limited quantity or previously consumed by the cattle (such as legumes and forbs). Further, samples collected were representative of an average diet and did not reflect individual animal preferences.

Few differences were observed in forage quality or pasture performance between Split and Full pasture treatments. Grazing started and ended on the same date in late summer for all pasture treatments, regardless of available forage biomass in the spring or autumn. Manured pastures reached high forage biomass levels early in the spring due to higher soil fertility in response to applied nutrients, but grazing was delayed in the manured pastures to allow for Control pastures to achieve a minimum standing forage biomass of 1.0 t DM ha^{-1}. As a result, manured pasture biomass was quite high at pasture introduction, when stocking densities were generally insufficient in manured pastures to account for the available forage biomass. In response to the low grazing pressure, forage would begin to mature. The decision to end the grazing season was also limited by available forage biomass in any one treatment. By assessing each pasture individually and extending the grazing season as available forage biomass allowed, further differences between treatment CC and LWG might have been observed. Further, with the grazing season extended to maximize time spent on pasture, pastures could be more efficiently utilized such that any differences in productivity, quality and nutrient removal that exist between Split and Full treatments could be determined. The availability of the nutrients from the half-rate application in Split pastures could also function to increase forage yield in the autumn, provided sufficient heat and moisture were available. This could result in further improvements in CC and LWG in Split treatments beyond those observed with Full treatments.

6.2. Application technique

Liquid hog manure was applied to grasslands at a rate of 123 kg available N ha^{-1}, based on the assumption that liquid hog manure was applied under cool wet or cool dry conditions, which would result in the volatilization of 25% of the ammoniacal-N (http://www.gov.mb.ca/agriculture/livestock/beef/pdf/baa08s01a.pdf 2006). Further, the assumptions state that 25% of the organic nitrogen will mineralize and become available to the crop within the year of application. The remaining organic N becomes available slowly, over a series of years. The large variability in volatilization rates available in literature has been condensed to only a few values for the purpose of calculating expected volatilization rates (P. Loro, personal communication, Manitoba Agriculture, Food and Rural Initiatives, Winnipeg, MB). As such, volatilization losses can be much higher or lower as a consequence of application method, temperature, wind speed and the presence or absence of precipitation (http://www.gov.mb.ca/agriculture/livestock/beef/pdf/baa08s01a.pdf 2006). In the current study, manure application tended to occur in cooler periods of the spring and autumn, which would agree with recommended conditions for a 25% loss of ammoniacal-N. However, the presence of strong winds on the open prairie grasslands was not accounted for, which could have resulted in higher rates of volatilization than were assumed. As such, there is a degree of uncertainty in the calculation of N removal efficiencies from the manured grasslands. Injecting manure into the land base is an alternative strategy which minimizes N losses to the environment.

There was little difference in terms of productivity and environmental sustainability between the Split and Full treatments as measured by forage yield of grasslands, harvest of hayfields, nutrient content of forage, enteric CH_4 emissions, LWG ha^{-1}, or nutrient removal from the grasslands. The advantage of one strategy over the other is mainly associated with the labour requirements. The Full treatment requires application only once per year, which maximizes efficiency in terms of the time spent agitating manure pits and preparing equipment for use, reduces the costs and labour for application and minimizes the potential for soil compaction as a consequence of spreading manure; Split treatments doubled the efforts involved in that agitation and spreading would be required twice per year. If considering the effort and labour of manure application, the Full application would be the most appealing fertilization strategy of those tested. However, application in the spring can be problematic due to climatic conditions and the time span required between manure application and introduction to grazing. Late spring snow storms have the potential to delay manure application, while animal aversion to manured land can resulted in altered grazing behaviour. The delay in manure application in the first year of the study resulted in very high CP content in some forage samples collected in the Full treatment pastures. By applying manure in the autumn, these problems can be avoided while still providing the benefits of improved grassland yield and quality.

6.3. Environmental sustainability

Removal efficiency ranged from 75% for K to 13% for Mg. The efficiency of N removal was 34% for both manured hayfields, and up to 27% of applied P was removed from the site. From these low rates of nutrient removal, it is clear that maintaining the manure application rates at current levels will result in an accumulation of nutrients in the grassland. Even with simulated optimum harvest efficiency, much of applied the nutrients were left behind in the soil, indicating that repeated manure application was not sustainable in this grassland management system.

The removal of nutrients from the pasture system was dependent upon body weight gain of grazing steers. Of the total N applied to the manured pastures, only up to 4.7% was removed in animal gain. Levels of P removal were similarly low, with up to 6.1% of the total P removed from the pasture system. Loose mineral was provided to animals based on the requirements of steers grazing the often nutrient deficient Control pastures. As a result, mineral (including P) beyond the requirements of the steers grazing manured pastures was supplied to animals in excess and would have been redeposited to the pastures. This was not accounted for in nutrient removal efficiency calulations. Extending the grazing season by pasturing animals earlier in the spring or later into the autumn would be insufficient to make a substantial improvement in nutrient export. The low nutrient removal efficiencies observed in the manured pasture system indicates that grazing alone is insufficient to remove nutrients from the site if application rates remain unchanged. As a result, pasture systems would require reduced application rates and frequencies in order to prevent nutrients from accumulating.

The manure application rate in this study had been based on available N content of manure, where the target application rate was 123 kg available N ha^{-1}. If manure had been applied on the basis of P content, nutrient removal efficiencies would have been much greater, assuming plant uptake of stated nutrients did not change. As such, the potential for nutrient accumulation would have been reduced.

Steers' enteric CH_4 emissions were not influenced ($P > 0.05$) by the application of hog manure to grasslands. Previous research has indicated that CH_4 production is influenced by the availability and quality of the forage being consumed (Ominski et al. 2006). In this study, pasture forage availability was never limiting and was adequate for selective grazing, a behaviour in which cattle often select forages that have higher levels of CP and lower levels of ADF than is available in the average pasture forages present (Coleman and Barth 1973). Even in Control pastures, where CP content was often low, treatment steers had sufficient forage availability to allow for selective grazing. Selection of forbs and legumes in Control pastures could have supplied steers with forage of sufficient quality such that overall CH_4 production was reduced. As such, no differences in CH_4 production were observed between treatments. In order to control for selective grazing, while maintaining forage quality more consistently throughout the pastures, a rotational grazing system could have been employed. In order to further reduce selection, stocking density could be increased such that cattle would be less discerning about forage selection. While this method would encourage cattle to consume the lower quality forages, it would likely result in higher CH_4 production and lower weight gains, while reducing the native pasture biomass below the targeted 1.0 to 1.5 t DM ha^{-1} required to sustain sufficient forage throughout the grazing season. A further concern with this management strategy is the potential to overgraze pastures such that their future productivity and survival is compromised as a consequence of reduced below-ground biomass.

6.4. Best management practices and recommendations

The application of hog manure to pastures has been shown to increase forage productivity and quality. In order for liquid hog manure application on grasslands to be a sustainable practice, the nutrients applied must be utilized and removed through hay harvest or animal gain to prevent nutrient accumulation. When compared with the nutrient export from grazing animals, the removal of hay from grasslands was more efficient at exporting nutrients from the site.

The current rate of application for this trial provided nutrients in excess of plant requirements, allowing nutrients to accumulate in the soil. Haying grasslands provided the best nutrient utilization of the strategies tested, but frequency and rate of liquid hog manure application must be reduced to limit the potential for nutrient accumulation. Application of nutrients to grassland pastures should be reduced by rate or frequency to improve nutrient utilization efficiency. In order to prevent a build-up of nutrients in the soil while meeting the needs of the grasslands, application rates should be based on existing soil nutrients as determined by soil testing, as well as crop uptake.

6.5. Future research work

Hog manure composition is highly variable, a factor which can lead to inconsistent levels of nutrients being applied when application rate is based on a particular nutrient or form of nutrient, such as available N. A unique feature to this study is that the manure lagoon, from which manure was applied to the research site, was agitated for several hours prior to manure application. The extended length of agitation allowed for the greatest uniformity of hog manure nutrient composition throughout the land application process. A more common practice within the hog industry is for manure to be applied after little or no manure agitation, and thus with great variability in nutrient content throughout application. Given the variability known to hog manure, samples must be taken frequently throughout the application process to ensure that the application rate remains accurate. Further research examining methods to reduce variability in hog manure composition on application would serve to provide a more consistent application of nutrients.

Grassland botanical composition appears to have been influenced by the application of liquid hog manure, but it is difficult to determine whether the application of manure or the grazing pressure was the causal effect of the botanical composition shift due to the absence of measurements prior to hog manure application and introduction to grazing. After an initial assessment of botanical composition, future research could examine the shift in botanical composition in pastures as a consequence of both grazing and manure application, and in hayfields to evaluate the shift in botanical composition without the influence of grazing.

Concerns presented in the current study were the inefficient removal of applied nutrients and the accumulation of nutrients in the grassland system. At the same time, the nutrient holding capacity of the soil under the grazing and haying management strategies utilized for this study, in terms of nutrient incorporation into below ground biomass, is not known and requires further investigation. In order to prevent nutrient loading, alternate land management practices need to be employed. Nutrient application that includes commercial fertilizer in a rotation with hog manure could effectively supply nutrients required, while reducing the application of nutrients already present in the grassland system. Rotating grassland use between hay and pasture would result in a more regular export of nutrients from the grassland when compared to pasture use only. A reduction of the manure application rate or frequency would also serve to balance the nutrients applied and those exported from the grassland.

7.0. CONCLUSION

The addition of nutrients in the form of liquid hog manure to grasslands increased forage yield and quality. Hay yield, CP, NDF, GE and nutrient removal from the hayfields was affected by manure application. Pasture CP, CC, LWG ha^{-1} and nutrient removal from pastures, as well as steer ADG and SUN were influenced by pasture treatments. While no benefit was observed in individual animal performance in terms of ADG, pastures receiving manure applications were more efficiently utilized in that they had a greater CC and harvested a greater LWG ha^{-1} due to the increase in pasture productivity. Serum urea nitrogen levels of steers were improved with fertilization of pastures. Enteric CH_4 emissions were not influenced by application of liquid hog manure to grassland pastures, due to high forage availability and the steers' ability to select for higher forage quality in all pasture treatments.

Of the application strategies tested, there is little difference in terms of productivity and environmental sustainability between the Split and Full treatments as measured by forage yield of grasslands, harvest of hayfields, nutrient content of forage, enteric CH_4 emissions, LWG ha^{-1}, or nutrient removal from the grasslands. The advantage of one strategy over the other is mainly associated with the labour required for each. The Full treatment requires application only once per year, which maximizes efficiency in terms of the time spent agitating manure pits and preparing equipment for use, reduces the costs and labour for application and minimizes the potential for soil compaction as a consequence of spreading manure; Split treatments doubled the efforts involved in that agitation and spreading would be required twice per year. If considering the effort and labour of manure application, the Full application would be the most appealing fertilization strategy of those tested. There is, however, the opportunity to improve forage production into the autumn with Split manure application, if heat and moisture are not limiting, when nutrients are applied in the form of hog manure. Such a practice could serve to extend the grazing season.

The low nutrient removal efficiencies in both hayfields and pastures indicate a change in fertility management is required in order to prevent the loading of nutrients within the grassland systems. Alternating land-use between the higher removal efficiencies observed with hayfields and the lower removal efficiencies of pasture systems could increase nutrient export from the land base currently employed as pasture, but would still result in unutilized nutrients if application rates remained unchanged. Additional strategies to prevent nutrient loading would include reducing manure application rates, applying manure based on soil fertility and crop uptake, fertilizing with inorganic N on an as-needed basis to reduce the addition of P and other nutrients found in hog manure to the grassland, or by reducing the frequency of nutrient application.

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8.0. APPENDIX

Appendix 1. The effect of applying no (Control) or 155 kg ha^{-1} available nitrogen in the form of liquid hog manure in one (Full) or two (Split) applications annually on the annual removal of nutrients in the form of hay assuming 80% harvest efficiency (n=4).

	Control	Split	Full	SE	P-value
Total forage biomass generated, t ha^{-1}	3.7b	8.8a	8.4a	0.31	0.0001
Hay harvested, t ha^{-1} y^{-1}	3.0b	7.0a	6.7a	0.24	0.0001
Nutrients[z] removed in the form of hay, kg ha^{-1} y^{-1}					
Nitrogen	34.5b	101.6a	109.5a	5.38	0.0003
Phosphorus	5.0b	17.0a	19.3a	1.25	0.0010
Potassium	30.9b	92.7a	104.3a	6.39	0.0009
Magnesium	4.8b	10.5a	11.7a	0.69	0.0019
Nutrients removed in the form of hay, % of total applied					
Nitrogen[y]	NA	48.8	46.2		
Phosphorus	NA	36.9	28.1		
Potassium	NA	83.3	106.4		
Magnesium	NA	20.7	17.6		

[z]Nutrient content determined from first haycut bale core samples

[y] The % nitrogen removed is the N removed as hay divided by applied N after subtracting 25% of ammoniacal N for volatilization, multiplied by 100.

a,b Values within a row are different ($P < 0.05$)

NA - no manure applied

Appendix 2. Potential[z] nutrient exported as body weight gain, by steers grazing pastures receiving no (Control) or 155 kg ha^{-1} available nitrogen in the form of liquid hog manure in one (Full) or two (Split) applications annually over a two year period (n=4).

Nutrient exported, kg ha^{-1} y^{-1}	Control	Split	Full	SE	P-value
Nitrogen	7.5b	11.3ab	17.0a	1.49	0.0159
Phosphorus	2.2b	3.3ab	4.9a	0.43	0.0159
Nutrients removed in the form of gain, % of total applied					
Nitrogen[y]	NA	5.4	7.2		
Phosphorus	NA	7.1	7.2		

[z] Calculated as if grazing extended until residual forage levels of 0.5 t ha^{-1} attained using Period 3 ADGs.

[y] The % nitrogen removed is the N removed as gain divided by applied N after subtracting 25% of ammoniacal N for volatilization, multiplied by 100.

a,b Values within a row are different ($P < 0.05$)

NA - no manure applied

Appendix 3. Rancher's Choice 8:4:50 Interlake Beef Pasture Premix[z]

Calcium (actual)	8.0%
Phosphorus (actual)	4.0%
Sodium (actual)	20.0%
Magnesium (actual)	1.0%
Iron (actual)	2000 mg/kg
Copper (actual)	3000 mg/kg
Zinc (actual)	6000 mg/kg
Manganese (actual)	4000 mg/kg
Iodine (actual)	600 mg/kg
Cobalt (actual)	40 mg/kg
Fluorine (maximum)	2000 mg/kg

[z]Puratone Feeds, Niverville, MB